NON-PROVISIONAL UTILITY PATENT APPLICATION TRANSMITTAL - 37 CFR 1.53(b)

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11/12/03 U.S. PTO 10/706513

MAIL STOP PATENT APPLICATION
Commissioner for Patents
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Alexandria, VA 22313-1450

Attorney Docket No.: 10000-25US (100137/US/WO)
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Express Mail Label No.:EV312205282US
Total Pages of Transmittal Form: 3

Transmitted herewith for filing is the non-provisional utility patent application entitled:

METHOD FOR CAPTURING AND DISPLAYING A VARIABLE RESOLUTION DIGITAL PANORAMIC IMAGE

which is:

an [ ] Original; or

a [X] Continuation, [ ] Divisional, or [ ] Continuation-in-part (CIP)

of prior International Application No. PCT/FR02/01588 filed May 10, 2002.

Anticipated Group/Art Unit: or Class , Subclass .

[ ] This non-provisional patent application is based on Provisional Patent Application No. , filed .

Enclosed are:

- [X] Specification (including Abstract) and claims: 31 pages.
- [X] 11 sheets of drawings (formal).
- [ ] Application Data Sheet.
- [ ] Newly executed/unexecuted Declaration (original/copy).
- [ ] Copy of Declaration from prior application.
- [ ] Separate Power of Attorney (including 37 CFR 3.73(b) statement, if applicable).
- [ ] Microfiche computer program (Appendix).
- [ ] Nucleotide and/or Amino Acid Sequence Submission, including:
- [ ] Computer readable copy [ ] Paper Copy [ ] Verified Statement.
- [ ] Under PTO-1595 Cover Sheet, an assignment of the invention
- [X] Name of Assignee: 6115187 CANADA INC.
- [ ] Certified copy(ies) of Application No(s). filed is/are filed:
  [ ] herewith or [ ] in prior application .

[ ] Applicant(s), by its/their undersigned attorney, claim(s) Small Entity Status under 37 C.F.R. §1.27 as [ ] an Independent Inventor, or [ ] a Small Business Concern, or [ ] a Non-Profit Organization.

[ ] Preliminary Amendment.

[X] Information Disclosure Statement, PTO/SB/08A, and cited references.

[ ] Request for Nonpublication of Application Under 35 U.S.C. §122(b)

[ ] Other:

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Enclosures

TITLE OF THE INVENTION

[0001] Method For Capturing And Displaying A Variable Resolution Digital Panoramic Image

CROSS-REFERENCE TO RELATED APPLICATIONS

[0002] This application is a continuation of International Application No. PCT/FR02/01588, filed May 10, 2002 the disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0003] The present invention relates to obtaining digital panoramic images and displaying panoramic images on computer screens.

[0004] Fig. 1 represents a classical device allowing a digital panoramic image to be produced and presented on a computer screen. The device comprises a digital camera 1 equipped with a panoramic objective lens 2 of the "fish-eye" type, having an angular aperture on the order of 180°. The camera 1 is connected to a computer 5, such as a microcomputer for example, equipped with a screen 6. The connection to the microcomputer 5 may be permanent, when, for example, the camera 1 is a digital video camera, or temporary, when, for example, the camera 1 is a still digital camera equipped with an image memory, the connection then being carried out at the time the image files are to be transferred into the microcomputer.

[0005] Fig. 2 schematically represents the appearance of a panoramic image 3 obtained by means of the panoramic objective lens 2. The round appearance of the image is characteristic of the axial symmetry of panoramic objective lenses and the image has dark edges 4 that will subsequently be removed. This digital panoramic image is delivered by the camera 1 in the form of a computer file containing image points coded RGBA arranged in a two-dimensional table, "R" being the red pixel of an image point, "G" the green pixel, "B" the blue pixel, and "A" the Alpha parameter or transparency. The parameters R, G, B, A are generally being coded on 8 bits.

[0006] The image file is transferred into the microcomputer 5 which transforms the initial image into a three-dimensional digital image, then presents the user with a sector of the three-dimensional image in a display window 7 occupying all or part of the screen 6.

[0007] Fig. 3 schematically shows classical steps of transforming the two-dimensional panoramic image into a panoramic image offering a realistic perspective effect. After removing the black edges of the image, the microcomputer has a set of image points forming an image disk 10 of center O and axes OX and OY. The image points of the image disk are transferred into a three-dimensional space defined by an orthogonal coordinate system of axes O'X'Y'Z, the axis O'Z being perpendicular to the plane of the image disk. The transfer is performed by a mathematical function implemented by an algorithm executed by the microcomputer, and leads to obtaining a set of image points referenced in the coordinate system O'X'Y'Z. These image points are for example coded in spherical coordinates RGBA(φ,θ), φ being the latitude and θ the longitude of an image point. The angles φ and θ are coded in 4 to 8 bytes (IEEE standard). These image points form a hemisphere 11 when the panoramic objective lens used has an aperture of 180°, otherwise a portion of a hemisphere. The microcomputer thus has a virtual image in the shape of a hemisphere one sector 12 of which, corresponding to the display window 7, is presented on the screen (Fig. 1) considering that the observer is on the central point O' of the system of axes O'X'Y'Z, which defines with the center O" of the image sector 12, a direction O'O" called "viewing direction".

[0008] In order to avoid the image sector displayed 12 having geometrical distortions unpleasant for the observer, the classical panoramic objective lenses must have a distribution function of the image points according to the field angle of the object points of a panorama that is as linear as possible. Therefore, if two points A', B', situated on the same meridian of the hemisphere 11, and the corresponding points A, B on the image disk 10 are considered, the ratio between the angles (A'O'Z) and (B'O'Z) must be equal to the ratio between the distances OA and OB on the image disk.

[0009] Due to this property of linearity of a classical panoramic objective lens, image points corresponding to object points having an identical field angle form concentric circles C10, C20... C90 on the image disk 10, as represented in Fig. 4A. Classically, "field angle of an object point" means the angle of an incident light ray passing through the object point considered and through the center of the panorama photographed, relative to the optical axis of the objective lens. The field angle of an object point can be between 0 and 90° for an objective lens having an aperture of 180°. Therefore, the circle C10 is formed by the image points corresponding to object points having a field angle of l0°, the circle C20 is formed by image points corresponding to object points having a field angle of 20°, etc., the circle C90 being formed by the image points having a field angle of 90°.

[0010] Fig. 4B represents the shape of the distribution function Fdc of a classical panoramic objective lens, which determines the relative distance *dr* of an image point in relation to the center of the image disk according to the field angle α of the corresponding object point. The relative distance *dr* is between 0 and 1 and is equal to the distance of the image point in relation to the center of the image divided by the radius of the image disk. The ideal form of the function Fdc is a straight line of gradient K:

$$dr = \mathrm{Fdc}\ (\alpha) = \mathrm{K}\ \alpha$$

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in which the constant K is equal to 0.111 degree^{-1} (1/90°).

[0011] This technique of displaying a digital panoramic image sector on a computer screen has various advantages, particularly the possibility of "exploring" the panoramic image by sliding the image sector presented on the screen to the left, the right, upwards or downwards, until the limits of the panoramic image are reached. This technique also allows complete rotations of the image to be carried out when two complementary digital images have been taken and supplied to the microcomputer, the latter thus reconstituting a complete panoramic sphere by assembling two hemispheres. Another advantage provided by presenting a panoramic image on screen is to enable the observer to make enlargements or zooms on parts of the image. The zooms are performed digitally, by shrinking the image sector displayed and expanding the distribution of the image points on the pixels of the screen.

[0012] Various examples of interactive panoramic images can be found on the Web. Reference could be made in particular to the central site "http://www.panoguide.com" ("*The Guide to Panoramas and Panoramic Photography*") which gives a full overview of all the products available to the public to produce these images. Software programs allowing digital panoramic photographs to be transformed into interactive panoramic images are offered to the public in the form of downloadable programs or CD-ROMs available in stores.

[0013] Despite the various advantages that this technique for displaying digital images offers, the digital enlargements have the disadvantage of being limited by the resolution of the image sensor used when taking the initial image and the resolution of an image sensor is generally much lower than that of a classical photograph. Therefore, when the enlargement increases, the granulosity of the image appears as the limits of the resolution of the image sensor are being reached.

[0014] To overcome this disadvantage, it is well known to proceed with pixel interpolations so as to delay the apparition of the blocks of color which betray the limits of the resolution of the sensor. However, this method only improves the appearance of the enlarged image sector and does not in any way increase the definition. Another obvious solution is to provide an image sensor with a high resolution, higher than the resolution required to present an image sector without enlargement, so that there is a remaining margin of definition for zooms. However, this solution is expensive as the cost price of an image sensor rapidly rises with the number of pixels per unit of area.

[0015] Some attempts have been made to improve the quality of the enlargements, by changing the optical properties of the panoramic objective lenses themselves. Thus, U.S. Patent No. 5,710,661 teaches capturing a panoramic image with two overlocking objective lenses using a set of mirrors. A first set of mirrors provides an overall view, and a mobile central mirror provides a detailed view on a determined zone of the panorama. However, this solution does not offer the same flexibility as digital zooms, particularly when the image is not displayed in real time, as the observer no longer has the possibility of choosing the image portion that he wants to enlarge once the photograph has been taken.

BRIEF SUMMARY OF THE INVENTION

[0016] Therefore, the present invention comprises a method allowing the physical limits of image sensors to be circumvented and the definition offered by digital enlargements concerning certain parts of a digital panoramic image to be improved, without the need to increase the number of pixels per unit of area of an image sensor or to provide an overlocking optical enlargement system in a panoramic objective lens.

[0017] The present invention is based on the observation that, in several applications, only certain zones of a panoramic image are of a practical interest and are likely to be expanded by the observer by means of a digital zoom. Thus, in applications such as video surveillance, videoconferencing, visio-conferencing, a panoramic camera can be installed against a wall or on the ceiling and there is generally no reason to make enlargements on the zones of the panoramic image corresponding to the wall or the ceiling. Similarly, as part of a videoconference performed by means of a panoramic camera, the most interesting zone is generally situated at a specific place situated towards the center of the image (in the case of individual use) or on the edges of the image (in the case of collective use or visio-conferencing). Furthermore, when used for recreation and leisure, most panoramic images comprise parts that are less interesting than others, such as the parts representing the sky or a ceiling for example, the most useful part generally being in the vicinity of the center of the image.

[0018] Therefore, the present invention is based on the premise that a panoramic image has some zones that are not very useful and that can tolerate a reasonable definition to the benefit of other zones of the image.

[0019] On the basis of this premise, the idea of the present invention is to produce panoramic photographs by means of a panoramic objective lens that is not linear, which expands certain zones of the image and compresses other zones of the image. The technical effect obtained is that the expanded zones of the image cover a number of pixels of the image sensor that is higher than if they were not expanded, and thus benefit from a better definition. By choosing an objective lens that expands the most useful zones of an image (which depend on the intended application), the definition is excellent in these zones and the definition is mediocre in the zones of lesser importance.

[0020] Thus, the present invention proposes a method for capturing a digital panoramic image, by projecting a panorama onto an image sensor by means of a panoramic objective lens, in which the panoramic objective lens has an image point distribution function that is not linear relative to the field angle of object points of the panorama, the distribution function having a maximum divergence of at least ±10% compared to a linear distribution function, such that the panoramic image obtained has at least one substantially expanded zone and at least one substantially compressed zone.

[0021] According to one embodiment, the objective lens has a non-linear distribution function that is symmetrical relative to the optical axis of the objective lens, the position of an image point relative to the center of the image varying according to the field angle of the corresponding object point.

[0022] According to one embodiment, the objective lens expands the center of the image and compresses the edges of the image.

[0023] According to one embodiment, the objective lens expands the edges of the image and compresses the center of the image.

[0024] According to one embodiment, the objective lens compresses the center of the image and the edges of the image, and expands an intermediate zone of the image located between the center and the edges of the image.

[0025] According to one embodiment, the objective lens comprises a set of lenses forming an apodizer.

[0026] According to one embodiment, the set of lenses forming an apodizer comprises at least one aspherical lens.

[0027] According to one embodiment, the set of lenses forming an apodizer comprises at least one diffractive lens.

[0028] According to one embodiment, the objective lens comprises a set of mirrors comprising at least one distorting mirror.

[0029] The present invention also relates to a method for displaying an initial panoramic image obtained in accordance with the method described above, comprising a step of correcting the non-linearity of the initial image, performed by means of a reciprocal function of the non-linear distribution function of the objective lens or by means of the non-linear distribution function.

[0030] According to one embodiment, the step of correcting comprises a step of transforming the initial image into a corrected digital image comprising a number of image points higher than the number of pixels that the image sensor comprises.

[0031] According to one embodiment, the method comprises a step of calculating the size of the corrected image, by means of the reciprocal function of the distribution function, so that the resolution of the corrected image is equivalent to the most expanded zone of the initial image, and a step of scanning each image point of the corrected image, searching for the position of a twin point of the image point on the initial image and allocating the color of the twin point to the image point of the corrected image.

[0032] According to one embodiment, the initial image and the corrected image comprise an image disk.

[0033] According to one embodiment, the method comprises a step of transferring the image points of the corrected image into a three-dimensional space and a step of presenting one sector of the three-dimensional image obtained on a display means.

[0034] According to one embodiment, the method comprises a step of determining the color of image points of a display window, by projecting the image points of the display window onto the initial image by means of the non-linear distribution function, and allocating to each image point of the display window the color of an image point that is the closest on the initial image.

[0035] According to one embodiment, the projection of the image points of the display window onto the initial image comprises a step of projecting the image points of the display window onto a sphere or a sphere portion, a step of determining the angle in relation to the center of the sphere or the sphere portion of each projected image point, and a step of projecting onto the initial image each image point projected onto the sphere or the sphere portion, the projection being performed by means of the non-linear distribution function considering the field angle that each point to be projected has in relation to the center of the sphere or the sphere portion.

[0036] The present invention also relates to a panoramic objective lens comprising optical means for projecting a panorama into an image plane of the objective lens, the panoramic objective lens having an image point distribution function that is not linear relative to the field angle of object points of the panorama, the distribution function having a maximum divergence of at least ±10% compared to a linear distribution function, such that a panoramic image obtained by means of the objective lens comprises at least one substantially expanded zone and at least one substantially compressed zone.

[0037] According to one embodiment, the panoramic objective lens has a non-linear distribution function that is symmetrical relative to the optical axis of the objective lens, the position of an image point relative to the center of an image obtained varying according to the field angle of the corresponding object point.

[0038] According to one embodiment, the panoramic objective lens expands the center of an image and compresses the edges of the image.

[0039] According to one embodiment, the panoramic objective lens expands the edges of an image and compresses the center of the image.

[0040] According to one embodiment, the panoramic objective lens compresses the center of an image and the edges of the image, and expands an intermediate zone of the image located between the center and the edges of the image.

[0041] According to one embodiment, the panoramic objective lens comprises a set of lenses forming an apodizer.

[0042] According to one embodiment, the set of lenses forming an apodizer comprises at least one aspherical lens.

[0043] According to one embodiment, the set of lenses forming an apodizer comprises at least one diffractive lens.

[0044] According to one embodiment, the panoramic objective lens comprises polymethacrylate lenses.

[0045] According to one embodiment, the panoramic objective lens comprises a set of mirrors comprising at least one distorting mirror.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0046] The foregoing summary, as well as the following detailed description of preferred embodiments of the invention, will be better understood when read in conjunction with the appended drawings. For the purpose of illustrating the invention, there are shown in the drawings embodiments which are presently preferred. It should be understood, however, that the invention is not limited to the precise arrangements and instrumentalities shown.

[0047] In the drawings:

[0048] Fig. 1 described above represents a system for displaying a digital panoramic image on a screen;

[0049] Fig. 2 described above represents a panoramic image before it is processed by a computer;

[0050] Fig. 3 described above shows a classical method for transforming a two-dimensional panoramic image into a three-dimensional digital panoramic image;

[0051] Fig. 4A and 4B described above show the linearity of a classical panoramic objective lens;

[0052] Figs. 5 and 6 show one aspect of the method according to the present invention and respectively represent a distribution of image points obtained with a classical panoramic objective lens and a distribution of image points obtained with a non-linear panoramic objective lens according to the present invention;

[0053] Figs. 7A and 7B show a first example of non-linearity of a panoramic objective lens according to the present invention;

[0054] Fig. 8 shows a second example of non-linearity of a panoramic objective lens according to the present invention;

[0055] Fig. 9 shows a third example of non-linearity of a panoramic objective lens according to the present invention;

[0056] Fig. 10 represents a system for displaying a digital panoramic image by means of which a method for correcting the panoramic image according to the present invention is implemented;

[0057] Fig. 11 schematically shows a first embodiment of the correction method according to the present invention;

[0058] Fig. 12 is a flow chart describing a method for displaying a panoramic image incorporating the first correction method according to the present invention;

[0059] Fig. 13 schematically shows a second embodiment of the correction method according to the present invention;

[0060] Fig. 14 is a flow chart describing a method for displaying a panoramic image incorporating the second correction method according to the present invention;

[0061] Fig. 15 is a cross-section of a first embodiment of a non-linear panoramic objective lens according to the present invention;

[0062] Fig. 16 is an exploded cross-section of a system of lenses present in the panoramic objective lens in Fig. 15;

[0063] Fig. 17 is a side view of a lens present in the panoramic objective lens in Fig. 15; and

[0064] Fig. 18 is the diagram of a second embodiment of a non-linear panoramic objective lens according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0065] A - Compression/expansion of an initial image

[0066] Fig. 5 schematically represents a classical system for taking panoramic shots, comprising a panoramic objective lens 15 of optical axis OZ and a digital image sensor 17 arranged in the image plane of the objective lens 15. Here, four object points a, b, c, d will be considered that belong to a panorama PM located opposite the objective lens and respectively having angles of incidence $\alpha 1$, $\alpha 2$, $-\alpha 2$, $-\alpha 1$. As explained in the preamble, the field angle of an object point is the angle that an incident light ray passing through the object point considered and through the center of the panorama PM, marked by a point "p" on Fig. 5, has relative to the optical axis OZ of the objective lens. In this example, the angle $\alpha 1$ is equal to two times the angle $\alpha 2$. On the image sensor 17, image points a', b', c', d' corresponding to the object points a, b, c, d are located at distances from the center of the image respectively equal to d1, d2, -d2, -d1. As the distribution of the image points according to the field angle of the object points is linear with a classical panoramic objective lens, the distances d1 and d2 are linked by the following relation:

$$d1/\alpha 1 = d2/\alpha 2$$

As the angle $\alpha 1$ is here equal to $2\alpha 2$, it follows that:

$$d1 = 2d2$$

[0067] As is well known by those skilled in the art, the term "linearity" here refers to a ratio of proportionality between the distance of an image point measured relative to the center of the image and the field angle of the corresponding object point. The notion of "linearity" in the field of panoramic objective lenses is therefore different from that prevailing in the field of paraxial optics (in the vicinity of the optical axis) when the conditions of Gauss are met.

[0068] Fig. 6 represents a system for taking shots of the same type as above, but in which the classical panoramic objective lens 15 is replaced by an objective lens 18 according to the present invention, the image sensor 17 being arranged in the image plane of the objective lens 15. The projection onto the image sensor 17 of the object points a, b, c, d having angles of incidence $\alpha 1$, $\alpha 2$, $-\alpha 2$ and $-\alpha 1$ relative to the axis OZ of the objective lens and to the center "p" of the panorama are considered again. On the image sensor 17, the corresponding image points a", b", c", d" are located at distances from the center of the image respectively equal to d1', d2', -d2', -d1'.

[0069] According to the present invention, the objective lens 18 has a distribution function of the image points that is not linear. The ratio of the distances d1', d2', -d2', -d1' are not equal to the ratio of the angles of incidence $\alpha 1$, $\alpha 2$, $-\alpha 2$, $-\alpha 1$. In the example represented, the distance d2' is clearly greater than d1'/2, such that the central part of the panoramic image projected onto the image sensor 17, which corresponds to a solid angle 2α2 centered on the optical axis OZ, occupies a greater area on the image sensor 17 than the area it occupies in Fig. 5 with the classical panoramic objective lens (hatched zone). This central part of the panoramic image is therefore projected onto the image sensor with expansion of its area, in relation to the area the central part would occupy if the objective lens were linear. The result is that the number of pixels of the image sensor covered by this part of the image is greater than in previous practices and that the definition obtained is improved. On the other hand, the part of the image delimited by two circles respectively passing through the points a", d" and through the points b", c" is compressed relative to the corresponding part in Fig. 5, and the definition on the edges of the image is less than that obtained with a classical linear objective lens, to the benefit of the central part of the image.

[0070] By applying the principle according to the present invention, which involves expanding one part of the image and compressing another part of the image, the part to be expanded and the part to be compressed can be chosen according to the intended application, by producing several types of non-linear objective lenses and by choosing an objective lens suited to the intended application. Depending on the intended application, the most useful part of a panoramic image may be located in the center of the image, on the edge of the image, in an intermediate zone situated between the center and the edge of the image, etc.

[0071] Figs. 7A-7B, 8 and 9 show three examples of non-linear distribution functions according to the present invention.

[0072] The distribution function shown in Figs. 7A and 7B corresponds to the example in Fig. 6, that is a panoramic objective lens that expands the image in the center. Fig. 7A represents equidistant concentric circles C10, C20,..., C90 present on an image disk, each circle being formed by image points corresponding to object points having the same field angle. The circle C10 is formed by the image points corresponding to object points having a field angle of 10°, the circle C20 is formed by image points corresponding to object points having a field angle of 20°, etc. By comparing Fig. 7A with Fig. 4A described in the preamble, it appears that the circles C10 and C20 are further from the center of the image and further from each other than the circles C10 and C20 obtained with a classical objective lens, while the circles C30 to C90 are closer to each other. This panoramic image thus has an expanded zone in the center and a compressed zone on the edge of the image disk.

[0073] Fig. 4B represents the curve of the corresponding distribution function Fd1. The classical linear distribution function, expressed by Fdc = Kα and in the form of a straight line of gradient K, is also represented as a guide mark (the constant K being equal to 1/90 for an objective lens having an aperture of 180°, i.e., a gradient of 0.111 per degree). The field angle α of the object points is represented on the X-axis and is between 0 and 90°. The relative distance *dr* of an image point in relation to the center of the image disk is represented on the Y-axis and is between 0 and 1. The curve of the function Fd1 has a higher gradient than the straight line Fdc for angles α of between 0 and 20°, then a lesser gradient after 20° and up to 90°. A high gradient means an expansion of the image and a low gradient means a compression of the image.

[0074] As demonstrated in this example, the curve Fd1 has a point of maximum divergence Pd at the angle α = 20°. "Point of maximum divergence" refers to the image point Pd(α) at which the greatest gap in relative distance *dr* in relation to a corresponding point Pdl(α) on the linear distribution straight line Kα can be observed. In this example, the point Pd(α=20°) has a relative distance *dr* equal to 0.5 relative to the center of the image while the corresponding point Pdl(α=20°) on the linear curve Fdc has a relative distance *dr* of 0.222. The maximum divergence DIVmax of the distribution function Fd1 according to the present invention can be calculated by a formula of the type:

$$DIVmax\% = [[dr(Pd) - dr(Pdl)]/[dr(Pdl)]]*100$$

i.e.:

$$DIVmax\% = [[dr(Pd) - K*\alpha(Pd)]/[K*\alpha(Pd)]]*100$$

In which *dr*(Pd) is the relative distance in relation to the center of the point of maximum divergence Pd, *dr*(Pdl) is the relative distance in relation to the center of the corresponding point on the linear distribution straight line Fdc, α(Pd) being the abscissa of the point Pd, i.e., the field angle of the corresponding object point.

[0075] In the example considered here, the maximum divergence is therefore equal to +125%. This value of maximum divergence according to the present invention is clearly higher than that due to the possible design errors or manufacturing errors of a classical panoramic objective lens, which is of a few percent. Generally speaking, a non-linear objective lens according to the present invention has a maximum divergence on the order of 10% at least, to obtain an expansion of the useful parts of the image which results in a clear increase in the number of pixels of the image sensor covered by the useful parts and a substantial improvement in the definition obtained.

[0076] An average rate TX of expansion or compression of one part of the image contained between two circles passing through points Pd1 and Pd2 is also defined. The rate TX is the ratio between the area delimited by the two circles passing through the points Pd1, Pd2 and the area delimited by two circles passing through points Pdl1, Pdl2 of the same abscissa belonging to the linear distribution function Fdc. The rate TX can be determined by a formula of the type:

$$TX = [dr(Pd1)^2 - dr(Pd2)^2] / [(dr(Pdl1))^2 - (dr(Pdl2))^2]$$

i.e.:

$$TX = [dr(Pd1)^2 - dr(Pd2)^2] / [K^2[(\alpha(Pd1))^2 - (\alpha(Pd2))^2]]$$

[0077] A rate TX higher than 1 indicates an expansion of the part of image considered while a rate TX lower than 1 indicates a compression of the part of image considered. In the example of function Fd1 considered here, the average rate of expansion/compression TX of the central part of the image, delimited by the circle C20, is equal to 5.07, i.e., an average expansion by a factor 5 of the central part of the image and consequently a 500% improvement of the definition obtained for a constant number of pixels of the image sensor.

[0078] Fig. 8 represents another example of distribution function Fd2 according to the present invention, here having a point of maximum divergence Pd at the angle α=70°, and having a relative distance in relation to the center of the image of 0.3. The maximum divergence of the curve Fd2 is –61.4% here, and the average rate of expansion/compression TX of the central part of the image delimited by the circle C70 (not represented) is 0.5, i.e., an average compression by a factor of 0.15 of the central part of the image. The expanded part of the image here is thus located here on the edge of the image, between the circle C70 and the circle C90, and has an average rate of expansion/compression of 2.3. Thus, an image disk obtained with a panoramic objective lens having a distribution function conforming to the function Fd2, has a high definition zone on its edges, that lend themselves well to digital enlargements, and a low definition zone in its central part.

[0079] Fig. 9 represents a third example of distribution function Fd3 according to the present invention, having a first point of maximum divergence Pd1 (α=30°, *dr*=0,1) and a second point of maximum divergence Pd2 (α=70°, *dr*=0,9). Thus, two maximum divergences can be seen, one negative and equal to -70%, and the other positive and equal to 15.8%. A compressed image zone can also be seen between the center O of the image and the circle C30 passing through the point Pd1, an expanded image zone between the circle C30 and the circle C70 passing through the point Pd2, and a compressed image zone between the circle C70 and the circle C90 forming the edge of the image disk. The average rates of expansion/compression TX(0,C30), TX(C30, C70), TX(C70, C90) for each of these zones are respectively equal to 0.09, 1.6 and 0.48. An image disk obtained with a panoramic objective lens having a distribution function conforming to the function Fd3, has a high definition zone in its intermediate part, which lends itself well to digital enlargements, and two low definition zones in its central part and on its edges.

[0080] B - C rrection of the non-linearity of the initial image

[0081] A first aspect of the present invention was described above, according to which a non-linear distribution of image points onto a digital image was provided to improve the definition of the image in expanded zones, by increasing the number of pixels of the image sensor covered by the expanded zones. Before describing examples of embodiments of non-linear panoramic objective lenses according to the present invention, a second aspect of the present invention will be described which involves correcting the non-linearity of the image disk obtained in order to present the observer with an image free from optical distortion.

[0082] This second aspect of the present invention is implemented at the stage of the processing of the initial image by computer, to present an interactive panoramic image on a screen. The means for implementing the method of the present invention are shown in Fig. 10 and are classical in themselves. A digital camera 20 can be equipped with a non-linear panoramic objective lens 21 and connected to a microcomputer 22 comprising a screen 23. The digital images IMi taken by means of the camera 20 are transferred to the microcomputer to be processed and displayed on the screen 23, in a display window 24. A processing program comprising an algorithm for transforming and displaying the images is first loaded into the microcomputer, by means of a CD-ROM 25 or by downloading via the Internet for example. The camera 20 can be a still digital camera or a digital video camera and the connection to the microcomputer can be permanent or otherwise. In the case of a video camera, the microcomputer receives a flow of images that it processes in real time to display them on the screen.

[0083] In this context, the correction method according to the present invention can be performed according to two embodiments. A first embodiment involves correcting the initial image by means of a function Fd^{-1} that is the reciprocal function of the distribution function Fd according to the present invention. As the distribution function Fd is known and determined at the time the non-linear objective lens is designed, it is easy to deduce the reciprocal function Fd^{-1} therefrom. This correction step allows a corrected image to be obtained in which the non-linearity due to the objective lens according to the present invention is removed. The corrected image is equivalent to an image taken by means of a classical panoramic objective lens and can then be processed by any classical display software program available in stores, provided for transferring the image points of an image disk into a three-dimensional space and for interactively displaying a sector of the image obtained.

[0084] The second alternative of the method involves using the distribution function Fd in an image display algorithm working backwards, that is defining in real time the color of the pixels of a display window using the image points of the image disk.

[0085] First embodiment of the correction method

[0086] Fig. 11 shows the first embodiment of the method according to the present invention. Here it is assumed that there is an initial image Img1 comprising a non-linear image disk ID1 of radius R1, having for example an expansion zone in the center (circles C10 and C20). The initial image Img1 is transformed into a corrected image Img2 comprising a linear image disk ID2 of radius R2. The radius R2 of the image disk ID2 is higher than the radius R1 of the initial image disk ID1 and the image disk ID2 has a resolution equal or substantially equal to the resolution offered by the zone of the image disk Img1 in which the greatest density of information (i.e. the zone in which the image is the most expanded) is to be found. Here, the zone with the greatest density of information is the central part of the image delimited by the circle C20.

[0087] The main steps of this method are the following:

initially, the size R2 of the linearized image disk ID2 is calculated by means of the reciprocal function Fd^{-1}, considering on the initial image disk ID1 the place in which the image is the most expanded, so that the corrected image Img2 has a resolution equal or substantially equal to the resolution offered by the zone of the image Img1 in which the greatest density of information is to be found,

then each pixel of the image to be calculated Img2 is scanned, and the position of its twin point on the image Img1 is searched for, and then

the color of the corresponding point on the initial image Img1 is allocated to the point of the new image Img2.

[0088] This method is implemented by means of an algorithm described below (algorithm 1), in which:

A is the angular aperture of the objective lens,

D is the distance of an image point relative to the center of the initial image disk ID1,

R1 is the size in pixels of the radius of the initial image disk ID1 (i.e. the number of pixels between the center and the edge of the image disk),

R2 is the size in pixels of the radius of the linearized image disk ID2, I and J are the coordinates of an image point in the image produced, the coordinate point (0,0) being in the center of the image,

U and V are the coordinates of a twin point in the original image, the coordinate point (0,0) being in the center of the image,

"Current_angle" and "Previous_angle" are iterative parameters,

DAM is the minimum angular difference between two object points corresponding to two adjacent image points on the initial image disk ID1 (i.e., the maximum resolution of the image disk ID1 expressed in angular difference), and

$Fdlin^{-1}$ is the reciprocal function of a distribution function of a classical linear objective lens, of the type: $Fdlin(\alpha)=K\alpha$, with K=2/A, i.e. K=1/90 with an objective lens having an angular aperture of 180°.

<u>Algorithm 1</u>

[finding DAM]

1/ DAM = A/2

2/ Current_angle = 0

3/ For D = 1 to R1 [with increments of 1]

4/ Previous_angle = Current_angle

5/ Current_angle = Fd^{-1}(D/R1)

6/ If DAM > (Current_angle - Previous_angle) then

7/ DAM = (Current_angle - Previous_angle)

8/ End if

9/ End for

[determining the radius R2 of the disk ID2]

10/ R2 = (A/2)/DAM

[calculating the new image]

[scanning each pixel of the image to be calculated Img2]

11/ For I =–R2 to +R2 [with an increment of 1]

12/ For J =–R2 to +R2 [with an increment of 1]

[searching for polar coordinates (R',θ) of the twin point on the image Img1 using the coordinates (R,θ) of the point of the image Img2]

13/ $R = \sqrt{(I^2+J^2)}$

```
14/          If R < R2 then
15/                  If J < 0 then
16/                          θ = arc cosine(I/R)
17/                  If not
18/                          θ = -arc cosine(I/R)
19/                  End if
[conversion of the radius R to find the radius R']
                     20/ R'= R1*Fd(Fdlin^-1 (R/R2))
as Fdlin^-1(R) = R/K and K=2/A, it follows that:
20'          /R'= R1*Fd((R/R2) * (A/2))
[return to the Cartesian coordinates]
21/          U = R'*cos(θ)
22/          V = R'*sin(θ)
[allocation of the color of the point]
23/          Img2[I,J] = Img1[U,V]
24/    If not
[allocation of the color black to the points outside the image disk]
25/          Img2[I,J] = Black
26/    End if
27/  End for
28/  End for
```

[0089] Note that the step 14 avoids calculating all the points situated outside the image disk (the points are outside the image disk when R > R2). Moreover, the algorithm 1 can be improved by subsequently performing a bilinear interpolation on the image Img2, in itself well known by those skilled in the art, so as to smooth out the final image.

[0090] Fig. 12 is a flow chart giving a general overview of the steps of a method for capturing and interactively presenting a panoramic image on a screen. This flow chart is described in table 1 in the Appendix, that is an integral part of the description. The steps S1 and S2, respectively the acquisition of the image and the transfer of the image into a computer, are classical in themselves. The step of linearising the image disk S3 is performed in accordance with the method of the present invention, by means of the algorithm described above for example. The step S4, called "digitization", is also classical. This step involves transferring the image points of the corrected image disk Img2 into a three-dimensional space of axes Oxyz in which the image points are for example referenced in spherical coordinates. The step S5 is also classical, and involves displaying a sector of the three-dimensional image called display window on a screen. The display window is moved upwards or downwards depending on the user's actions, or is enlarged at the user's request. When enlarged, the definition is better than in previous practices in the zones corresponding to the expanded parts of the initial image.

[0091] Second embodiment of the correction method

[0092] The second embodiment of the correction method according to the present invention is shown in Fig. 13. Schematically, this method involves projecting the image points of an image sector corresponding to a display window DW onto the image disk ID1 of the initial image Img1. This method does not require calculating a corrected image disk, contrary to the previous embodiment.

[0093] The image points of the display window DW are referenced E(i,j) in the coordinate system of the display window, expressed in line coordinates i and in column coordinates j. The points E(i,j) are first projected onto a sphere portion HS of center O and of axes OX, OY, OZ, to obtain image points P(px, py, pz) belonging to the sphere portion. This sphere portion covers a solid angle that corresponds to the aperture of the objective lens used. The example considered until now was of a panoramic objective lens having an aperture of 180° and the sphere portion HS considered here is therefore a hemisphere. The image points P thus determined are then projected onto the image disk Img1 by means of the non-linear distribution function Fd according to the present invention, which first requires calculating the field angle α of the points P in relation to the center O of the hemisphere. The center O of the hemisphere is the virtual equivalent of the center "p" of the panorama, having been used as the reference, in the description above, to determine the angles of incidence α of the object points and the shape of the function Fd. The projection of the image points P onto the image disk ID1 allows image points p(pu, pv) to be obtained on the image disk, in a coordinate system of center O' (corresponding to the center of the image disk) and of axes O'U and O'V. The axis OZ in the system of the hemisphere HS is perpendicular to the plane of the image disk ID1 and passes through the center O' of the image disk, such that the axes O'Z and OZ are merged.

[0094] As it will be clear to those skilled in the art, the correction of the non-linearity of the image disk is implicit here since the image points p(pu, pv) corresponding to the image points E(i, j) of the display window DW are "retrieved" from the image disk ID1, by means of the function Fd.

[0095] The method according to the present invention is implemented by means of an algorithm described below (algorithm 2), in which:

i and j are the coordinates of a point E(i, j) of the display window,

Imax and Jmax are the number of columns and the number of lines of the display window, corresponding to the dimensions in number of pixels of the display window,

Ex, Ey and Ez are the Cartesian coordinates of a point E(i,j) of the display window DW in the coordinate system OXYZ,

Px, Py and Pz are the Cartesian coordinates of a point P on the hemisphere HS,

pu and pv are the Cartesian coordinates of an image point p of the image disk in the coordinate system O'UV,

L is the size of the image disk, in number of pixels,

M is the center of the display window DW,

the "viewing direction" is the direction materialised by the point O and the center of the display window M, the display window forming the base of a pyramid of vision of the observer the top of which is the point O (observer's position),

θ0 and φ0 are the longitudes and latitudes corresponding to the viewing direction from the point O towards the center M of the display window,

Screen_Pixel[i,j] is the color (RGBA) of a point E (i,j) of the display window DW,

Image_Pixel[i,j] is the color of the point P(i,j) of the hemisphere HS corresponding to the image disk, the coordinate point (0,0) being situated in the center of the image disk,

R is the radius of the hemisphere HS (arbitrary value chosen so as to improve the accuracy of the calculations, R is for example chosen to be equal to 10,000),

α is the angle in relation to the center O of an image point P situated on the hemisphere (represents the field angle at the moment the shot of the corresponding object point is taken),

aux1, aux2 are intermediate variables,

"Zoom" is a variable defining the enlargement, having a default value equal to R, and

"√" is the square root function.

<u>Algorithm 2</u>

1/ For i=-Imax/2 to i=Imax/2 do *[by increments of 1]*

```
For j=-Jmax/2 to j=Jmax/2 do [by increments of 1]
[calculation of the Cartesian coordinates Ex, Ey, Ez of the point E of the display window in the system OXYZ]
        Ey = j*cos(φ0) – Zoom*sin(φ0)
        Ez = Zoom*cos(φ0) + j*sin(φ0)
        aux1 = Ez
        Ez = Ez*cos(θ0) – i*sin(θ0)
        Ex = i*cos(θ0) + aux1*sin(θ0)
[calculation of the coordinates of the point P corresponding to the point E]
        aux2 = R/√(Ex*Ex + Ey*Ey + Ez*Ez)
        Px = Ex*aux2
        Py = Ey*aux2
        Pz = Ez*aux2
[calculation of the coordinates of the point p corresponding to the point P, in the coordinate system (O'UV), by means of the function Fd]
        X = Px/R
        Y = Py/R
        r = √(X*X + Y*Y)
        α = arcsine(r)
        U = X/r
        V = Y/r
        pu = L*U*Fd(α)
        pv = L*V*Fd(α)
        Screen_Pixel[i,j] = Image_Pixel[pu,pv]
    end for
end for
```

[0096] A request for enlargement (zoom) by the user results in the algorithm modifying the "Zoom" parameter. When the "Zoom" parameter is equal to the radius R of the hemisphere, the display window DW is tangential to the hemisphere (Fig. 13). When the parameter "Zoom" is higher than R, the window DW moves away from the hemisphere (along the axis given by the viewing position 0M), which corresponds to a shrinking of the pyramid of vision and an enlargement of the image sector presented in the window DW. The enlargement of the image sector presented to the observer is therefore equal to the ratio of the "Zoom" parameter by the radius R.

[0097] When the steps 18 and 19 have been performed with a "Zoom" parameter higher than R, a gain in definition is obtained in the zones in which the image has been expanded at the time the shot is taken as there are still. While the resolution limit is not reached, two adjacent pixels on the image disk which correspond to two adjacent pixels of the display window. In the compressed zones of the image, the search for the closest pixel by means of the relations $L*U*Fd(\alpha)$ and $L*V*Fd(\alpha)$ results, on the other hand, in the algorithm finding the same image pixel for several adjacent pixels of the display window on the image disk. However, these compressed image zones, benefiting from a lesser definition on the image disk, are considered secondary for the intended application, in accordance with the premise on which the present invention is based.

[0098] Generally speaking, any other projection method can be used, the essential step according to the present invention being that of finding the field angle α of the object points on the hemisphere, in relation to the center of the hemisphere, so as to use the distribution function Fd in the calculations.

[0099] It will be understood that the algorithm 2 is applicable when there are two complementary image disks, one corresponding to a front photograph and the other to a rear photograph of a panorama at 360°, the second photograph being taken by rotating the panoramic objective lens by 180° around an axis passing through the center of the panorama. In this case, two hemispheres and two image points called "Front_Image_Pixel" and "Rear_Image_Pixel" are defined:

Front_Image_Pixel[i,j]: color of a point E(i,j) on the hemisphere corresponding to the front photo, the coordinate point (0,0), being situated in the center of the image disk,

Rear_Image_Pixel[i,j]: color of a point E(i,j) on the hemisphere corresponding to the rear photo, the coordinate point (0,0) being situated in the center of the image disk.

[0100] The steps 18 and following of the algorithm 2 are therefore modified as follows:

18/ pu = L*U*Fd(α)

19/ pv = L*V*Fd(α)

20/ If Pz >= 0 then

21/ Screen_Pixel[i,j] = Front_Image_Pixel[pu,pv]

22/ If not Screen_Pixel[i,j] = Rear_Image_Pixel[L-pu,pv]

23/ End if

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24/ end for

25/ end for

[0101] Fig. 14 is a flow chart giving a general overview of the steps of a method for capturing and interactively presenting a panoramic image on a screen. This flow chart is described in table 2 in the Appendix, that is an integral part of the description. The acquisition S1 and transfer S2 steps described above are again included. The step S2 is followed by an interactive display step S3' performed in accordance with the method that has just been described, implicitly incorporating a correction of the non-linearity of the image disk through the use of the distribution function Fd to find the points corresponding to the pixels of the display window on the image disk.

[0102] II - Examples of embodiments of a non-linear panoramic objective lens according to the present invention

[0103] Here, one object of the present invention is to provide a panoramic objective lens having a non-linear distribution function Fd, that is simple in structure and with a low cost price. Below, two examples of embodiments of non-linear panoramic objective lenses according to the present invention will be described, the first being a direct-type objective lens and the second of indirect type, that is using mirrors.

[0104] First embodiment

[0105] Apodizers are optical systems well known by those skilled in the art, used to change the energy distribution (amount of light) of a source of light at the pupil. They are particularly used to level out the energy in a laser beam or even, in the field of photography, to limit the diffraction of light through the lenses. Using an apodizer as a filter is also well known, to cover the aperture of an optical instrument in order to remove the secondary rings of a diffraction pattern. When it is desirable to separate the images of two neighbouring pin-point sources, these secondary rings are a nuisance and reduce the resolution. "Apodization" can thus be performed, that is these secondary rings can be removed by placing an adequate filter in the plane of the pupil.

[0106] Here, the idea of the present invention is to use an apodizer for a different purpose: the principle of the apodizer is used to control the angular distribution of a panoramic objective lens and to obtain the non-linearity sought.

[0107] Fig. 15 represents, by a cross-section, an example of an embodiment of a non-linear objective lens 30 according to the present invention. The distribution function Fd obtained by means of the objective lens 30 is the function Fd1 described above in relation with Fig. 7B, the objective lens 30 thus expanding the image in the center.

[0108] The objective lens 30 comprises a system of lenses that is also represented in Fig. 16 by an exploded view. A divergent optical group formed by lenses L1, L2, L3, and a convergent optical group formed by lenses L4, L5, L6, L7 can be distinguished. A diaphragm D1 is arranged between the lenses L6 and L7.

[0109] Parts B1 to B4 and parts I3 to I6 are provided to hold the lenses. The part B1 forms the body of the objective lens and comprises a cylindrical cavity in which the lenses L2 to L6 are arranged. The part B2 is screwed onto the body B1 and allows the front lens L1 to be fastened against the front of the part B1, the back of the lens L1 being in contact with the front of the lens L2. The parts B3 and B4 are fastened with screws (not represented) against the rear part of the body B1. The part B3 holds the diaphragm D1 and comprises a cavity for receiving the back lens L7. The part B4 presses the lens L7 into the part B3 and comprises a rear sleeve F1 equipped with a thread allowing an image sensor to be fastened, such as a CCD sensor for example. The parts I3 to I6 are dividers allowing the distances between the lenses L2 to L6 inside the body B1 to be adjusted with precision.

[0110] The divergent optical group L1, L2, L3 defines the field angle of the objective lens 30, here of 180°. The front lens L1 is a divergent meniscus in PMMA with an aspherical front and a concave back. It must be said that PMMA or polymethacrylate is organic glass with a low cost price, belonging to the category of plastics. The lens L2 is of the planoconcave type and is made of borosilicate BK7 (standard optical mineral glass). Its front (plane side) is pressed against a flat part of the back of the lens L1, which extends at the periphery of the concave part (useful part) of the back of the lens L1. The lens L3 is also of the planoconcave type and is in BK7. Its concave side is oriented towards the front, opposite the back of the lens L2.

[0111] The convergent optical group L4, L5, L6, L7 forms an apodizer within the meaning of the present invention and determines the non-linear distribution function Fd, which is obtained here by means of a-spherical lenses and a diffractive lens.

[0112] The lens L4 is of the planoconcave type and is in PMMA. Its concave front is a-spherical. The lens L5 is of the planoconvex type and is in BK7, its plane side being oriented towards the front. The lens L6 is a meniscus in PMMA having a concave and aspherical front and a diffractive convex back. This diffractive back has a diffraction grating made up of circular diffractive zones centered on the optical axis of the lens, the profile of which is represented in Fig. 17. Finally, the back lens L7 is of the biconvex type and is in BK7. The back lens L7 focuses the luminous flux onto the image plane, at the spot provided for the image sensor.

[0113] The aspherical fronts of the lenses L1, L4 and L6 are determined by means of a formula of the type:

$$z(r) = [(C^*r^2)/(1 + \sqrt{}(1-(1+k)^*C^{2*}r^2)] + A_1r^2 + A_2r^4 + A_3r^6 + A_4r^8 + A_5r^{10}$$

in which:

"k" is a conicity constant,

"A1", "A2", "A3", "A4", "A5" are constants for adjusting the coefficient of conicity according to the position,

"z" is the shape of the surface,

"r" is the radius at the center, and

"C" is the radius of curvature.

[0114] The diffractive back of the lens L6 allows the number of lenses required to produce the objective lens 30 to be reduced. In the present embodiment, it avoids for example providing at least three supplementary complex lenses. It is determined by means of a formula of the type:

$$\varphi(r) = \alpha 1\ (r/R0)^2 + \alpha 2\ (r/R0)^4$$

in which:

"r" is the distance in relation to the center of the lens of a point considered, located on the surface of the lens,

$\alpha 1$ and $\alpha 2$ are constants defining the phase shift of the wave surface,

"R0" is a constant allowing r to be normalized, and

"φ" is the phase shift introduced by the diffractive surface at the point considered.

[0115] The lenses in PMMA L1, L4 and L6 are manufactured using a method called "diamond turning" well known by those skilled in the art, which involves milling the surface of the lenses along a mesh of points.

[0116] The solid angle of propagation of the light rays in each lens is marked on Fig. 15 by black lines. The light rays pass through the optical group L1, L2, L3, pass through the apodizer L4, L5, L6, L7 while being stopped down by D1.

[0117] The determination of the parameters defining the aspherical sides mentioned above, the formula of the diffraction grating of the lens L6, the calculation of the diameters of the lenses and of the distances between the lenses, are within the understanding of those skilled in the art using the classical computer-aided lens design tools.

[0118] **Second embodiment**

[0119] Fig. 18 schematically represents a non-linear objective lens 40 using a distorting mirror. The objective lens 40 comprises, at input, a divergent optical group consisting, for example, of the three lenses L1, L2, L3 described above, defining the field angle of the objective lens. Opposite the optical group a plane mirror M1 is located which reflects the luminous beam onto a distorting mirror M2 of aspherical concave shape. The beam reflected by the mirror M2 is sent onto an image sensor 43.

[0120] In this embodiment, the irregularities of sphericity that the concave part of the mirror has determined the angular distribution function Fd sought for the intended application (distortion in the center, on the edges...). The result obtained is equivalent to that of the optical system described above. Obtaining the distribution function Fd is within the understanding of those skilled in the art using computer-aided lens design tools which allow, in addition to designing lenses, reflecting surfaces to be designed and focused.

[0121] One alternative of this embodiment involves providing several distorting mirrors so as to combine distortions or simplify complex distortions by characterising a type of distortion per mirror, which has the advantage of facilitating the engineering work.

[0122] Yet another alternative involves using one or more deformable mirrors to produce a so-called "adaptive" optical system. Deformable mirrors comprise a layer of piezoelectric micro-pistons covered by a reflecting layer. Each piezoelectric piston is activated individually, so that the distortions of the mirror can be controlled at several points to obtain the desired shape. This device can be driven by an integrated circuit comprising several configurations of the micro-pistons in its memory, to obtain a distribution function Fd that is adjustable according to the intended use, which avoids providing several objective lenses.

[0123] Generally speaking, adaptive optics are in themselves known by those skilled in the art and used in high-precision telescopes to correct the optical defects of the lenses or atmospheric distortions. Deformable mirrors also exist in the field of optical disks, if reference is made for example to the U.S. Patent Nos. 5,880,896 and 5,745,278.

[0124] Therefore, means that are in themselves known are also used for different purposes, not to correct a lens but to obtain, on the contrary, a non-linear angular distribution function.

[0125] It will be understood that various other alternatives of the present invention may be made. In particular, although the description above was of non-linear panoramic objective lenses with axial symmetry relative to the optical axis, in which the position of an image point only varies with the field angle relative to this axis of the corresponding object point (which gives a distribution of points in concentric circles, as seen above), the framework of the present invention also covers providing objective lenses the non-linearity of which is not symmetrical relative to the optical axis, such that the expanded parts of the image may, in this case, not be set on the center of the image.

[0126] It will be appreciated by those skilled in the art that changes could be made to the embodiments described above without departing from the broad inventive concept thereof. It is understood, therefore, that this invention is not limited to the particular embodiments disclosed, but it is intended to cover modifications within the spirit and scope of the present invention as defined by the appended claims.

APPENDIX (forming an integral part of the description)

Table 1

S1 - Acquisition
- Taking a panoramic image by means of a still digital camera or a digital video camera equipped with a panoramic objective lens having a non-linear distribution function Fd
S2 – Transfer of the image file into a computer
- Transfer of the image file (image disk) into a microcomputer - Storage in the auxiliary storage (optional)
S3 -Linearisation of the image disk
- Transfer of the image points of the initial image disk into a second virtual image disk comprising more image points than the initial image disk, by means of the function Fd^{-1} ⇒ Obtaining a linear image disk
S4 - Digitization
- Transfer of the image points of the second image disk into a system of axes OXYZ in spherical coordinates ⇒ Obtaining a panoramic image in a hemisphere
S5 – Interactive display
- Determination of the image points of an image sector to be displayed - Display of the image sector on a display window - Detection of the user's actions on a screen pointer or any other control means, - Detection of the user's actions on keys for image enlargement, - Modification of the sector displayed (sliding the image sector displayed on the surface of the hemisphere and/or shrinking/expanding the image sector displayed)

Table 2

S1 – Acquisition - Taking a panoramic image by means of a still digital camera or a digital video camera equipped with a panoramic objective lens having a non-linear distribution function Fd
S2 – Transfer of the image file into a computer - Transfer of the image file (image disk) into a microcomputer - Storage in the auxiliary storage (optional)
S3' – Interactive display with implicit correction of the non-linearity of the initial image A - Determination of the color of the points E(i, j) of an image sector to be displayed using the points p(pu, pv) of the image disk: 1 - determination of the coordinates Ex, Ey, Ez in the coordinate system OXYZ of each point E(i, j) of the sector to be displayed, 2 - determination of the coordinates Px, Py, Pz of points P of the hemisphere corresponding to the points E(i, j), 3 – calculation of the coordinates, in the coordinate system O'UV of the image disk, of points p(pu, pv) corresponding to the points P of the hemisphere, by means of the function Fd, B - Presentation of the image sector in a display window, C - Detection of the user's actions on a screen pointer or any other control means, D - Detection of the user's actions on enlargement keys, E - Modification of the image sector displayed (moving and/or shrinking/expanding the image sector)

CLAIMS

We claim:

1. A method for capturing a digital panoramic image, by projecting a panorama onto an image sensor by means of a panoramic objective lens, the panoramic objective lens having an image point distribution function that is not linear relative to the field angle of object points of the panorama, the distribution function having a maximum divergence of at least ±10% compared to a linear distribution function, such that the panoramic image obtained has at least one substantially expanded zone and at least one substantially compressed zone.

2. The method according to claim 1, wherein the objective lens has a non-linear distribution function that is symmetrical relative to the optical axis of the objective lens, the position of an image point relative to the center of the image varying according to the field angle of the corresponding object point.

3. The method according to claim 1, wherein the objective lens expands the center of the image and compresses the edges of the image.

4. The method according to claim 1; wherein the objective lens expands the edges of the image and compresses the center of the image.

5. The method according to claim 1, wherein the objective lens compresses the center of the image and the edges of the image and expands an intermediate zone of the image located between the center and the edges of the image.

6. The method according to claim 1, wherein the objective lens comprises a set of lenses forming an apodizer.

7. The method according to claim 6, wherein the set of lenses forming an apodizer comprises at least one aspherical lens.

8. The method according to claim 6, wherein the set of lenses forming an apodizer comprises at least one diffractive lens.

9. The method according to claim 1, wherein the objective lens comprises a set of mirrors including at least one distorting mirror.

10. A method for displaying an initial panoramic image obtained in accordance with the method according to claim 1, the method for displaying comprising:

correcting the non-linearity of the initial image, performed by means of a reciprocal function of the non-linear distribution function of the objective lens or by means of the non-linear distribution function.

11. The method according to claim 10, wherein the step of correcting comprises a step of transforming the initial image into a corrected digital image comprising a number of image points higher than the number of pixels that the image sensor comprises.

12. The method according to claim 11, further comprising:

calculating the size of the corrected image, by means of the reciprocal function of the distribution function, so that the resolution of the corrected image is equivalent to the most expanded zone of the initial image, and

scanning each image point of the corrected image, searching for the position of a twin point of the image point on the initial image and allocating the color of the twin point to the image point of the corrected image.

13. The method according to claim 11, wherein the initial image and the corrected image comprise an image disk.

14. The method according to claim 11, further comprising:

transferring the image points of the corrected image into a three-dimensional space, and

presenting one sector of the three-dimensional image obtained on a display means.

15. The method according to claim 10, further comprising:

determining the color of image points of a display window, by projecting the image points of the display window onto the initial image by means of the non-linear distribution function, and

allocating to each image point of the display window the color of an image point that is the closest on the initial image.

16. The method according to claim 15, wherein the projection of the image points of the display window onto the initial image comprises:

projecting the image points of the display window onto a sphere or a sphere portion,

determining the angle in relation to the center of the sphere or the sphere portion of each projected image point, and

projecting onto the initial image each image point projected onto the sphere or the sphere portion, the projection being performed by means of the non-linear distribution function considering the field angle that each point to be projected has in relation to the center of the sphere or the sphere portion.

17. A panoramic objective lens comprising:

optical means for projecting a panorama into an image plane of the objective lens, the optical means having an image point distribution function that is not linear relative to the field angle of object points of the panorama, the distribution function having a maximum divergence of at least ±10% compared to a linear distribution function, such that a panoramic image obtained by means of the objective lens comprises at least one substantially expanded zone and at least one substantially compressed zone.

18. The panoramic objective lens according to claim 17, having a non-linear distribution function that is symmetrical relative to the optical axis of the objective lens, the position of an image point relative to the center of an image obtained varying according to the field angle of the corresponding object point.

19. The panoramic objective lens according to claim 17, wherein the lens expands the center of an image and compresses the edges of the image.

20. The panoramic objective lens according to claim 17, wherein the lens expands the edges of an image and compresses the center of the image.

21. The panoramic objective lens according to claim 17, wherein the lens compresses the center of the image and the edges of the image, and expands an intermediate zone of the image located between the center and the edges of the image.

22. The panoramic objective lens according to claim 17, further comprising a set of lenses forming an apodizer.

23. The panoramic objective lens according to claim 22, wherein the set of lenses forming an apodizer comprises at least one aspherical lens.

24. The panoramic objective lens according to claim 22, wherein the set of lenses forming an apodizer comprises at least one diffractive lens.

25. The panoramic objective lens according to claim 22, comprising polymethacrylate lenses.

26. The panoramic objective lens according to claim 17, comprising a set of mirrors comprising at least one distorting mirror.

ABSTRACT OF THE DISCLOSURE

A method for capturing a digital panoramic image includes projecting a panorama onto an image sensor by means of a panoramic objective lens. The panoramic objective lens has a distribution function of the image points that is not linear relative to the field angle of the object points of the panorama, such that at least one zone of the image obtained is expanded while at least another zone of the image is compressed. When a panoramic image obtained is then displayed, correcting the non-linearity of the initial image is required and is performed by means of a reciprocal function of the non-linear distribution function of the objective lens or by means of the non-linear distribution function.

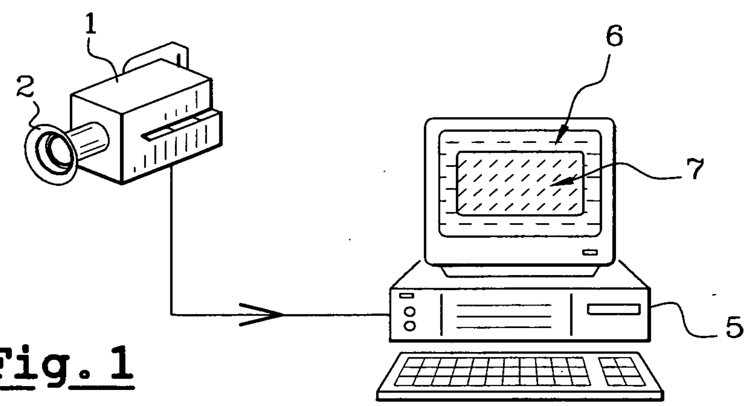


Fig. 1

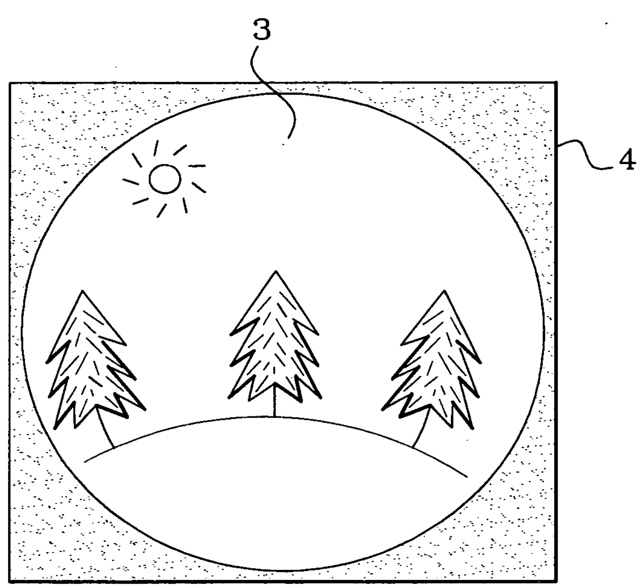


Fig. 2

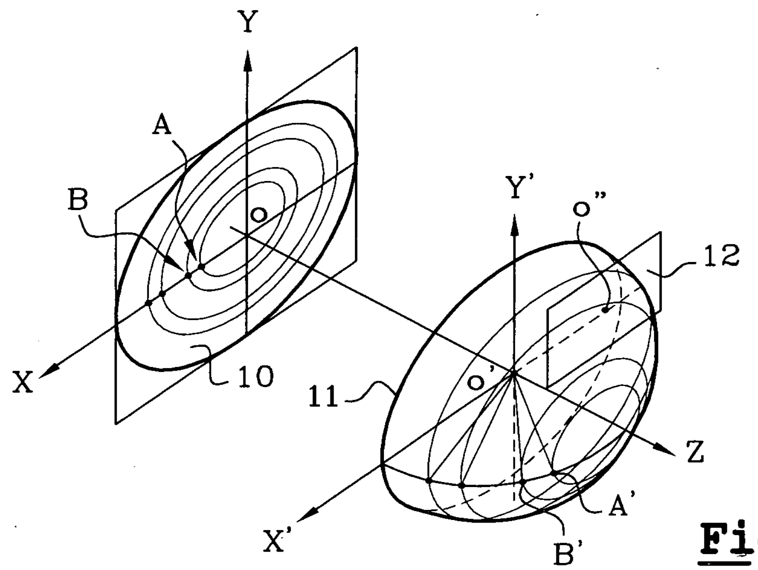


Fig. 3

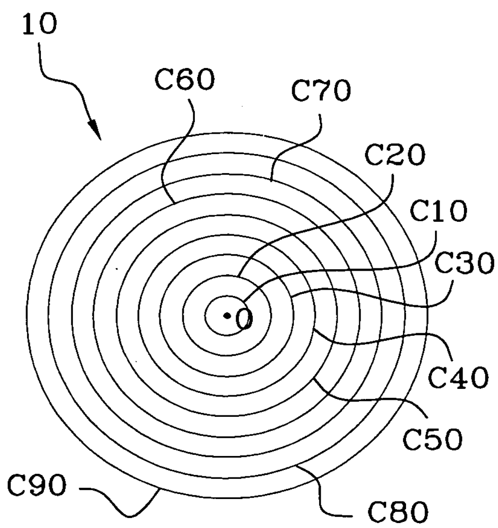
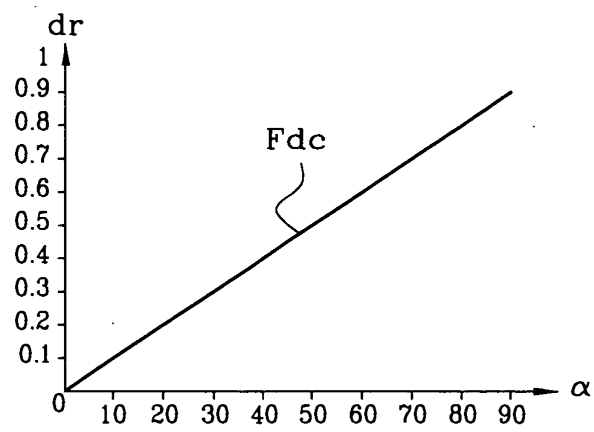


Fig. 4A



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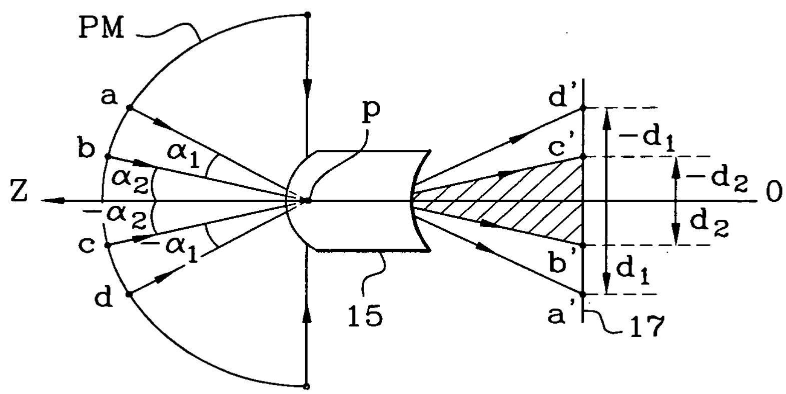

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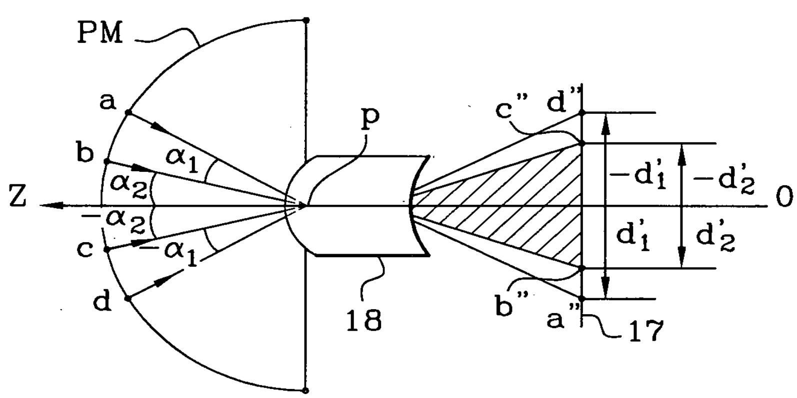

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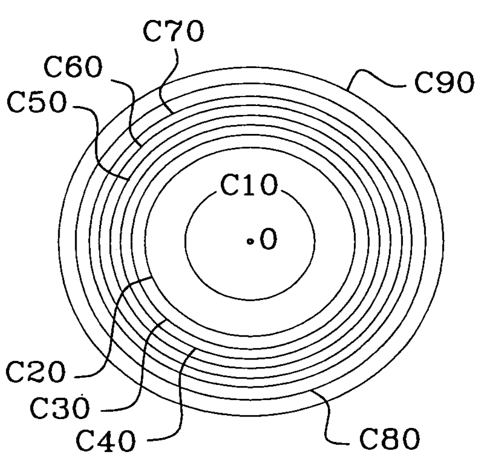

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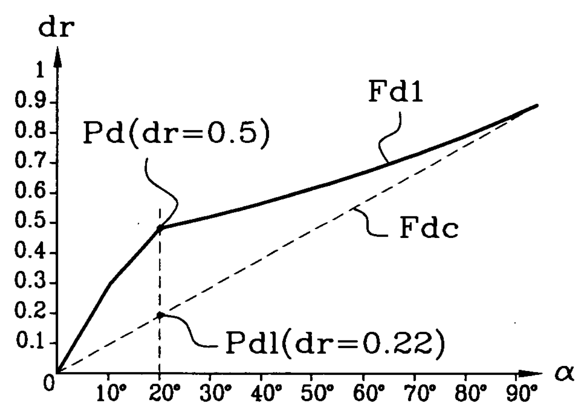

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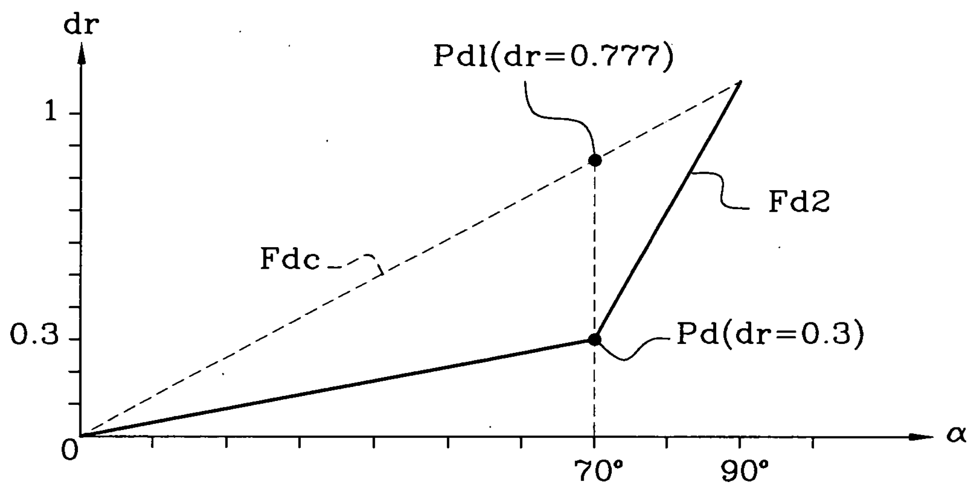
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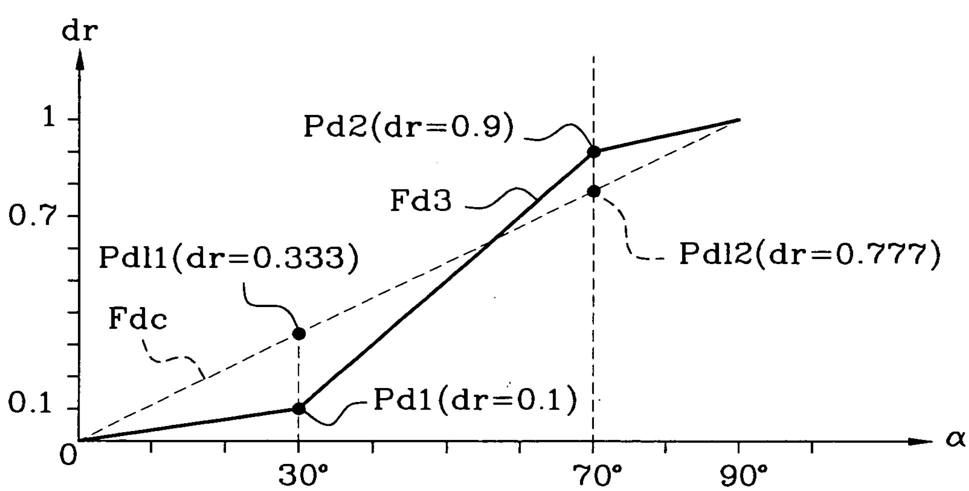
Fig. 8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90°
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Fig. 9

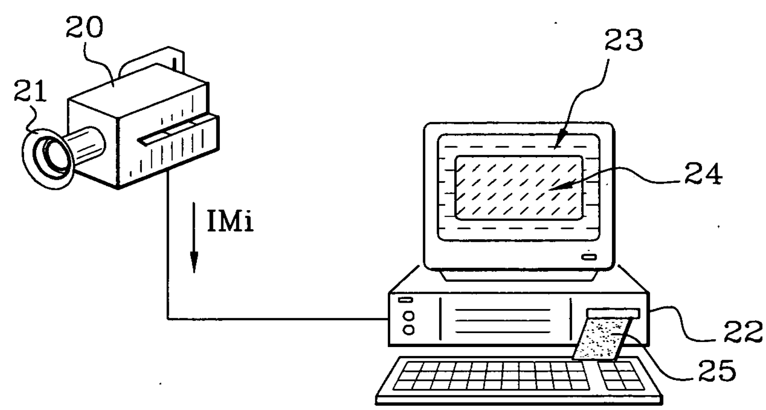
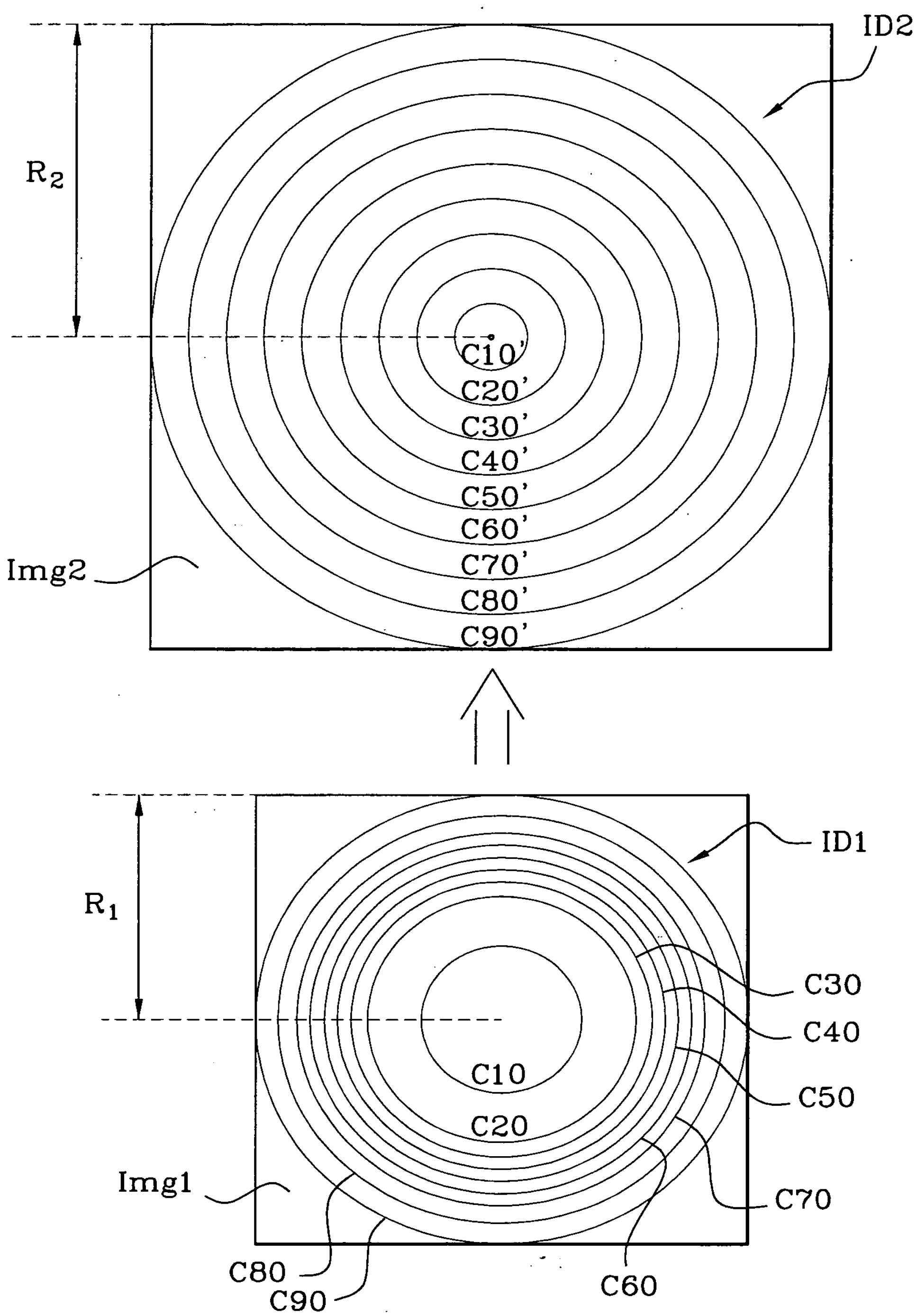


Fig. 10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C30
C40
C50
C10
C20
C70
Img1
C80
C90
C60

Fig. 11

Fig. 12

S1 – Acquisition

- Taking a panoramic image by means of a still digital camera or a digital video camera equipped with a panoramic lens having a non-linear distribution function Fd

S2 – Transfer of the image file into a computer

- Transfer of the image file (image disk) into a microcomputer
- Storage in the auxiliary storage (optional)

S3 -Linearisation of the image disk

- Transfer of the image points of the initial image disk into a second virtual image disk comprising more image points than the initial image disk, by means of the function Fd^{-1}

Obtaining a linear image disk

S4 – Digitisation

- Transfer of the image points of the second image disk into a system of axes OXYZ in spherical coordinates Obtaining a panoramic image in a hemisphere

S5 – Interactive display

- Determination of the image points of an image sector to be displayed
- Display of the image sector on a display window
- Detection of the user's actions on a screen pointer or any other control means,
- Detection of the user's actions on keys for image enlargement,
- Modification of the sector displayed (sliding the image sector displayed on the surface of the hemisphere and/or shrinking/expanding the image sector displayed)

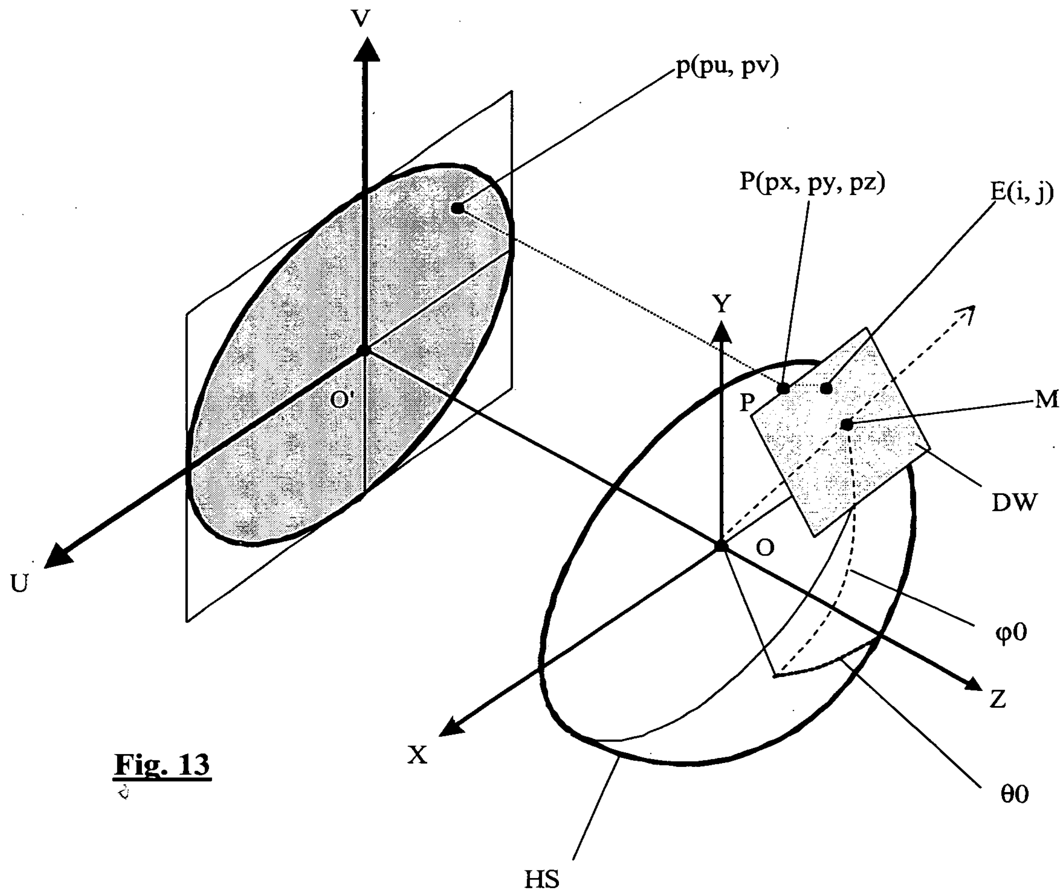

Fig. 13

Fig. 14

S1 – Acquisition

- Taking a panoramic image by means of a still digital camera or a digital video camera equipped with a panoramic lens having a non-linear distribution function Fd

S2 – Transfer of the image file into a computer

- Transfer of the image file (image disk) into a microcomputer
- Storage in the auxiliary storage (optional)

S3' – Interactive display with implicit correction of the non-linearity of the initial image

A - Determination of the colour of the points E(i, j) of an image sector to be displayed using the points p(pu, pv) of the image disk:

1- determination of the coordinates Ex, Ey, Ez in the coordinate system OXYZ of each point E(i, j) of the sector to be displayed,
2- determination of the coordinates Px, Py, Pz of points P of the hemisphere corresponding to the points E(i, j),
3- calculation of the coordinates, in the coordinate system O'UV of the image disk, of the points p(pu, pv) corresponding to the points P of the hemisphere, by means of the function Fd,

B - Presentation of the image sector in a display window,
C - Detection of the user's actions on a screen pointer or any other control means,
D - Detection of the user's actions on enlargement keys,
E - Modification of the image sector displayed (moving and/or shrinking/expanding the image sector)

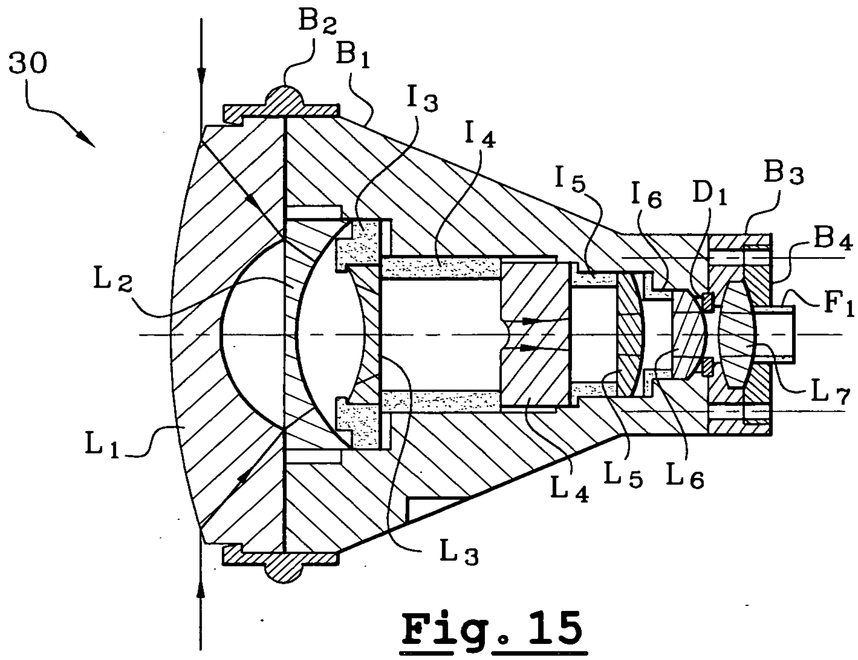

Fig. 15

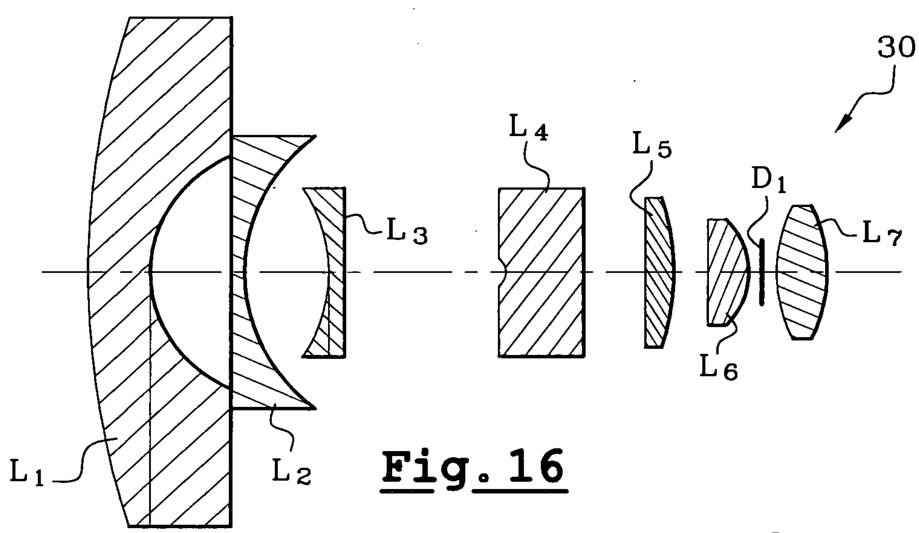

Fig. 16

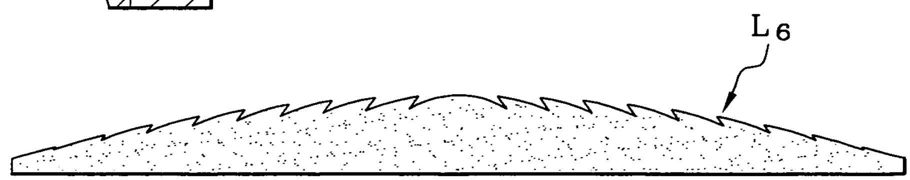

Fig. 17

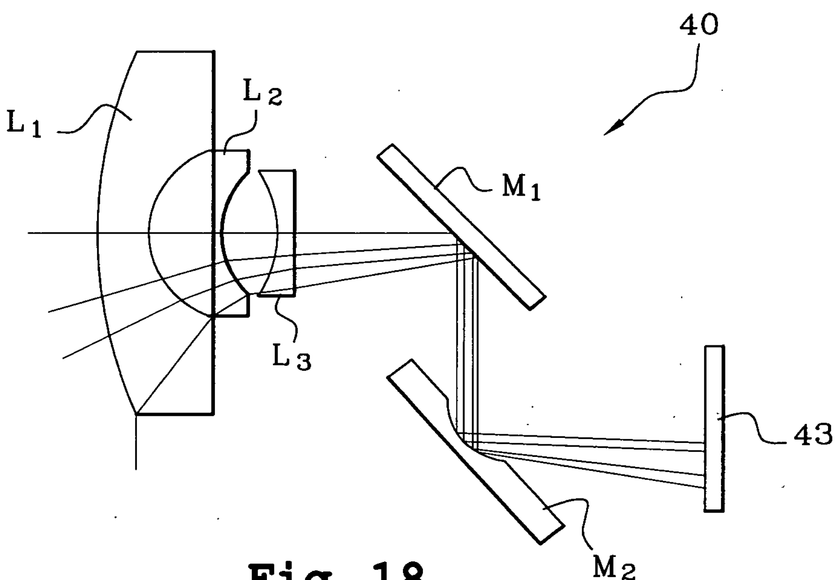

Fig. 18

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor: ARTONNE, et al.	Jean-Claude	§		
		§		
Conf. No.:	Not Yet Assigned	§	Group Art Unit:	Not Yet Assigned
		§		
Appln. No.:	Not Yet Assigned	§	Examiner:	Not Yet Assigned
		§		
Filing Date:	November 11, 2003	§	Attorney Docket No.: 10000-25US (100137 US/WO)	

Title: METHOD FOR CAPTURING AND DISPLAYING A VARIABLE RESOLUTION DIGITAL PANORAMIC IMAGE

INFORMATION DISCLOSURE STATEMENT UNDER 37 C.F.R. §1.97(b)

Enclosed are copies of each of the documents listed on the attached Information Disclosure Citation Form(s) PTO/SB/08A and/or B, which may be material to the patentability of this application and/or for which there may be a duty to disclose in accordance with 37 C.F.R. §1.56.

The enclosed references were cited in a French Search Report (copy enclosed) dated November 25, 2002 from the European Patent Office concerning counterpart International Application No. PCT/FR02/01588.

In accordance with the official waiver posted July 11, 2003, wherein the U.S. Patent and Trademark Office officially waives the requirement under 37 C.F.R. § 1.98(a)(2)(i) for submitting copies of each cited U.S. Patent and U.S. Patent Application Publications with respect to applications filed after June 30, 2003, we have not included copies of such cited U.S. patent and U.S. Patent Application Publications. However, we will provide copies upon request. Copies of the foreign references are attached hereto for the Examiner's convenience.

The filing of this Information Disclosure Statement shall not be construed as an admission that any of the listed documents constitutes prior art, nor as an admission against interest in any manner.

No fee is believed to be due in connection with the filing of this Information Disclosure Statement since it is being filed within three months of the filing date of the above-identified application. However, the Commissioner is hereby authorized to charge any deficiencies or credit any overpayments to Deposit Account No. 50-1017.

It is respectfully requested that this Information Disclosure Statement and the documents listed on the attached Form PTO/SB/08A and/or B be considered and acknowledged by the Examiner in connection with the above-identified patent application, be made of record therein, and that the listed document(s) be cited in the issued patent.

Respectfully submitted,

Jean-Claude ARTONNE, et al.

November 11, 2003
(Date)

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Form PTO/SB/08A	Complete if Known	
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	**Applicati n Number**	Not Yet Assigned
	Filing Dat	November 11, 2003
	First Named Invent r	Jean-Claude ARTONNE, et al.
(use as many sheets as necessary)	**Gr up Art Unit**	Not Yet Assigned
	Examin r Nam	Not Yet Assigned
Sheet 1 of 1	**Attorney Docket Number**	10000-25US (100137 US/WO)

U.S. PATENT DOCUMENTS

Exr Initials	U.S. Patent Document Number	Kind Code (if known)	Name of First Inventor of Cited Document	Date of Publication of Cited Document MM-YYYY
	3,953,111		FISHER et al.	04-1976
	5,880,896		ISHII et al.	03-1999
	6,031,670		INOUE	02-2000

FOREIGN PATENT DOCUMENTS

Exr Initials	Foreign Patent Document: Country Code	Number	Kind Code (if known)	Name of Applicant of Cited Document	Date of Publication of Cited Document MM-YYYY	T1
	WO	00/42470	A1	The Australian National University	07-2000	X
	EP	0 695 085	A1	International Business Machines Corporation	01-1996	X
	EP	1 004 915	A1	Fit Corporation Rios Corporation	05-2000	X

OTHER PRIOR ART - NON PATENT LITERATURE DOCUMENTS

Exr Initials	Include Name of first Author (in CAPITAL LETTERS), title of the article (where appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), volume-issue number(s), page(s), date (in parentheses). If a book, also include publisher and city and/or county where published.	T1

Examiner Signature		Date Considered	

7086001 v1

PATENT APPLICATION FEE DETERMINATION RECORD

Effective October 1, 2003

Application or Docket Number

10706513

CLAIMS AS FILED - PART I

	(Column 1)	(Column 2)
TOTAL CLAIMS	26	
FOR	NUMBER FILED	NUMBER EXTRA
TOTAL CHARGEABLE CLAIMS	26 minus 20=	* 6
INDEPENDENT CLAIMS	2 minus 3 =	* —
MULTIPLE DEPENDENT CLAIM PRESENT ☐		

* If the difference in column 1 is less than zero, enter "0" in column 2

SMALL ENTITY TYPE ☐ RATE	FEE	OR	OTHER THAN SMALL ENTITY RATE	FEE
BASIC FEE	385.00	OR	BASIC FEE	770.00
X$ 9=		OR	X$18=	108
X43=		OR	X86=	
+145=		OR	+290=	
TOTAL		OR	TOTAL	878

CLAIMS AS AMENDED - PART II

AMENDMENT A	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA
Total	*	Minus	**	=
Independent	*	Minus	***	=
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM ☐				

SMALL ENTITY RATE	ADDITIONAL FEE	OR	OTHER THAN SMALL ENTITY RATE	ADDITIONAL FEE
X$ 9=		OR	X$18=	
X43=		OR	X86=	
+145=		OR	+290=	
TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

17

AMENDMENT B	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA
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Independent	*	Minus	***	=
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM ☐				

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TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

AMENDMENT C	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA
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FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM ☐				

RATE	ADDITIONAL FEE	OR	RATE	ADDITIONAL FEE
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+145=		OR	+290=	
TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20."
***If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3."
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PATENT APPLICATION SERIAL NO. ____________________

U.S. DEPARTMENT OF COMMERCE
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FEE RECORD SHEET

11/17/2003 ZJUHAR1 00000141 10706513

01 FC:1001 770.00 OP
02 FC:1202 108.00 OP

PTO-1556
(5/87)

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(51) International Patent Classification [7] :
G03B 37/00, G02B 5/10, 13/06, 17/06, B25J 19/04

A1

(11) International Publication Number: WO 00/42470

(43) International Publication Date: 20 July 2000 (20.07.00)

(21) International Application Number: PCT/AU00/00022

(22) International Filing Date: 14 January 2000 (14.01.00)

(30) Priority Data:
PP 8191 15 January 1999 (15.01.99) AU

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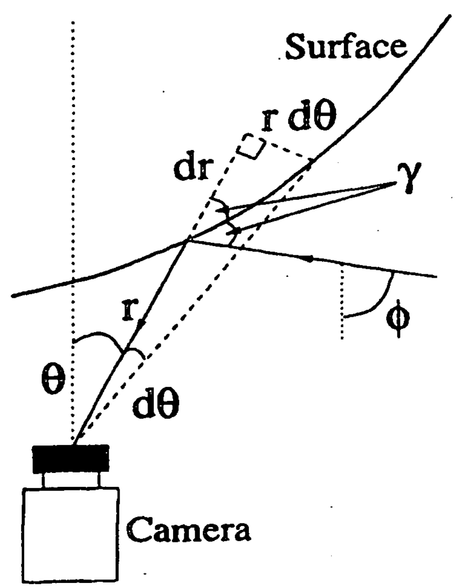
(81) Designated States: AU, CA, JP, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: RESOLUTION INVARIANT PANORAMIC IMAGING

(57) Abstract

A panoramic imaging system includes an imaging device having an image plane and a first field of view, a first reflective surface having at least one circularly symmetric portion convex in a radial direction disposed in the first field of view to provide an expanded panoramic second field of view. The profile of the or each convex portion provides a varying gain between the fields of view in the radial direction to limit variation in the solid angle of view across the image plane of the imaging device.



RESOLUTION INVARIANT PANORAMIC IMAGING

FIELD OF THE INVENTION

This invention relates to generating wide angle images of spaces, generally referred to as panoramic imaging.

BACKGROUND ART

Panoramic imaging is becoming an important tool in the area of mobile robotics and machine vision. There are many documented methods for recording a panoramic view of a scene. One simple method involves having a series of cameras mounted on a ring to give views around the entire 360° of horizon. This involves, say, four cameras if they each have a field of view of 90° and some integration of images. There are also a number of single camera methods for panoramic imaging, including rotating a camera about its vertical axis and taking pictures continuously to obtain a full panoramic view. Another approach uses wide angle lenses to achieve a large field of view, but these lenses are heavy, expensive and distort the image.

An attractive approach to panoramic imaging is to mount a single fixed camera under a curved reflective surface covering a hemisphere such as with a conical, spherical, hyperboloidal, or other profile. The optical axis of the camera is aligned with the central axis of the mirror. A known family of constant gain reflective surfaces have the advantage that they can produce large fields of view such as for a hemispherical or hyperboloidal mirror yet preserve a linear relationship between changes in angles of incidence and reflection of light rays viewed by the camera. This linear relationship simplifies image processing and ensures constant elevational resolution of the image. The shape of the surface is determined by the gain of the linear relationship. For a unity gain, the surface is a cone; for higher gains, the surface is specified by a family of polynomial functions. For ease of explanation in this specification the panoramic plane will be considered as being horizontal and the field of view as vertical as would be the case for a robot moving in a horizontal plane. It will be apparent that in the general case orientation of the planes is arbitrary.

All the mirror shapes mentioned above share a common draw back. That is that the CCD cameras used for imaging invariably have uniform Cartesian arrays of pixels to capture the polar image of the scene, and so the pixel density per solid angle increases with the radius of the polar image. The unwarping process transforms the image from polar to Cartesian coordinates so that the angular coordinate in the original polar image maps to the x-coordinate in the unwarped image while the radial coordinate maps to the y-coordinate. Thus the pixel density in the unwarped image varies from low for small x values which correspond to the centre of the original image to high for large x values which correspond to the outer rim of the polar image. This is illustrated in Figure 1 which shows the unwarping of an image captured with a hyperboloidal mirror. The variation in image quality is clearly evident in the unwarped version.

One way to circumvent this problem is to use a specially designed CCD camera with a polar array of pixels with a pixel density which decreases with radius. There are alignment problems with such an approach.

DISCLOSURE OF THE INVENTION

In a first aspect this invention provides a panoramic imaging system including an imaging device having an image plane and a first field of view, a first reflective surface having at least one circularly symmetric portion convex in a radial direction disposed in said first field of view to provide an expanded panoramic second field of view, the profile of the or each convex portion providing a varying gain between the fields of view in the radial direction to limit variation in the solid angle of view across the image plane of the imaging device.

Preferably, the profile of the convex portion provides a substantially uniform solid angle of view across the image plane. That is, the shape ensures that the resolution in the image is invariant to changes in elevation. Thus, where the imaging system involves a device with an array of uniformly spaced pixels in the image plane, the shape of the reflective surfaces results in solid angle pixel density invariance.

The profile of the reflective surface in polar coordinates is preferably determined by solving the equation

$$\frac{dr}{d\theta} = r \cot\left[-\tfrac{1}{2}\int(1 + \alpha(\theta))\,d\theta\right]$$

where r is the radial distance from the reflective surface to the imaging device

θ is the angle from the optical axis of the imaging device

$\alpha(\theta)$ is the mirror gain given by

$$\alpha(\theta) = B_\alpha\,[\tan(\theta) + \tan^3(\theta)]$$

$$B_\alpha = \frac{2(\overline{\Phi} - \underline{\Phi})}{\tan^2(\overline{\theta}) - \tan^2(\underline{\theta})}$$

$\overline{\Phi}$ and $\underline{\Phi}$ are the maximum and minimum elevations viewed $\overline{\theta}$ and $\underline{\theta}$ are the maximum and minimum radial angles imaged.

In one approach r can be plotted against θ at selected intervals to describe the profile by solving the above equation for selected values of θ. For example determining values of r for incremental values of θ of about 1/5° has been found to produce a sufficiently accurate profile for practical application.

There are a number of methods for panoramic range finding. One method uses a cone mirror above a camera. The camera mirror assembly is either displaced during image collection, or two camera mirror assemblies are used to obtain the two views necessary for range finding. Although this method provides range information in the horizontal plane at video rates, its drawbacks are that no range information is available in the vertical (elevation) direction, objects must be more than a minimum distance from the camera and there may be a blind spot due to the second camera system.

A discontinuous, axially symmetric mirror, which is in essence a coaxial mirror pair, mounted above a camera to obtain two views of a panoramic scene for stereo disparity range finding is known. There are however no proposals concerning specific mirror shapes to achieve specific desirable properties. Additionally, known constant gain mirror profiles have been generalised to derive a family of such coaxial mirror pair profiles for panoramic stereo imaging and processing based on disparities in the vertical plane.

In another aspect this invention provides for range finding using a panoramic imaging system containing two resolution invariant mirrors. Preferably the mirror or reflector surface has at least two of said convex portions arranged to respectively provide at least partially overlapping panoramic second fields of view for range determination. The second fields of view are preferably substantially co-incident. In the preferred form of the invention the two convex portions form a continuous mirror or reflective surface.

In a further aspect this invention provides a design for a back to back stereo mirror system with the desirable property of equal pixel sharing between two cameras and thus the two stereo images. The stereo cone in this case is preferably symmetric in the directions orthogonal to the camera axis which is a desirable property for some applications. In this aspect of the invention the imaging system preferably includes two first reflective surfaces each having an associated image plane with corresponding first fields of view, and at least one convex portion of each first reflective surface providing respective panoramic second fields of view, said first reflective surface being arranged back to back such that said reflective second fields of view at least partially overlap.

A second reflective surface can, in some applications be interposed between the image plane and the second reflective surface. This allows positioning of the imaging device for example behind the first reflective surface. In some variations an apperture can be provided in the first reflective surface to provide the first field of view from the imaging device.

In another aspect this invention provides a reflective surface for use in a panoramic imaging system including an imaging device having an imaging plane and a first field of view, said reflective surface having at least one circularly symmetric portion convex in a radial direction with a profile providing varying gain in the radial direction between an expanded panoramic second field of view provided by the reflective surface and the first field of view to limit variation in the solid angle of view across the image plane of the imaging device.

In yet a further aspect this invention provides mirrors having minimal intrusive designs, which intrude to a minimal extent into the viewing "hemisphere". These are also termed forward facing designs. They involve an additional planar mirror and camera relocation within the primary reflective surface. The attraction of this arrangement is that the first reflective mirror surface profile is the same design as in a more conventional arrangement.

The invention will be further described, by way of example only with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates an unwarping process for a prior art panoramic imaging system;

Figure 2 schematically shows the relationship between camera image and horizontal view direction in a panoramic imaging system;

Figure 3 illustrates geometric relationships between a reflecting surface and a camera used to derive mirror profiles according to this invention;

Figures 4A and 4B, are graphs showing a comparison of a constant gain mirror with a variable gain mirror used in the imaging system according to this invention;

Figures 5A and 5B, shows ray traced scenes respectively reflected in constant and variable gain mirrors;

Figures 6A and 6B, graphically illustrates a comparison of panoramic imaging systems respectively utilising double constant and variable gain mirror configurations;

Figures 7A and 7B, shows raced traced images of scenes respectively corresponding to panoramic imaging systems utilising double constant and variable gain mirror configurations;

Figure 8 schematically illustrates relationships between camera and reflective surfaces used in range calculation utilising a resolution invariant double mirror according to this invention;

Figure 9 schematically illustrates a back to back mirror configuration according to this invention;

Figure 10 schematically illustrates a double back to back mirror configuration according to this invention;

Figure 11 schematically illustrates a forward looking panoramic imaging system according to this invention; and

Figure 12 shows a system utilising a combination of the arrangements in Figures 10 and 11.

BEST MODE FOR CARRYING OUT THE INVENTION

The various aspects of this invention will, for clarity, be described under separate subheadings.

1 Resolution Invariant Mirror Families

This section describes a family of mirror designs that achieve the objective of resolution invariance, or equivalently solid angle pixel density invariance.

1.1 Constant Image Pixel Density - The Variable Gain (α) Mirror

In accordance with one aspect of this invention resolution invariance is achieved by adjusting the mirror profile to image relatively less of the scene in the centre of the image and relatively more at the perimeter. That is, a mirror profile is selected to maintain a constant relationship between the pixel density and the angle of elevation in the scene or more precisely, the solid angle. The mirror gain α, is the relationship between the change in elevation of rays incident on the mirror and the change in the angle of rays reflected into the camera as follows

$$\alpha = \frac{\delta\phi}{\delta\theta} \qquad (1)$$

where $\delta\phi$ is the change in vertical elevation and $\delta\theta$ is the change in angle of reflected rays received by the camera. With resolution invariance α becomes a function of image angle θ which is related to the radial coordinate in the image, ρ, as shown in Figure 2.

Figure 3 schematically shows an imaging system including an imaging device in the form of a camera having an image plane and a first field of view. A reflective surface or mirror is ... in the first field of view to provide an expanded panoramic second field of view. The surface is circularly symmetric and convex in a radial direction.

Consider a mirror profile (r, θ) in polar coordinates where r is the radial distance to the camera and θ is the angle from the optical axis of the camera to the point on the mirror surface as shown in Fig. 3. The angle of incidence of a light ray relative to the mirror is γ and the angle of an incoming light ray with respect to the vertical is ϕ. Then

$$\gamma = \tan^{-1}\left(\frac{rd\theta}{dr}\right) \tag{2}$$

subject to the geometric constraint (from the law of reflection)

$$2\gamma + \theta + \phi = \pi \tag{3}$$

Differentiating (2) and (3) with respect to θ

$$\frac{d\gamma}{d\theta} = \frac{d}{d\theta}\left[\tan^{-1}\left(\frac{rd\theta}{dr}\right)\right] \qquad \textit{From } (2)$$

$$\frac{d\gamma}{d\theta} = -\frac{1}{2}\left(1 + \frac{d\phi}{d\theta}\right) \qquad \textit{From } (3)$$

so, substituting α from (1) gives

$$\frac{d}{d\theta}\left[\tan^{-1}\left(\frac{rd\theta}{dr}\right)\right] = -\frac{1}{2}\,(1+\alpha) \tag{4}$$

Now, for a variable gain mirror, α is a function of image angle θ (related to the radial coordinate in the image, ρ) so (4) becomes

$$\frac{d}{d\theta}\left[\tan^{-1}\left(\frac{rd\theta}{dr}\right)\right] = -½(1+\alpha(\theta)) \tag{5}$$

or, rearranging

$$\frac{dr}{d\theta} = r \cot\left[-\tfrac{1}{2}\int(1+\alpha(\theta))d\theta\right] \qquad \textbf{(6)}$$

The equation for the mirror gain, $\alpha(\theta)$ to achieve pixel density invariance can be found using the following theory.

1.1.1 Pixel Density Invariance Profiles

There are $p(\rho)$ pixels in an area of radius ρ in the image. More formally, there are

$$p(\rho) = \pi\kappa\rho^2$$

pixels in an area of radius ρ, where κ is the number of pixels per unit area, a constant. Differentiating by ρ gives

$$\frac{\partial p(\rho)}{\partial\rho} = 2\pi\kappa\rho \qquad \textbf{(7)}$$

Now, the radius in the image, ρ is related to the radial angle of a ray reflected from the mirror, θ by the focal length of the camera, f (a constant)

$$\rho = f\tan(\theta) \qquad \textbf{(8)}$$

so differentiating $p(\rho)$ by θ and substituting (7) and (8) gives

$$\begin{aligned}\frac{\partial p(\rho)}{\partial\theta} &= \frac{\partial p(\rho)}{\partial\rho}\frac{\partial\rho}{\partial\theta} \\ &= 2\pi\kappa\rho f\frac{\partial\tan(\theta)}{\partial\theta} \\ &= 2\pi\kappa f^2\tan(\theta)(1+\tan^2(\theta))\end{aligned} \tag{9}$$

Now, it is required that the image pixel density be invariant to angle of elevation in the scene which leads to more of the scene being imaged towards the perimeter, so

$$p(\rho) = \beta\phi + C(\phi) \tag{10}$$

where β and C(ϕ) are constants. Differentiating both sides of (10) by ϕ and substituting (1) and (9) gives

$$\begin{aligned}\beta\frac{\partial\phi}{\partial\phi} &= \frac{\partial p(\rho)}{\partial\phi} \\ \beta &= \frac{\partial p(\rho)}{\partial\theta}\bullet\frac{\partial\theta}{\partial\phi} \\ &= \frac{2\pi\kappa f^2\tan(\theta)(1+\tan^2(\theta))}{\alpha(\theta)}\end{aligned} \tag{11}$$

Rearranging (11) gives

$$\begin{aligned}\alpha(\theta) &= \left(\frac{2\pi f^2\kappa}{\beta}\right)\tan(\theta)[1+\tan^2(\theta)] \\ &= B_\alpha[\tan(\theta)+\tan^3(\theta)]\end{aligned} \tag{12}$$

where B_α is a constant. Integrating this expression for α(θ) by θ gives an expression for ϕ (see (1)), the elevation of an object imaged at angle θ. That is

$$\phi = \frac{B_\alpha}{2}\tan^2(\theta) + \phi(\theta = 0) \tag{13}$$

where ϕ $(\theta = 0)$ is a constant of integration.

The constants B_α and ϕ $(\theta = 0)$ can be determined from the maximum and minimum values of θ and ϕ which are known for a desired mirror configuration, using (13).

$$B_\alpha = \frac{2(\overline{\phi} - \underline{\phi})}{\tan^2(\overline{\theta}) - \tan^2(\underline{\theta})}$$
$$\phi(\theta = 0) = \underline{\phi} - \frac{B_\alpha}{2}\tan^2(\underline{\theta}) \tag{14}$$

It appears not possible to find an analytical solution to (6) if α is a function of θ, so there is no explicit equation for the mirror shape. Instead, a differential equation solver is needed to find solutions to (6) over the range of θ (the mirror surface).

Figures 4A and 4B show for comparison a constant gain mirror and a variable gain mirror with the same camera field of view and range of elevations imaged. The rays shown are constantly spaced in θ, with about 2° between each ray. It is clear from Fig. 4A that in the constant gain case these rays are constantly spaced in ϕ, with about 8.5° between each ray, and from Fig. 4, that the spacing between the rays in the variable gain case increases with increasing ϕ. So, in the variable gain case, a greater proportion of the scene is imaged towards the outer edge of the polar image. This is also shown in Figures 5A and 5B, ray traced images reflected in a constant gain and variable gain mirror with the same range of elevations visible.

1.2 Panoramic Stereo Using a Variable Gain Mirror

A mirror with two convex portions or a double mirror is required. The radial profile of a double mirror is shown in Figure 8. The mirror arrangement for panoramic stereo with variable gain mirrors will necessarily be different than for constant gain mirrors due to the variation of the mirror gain, α. The gain must vary in a constant fashion over the entire double mirror so that the constant pixel density theorem will hold over the entire image. If the minimum and maximum elevations viewed ($\underline{\phi}$ and $\overline{\phi}$) are to be equal for both mirrors in the double mirror system, the range of reflected angles ($\overline{\theta} - \underline{\theta}$) cannot be equal for the two mirrors. The minimum and maximum angles of reflected rays captured by the camera over the entire mirror surface are known from camera geometry. Therefore the minimum ray reflected from the lower mirror ($\underline{\theta_1}$) and the maximum ray reflected from the upper mirror ($\overline{\theta_2}$) are known. So, since (12) holds over the entire mirror, B_α is constant, and from (14)

$$\begin{gathered}\frac{2(\overline{\phi} - \underline{\phi})}{(\tan^2(\overline{\theta_1}) - \tan^2(\underline{\theta_1}))} = \frac{2(\overline{\phi} - \underline{\phi})}{\tan^2(\overline{\theta_2}) - \tan^2(\underline{\theta_2})}\\ \tan^2(\overline{\theta_1}) - \tan^2(\underline{\theta_1}) = \tan^2(\overline{\theta_2}) - \tan^2(\underline{\theta_2})\\ \tan^2(\overline{\theta_1}) + \tan^2(\underline{\theta_2}) = \tan^2(\overline{\theta_2}) + \tan^2(\underline{\theta_1})\end{gathered} \tag{15}$$

It is desirable to minimise the gap in the radial direction between the images from the two mirrors so as to maximise usage of the camera field of view. For minimum gap $\overline{\theta_1} = \underline{\theta_2}$, so

$$\begin{gathered}2\tan^2(\overline{\theta_1}) = \tan^2(\overline{\theta_2}) + \tan^2(\underline{\theta_1})\\ \overline{\theta_1} = \tan^{-1}\left[\left(\frac{\tan^2(\overline{\theta_2}) + \tan^2(\underline{\theta_1})}{2}\right)^{1/2}\right]\end{gathered} \tag{16}$$

Figures 6A, 6B and 7A, 7B show graphical and ray traced comparisons of constant and variable gain double mirror systems viewing the same scene.

2.4 Calculation of Range for a Variable Gain Panoramic Stereo System

The information available for range calculation are the image angles for a single object reflected in both mirrors, θ_1 and θ_2 as shown in Figure 8. The two mirrors θ_1 and θ_2 form a reflective surface. The differential equations (6) for the surfaces are known. In the calculations that follow only the lower mirror is examined as the results are identical for the upper mirror.

In order to find the position of object P, the equations of the incident beams from P to each mirror reflection point (r_1, θ_1) and (r_2, θ_2) must be found. These equations can then be solved simultaneously to give the position of object P, (x_P, y_P).

$$\begin{bmatrix} y_P \\ x_P \end{bmatrix} = \begin{bmatrix} 1 & -m_{11} \\ 1 & -m_{12} \end{bmatrix}^{-1} \begin{bmatrix} C_{11} \\ C_{12} \end{bmatrix} = \begin{bmatrix} -\dfrac{m_{12}}{m_{12}-m_{11}} & \dfrac{m_{11}}{m_{12}-m_{11}} \\ -\dfrac{1}{m_{12}-m_{11}} & \dfrac{1}{m_{12}-m_{11}} \end{bmatrix} \begin{bmatrix} C_{11} \\ C_{12} \end{bmatrix} \quad (17)$$

where m_{I1} is the gradient of the incident beam to the lower mirror and C_{I1} is the equation constant. The equation constant is given by

$$C_{I1} = y_1 - m_{I1} x_1 \qquad \textbf{(18)}$$

where

$$x_1 = r_1 \sin \theta_1$$
$$y_1 = r_1 \cos \theta_1 \qquad \textbf{(19)}$$

are the Cartesian coordinates of the reflection point (r_1, θ_1). The gradient of the incident beam is found using the law of reflection

$$m_{I1} = \tan\left[\tan^{-1}\left(\frac{dy_1}{dx_1}\right) + \tan^{-1}\left(\frac{1}{m_{R1}}\right) - \tan^{-1}\left(\frac{dx_1}{dy_1}\right)\right] \qquad \textbf{(20)}$$

where m_{R1} is the gradient of the reflected beam from the lower mirror to the camera and dy_1/dx_1 is the gradient of the lower mirror profile at the reflection point. The gradient of the reflected beam is

$$m_{R1} = \tan\theta_1 \qquad \textbf{(21)}$$

The gradient of the mirror profile for the lower variable gain mirror is found as in the constant gain case, from

$$\frac{dy_1}{dx_1} = \frac{dy_1}{d\theta_1} / \frac{dx_1}{d\theta_1} = \frac{\dfrac{dr_1}{d\theta_1}\cos\theta_1 - r_1\sin\theta_1}{\dfrac{dr_1}{d\theta_1}\sin\theta_1 + r_1\cos\theta_1} \qquad (22)$$

where $dr/d\theta$ for either mirror of the variable gain mirror configuration is found by integrating (5) and substituting (12).

$$\int d\tan^{-1}\left(r\frac{d\theta}{dr}\right) = -\frac{1}{2}\int (1 + \alpha(\theta))\, d\theta$$

$$\tan^{-1}\left(r\frac{d\theta}{dr}\right) = -\frac{1}{2}\theta - \frac{B_\alpha}{2}\int (\tan(\theta) + \tan^3(\theta))\, d\theta \qquad (23)$$

$$= -\frac{1}{2}\theta - \frac{B_\alpha}{4}\tan^2(\theta) + D$$

where D is a constant of integration. Rearranging (23) gives

$$\frac{dr}{d\theta} = r\cot\left(-\frac{1}{2}\theta - \frac{B_\alpha}{4}\tan^2(\theta) + D\right) \qquad (24)$$

Now from (23) and (2),

$$D = \gamma + \frac{1}{2}\theta + \frac{B_\alpha}{4}\tan^2(\theta) \qquad (25)$$

so, for the lower variable gain mirror profile

$$D_1 = \underline{\gamma_1} + \frac{1}{2}\underline{\theta_1} + \frac{B_\alpha}{4}\tan^2(\underline{\theta_1})$$

similarly for D_2, for the upper variable gain profile.

So, by substituting (24) into (22) gives the gradient of the variable gain mirror profiles at any point. Note that as in the constant gain case, the gradient depends only on θ.

The equation constants for the incident beam equations from (18) require the polar coordinates of the reflection points from each mirror, (r_1, θ_1) and (r_2, θ_2). Since the variable gain mirror equations are not known exactly, r_1 and r_2 must be found using a differential equation solver to find solutions to (26) at θ_1 and θ_2.

2 Back-to-back Stereo Mirror Families

A key disadvantage of single camera stereo panoramic systems is that since there are two images of the "same" scene, the pixels assigned to each image is half that for non stereo panoramic imaging and the two images do not share an equal number of pixels in constant gain schemes. Actually, the panoramic stereo double mirror method typically causes the view of a scene in one radial direction to be compressed into around 1/4 the field of view of the camera.

A method to achieve panoramic stereo with less image compression is to use two cameras and two single curved mirror surfaces back to back, as shown in Fig. 9. This method compresses the imaged scene into 1/2 the field of view of the camera, and indeed each image has an equal share of the total number of pixels available. There are, however, possible alignment problems with this system as with any stereo system using two cameras to capture two views of a scene.

An advantage of the scheme proposed in Fig. 9 is that the stereo cone can be symmetric about the horizon using two cameras with equal fields of view and the maximum and minimum angles of elevation reflected by the two mirrors being equal. The angle covered by the stereo cone in this case is $2\bar{\phi} - \pi$. Fig.9 shows the general case where the maximum and minimum angles of elevations viewed by each camera need not be equal. The range of elevations must still be equal for the fields of view to be aligned.

The number of free parameters to be specified are reduced here as the minimum angle of elevation ($\underline{\phi}$) and from one mirror must be parallel to the maximum angle of elevation ($\bar{\phi}$) from the other mirror. This is to ensure that the fields of view are parallel. So, with reference to Fig. 9

$$\underline{\phi} = \pi - \bar{\phi} \qquad \textbf{(26)}$$

In the scheme of Fig. 9, the mirror families can be either constant gain or resolution invariant.

2.1 The Use of Double Mirrors in a Back to Back Design

Fig. 10 shows a back to back design incorporating double mirrors. Although the figure shows constant gain mirrors, the double mirror can also have a variable gain. The advantage to this system is that the stereo cone from the back to back configuration combines with the stereo cones from the double mirror configuration to increase the total area imaged in stereo. In this configuration, the fields of view of each double mirror pair need not be aligned as in previous examples. For symmetry about the horizon $\underline{\phi}_3 = \underline{\phi}_1$, $\underline{\phi}_4 = \underline{\phi}_2$, $\bar{\phi}_3 = \bar{\phi}_1$ and $\bar{\phi}_4 = \bar{\phi}_2$. The constraints

$$\overline{\phi_3} = \pi - \overline{\phi_2}$$
$$\overline{\phi_4} = \pi - \overline{\phi_1}$$

align the three stereo cones.

It is also possible to increase the total stereo cone further by allowing the mirror pairs to have different gains.

3 Forward Looking Mirror Design

An example of a forward looking mirror design is shown in Fig. 11. For many applications, it is desirable to have a panoramic camera looking out from, say, a hemisphere, somewhat as an eye of a bird, or perhaps two such on either side of a "nose cone". There are aerodynamic considerations or other protrusion considerations which motivate such a "forward looking" system. This configuration is termed forward looking because the camera faces towards the scene. Either a constant or variable gain mirror (double or single) could be used for the curved mirror in the system. The planar mirror is an annulus or circle interposed such that all rays reflected from the curved mirror are reflected into camera o positioned behind the curved mirror. The dotted lines in Fig. 11 show where the reflected rays would converge if the planar mirror was removed and the dotted camera shows the camera o' for an equivalent system without the planar mirror.

In order for the rays reflected by the planar mirror to converge at the new camera position, the planar mirror must be the perpendicular bisector of the line joining the old and new camera locations. Hence the distance between the camera locations is $2D$ where D is defined in Fig. 11 as the distance from either camera to the planar mirror. The introduction of the planar mirror into the system does increase the possibility of alignment difficulties as the planar mirror must be perpendicular to the camera axis and also be positioned so as to reflect all rays from the curved mirror into the camera without occluding the view of the curved mirror.

The maximum value for $D, \bar{D}$, is when the maximum beam reflected from the mirror system (the $\bar{\theta}$ beam reflected at point *b* on the planar mirror) into camera *o* grazes the curved profile at *c*. In this case

$$\bar{D} = \frac{\underline{r}\cos(\underline{\theta})[\tan(\underline{\theta}) + \tan(\bar{\theta})]}{2\tan(\bar{\theta})} \qquad \textbf{(27)}$$

$\bar{D}$, defines the minimum height for the mirror system, $\underline{H}$. In practice, the value for D needs to be slightly smaller to avoid occlusion, leading to a larger mirror system height. The general equation for the height of the mirror system is

$$H = \bar{r}\cos(\bar{\theta}) - D \qquad \textbf{(28)}$$

It should also be noted that $\underline{\theta}$ must be greater than zero for camera *o* to be located behind the curved mirror. Also, $\underline{\phi} \geq \bar{\theta}$ if the minimum elevation ray $\underline{\phi}$ is not to be occluded by the planar mirror.

Fig. 12 shows a design that incorporates the ideas of Sections 2 and 3. It consists of two forward looking systems back to back, giving a design reminiscent of a eye mounted on a stalk, such as a crab's eye. The "stalk" for this system would be hidden from view by the lower planar mirror. In this arrangement portions are provided in the curved mirror to provide for reflection of rays from the curved surface to the camera by the plane mirrors.

The foregoing describes only some aspects of the present invention and modifications can be made without departing from the scope of the invention.

CLAIMS:

1. A panoramic imaging system including an imaging device having an image plane and a first field of view, a first reflective surface having at least one circularly symmetric portion convex in a radial direction disposed in said first field of view to provide an expanded panoramic second field of view, the profile of the or each convex portion providing a varying gain between the fields of view in the radial direction to limit variation in the solid angle of view across the image plane of the imaging device.

2. A panoramic imaging system as claimed in claim 1 wherein the profile of the or each convex portion provides a substantially uniform solid angle of view across the image plane.

3. A panoramic imaging system as claimed in claim 1 or claim 2 wherein the profile of the or each convex portion at least approximates a profile defined in polar co-ordinates by the equation:

$$\frac{dr}{d\theta} = r \cot\left[-\tfrac{1}{2}\int (1 + \alpha(\theta))\, d\theta\right]$$

where r is the radial distance from the reflective surface to the imaging device

θ is the angle from the optical axis of the imaging device

$\alpha(\theta)$ is the mirror gain given by

$$\alpha(\theta) = B_\alpha \left[\tan(\theta) + \tan^3(\theta)\right]$$

$$B_\alpha = \frac{2(\overline{\phi} - \underline{\phi})}{\tan^2(\overline{\theta}) - \tan^2(\underline{\theta})}$$

$\overline{\phi}$ and $\underline{\phi}$ are the maximum and minimum elevations viewed $\overline{\theta}$ and $\underline{\theta}$ are the maximum and minimum radial angles imaged.

4. A panoramic imaging system as claimed in claim 3 wherein the profile of the or each convex portion includes by a series spaced apart points defined by determining distance r for selected values of angle θ.

5. A panoramic imaging system as claimed in claim 4 wherein the selected values of θ are separated by about 1/5°.

6. A panoramic imaging system as claimed in any one of claims 1 to 5 including a first reflector surface having at least two of said convex portions arranged to respectively provide at least partially overlapping panoramic second fields of view for range determination.

7. A panoramic imaging system as claimed in claim 6 wherein said panoramic second fields of view are substantially co-incident.

8. A panoramic imaging system as claimed in claim 7 wherein said at least two convex portions form a continuous reflective surface.

9. A panoramic imaging system as claimed in any one of claims 1 to 8 including two of said first reflective surfaces each having an associated image plane with corresponding first fields of view, and at least one convex portion of each first reflective surface providing respective panoramic second fields of view, said first reflective surface being arranged back to back such that said reflective second fields of view at least partially overlap.

10. A panoramic imaging system as claimed in any one of claims 1 to 9 further including a second reflective surface interposed between the image plane and said second reflective surface.

11. A panoramic imaging system as claimed in claim 10 wherein the imaging device is positioned behind the second reflective surface.

12. A panoramic imaging system as claimed in claim 11 wherein an aperture is provided in said first reflective surface to provide said first field of view from the imaging device.

13. A panoramic imaging system as claimed in any of claims 10 to 12 wherein said second reflective surface is substantially planar.

14. A reflective surface for use in a panoramic imaging system including an imaging device having an imaging plane and a first field of view, said reflective surface having at least one circularly symmetric portion convex in a radial direction with a profile providing varying gain in the radial direction between an expanded panoramic second field of view provided by the reflective surface and the first field of view to limit variation in the solid angle of view across the image plane of the imaging device.

15. A reflective surface as claimed in claim 14 wherein the profile of the or each convex portion provides a substantially uniform solid angle of view across the image plane.

16. A reflective surface as claimed in claim 14 or claim 18 wherein the profile of the or each convex portion at least approximates a profile defined in polar co-ordinates by the equation:

$$\frac{dr}{d\theta} = r \cot \left[-\tfrac{1}{2} \int (1 + \alpha(\theta))\, d\theta \right]$$

where r is the radial distance from the reflective surface to the imaging device

θ is the angle from the optical axis of the imaging device

$\alpha(\theta)$ is the mirror gain given by

$$\alpha(\theta) = B_\alpha [\tan(\theta) + \tan^3(\theta)]$$

$$B_\alpha = \frac{2(\overline{\phi} - \underline{\phi})}{\tan^2(\overline{\theta}) - \tan^2(\underline{\theta})}$$

$\overline{\phi}$ and $\underline{\phi}$ are the maximum and minimum elevations viewed $\overline{\theta}$ and $\underline{\theta}$ are the maximum and minimum radial angles imaged.

17. A reflective surface as claimed in claim 16 wherein the profile of the or each convex portion includes by a series spaced apart points defined by determining distance *r* for selected values of angle θ.

18. A reflective surface as claimed in claim 17 wherein the selected values of θ are separated by about 1/5°.

19. A reflective surface as claimed in any one of claims 14 to 18 including a first reflector surface. having at least two of said convex portions arranged to respectively provide at least partially overlapping panoramic second fields of view for range determination.

20. A reflective surface as claimed in claim 19 wherein said panoramic second fields of view are substantially co-incident.

21. A reflective surface as claimed in claim 20 wherein said at least two convex portions form a continuous reflective surface.

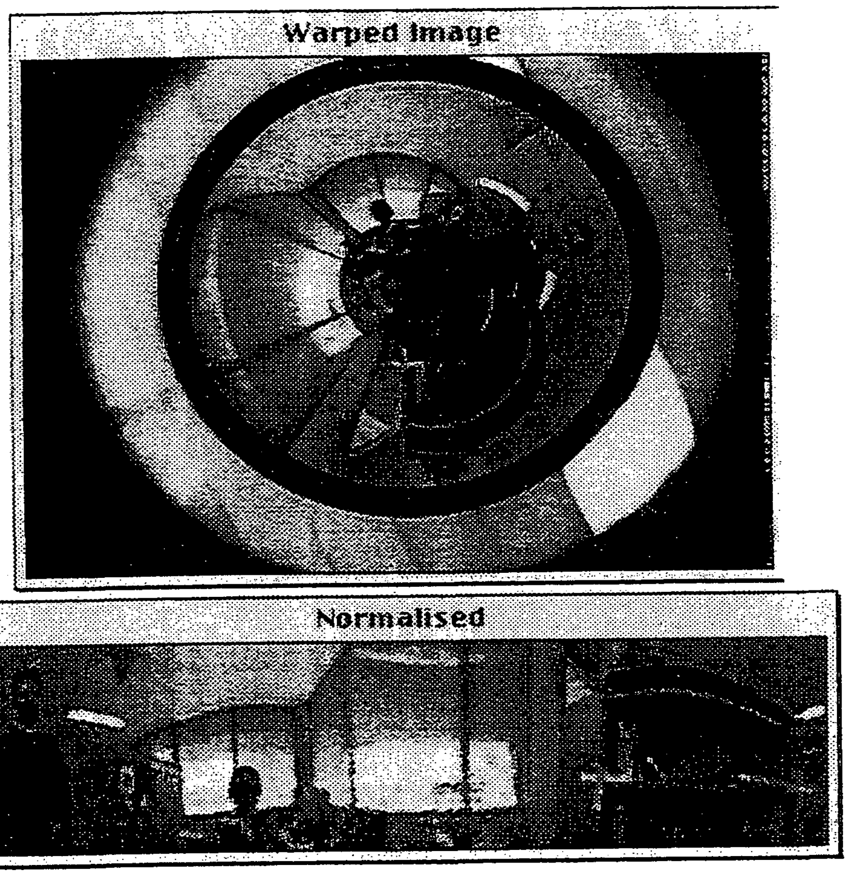


FIGURE 1

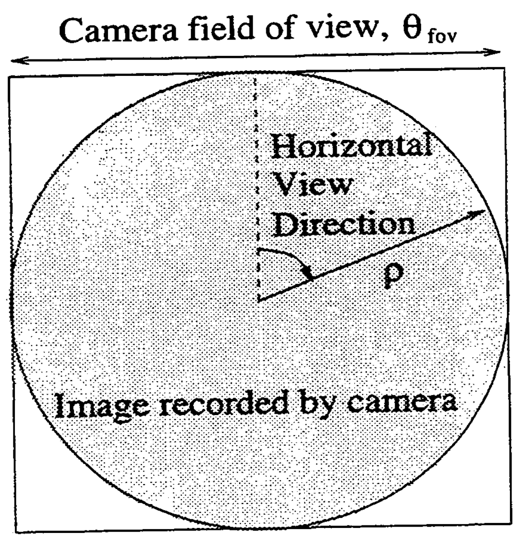

Camera field of view, θ_{fov}
Horizontal View Direction
ρ
Image recorded by camera

FIGURE 2

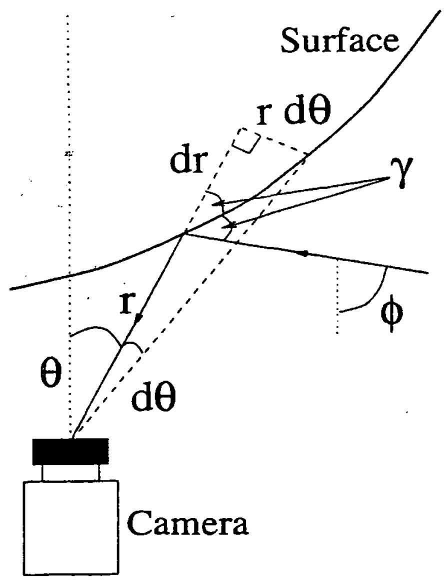


FIGURE 3

4/12

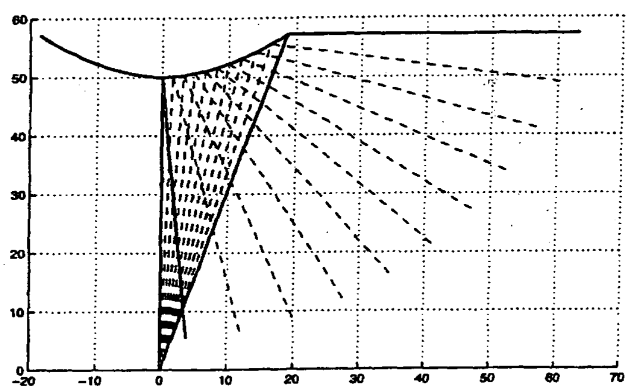


FIGURE 4A

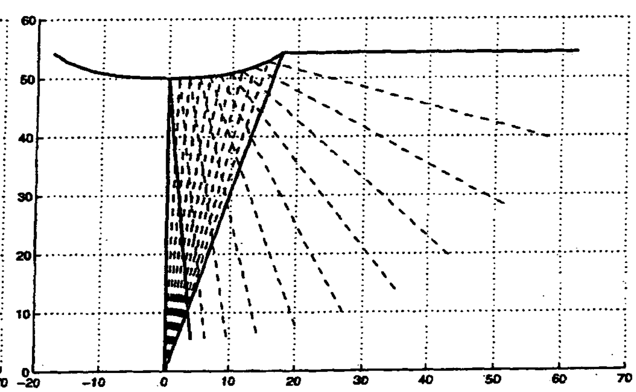


FIGURE 4B

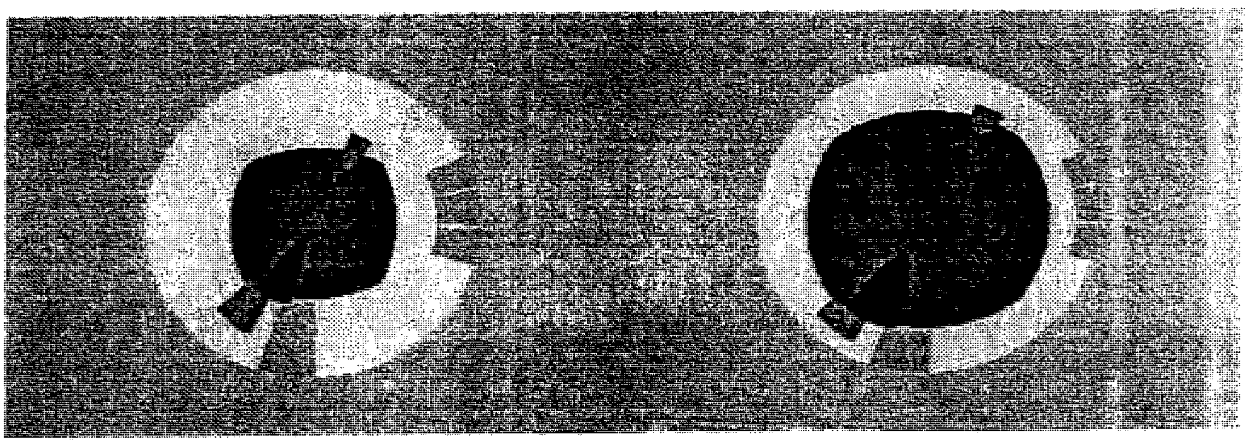


FIGURE 5A FIGURE 5B

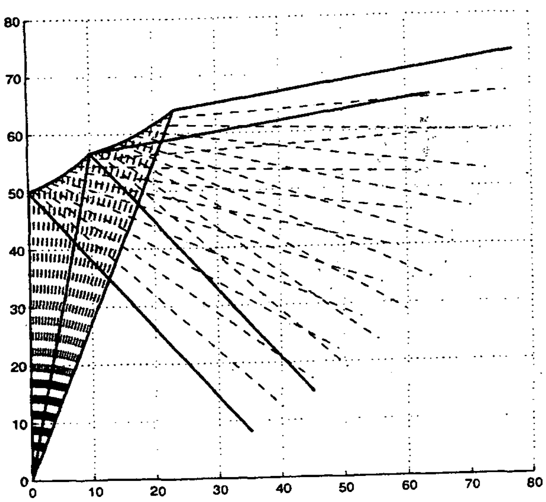


FIGURE 6A

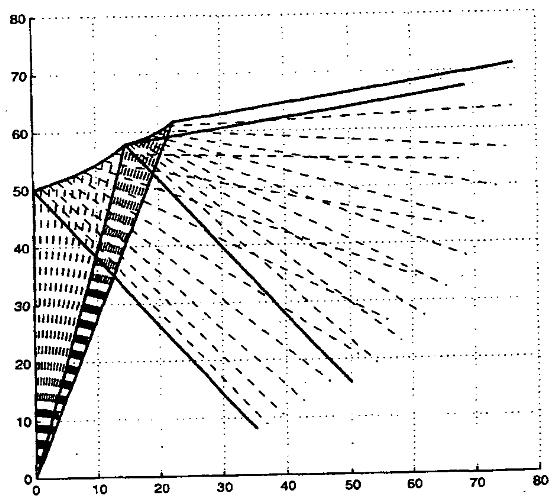


FIGURE 6B

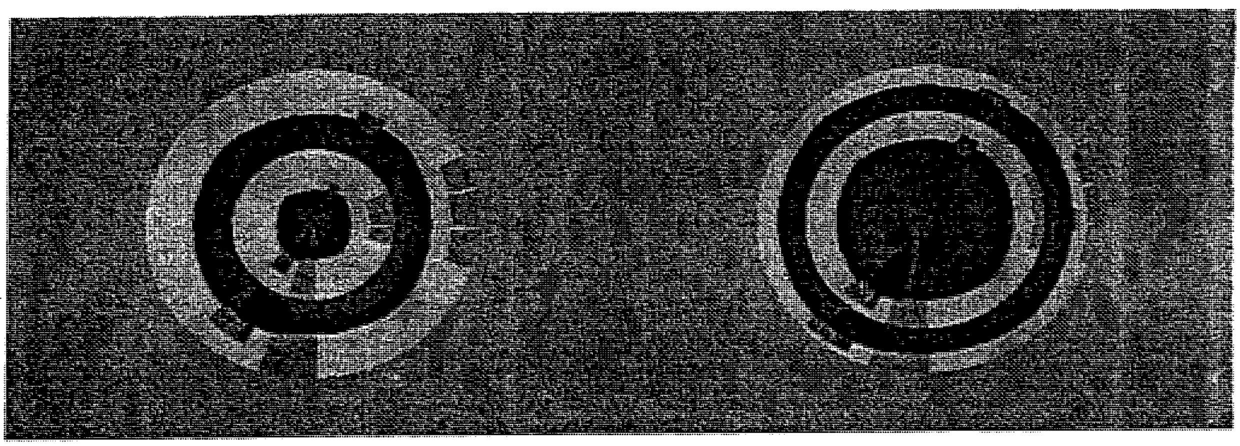


FIGURE 7A FIGURE 7B

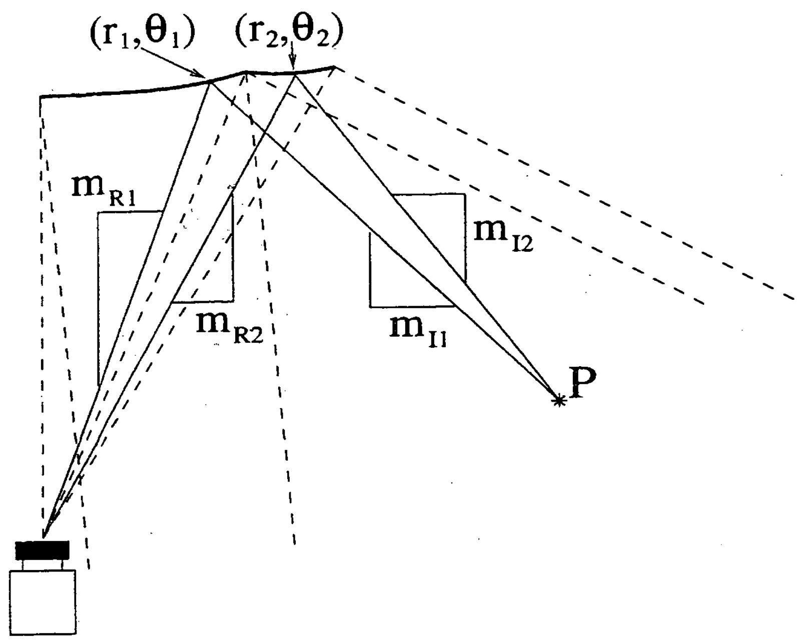


FIGURE 8

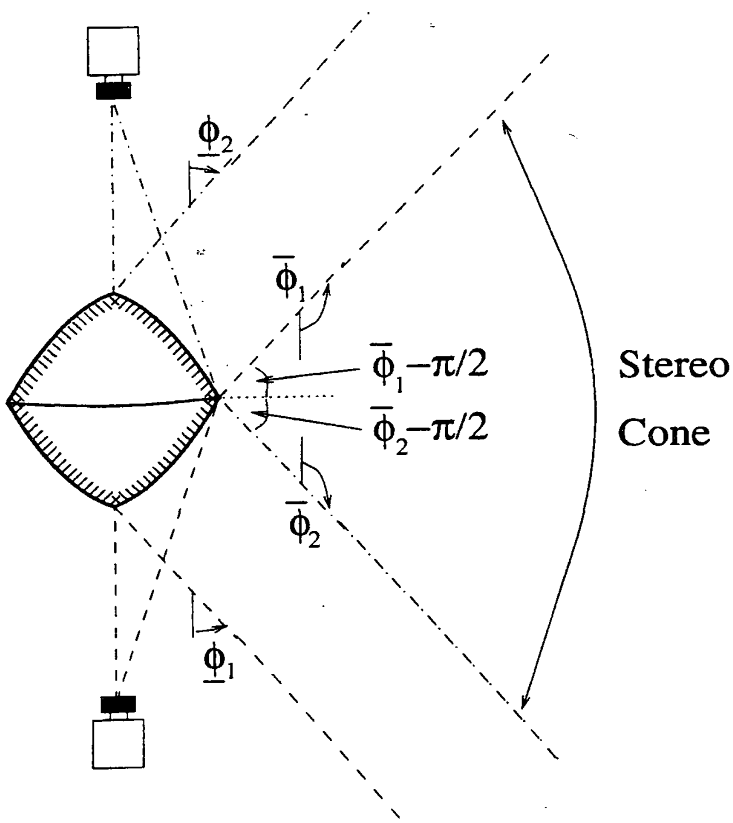

$\underline{\phi}_2$
$\bar{\phi}_1$
$\bar{\phi}_1-\pi/2$
$\bar{\phi}_2-\pi/2$
$\bar{\phi}_2$
$\underline{\phi}_1$
Stereo
Cone

FIGURE 9

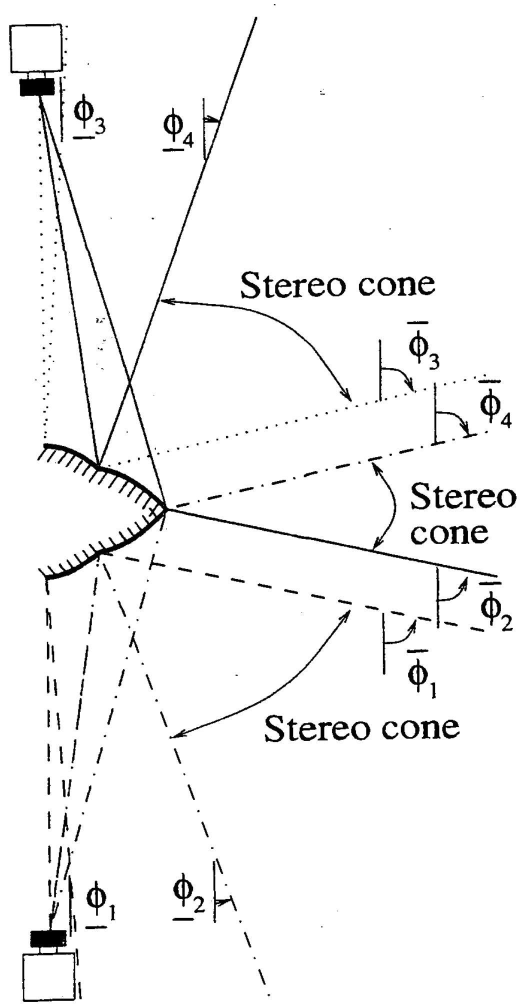


FIGURE 10

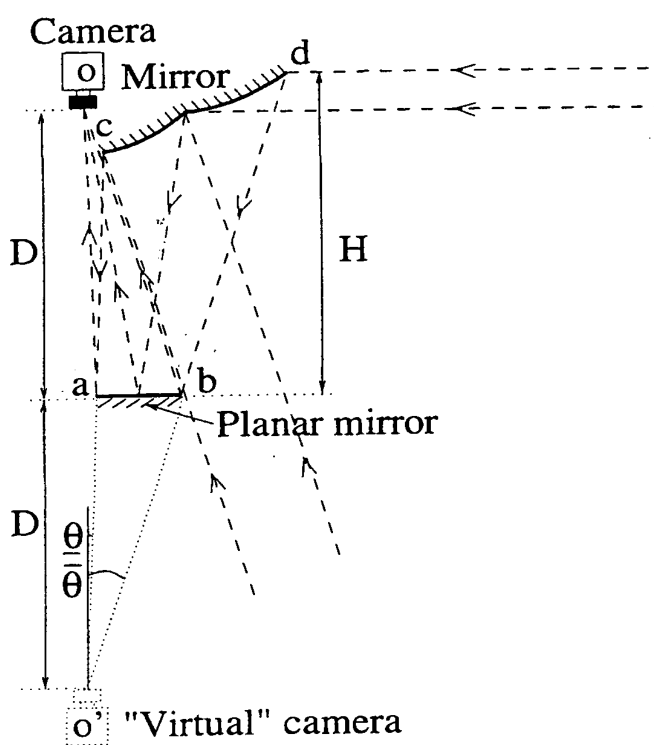


FIGURE 11

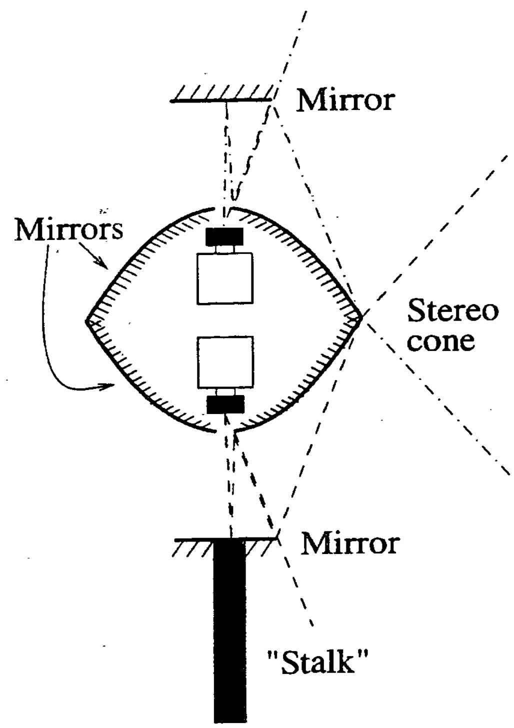


FIGURE 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU 00/00022

A.	**CLASSIFICATION OF SUBJECT MATTER**
Int Cl^{7}:	G03B 37/00, G02B 5/10, 13/06, 17/06, B25J 19/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: G03B 37/00, G02B 5/10, 13/06, 17/06, 23/08, B25J 19/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU: IPC AS ABOVE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI, JAPIO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	AU 74861/94 (673951) B (THE AUSTRALIAN NATIONAL UNIVERSITY) 21 March 1995 page 6 line 4 - page 14 line 14	1-5, 14-18
X	US 4566763 A (GREGUSS) 28 January 1986 Col 1 line 66 - col 2 line 16, fig 4	1, 14
A	US 5627675 A (DAVIS et al) 6 May 1997 Whole document	

[X] Further documents are listed in the continuation of Box C

[X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 17 February 2000	Date of mailing of the international search report 21 FEB 2000
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer M.E. DIXON Telephone No.: (02) 6283 2194

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU 00/00022

C (Continuation).	DOCUMENTS CONSIDERED TO BE RELEVANT	
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5502309 A (DAVIS) 26 March 1996 Fig 5	
A	US 4549208 A (KAMEJIMA et al) 22 October 1985 Col 3	
A	US 4449786 A (McCORD) 22 May 1984 Col 5 line 38 - col 7 line 24, Figs 5, 8, 13	

Form PCT/ISA/210 (continuation of Box C) (July 1998)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU 00/00022

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
AU	74861/94	WO	9506303	EP	715743	US	5790181
US	4566763	DE	3402847	FR	2540642	JP	59192220
US	5627675	EP	833178				

END OF ANNEX

Form PCT/ISA/210 (citation family annex) (July 1998)

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(19) Europäisches Patentamt
European Patent Offic
Offic europé n des brevets

(11) EP 0 695 085 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
31.01.1996 Bulletin 1996/05

(51) Int Cl.6: **H04N 5/262**, G02B 13/06

(21) Application number: **95304930.1**

(22) Date of filing: **14.07.1995**

(84) Designated Contracting States:
CH DE FR GB IT LI NL SE

(30) Priority: **27.07.1994 US 281331**

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(54) Method and apparatus for hemispheric imaging

(57) A system for electronic imaging of a hemispheric field of view includes a camera for receiving optical images of the field of view and for producing output data corresponding to the optical images. The camera includes an optical assembly for producing images throughout a hemispheric field of view for optical conveyance to an imaging device or photographic film. The optical system assembly has lens components that selectively emphasize the peripheral content of the hemispheric field of view. An electronic imaging device within the camera or a film-to-digital data conversion system provides digitized output signals to input image memory or electronic storage devices. A transform processor selectively accesses and processes the digitized output signals from the input image memory according to user-defined criteria and stores the signals in output image memory. The signals in the output image memory can then be displayed according to the user-defined criteria.

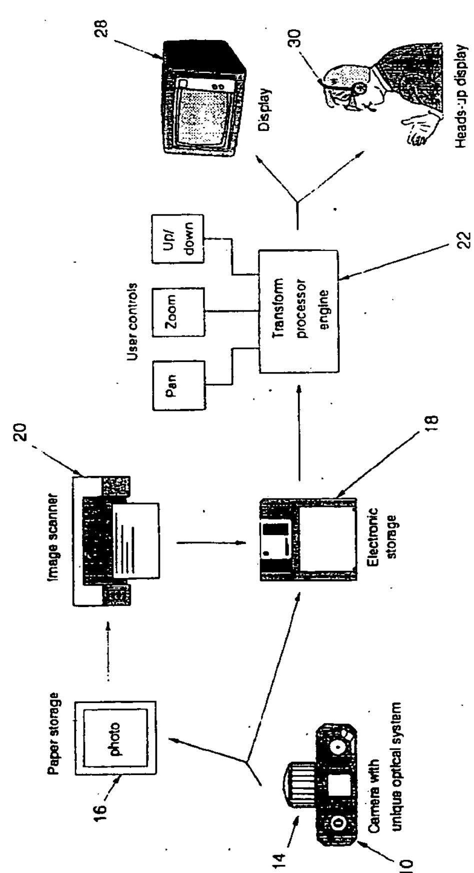


FIG. 1

EP 0 695 085 A1

Printed by Jouve (FR), 18, rue Saint-Denis, 75001 PARIS

D s ription

The present invention relates generally to visual imaging systems, and more particularly to visual imaging systems and techniques which provide useful electronic manipulation of wide angle hemispheric scenes.

The collection, storage, and display of large areas of visual information can be an expensive and difficult process to achieve accurately. With the recent increased emphasis on multimedia applications, various methods and apparatus have been developed to manage visual data. A unique class of multimedia data sets is that of hemispheric visual data. Known multimedia methods and apparatus attempt to combine various multimedia imaging data, such as still and motion (or video) images, with audio content using storage media such as photographic film, computer diskettes, compact discs (CDs), and interactive CDs. These are used in traditional multimedia applications in various fields, such as entertainment and education. Non-multimedia applications also exist that would employ hemispheric visual data, such as in security, surveillance, unmanned exploration, and fire and police situations. However, as will be described below, the known methods and apparatus have certain limitation in capturing and manipulating valuable information of hemispheric scenes in a rapid (ie real-time) and cost-effective manner.

One well-known multimedia technique is used at theme parks, wherein visual information from a scene is displayed on a screen or collection of screens that covers almost 360 degrees field of view. Such a technique unfortunately results in the consumption of vast quantities of film collected from multiple cameras requires specially-designed carriages to carry and support the cameras during filming of the scene,and necessitates synchronization of shots during capture and display. The technique is also limited in that the visual image cannot be obtained with a single camera nor manipulated for display, eg pan, tilt, zoom, etc., after initial acquisition. Hence, this technique, while providing entertainment, is unable to fulfil critical technical requirements of many functional applications. Other known techniques for capturing and storing visual information about a large field of view (FOV) are described in US Patent Nos. 4,125,862; 4,442,453 and 5,185,667. In US Patent No. 4,125,862, a system is disclosed that converts single information from a scene into digital form, stores the data of the digitized scene serially in two-dimensional format, and reads out the data by repetitive scan in a direction orthogonally related to the direction in which the data was stored. US Patent No. 4,442,453 discloses a system in which a landscape is photographed and stored on film. The film is then developed, with display accomplished by scanning with electro-optical sensors at "near real-time" rates. These techniques, however, do not provide instant visual image display, do not cover the field of view required for desired applications (hemispheric or 180 degrees field of view, do not generate visual image data in the format provided by the techniques of this invention, and are also not easily manipulated for further display, eg pan, tilt, etc.

The technique disclosed in the U.S. Patent No. 5,185,667 overcomes some of the above-identified drawbacks in that it is able to capture a near-hemisph ric field of view, correct the image using high speed circuitry to form a normal image, and electronically manipulate and display the image at real-time rates.

For many hemispheric visual applications, however, a system of the type described by the '667 patent has limitations in obtaining sufficient information of critical and useful details. This is particularly true when the camera is oriented with the central axis of the lens perpendicular to the plane bounding the hemisphere of acquisition (i.e. lens pointing straight up). In such applications, the majority of critical detail in a scene is contained in areas of the field along the horizon and little or no useful details are contained in central areas of the field located closer to the axis of the lens (the horizon being defined as the plane parallel to the image or camera plane and perpendicular to the optical axis of the imaging system). For example, in surveillance, the imaging system is aimed upward and the majority of the critical detail in the scene includes people, buildings, trees, etc. most of which are located within only a few degrees along the horizon (i.e., this is the peripheral content). Also, in this example, although the sky makes up the larger central area of the view, it contains little or no useful information requiring higher relative resolution.

To obtain sufficient detail on the critical objects in the scene, the technique should be able to differentiate between the relevant visual information along the horizon and the remaining visual information in the scene in order to provide greater resolution in areas of higher importance. The system described by the '667 patent does not differentiate between this relevant visual information contained along the horizon and the remaining visual information in this scene. Thus, it fails to yield a sufficient quality representation of the critical detail of the scene for projected applications.

Instead, techniques described above concentrate on obtaining, storing, and displaying the entire visual information in the scene, even when portions of this information are not necessary or useful. To obtain the near-hemispheric visual information, such techniques require specific lens types to map image information in the field of view to an image plane (where either a photographic film or electronic detector or imager is placed). Known examples of U.S. Patent No. 5,185,667 and U.S. Patent No. 4,442,453 respectively use a fish-eye lens and a general wide-angle lens. As these lenses map information of a large field without differentiation between the central and peripheral areas, information from the periphery will be less fully represented in the image plane than from the central area of acquisition.

U.S. Patent No. 4,170,400 describes a wide-angle optical system employing a fibre optic bundle that has differing geometric shapes at the imaging ends. Although this is useful in itself for collecting and repositioning image data, bending of light is a natural characteristic of optical fibres and not exclusive to that patent. Further, 4,170,400 employs a portion of a spherical mirror to gather optical information, rendering a very reduced subset of the periphery in the final imaging result. This configuration is significantly different from the multi-element lens combination described in the present invention.

Imperfections in the image representation of any field inherently result from the nature of creating an image with any spherical glass (or plastic) medium such as a lens. The magnitude of these imperfections increases proportionally to the distance a point in the field is from the axis perpendicular to the optical imaging system. As the angle between the optical axis and a point in the field increases, aberrations of the corresponding image increase proportional to this angle cubed. Hence, aberrations are more highly exaggerated in the peripheral areas with respect to more central areas of a hemispheric image.

Although the lens types above achieve a view of a large field, the valuable content from the peripheral areas lacks in potential image quality (resolution) mapping because the imaging device and system does not differentiate between these areas and the central areas of less valuable detail. Often, the difference between the imaging capabilities between the two areas is compensated for by using only the central portion of a lens to capture the scene ("stopping the lens down"). This works in effect to reduce the image quality of both areas such that the difference in error is a lesser percentage of the smallest area even the central area can resolve. Simultaneously, this compensation technique further degrades the performance of the lens by limiting the amount of light which is allowed to enter the lens, and thus reducing the overall intensity of the image.

More typically, the peripheral content imaged by a conventional lens is so degraded in comparison with the central area that the lens allows for only a minimal area of the periphery to be recorded by the film or electronic imager. As a result of these "off-axis" aberrations inherent to large fields, the relevant information of the horizon in the scene can be underutilized or worse yet -- lost.

Another limitation in patent 5,185,667 is its organization for recording only views already corrected for perspective. The nature of that methodology is that the specific view of interest must be selected and transformed prior to the recording process. The result is that no additional selection of views can be accomplished after the storage process, reducing system flexibility from the user's perspective.

Hence, there is a demand in the industry for single camera imaging systems that efficiently capture, store, and display valuable visual information within a hemispheric field of view containing particularly peripheral content, and that allow electronic manipulation and selective display of the image post-acquisition while minimizing distortion effects.

The present invention provides a new and useful visual imaging system that emphasizes the peripheral content of a hemispheric field of view using a single camera. The captured visual information can be stored as a single image using conventional chemical-based (film) or electronic data storage techniques. The invention allows user-selected portions of a hemispheric scene to be electronically manipulated and displayed from the stored visual database in a real-time and cost-effective manner.

According to the present invention there is provided a system for electronic imaging and manipulation of a hemispheric field of view, comprising:

a camera for receiving optical images of a hemispheric field of view and for producing output signals or affecting photographic film-based materials corresponding to the optical images;

an optical imaging device associated with the camera for producing optical images throughout the hemispheric field of view for optical conveyance to the camera, the optical system having a configuration adapted to capture and enhance an image of peripheral regions of the hemispheric field of view;

an image processing device associated with the camera and the optical imaging system for receiving optical images from the lens and for providing digitized output signals representative of the received optical images;

input image memory for receiving the digitized output signals from the imager device and for storing the digitized output signals;

image transform processing circuitry for selectively accessing and processing the digitized output signals from the input image memory according to user defined criteria;

output image memory for receiving the processed signals from the image transform processor, and

an output display or recording device connected to the output image memory for recording the signals in the output image memory.

Suitably the optical system magnifies a portion of the field of view within a range of approximately one to forty-five degrees above the horizon of a captured image of a hemispheric field of view, and preferably the optical system has a configuration which images a peripheral portion of the hemispheric scene onto at least 50% of an imaging area of an imaging device.

The optical system may include a wide field multi-element lens positioned to direct an image to a light transmitting fibre array, particularly one wherein the fibre array is geometrically arranged to have a generally annular input end and a generally rectangular output end, or wherein the fibre array is geometrically arranged to have a generally annular input end and a generally circular output end. Preferably the fibres of the fibre array have an imaging accuracy on the order of three microns. The system is most suitably one wherein the focal length of the wide field lens is scaled to match a desired magnification of the peripheral field of view.

The system is suitably configured such that the optical imaging system includes a colour-aberrated multiple element wide fi ld lens in combination with a gradient index hemispheric lens, in particular wherein the image processing device is an electronic imager, and preferably of the type wherein the image processing device is a charge-coupled device.

The system of the invention is preferably one wherein the image processing device is photographic film, and more preferably further includes a capture and conversion device that converts the optical images on the photographic film into digital output signals for input to the input image memory. A suitable capture and conversion device is an NTSC-to-digital converter.

Data from the capture and conversion device is preferably input to a source image frame buffer, in particular wherein the image transform processing circuitry comprises an image re-sampling sequencer; the image re-sampling sequencer preferably controls address sequencing of pixels in the source image frame buffer, and the image transform processing circuitry suitably further comprises row and column warp engines.

The image transform processing circuitry may further comprise a warped image buffer connected to the warp engines and to which an output of the source image frame buffer is input. The image transform processing circuitry may further comprise a look-up table containing transformation parameters for perspective correction of hemispheric field of view images. Such image transform processing circuitry preferably further comprises an interpolation coefficient buffer connected to the look-up table to update the transformation parameters, and connected to a multiply/accumulate unit.

In the system of the present invention the output display may be wom on or attached to a viewer's head, so that the orientation of the viewer with respect to the imaged surroundings is electronically conveyed and interpreted as user controls.

According to a second embodiment of the present invention there is provided a system for imaging and manipulation of a hemispheric field of view comprising:

(i) an optical system for producing an optical image of a hemispherical field of view, the optical system having a central lens axis coaxial with a central axis of the hemispherical field of view and a configuration which emphasizes through differential magnification of peripheral content of the hemispherical field of view, the optical image having a defined usable image area when projected onto a plane;

(ii) a camera optically coupled to the optical system for receiving optical images of the hemispherical field of view and for producing an output corresponding to the optical images;

(iii) input image memory coupled to the camera for receiving and storing the output from the camera;

(iv) a processor coupled to the input image m mory for selectively accessing from the input image memory and processing output from the camera, the processor for transforming the output from the camera according to user defined criteria into a processor output which has a peripheral image content emphasis which differs from that of the optical system;

(v) output image memory coupled to the processor for receiving and storing the processor output; and

(vi) an output device coupled to the output image memory for rendering the stored processor output into a visual image transformed from the optical image in accordance with the user defined criteria.

The optical system suitably has a configuration that images the peripheral portion of a hemispherical scene onto a portion of the optical image usable image area which is at least about fifty percent of the optical image usable image area.

Preferably the optical system has a configuration that images the peripheral portion of a hemispherical scene onto a portion of the optical image usable image area which ranges from about fifty percent to about ninety percent of the optical image usable image area.

Alternatively the optical system may have a configuration which emphasizes through differential magnification at least a portion of that content of the hemispherical field of view which lies between a base plane of the hemispherical field of view and a right cone defined about said central lens axis, said cone having an included angle of forty five degrees between said central lens axis and a line generating said cone and with said line generating said cone passing through the point of intersection of said central lens axis with said base plane.

More preferably the optical system has a configuration that images the peripheral portion of a hemispherical scene onto a portion of the optical image usable image area which is no more than about ninety percent of the optical image usable image area, and may suitably be an optical system comprising:

(i) a wide field multi-element lens; and a coordinated fibre array geometrically arranged to have a generally annular input end and a generally rectangular output end; or

(ii) a wide field multi-element lens; and a coordinated fibre array geometrically arranged to have a generally annular input end and a generally annular output end.

(iii) a colour-aberrated wide field lens; and a gradient index hemispheric lens.

The system may suitably further comprise an imager device interposed between the camera and the input image memory for receiving the output from the camera and for generating a digitized output, and further wherein the input image m mory, the processor, and said output image memory receive, store and process the digitized output. Preferably the camera comprises a light sensitive electronic image capture element and the imager device comprises an electronic digitizer circuit. More preferably the system further comprises photographic film for photographically capturing said output from the camera and further wherein the imager device comprises a capture and conversion device which converts the photographically captured output from the camera into the digitized output.

The system of this embodiment is preferably one wherein the processor comprises image processing and warping circuitry for transforming the output from the camera according to user defined criteria into a processor output which has a peripheral content emphasis which differs from that of the optical system, and more preferably the image processing and warping circuit comprises an arithmetic logic unit (ALU), and further the processor comprises a storage memory device coupled to the ALU for receiving and storing control programs for determining the functions served by the ALU, and a control program stored in the storage memory device and accessible to the ALU for controlling the operation of the ALU to transform the output from the camera according to user defined criteria into a processor output which has a peripheral/central content emphasis which differs from that of the optical system.

The processor suitably generates processor output which represents a selected portion of the hemispherical field of view.

The system aptly includes an output device comprising a visual display device for displaying a visual image closely adjacent the eyes of an observer.

In the preferred embodiment of the invention the processor generates processor output which represents a selected portion of the hemispherical field of view, and the system further comprises:

sensors for detecting the orientation of the head or eyes of an observer, and

a link between the sensors to the processor for modifying the generation of processor output as a function of the detected orientation of the eyes of an observer.

In a further preferred embodiment of the present invention there is provided a method for electronically capturing, storing, and manipulating a hemispheric field of view, comprising the steps of:

providing an optical system having a configuration that enhances the peripheral portion of the field of view,

capturing the hemispheric field of view with the periphery-enhancing optical system and imaging the field of view onto an imager device by enhancing the peripheral field of view,

storing the captured image as a single image,

selectively accessing a portion of the stored image according to user-defined criteria,

transforming the stored image so that the stored image can be displayed as a perspective-correct image,

displaying the perspective-correct image in a user-defined format.

Preferably the transforming step comprises manipulating the peripheral-enhanced image into a perspective-correct image.

In this preferred embodiment the periphery-enhancing optical system optionally selectively magnifies visual content within an arc of between 10 and 45 degrees up from the horizon in a hemispheric field of view onto the imager device.

The method may also include a storage step comprising storing the captured image onto photographic film and the step of selectively accessing a portion of the stored image comprising converting the image from the photographic film into digital output format. The storage step preferably comprises storing the captured image in electronic storage.

In a further embodiment of the present invention there is provided a method for electronically manipulating a hemispheric scene having an enhanced peripheral field of view stored as an image on photographic film, comprising the steps of:

converting the image on the photographic film into electronic output signals,

selectively accessing a portion of the output signals according to user-defined criteria,

transforming the accessed portion of the output signals by manipulating the peripheral-enhanced field of view so that the stored image can be displayed as a perspective-correct image,

displaying the perspective-correct image in the user-defined format.

In yet a further embodiment of the present invention there is provided a method for generating image sequences over physical distances from a reduced set of enhanced-periphery hemispheric images, wherein intermediate images are interpolated from a combination of adjacent hemispheric images, the method comprising the steps of:

defining how many intermediate images are needed to satisfy the simulation of motion-video or film-based movie cameras;

interpolating needed intermediate images from a combination of adjacent hemispheric images;

identifying or electronically tagging interpolated images, then storing or recording them for later introduction to the image processing subsystem;

loading original and interpolated image data sets in appropriate sequence to the image processing subsystem at rates sufficient to simulate real-time motion video, and

displaying the perspective-correct image in the user-defined format.

In yet a further embodiment of the present invention there is provided a system for electronic manipulation of a hemispheric scene, comprising:

a camera imaging system for imaging a hemispheric field of view;

an optical system associated with the camera imaging system for producing the optical images throughout the field of view for optical conveyance to the camera imaging system;

an imager device associated with the camera for receiving the optical images from the lens and for providing digitized output signals;

input image memory for receiving the digitized output signals from the imaging device and for storing the digitized output signals;

image transform processor circuitry for selectively accessing and processing the digitized output signals from the input image memory according to user-defined criteria;

output image memory for receiving the processed signals from the image transform processor means;

an output display device or electronic recording device connected to the output image memory for displaying or recording the signals in the output image memory according to user-defined criteria;

the optical system having a configuration that emphasizes the peripheral content of the field of view of a hemispheric scene as compared to the central content, such that the imager device receives magnified optical images of the peripheral portion of the hemispheric field of view.

The visual imaging system of the invention involves ither a still image or a moving picture camera, electronic or otherwise, having a lens with enhanced peripheral content imaging capabilities. The lens provides an enhanced view of the valuable information in the scene's periphery by imaging a field to the image plane such that the ratio of the size of the smallest detail contained within the periphery of the scene to the size of the smallest resolving pixel of an image device is increased. For this to be accomplished, the peripheral content must map to a larger percentage of a given image detector area and, simultaneously, the mapped image of the central area of the scene must be minimized by the lens so that it does not interfere with the peripheral content now covering a wider annulus in the image plane. Information in the image plane is then detected by an imager device (either a photographic film or electronic imager or video detector array). The detected information of the entire hemispheric scene is then stored as a single image in memory using traditional methods.

When a portion of the scene is to be displayed, the image information relating to the relevant portion of the scene is instantaneously retrieved from memory. A transform processor subsystem electronically manipulates the scene for display as a perspective-correct image on a display device, such as a conventional monitor or TV, as if the particular portion of the scene had been photographed with a conventional camera. The transform processor subsystem compensates for the distortion or difference in magnification between the central and peripheral areas of the scene caused by the lens by applying appropriate correction criteria to bring the selected portion of the scene into standard viewing format. The transform processor subsystem can also more fully compensate for any aberrations of the enhanced peripheral image because of the image's improved resolution as it covers a larger portion of the image device (increased number of pixels used to detect and measure the smallest detail in the periphery image). More pixels equates to more measurement data, hence more accurate data collection.

The stored image can also be manipulated by the transform processor subsystem to display an operator-selected portion of the image through particular movements, such as pan, zoom, up/down, tilt, rotation, etc.

By emphasizing the peripheral content of a scene, the visual imaging system can use a single camera to capture the relevant visual information within a panoramic field of view existing along the horizon, while being able to conventionally store and easily display the scene, or portions thereof, in real-time. Using a single optical system and camera is not only cost-effective but keeps all hemispheric visual data automatically time-synchronized.

One advantage of the present invention is that the unique visual imaging system lens can capture information from a hemispheric scene by emphasizing the peripheral portion of the hemispheric field of view and thus provide greater resolution with existing imaging devices for the relevant visual information in the scene. As an example, if an ordinary fish-eye lens focuses the lowest 15 degrees up from the horizon on 10% of the imager at the objective plane and the peripheral-enhancing lens focuses that same 15 degrees on 50% of the imager, there is a 5-fold increase in resolution using the same imaging device. Depending on the application and exact formulation of the lens equations, there will be at least a 5X increase in resolving power by this lens/imager combination.

Another advantage of the present invention is that the captured scene information having an enhanced peripheral content can be stored as a single image using conventional storage techniques, allowing post-acquisition selection of particular views.

Still another advantage of the present invention is that the image can be read out from storage and electronically manipulated at any time after acquisition to provide flexibility in display options, as opposed to being stored in conventional perspective formats only.

Another advantage is that the system can generate motion video from a reduced set of still images through interpolation and inter-scene warping. Still other advantages of the present invention should become apparent from the following detailed description and appended claims.

The following detailed description is made with reference to the accompanying Figures, wherein like reference numerals refer to like parts.

In the annexed drawings:

Figure 1 is a schematic illustration of the various components and organization of the visual imaging system of the present invention;

Figure 2A is a cross-sectional diagram of a wide angle lens system of the prior art;

Figure 2B is a box diagram indicating the field input and output rays and the resulting relative field coverage a lens of the prior art typically provides in an image plane for detection by an imager device;

Figure 2C is a cross-sectional diagram of a lens system of the prior art indicating angular key to visual field;

Figure 3A is a cross-sectional diagram of one embodiment of a peripheral image enhancing lens system of the present invention;

Figure 3B is a box diagram of the annulus field input of a bundled fibre array portion of the lens system of Figure 3A;

Figure 3C is a box diagram of the imager interface output of a bundled fibre array portion of the lens system of Figure 3A;

Figure 4A is a cross-sectional diagram of another embodiment of a peripheral image enhancing lens system of the present invention;

Figure 4B is a box diagram indicating the field input and output rays indicating the resulting field coverage of the lens system of Figure 4A;

Figure 5 is a schematic representation of the mapping locations of the lens systems of the present invention resulting upon an imaging device;

Figure 6 is a schematic block diagram of the image processing circuitry of the present invention including the transform processor subsystem thereof;

Figure 7 is a block diagram schematically indicating further integration of a portion of the image processing circuitry of Figure 6, and

Figure 8 is an alternate embodiment of the image processing circuitry of the present invention incorporating the integrated circuitry elements of Figure 7.

The invention will be defined initially with a brief description of the principles thereof.

The present invention stems from the realization by the inventors that in many of the technical hemispheric field applications, where the image detector is parallel to the horizon, much of the relevant visual information in the scene (eg trees, mountains, people, etc.) is found only in a small angle with respect to the horizon. Although the length of the arc from the horizon containing the relevant information varies depending upon the particular application, the inventors have determined that in many situations, almost all the relevant visual information is contained within about 10 to 45 degrees with respect to the horizon.

To maximize data collection and resolution for analysis and/or display of the relevant visual information located in this portion of the hemispheric scene, it is desirable to maximize the dedication of the available image detection area to this peripheral field portion. To accommodate this, it is necessary that the "central" portion of the scene (from 45 to 90 degrees with respect to the horizon) cover only the remaining areas of the imager plane so as not to interfere with light from the periphery.

In many cases, since the "central" area contains less detailed information, such as a solid white ceiling or a clear or lightly-clouded sky, it is allowable to maximize completely the dedication of the available image detection area to the peripheral field portion by reducing the portion of the imager device representing the "central" area to near zero. Of course, in certain instances, it is desirable to analyze this less detailed information, but this portion of the scene can be minimized to some extent without significant degradation of such visual information. As will be described herein in more detail, the present invention provides two manners (Example I and Example II) for capturing, storing, and selectively displaying the critical visual information in a scene for many important applications.

Referring now to the drawings, and initially to Figure 1, the visual imaging system of the invention includes a still image or moving picture camera 10, having a lens, indicated generally at 14, designed to capture and enhance the peripheral content of a hemispheric scene. The captured scene can be stored onto an assortment of media, eg photographic film 16, electronic storage 18, or other conventional storage means. Electronic storage 18 is preferred because of the ease of electronic manipulation thereof. Additionally, photographic film 16 requires an image scanner 20 or other capture-and-conversion method to change the image into electronic format before electronic manipulation can be performed.

The stored electronic image data is then selectively accessed by a transform processor engine 22 and can be electronically manipulated according to user-defined criteria, such as pan, up/down, zoom, etc. The transform processor 22 corrects the image for display on a conventional display device 28 in a normal viewer format or on head-mounted displays 30, in which integrated orientation-sensing devices having, for example, wearer eye focus detection function, can be used to manipulate and define the user controls.

I Image Acquisition

a. Camera

The camera 10 for the visual imaging system is an optical device that is capable of receiving a focused image from a lens and transforming that image into an electronic signal or into hard copy storage such as photographic film. Various types of cameras for wide-angle viewing are known to those in the art, such as 35mm cameras, 8mm cameras, NTSC, RS170 and HDTV-type cameras. The present invention is designed to be compatible with most commercially-available two-dimensional cameras, with scaling of the lens geometries. It also has the technological capability to be applied to three-dimensional cameras. The camera can be mounted and supported in a conventional manner.

b. Lens With Enhanced Peripheral Content

The fundamental principle behind the enhanced peripheral content lens is the selective magnification of the periphery and the focusing of more of that content on the objective plane. This recognizes the current limitations of imaging devices and film with regard to resolution. As such, the more of the peripheral content that can be focused on the objective plane surface, the more points of data that can be resolved with a given density of imaging device or material. Therefore, for this new class of selective magnification lenses, the surface area of the imaging plane reserved for peripheral content will be large relative to the central content and roughly similar for all lenses in this class, regardless of whether the lens is designed for 1-10 degree peripheral emphasis or 1-45 degree peripheral emphasis. However, it should be noted that the lens with 1-10 degree emphasis will have much better resolution for the same objects than the lens with 1-45 degree emphasis.

The lens 14 for camera 10 provides a collection of data for enhanced digital processing of the peripheral portion of a given field of view. The lens uniquely achieves this by filling the greater available area of an imager device with the peripheral areas rather than the central areas of the captured scene.

A periphery-enhancing optical system suitable for achieving the goals of the present invention can be configured in various ways to present an image of the field free of detrimental values of critical aberrations. Two examples or embodiments are preferred. Example I, as illustrated by Figures 3A-3C, preferably is a multi-medium system comprising a wide-angle multi-element optical lens and a fibre optic imager device. Example II as illustrated by Figures 4A-4B, preferably is a combination system comprised of multiple refractive optical elements, one of which is of gradient index material and hemispherical in shape. The inventors define that other configurations relying on binary optics could also be utilized to accomplish similar results.

The system of Example I is best suited for applications where the capture of the minimal information contained in the central area is irrelevant. A coordinated fibre bundle array 40, either rigid or flexible, carefully aligned and assembled by methods known to those skilled in the art, is used to capture a peripheral annulus of the wide field image provided by the multi-element wide field lens. The multi-element wide field lens 42 therefore, although covering the same field as standard wide field lenses, is required to provide a larger image of the entire field. This can be accomplished by those skilled in the art by scaling a standard lens to a larger focal length until the desired image size is reached. (REF. Journal of the Optical Society of America, 1964. Lens Designs Presented by Miyamota; Smith, W.J., Modern Lens Design, Ch. 5.4 "Scaling a Design", McGraw-Hill, Inc. 1992. Also see U.S. Patent No. 4,256,373 by M. Horimoto for additional wide-field lenses.)

The fibres, arranged in a specific mechanical manner, deliver the information in a geometrically annular shape from the peripheral image area to either the rectangular or circular shape of a specific imaging device. Specific configurations can be devised for desired peripheral coverage (up to 10 degrees through 45 degrees) and matched to required image detector plane geometry. (REF. Sect. 13, Fibre Optics, Handbook of Optics, McGraw-Hill Inc., 1978.) Referring to Figure 3A, for a desired angle 0 (theta), a standard wide-field lens design is scaled in "f", the focal length, to provide ry' such that the minimum pick-up area of the camera imaging device (2r') is met. In the "Camera/Imager Interface" portion of the figure, the equation for fibre bundle radius is related to the imager is:

$$\text{Area at imager} = (pi)r_{y'}^2 - (pi)r_{x'}^2 = (pi)(r_{y'}^2 - r_{x'}^2)$$

$$\text{Imager length} = 2r', \text{ where } r' = r_{y'}^2 - r_{x'}^2$$

A configuration in the form of Example I achieves an image in which the peripheral portion (0-45 degrees with respect to the horizon) of the field of view preferably encompasses between approximately 90% to 100% of the entire usable area of the imager device, rather than the 35% or less that is typical with commercially-available wide-angle, fish-eye, or other conventional lenses. A configuration in the form of Example II achieves an image in which the peripheral portion preferably encompasses between 50% to 70% of the usable area of the imaging device surface.

The system of Example II is best suited for applications where all information contained in the field of view is relevant, although to differing degrees. The combination system of Example II relies on the principle use of a Bravais System where a hemispherical lens 52 or a combination of lenslets magnify an object to an image, wherein the object and image lie in the same plane. In this case, the hemispherical lens 52 is made of gradient index material such that points impinging the image plane incur different factors of magnification depending on what index of refraction and what portion of the hemispherical curve or lenslets they pass through. This concept is used in combination with a multi-element refractive lens 54 that is designed to capture a wide field of view and also compensate for the colour aberration induced by insertion of the hemispherical lens. This colour compensation can be designed by those skilled in the art by using a computer optimization routine. (REF. M. Horimoto and U.S. Patent No. 4,256,373.) By use of the hemispherical gradient index unit with a wide field multi-element lens, the portion of the camera dedicated to the periphery is increased, thereby increasing the relative resolution of information detectable by the imaging device sensing elements. With the gradient index hemisphere, index values decrease from the centre, such that:

$$n_1 < n_2 < n_3 < n_4$$

The operation of the optical systems is schematically illustrated in Figures 2A-B, 4A and 4B. In Figure 2A, arc X represents the field of view of the "centre" of the lens system; while the arc Y represents the practically usable portion of the "peripheral" field. The areas X' and Y' in Figure 2A represent the resultant image focal locations on the imager at the object plane. Arc Z and area Z' represent areas outside the normal imaging range of the lens. (No actual demarcation lines would exist in actual use: this is merely for explanatory purposes.)

Figure 2A represents a typical wide-angle type lens 32, while Figure 4A represents a lens constructed according to the principles of the present invention. As should be apparent from comparing Figures 2A and 4A, a typical wide-angle type lens has a fairly significant portion of the image surface dedicated to the central field of the lens; while the lens constructed according to the present invention has a fairly significant portion of the objective surface dedicated to the peripheral field -- and consequently less of the surface dedicated to the central field.

The portion of the image surface used for the peripheral portion of the scene (as compared with the central portion of the scene) can vary depending upon the particular prescription of lens specified, which is selected to capture items of interest for a given application. For example, if the imaging system is used to capture a panorama of an outdoor scene, the relevant visual information may be contained within 10 degrees of the horizon. The lens of the present invention can thus be designed to enhance only the field of view within 10 degrees of the horizon. On the other hand, if the imaging system is being used to capture a room scene within a building, the relevant visual information may include objects on walls and thus be contained within about 45 degrees from the horizon. A peripheral enhancing lens can thus also be designed to enhance the field of view up to 45 degrees from the horizon. Of course, the enhanced portion of the field of view depends upon the needs of the particular application, with the enhanced portion preferably falling somewhere between these two extremes. In any case, the principles of the present invention can be applied to these types of situations with equal success, with any appropriate corrections being made with the image transform processors, as will be described herein in more detail.

As illustrated in Figure 3A, a preferred form of the Example I form of optical system comprises a standard wide field lens 42 and a coordinated fibre array 40. The focal length of the wide field lens is scaled in order to match the peripheral field of view desired. The coordinated fibre array consists of an annular input face 44 that collects the image projected from the standard wide field lens. The fibre bundle array then redirects the information from the peripheral view to its output end by total internal reflection. Fibres capable of 3 micron accuracy, covering the area of the annular region, are coordinated into a rectangular or circular shape at their output, depending on the geometry of the corresponding imaging device. The size of output is also matched to the camera imaging device used.

Of course, these system configurations and parameters are only exemplary in nature and other configurations and parameters of the present invention could be used to provide enhanced peripheral imaging capabilities, as should be apparent to those skilled in the art.

a. Imager Device

An electronic camera 10 used for exemplary purposes includes an imager device that records the optical image from the lens at the object plane. For a photographic process, the imaging medium is film, while for an electronic process, the imaging medium is an electronic device such as a charge-coupled device (CCD) or charge-injected device (CID). As indicated previously, electronic processes are typically preferred over photographic processes as they are easier to electronically manipulate. Photographic processes, however, can be preferred in certain situations. Numerous makes and models of film and electronic imaging devices are known to those skilled in the art that provide uniform resolution across the receiving surface.

When the imager device is used with a lens constructed according to the principles of the present invention, the imager device will collect more information along the horizon than it will from the central area of the hemispheric scene. With only a given limited resolution of either film emulsions or CCD pixel density, the lens focuses more useful information at the objective plane. The peripheral portion of the scene will therefore have a higher relative resolution in the resultant transformed image than the central portion. Thus, the details of any objects along the horizon will be highly accentuated. Further, any distortion (eg spherical aberration) that occurs in the peripheral region of the lens will be imaged onto a larger surface and can thus be more easily and fully compensated for. The image mapped onto the imager device can be described by a series of concentric circles, as schematically illustrated in Figure 5. As an example, each circle a, b, c, d, etc. on the imager device can be described by radii of arbitrary units, e.g., 2, 5, 9, 14, etc., respectively. The radii of the circles depends on the magnification of the different regions of the hemisphere, with the sections of the outer circles having a greater area as the magnification of the peripheral region increases. For example, in an arbitrarily selected illustration case, each concentric circle represents 18 degrees field of view from the horizontal plane, with the outer circumference of the outermost circle being level with the horizon. The inventors have determined that the arc subtending the two outer circles (i.e., 36 degrees from the horizon) contains the relevant information in many hemispheric scenes for many applications (although this value can be varied depending upon the particular application).

Calculating the total circular area of the entire image circle yields 1257 units squared. The area of the three inner circles is 254 units squared. Therefore, the two outer circles contain about 80% of the usable area on the imaging device. Note that the image blocks corresponding to the horizon are spread across more area on the imager device than those in the central area of the image. Thus, the image blocks of the imager device are dominated by objects along the horizon, and those are the area of interest. This correlates to greater resolution for the peripheral areas of the scene.

If for some reason an Example I circular-output optical system is configured with a square or rectangular imaging device, the corner areas of the imaging device are not useful for photographic purposes. However, these areas can be used to store other information, for example, such as digitized audio content or other secondary documentation from the scene, if the imager is radially mapped 1:1 with electronic memory.

II Image Storage

The image received on the imager device is passed on to the system components for storage. For photographic processes, a storage device might be film; while for electronic processes, the storage device might be electronic storage in the form of random access memories, a conventional diskette or hard file, or video recording tape. The entire display of the scene (along with any secondary documentation) can be stored as a single image on the storage device.

The image is stored in a "warped" form. The warped image is caused not only by the wide-angle nature of the lens (i.e. the "keystoning" effect), but also by the enhanced peripheral field of view of the lens (i.e., magnification along the periphery). The underlying concept is that a partial slice of the scene can be reproduced with the proper aspect ratio for the human visual system (i.e., as a perspective corrected view).

As schematically diagrammed in Figure 6, the stored image is loaded into the source image buffer 40 if it has been stored in electronic form on a host system such as a personal computer or controller. Alternatively, the image can be brought in for processing without going through storage. As one option, an analog signal from a video camera can connect into an NTSC-to-digital converter 60. This converts the image from analog information into a digital bit map (i.e., into "pixels"). The source image is then loaded into the source image frame buffer 62. However, as indicated previously, any type of camera can be used to provide the electronic input to buffer 62. The buffer preferably operates with sufficient speed so that real-time viewing is possible.

III Image Retrieval/Display

The stored image can be selectively accessed and transformed for display. If the storage is photographic film, an image scanner may be used to convert the stored image into an electronic format for subsequent manipulation. In order to recreate a proper display of the scene in two dimensions for perspective correct viewing, processor logic in transform processor engine 22 is utilized. The transform processors may be made of collections of small-scale, medium-scale, large-scale, or very-large-scale integrated (VLSI) circuits, examples of which are image resampling sequencers such as the TMC2301 and TMC2302, commercially available from Raytheon Semiconductors (formerly TRW LSI Products, Inc., LaJolla, CA.).

In Figure 6, resampling sequencers control the address sequencing of the pixels in the source image buffer 62 through a multiply/accumulate unit 64, and from there into the warped image buffer 66. The sequencers control the filtering or remapping of 2-dimensional images from a set of Cartesian coordinates (x,y) as defined within each sector "unit" (A1, B1, etc.) onto a newly transformed set of coordinates (u,v). The "fish-eye" type of transformations described in U.S. Patent No. 5,185,667 are based on non-constant second-order derivatives. A different set of second-order derivatives would be employed for the transforms associated with the peripheral-enhancing configurations of the present invention. The sequencers can also handle three-dimensional images by resampling them from a set of Cartesian coordinates (x,y,z) into a new, transformed set (u,v,w). Typically these sequencers can support nearest-neighbour, bilinear interpolation or convolution resampling, and can operate at speeds allowing real-time operation.

Remapped pixel locations (i.e., interpolation "kernels") of more than one pixel in the bit map require an external interpolation coefficient look-up table 68 and the multiply/accumulate unit 64. A table "walk" is typically performed on each source pixel, thus providing a smoother image by summing the products of the original lens image data with the appropriate interpolation coefficients. By capturing the hemispheric lens image data into source image buffer 62, the warp engine can be programmed to perform a perspective correction, much like an inverse keystoning effect. The remapping of the pixel locations is matched to the diff rential magnification of the particular periphery-enhancing lens system used.

Direct access to the interpolation coefficient look-up table 68 and to the transformation parameters is also desirable to allow dynamic modification of the interpolation algorithm. Thus, a local interpolation coefficient buffer 70 to update the varying transform parameters is included to allow for real-time still and motion image transformations.

The row and column warping engines 72a, 72b of the transform processor 22 supply addresses to the source image buffer 62. The addresses are determined by the interpolation algorithm chosen. The multiply/accumulate unit 64 takes the pixels supplied by the source image buffer 62 under warping engine control and multiplies the pixels together using combinational logic with weighting factors dependent on the algorithm. Compensation for aberration (e.g., spherical aberration) can also be made at this point. Finally, the composed interpolated pixels are sent to the warped image buffer 66. The address location within the warped image buffer is again determined by the warping. The algorithm parameters from look-up table 68 are input to the registers of the row and column warping engines 72a, 72b, as well as into the interpolation coefficient buffer 70.

The memory controller/clock circuitry 74 provides refresh control to the source and warped image buffers 62, 66. In addition, all clock sources are synchronized through this circuitry. The bus interface and control circuitry 76 also provide an interface to the host system bus (ie for MCA, ISA, etc.) and the remapping circuitry. This interface logic serves to load control information into the remapping circuitry and to provide a path to transport warped images to the system display buffer (not shown; part of host system), or store images to disk via the system bus prior to warping. An optional random access memory digital-to-analog converter (RAMDAC) 78 provides support for a local display connection if desired.

One feature of the transform processors is the valid source address flag within the transform processor engine. This allows the user to construct abutting subimages in the (x,y) plane without danger of edge interference. Thus, edge detection of the unused areas outside the circular image of Figure 5 can alert the system to ignore these values.

The image capture function can be accomplished with either still or motion video devices or as pre-recorded digital data. All types of image data are input to the source image buffer 62 for processing as desired. Note that while the preferred mode for still image capture will come from previously captured images through a local host bus interface 76, the NTSC digitizer 60, for example, can provide real-time data from an external video camera. Any similar device that converts an image to the appropriate digital format for input to the source image buffer can be substituted for digitizer 60. In the same fashion, an electronic still imager, such as an electronic still camera, line scanner, or table scanner, can provide still image data for processing. Prerecorded distorted images generated through this invention's optical system can also be input through an additional conversion device to allow dynamic manipulation of previously recorded image data.

The image transformation performed on the captured digitized image from modified hemispheric coordinates to planar coordinates for display is one of a multitude of possible image transformations, any of which can be invoked in real-time for smooth merging of effects. These transformations include, but are not limited to pans, up/downs, zooms, tilts, rotations, scaling, cropping and image shear, which can be controlled using human or computer input. Image filtering can be performed as well as edge detection in associated processes during the course of manipulation. These services can be applied to any system image loaded into the source image buffer, thus providing a host of added features beyond the simple application of the hemispheric lens and display system.

The advantage of the image transformation logic becomes apparent when describing particular applications. A security camera application can be implemented to view an entire panorama such that the security monitor will display full-motion rate images in real-time. Source image coordinates for still images can also be sequenced, allowing perceived animation or full-motion renditions by simply reloading new source image coordinates into the warping engines as frames are drawn from memory. Details from other stored images can be utilized to give the effect of full-motion panning of the horizon within the captured image by the lens.

An additional feature of the present invention is its ability to create motion video presentations with a reduced set of still frames, as compared with the number of full-motion frames ordinarily required. For example, when a set of building storefronts is filmed with a traditional motion picture camera from the back of a moving truck, each frame contains the time-based content of the image entering the traditional lens and only one limited field of view is available at a time. With the system of the present invention, motion can be reconstructed from a greatly reduced subset of frames because the greater field of captured data already contains picture content from the next frame and previous frame due to its exceptionally wide angle. By analyzing picture content within a host computer program, intermediate frame equivalents sufficient to complete a full-motion data set can be constructed and fed to the source image buffer in sequence for processing. Alternatively, separate circuits operating at real-time rat s can interpolate intermediate values and supply changes in transformation parameters for existing still images fast enough to synthesize motion sequences. Preference for one technique over another will be dependent on the specific application requirements and other development/market considerations.

Finally, the transform processor subsystem can produce multiple different outputs simultaneously from individual stored or currently-converted images. With the main transform processor circuits collected into a simplified single image processing subsystem 80 as shown in Figure 7, multiple outputs may be generated from a single image source, either motion or still, with individual effects for each scene as desired, allowing several scenes on different display devices or several windows on a single display. This is accomplished by incorporating several image processing subsystems 80 within one overall system, as shown in Figure 8.

In all cases, by having greater resolution of the peripheral image of a scene, the details of any objects along the horizon will be enhanced. Further, aberrations occurring around the periphery of the lens (i.e., spherical aberrations) can be more fully and completely compensated for, as the aberrations are spread across a greater area on the imager device.

As described above, the present invention provides a visual imaging system that efficiently captures, stores, and displays visual information about an enhanced hemispheric field of view existing particularly along the horizon, and that allows electronic manipulation and selective display thereof even after acquisition and storage, while minimizing distortion.

The principles, embodiments, and modes of operation of the present invention have been described in the foregoing specification. The invention that is intended to be protected herein should not, however, be construed to the particular form described as it is to be regarded as illustrative rather than restrictive. Variations and changes may be made by those skilled in the art without departing from the spirit of the present invention. Accordingly, the foregoing detailed description should be exemplary in nature and not limiting as to the scope of the invention as set forth in the appended claims.

Claims

1. A system for electronic imaging and manipulation of a hemispheric field of view, comprising:

   a camera for receiving optical images of a hemispheric field of view and for producing output signals or affecting photographic film-based materials corresponding to the optical images;

   an optical imaging device associated with said camera for producing optical images throughout the hemispheric field of view for optical conveyance to said camera, said optical system having a configuration adapted to capture and enhance an image of peripheral regions of the hemispheric field of view;

   an image processing device associated with said camera and said optical imaging system for receiving optical images from said lens and for providing digitized output signals representative of the received optical images;

   input image memory for receiving the digitized output signals from said imager device and for storing the digitized output signals;

   image transform processing circuitry for selectively accessing and processing the digitized output signals from said input image memory according to user defined criteria;

   output image memory for receiving the processed signals from the image transform processor, and

   an output display or recording device connected to said output image memory for recording the signals in said output image memory.

2. The system as claimed in claim 1, wherein said optical system magnifies a portion of the field of view within a range of approximately zero to forty-five degrees above the horizon of a captured image of a hemispheric field of view.

3. The system as claimed in claim 1 or 2, wherein said optical system has a configuration which images a peripheral portion of the hemispheric scene onto at least 50% of an imaging area of an imaging device.

4. The system as claimed in claim 3, wherein said optical system includes a wide field multi-element lens positioned to direct an image to a light transmitting fibre array.

5. The system as claimed in claim 4 wherein the fibre array is geometrically arranged to have a generally annular input end and a generally rectangular output end.

6. The system as claimed in claim 4, wherein the fibre array is geometrically arranged to have a generally annular input end and a generally circular output end.

7. The system as claimed in claim 4 wherein the fibres of the fibre array have an imaging accuracy on the order of three microns.

8. The system as claimed in claim 4 wherein the focal length of the wide field lens is scaled to match a desired magnification of the peripheral field of view.

9. The system as claimed in any one of claims 1 to 8, wherein said optical imaging system includes a colour-aberrated multiple element wide field lens in combination with a gradient index hemispheric lens.

10. A method for electronically capturing, storing, and manipulating a hemispheric field of view, comprising

the steps of:

providing an optical system having a configuration that enhances the peripheral portion of the field of view,

capturing the hemispheric field of view with the periphery-enhancing optical system and imaging the field of view onto an imager device by enhancing the peripheral field of view,

storing the captured image as a single image,

selectively accessing a portion of the stored image according to user-defined criteria,

transforming the stored image so that the stored image can be displayed as a perspective-correct image,

displaying the perspective-correct image in a user-defined format.

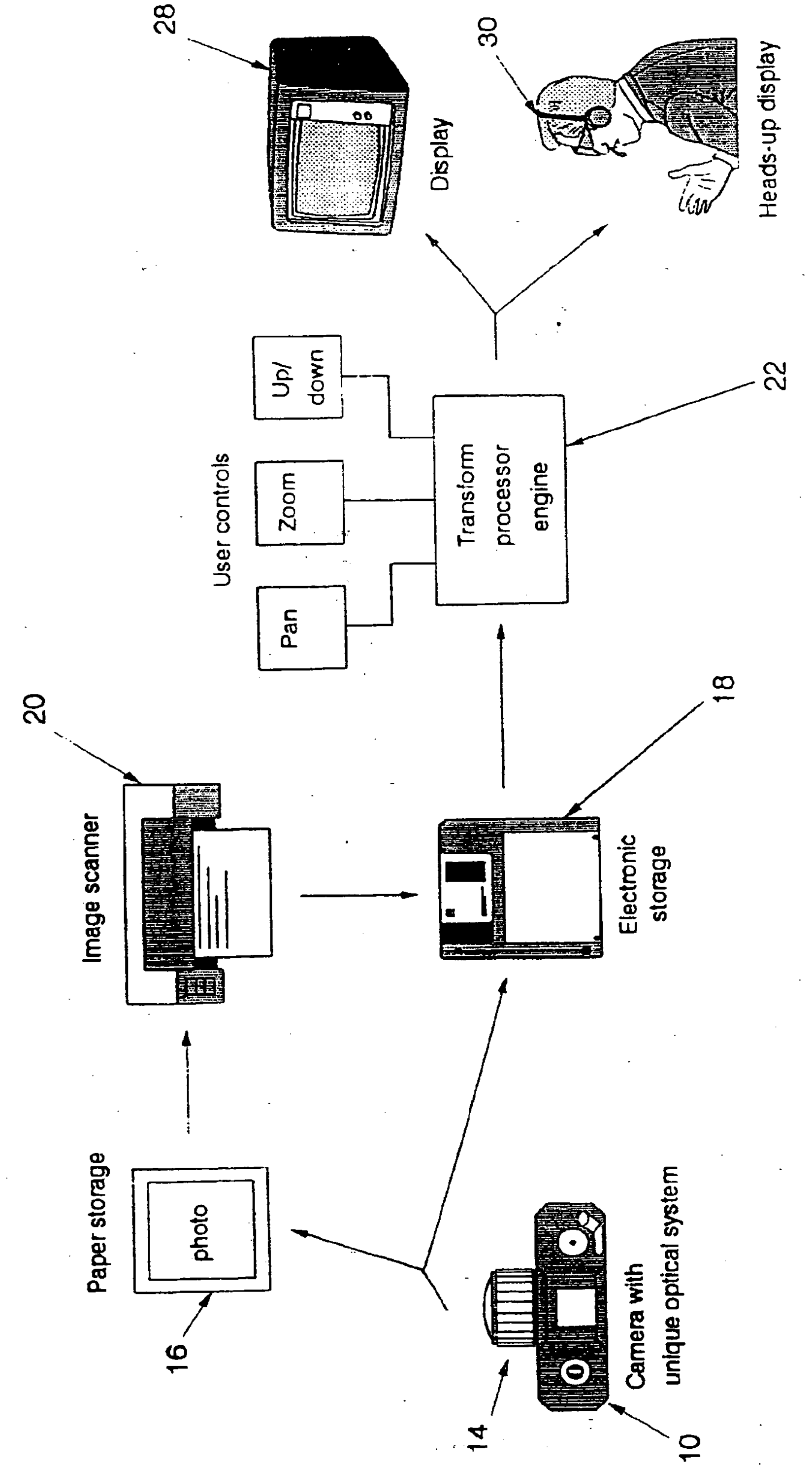

28
Display
30
Heads-up display
User controls
Pan
Zoom
Up/
down
Transform
processor
engine
22
20
Image scanner
Electronic
storage
18
Paper storage
photo
16
Camera with
unique optical system
14
10

FIG. 1

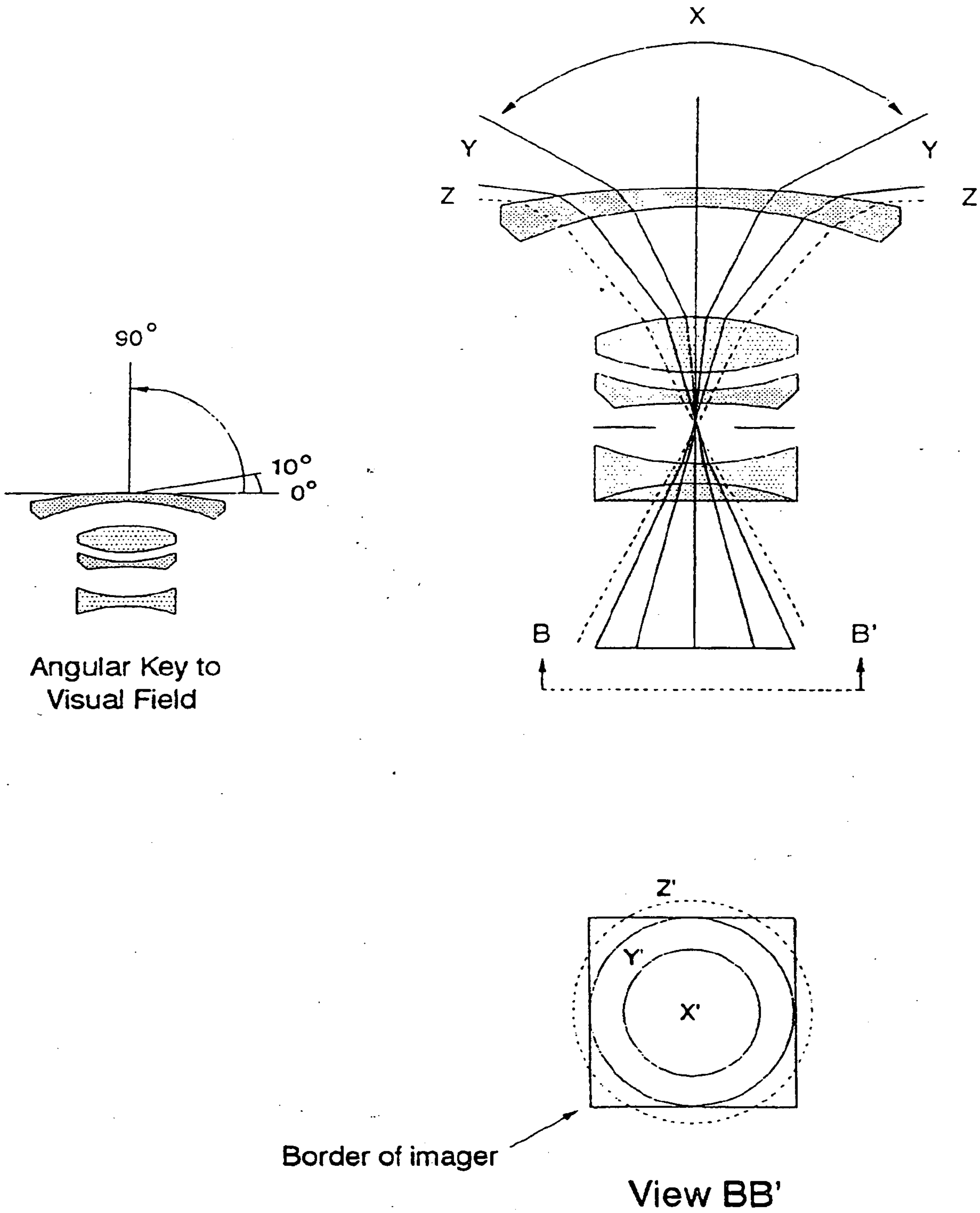
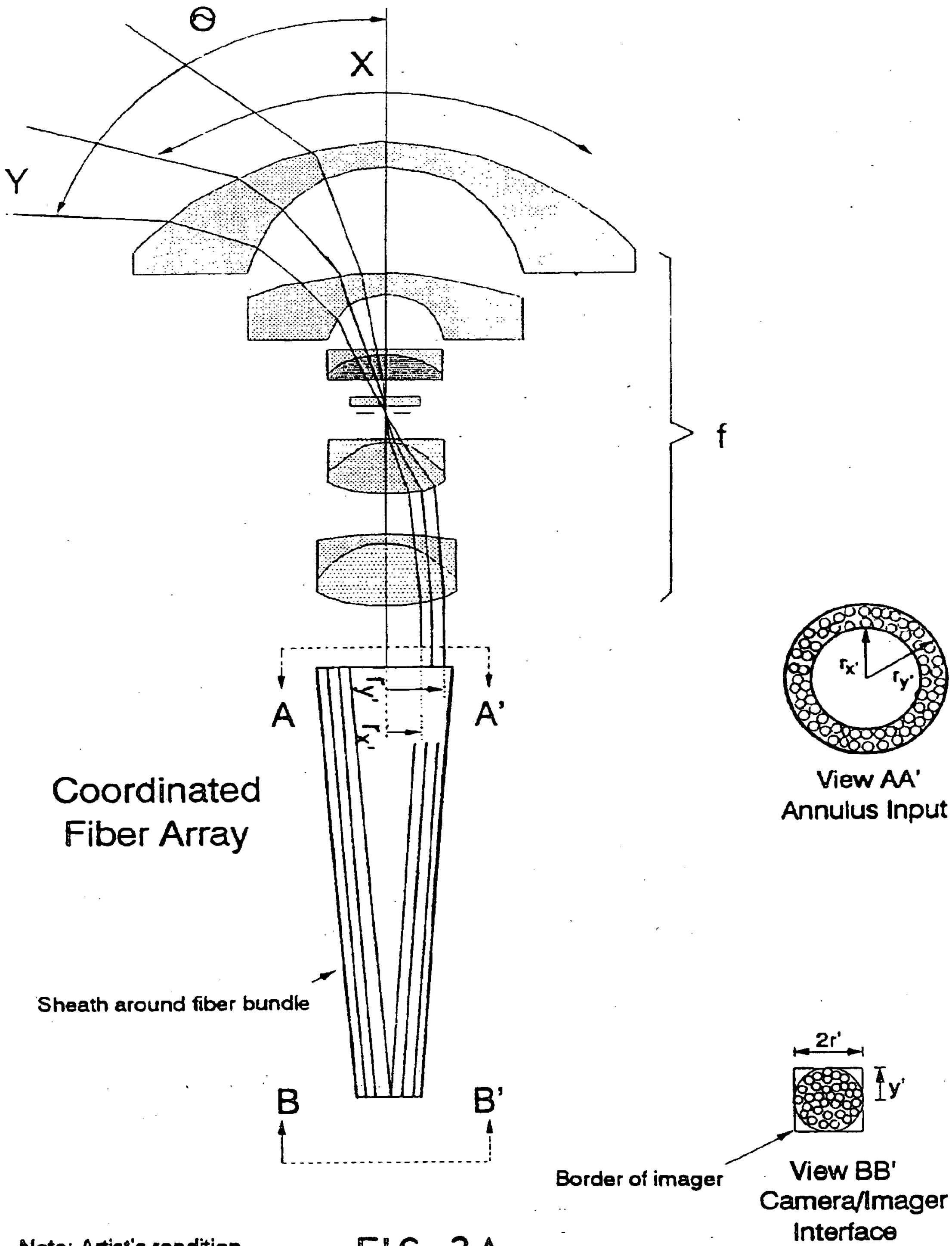

X
Y
Y
Z
Z
90°
10°
0°
Angular Key to Visual Field
B
B'
Z'
Y'
X'
Border of imager
View BB'

FIG. 2



Note: Artist's rendition
Drawing not to scale

FIG. 3A

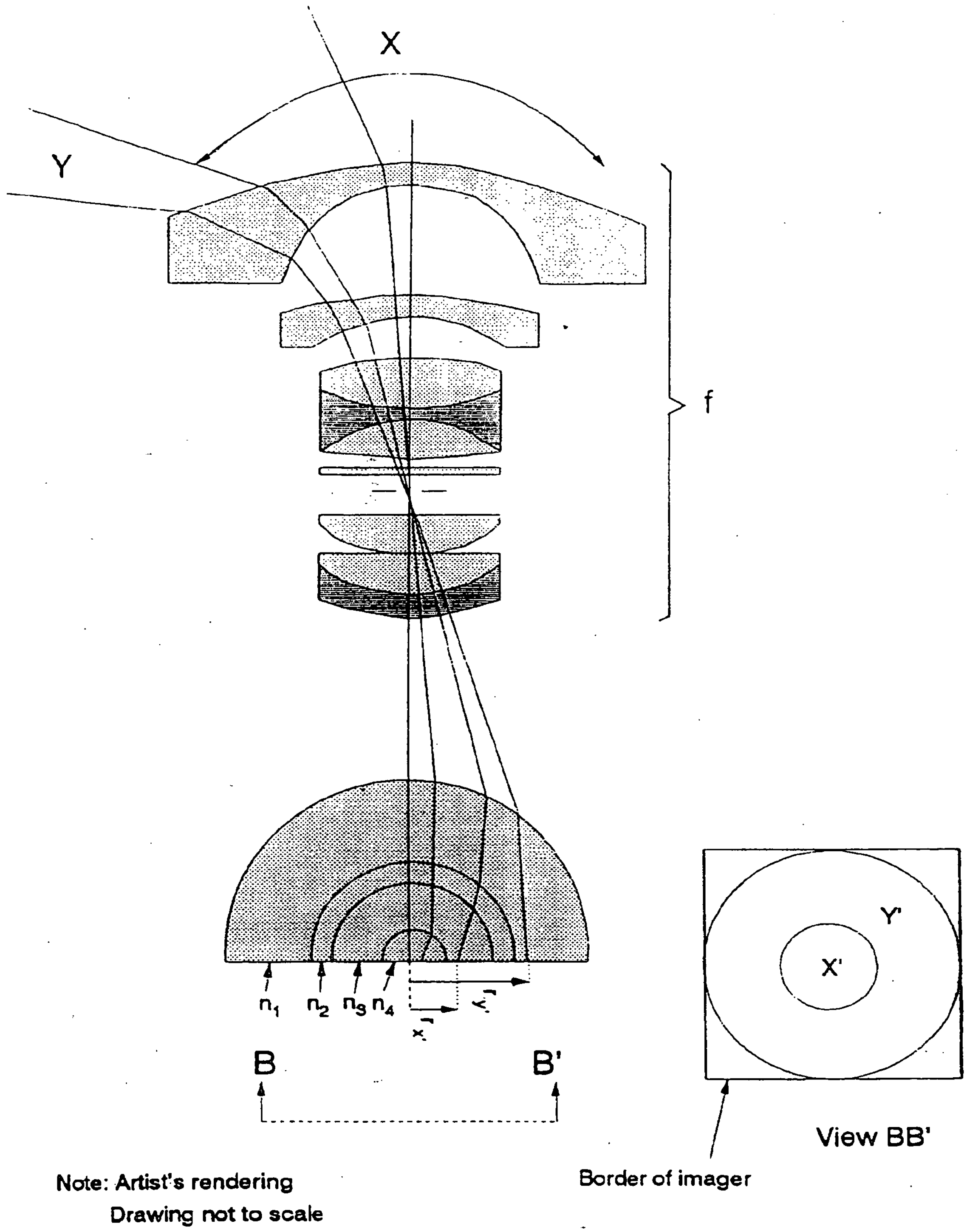

X
Y
f
n_1 n_2 n_3 n_4
B
B'
Y'
X'
View BB'
Border of imager
Note: Artist's rendering
Drawing not to scale

FIG. 3B

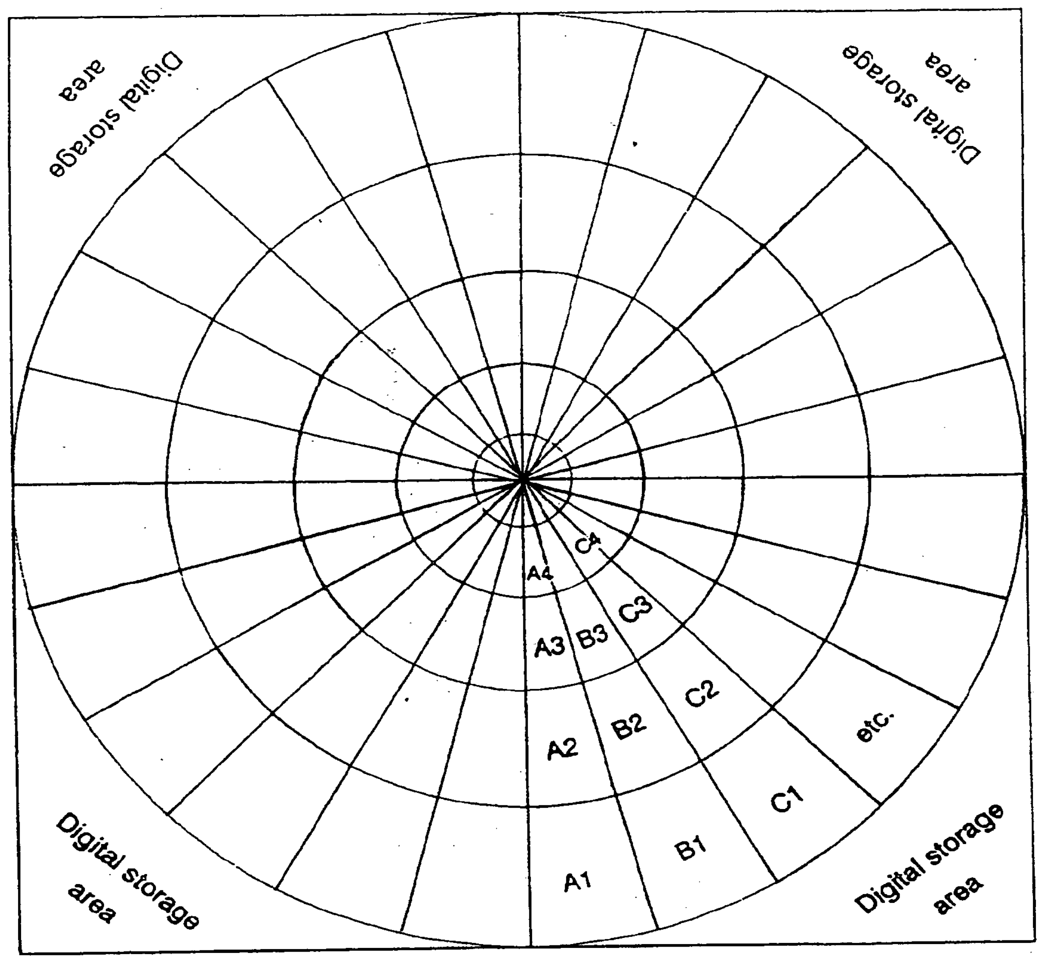
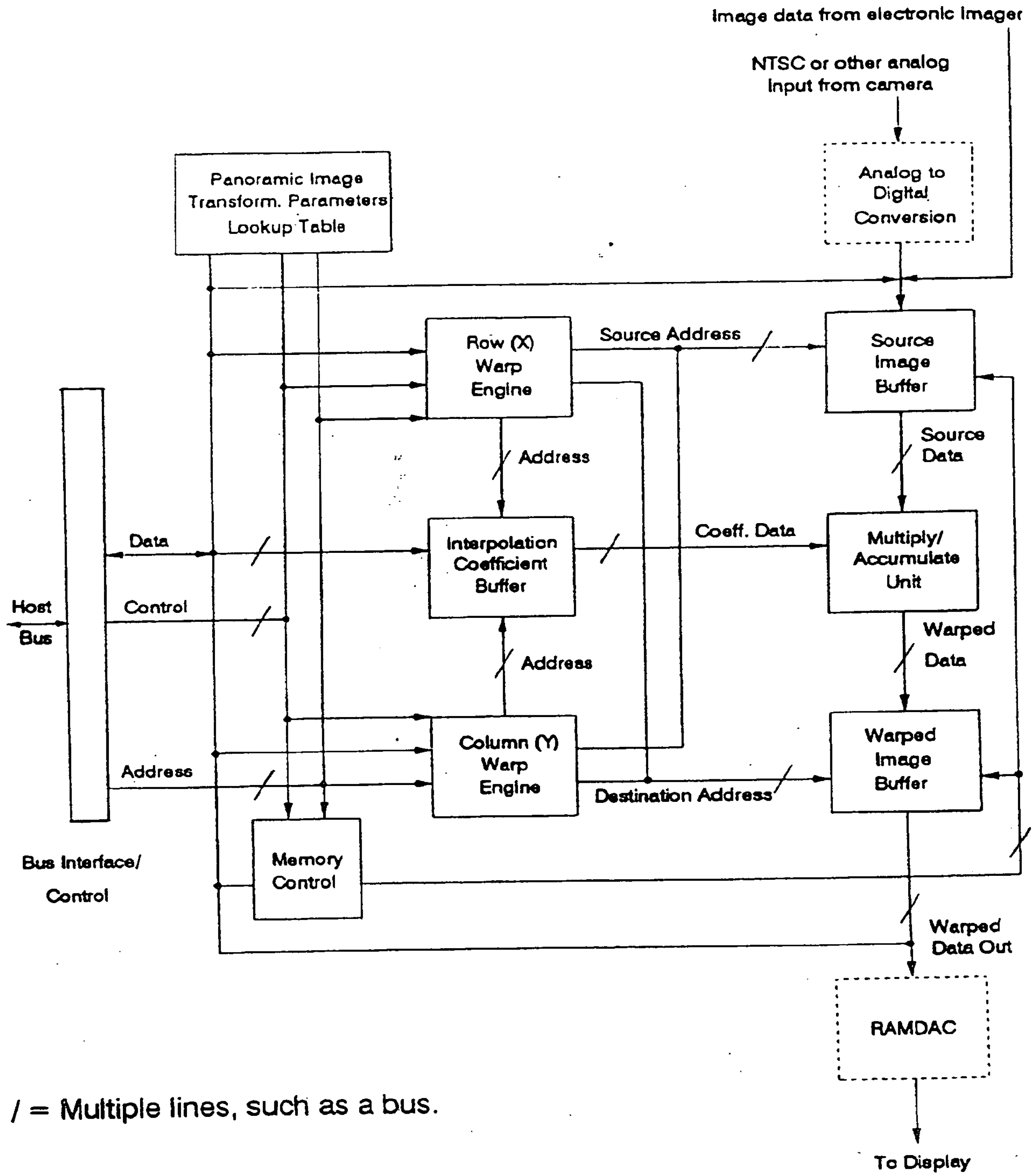

Digital storage area
Digital storage area
Digital storage area
Digital storage area
C4
A4
A3
B3
C3
A2
B2
C2
etc.
A1
B1
C1

FIG. 4



/ = Multiple lines, such as a bus.

FIG. 5

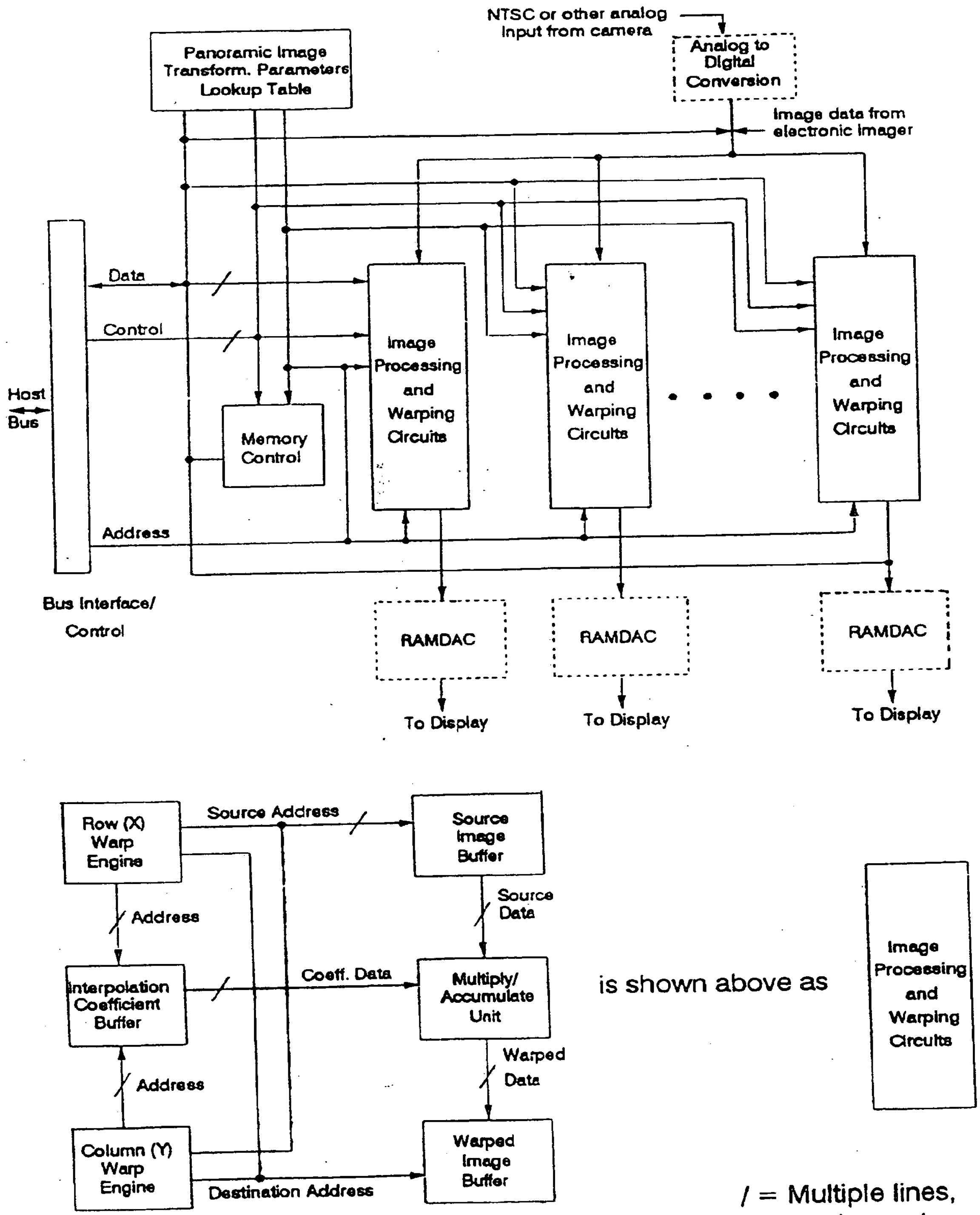

NTSC or other analog input from camera
Analog to Digital Conversion
Image data from electronic imager
Panoramic Image Transform. Parameters Lookup Table
Data
Control
Host Bus
Memory Control
Image Processing and Warping Circuits
Image Processing and Warping Circuits
Image Processing and Warping Circuits
Address
Bus Interface/ Control
RAMDAC
RAMDAC
RAMDAC
To Display
To Display
To Display
Row (X) Warp Engine
Source Address
Source Image Buffer
Source Data
Address
Interpolation Coefficient Buffer
Coeff. Data
Multiply/ Accumulate Unit
is shown above as
Image Processing and Warping Circuits
Warped Data
Address
Column (Y) Warp Engine
Destination Address
Warped Image Buffer
/ = Multiple lines, such as a bus

FIG. 6

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 30 4930

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
D,Y	WO-A-92 21208 (TELEROBOTICS INTERNATIONAL, INC.) * page 1, line 1 - page 9, line 25 * ---	1,10	H04N5/262 G02B13/06
Y	WO-A-89 03076 (U.K. SECRETARY FOR TRADE & INDUSTRY) * page 4, line 10 - line 16 * ---	1,10	
A	PROCEEDINGS OF THE SPIE, APPLICATIONS OF DIGITAL IMAGE PROCESSING XV, vol. 1771, July 1992 SAN DIEGO, CA, USA, pages 106-112, GILBERT ET AL. 'Endoscopic inspection and measurement' * page 106, line 24 - page 108, line 10 * ---	1-3,10	
A	PROCEEDINGS OF THE SPIE, APPLICATIONS OF DIGITAL IMAGE PROCESSING XV, vol. 1771, July 1992 SAN DIEGO, CA, USA, pages 567-573, GREGUSS ET AL. 'PALIMADAR: a PAL-optic based imaging modul for allround data acquisition and recording' * page 567, line 17 - page 569, line 43 * ---	1-3,10	TECHNICAL FIELDS SEARCHED (Int.Cl.6) H04N G02B
A	EP-A-0 574 325 (THOMSON-CSF) * column 1, line 1 - line 18 * * column 3, line 35 - line 45 * * column 4, line 38 - column 5, line 33 * ---	1,4,5,10	
A	EP-A-0 547 635 (EASTMAN KODAK COMPANY) * column 3, line 4 - line 18 * * column 3, line 46 - column 4, line 2 * * column 5, line 3 - line 33 * * column 6, line 39 - line 44 * ---	1,10	
A	US-A-4 832 472 (ROBB) * column 2, line 45 - line 53 * --- -/--	9	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	27 October 1995	De Dieuleveult, A

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 30 4930

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	PATENT ABSTRACTS OF JAPAN vol. 13 no. 425 (M-873) ,21 September 1989 & JP-A-01 163079 (NIPPON SHEET GLASS CO LTD) 27 June 1989, * abstract * -----	9	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	27 October 1995	De Dieuleveult, A

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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P : intermediate document

T : theory or principle underlying the invention
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L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

[0081] One feature of the transform processors is the valid source address flag within the transform processor engine. This allows the user to construct abutting subimages in the (x,y) plane without danger of edge interference. Thus, edge detection of the unused areas outside the circular image of Figure 5 can alert the system to ignore these values.

[0082] The image capture function can be accomplished with either still or motion video devices or as prerecorded digital data. All types of image data are input to the source image buffer 62 for processing as desired. Note that while the preferred mode for still image capture will come from previously captured images through a local host bus interface 76, the NTSC digitizer 60, for example, can provide real-time data from an external video camera. Any similar device that converts an image to the appropriate digital format for input to the source image buffer can be substituted for digitizer 60. In the same fashion, an electronic still imager, such as an electronic still camera, line scanner, or table scanner, can provide still image data for processing. Prerecorded distorted images generated through this invention's optical system can also be input through an additional conversion device to allow dynamic manipulation of previously recorded image data.

[0083] The image transformation performed on the captured digitized image from modified hemispheric coordinates to planar coordinates for display is one of a multitude of possible image transformations, any of which can be invoked in real-time for smooth merging of effects. These transformations include, but are not limited to pans, up/downs, zooms, tilts, rotations, scaling, cropping and image shear, which can be controlled using human or computer input. Image filtering can be performed as well as edge detection in associated processes during the course of manipulation. These services can be applied to any system image loaded into the source image buffer, thus providing a host of added features beyond the simple application of the hemispheric lens and display system.

[0084] The advantage of the image transformation logic becomes apparent when describing particular applications. A security camera application can be implemented to view an entire panorama such that the security monitor will display full-motion rate images in real-time. Source image coordinates for still images can also be sequenced, allowing perceived animation or full-motion renditions by simply reloading new source image coordinates into the warping engines as frames are drawn from memory. Details from other stored images can be utilized to give the effect of full-motion panning of the horizon within the captured image by the lens.

[0085] An additional feature of the present invention is its ability to create motion video presentations with a reduced set of still frames, as compared with the number of full-motion frames ordinarily required. For example, when a set of building storefronts is filmed with a traditional motion picture camera from the back of a moving truck, each frame contains the time-based content of the image entering the traditional lens and only one limited field of view is available at a time. With the system of the present invention, motion can be reconstructed from a greatly reduced subset of frames because the greater field of captured data already contains picture content from the next frame and previous frame due to its exceptionally wide angle. By analyzing picture content within a host computer program, intermediate frame equivalents sufficient to complete a full-motion data set can be constructed and fed to the source image buffer in sequence for processing. Alternatively, separate circuits operating at real-time rates can interpolate intermediate values and supply changes in transformation parameters for existing still images fast enough to synthesize motion sequences. Preference for one technique over another will be dependent on the specific application requirements and other development/market considerations.

[0086] Finally, the transform processor subsystem can produce multiple different outputs simultaneously from individual stored or currently-converted images. With the main transform processor circuits collected into a simplified single image processing subsystem 80 as shown in Figure 7, multiple outputs may be generated from a single image source, either motion or still, with individual effects for each scene as desired, allowing several scenes on different display devices or several windows on a single display. This is accomplished by incorporating several image processing subsystems 80 within one overall system, as shown in Figure 8.

[0087] In all cases, by having greater resolution of the peripheral image of a scene, the details of any objects along the horizon will be enhanced. Further, aberrations occurring around the periphery of the lens (i.e., spherical aberrations) can be more fully and completely compensated for, as the aberrations are spread across a greater area on the imager device.

[0088] As described above, the present invention provides a visual imaging system that efficiently captures, stores, and displays visual information about an enhanced hemispheric field of view existing particularly along the horizon, and that allows electronic manipulation and selective display thereof even after acquisition and storage, while minimizing distortion.

Claims

1. A visual imaging system for electronic imaging and manipulation of a hemispheric field of view, comprising:

   a camera (10) for receiving optical images of a hemispheric field of view and for producing output signals or affecting photographic film-based materials corresponding to the optical images;

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an optical imaging device (14,42,54) associated with said camera (10) for producing optical images throughout the hemispheric field of view for optical conveyance to said camera (10);

an image processing device (10,20) associated with said camera (10) and said optical imaging device for providing digitized output signals representative of the received optical images;

an input image memory (18) for receiving the digitized output signals from said image processing device and for storing the digitized output signals;

an image transform processor (22) for selectively accessing and processing the digitized output signals from said input image memory according to user defined criteria;

an output image memory for receiving the processed signals from the image transform processor, and

an output display (28,30) or recording device connected to said output image memory for displaying or recording the signals stored in said output image memory;

characterised by said optical imaging device having a configuration adapted to capture and enhance an image of peripheral regions of the hemispheric field of view and for magnifying a portion of the field of view within a range of approximately one to forty five degrees above the horizon of a captured image of a hemispherical field of view.

2. The system as claimed in claim 1 wherein said optical imaging device has a configuration which images a peripheral portion of the hemispheric scene onto at least 50% of an imaging area of an imaging device.

3. The system as claimed in claim 2, wherein said optical imaging device includes a wide field multi-element lens (42) positioned to direct an image to a light transmitting fibre array (40).

4. The system as claimed in claim 3 wherein the fibre array (40) is geometrically arranged to have a generally annular input end and a generally rectangular output end.

5. The system as claimed in claim 3, wherein the fibre array (40) is geometrically arranged to have a generally annular input end and a generally circular output end.

6. The system as claimed in claim 3 wherein the fibres of the fibre array (40) have an imaging accuracy on the order of three microns.

7. The system as claimed in claim 3 wherein the focal length of the wide field lens (42) is scaled to match a desired magnification of the peripheral field of view.

8. The system as claimed in any one of claims 1 to 7, wherein said optical imaging device includes a colour-aberrated multiple element wide field lens in combination with a gradient index hemispheric lens.

9. A method for electronically capturing, storing, and manipulating a hemispheric field of view, comprising the steps of:

providing an optical system having a configuration that enhances the peripheral portion of the field of view,

capturing the hemispheric field of view with the periphery-enhancing optical system and imaging the field of view onto an imager device while enhancing the peripheral field of view by selectively magnifying the visual content within an arc of between one to forty five degrees up from the horizon,

storing the captured image as a single image,

selectively accessing a portion of the stored image according to user-defined criteria,

transforming the stored image so that the stored image can be displayed as a perspective-correct image,

displaying the perspective-correct image in a user-defined format.

Patentansprüche

1. Visuelles Abbildungssystem zur elektronischen Abbildung und Bearbeitung eines halbkugelförmigen Sichtfeldes, das Folgendes umfasst:

eine Kamera (10), um optische Bilder eines halbkugelförmigen Sichtfeldes zu empfangen und Ausgangssignale zu erzeugen oder Materialien auf der Grundlage von fotografischem Film, die den optischen Bildern entsprechen, zu beeinflussen;

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Online European Patent Register - Results

Status of the database as of 20-05-2003 (dd-mm-yyyy)

Choose your View: All data mentioned in Rule 92 and EPIDOS, including file history

Most recent event
Lapse of the patent in a contracting state
Date of publication — 19-02-2003 [2003/08]

Publication numbers, publication type and publication dates
EP0695085 A1 31-01-1996 [1996/05]
EP0695085 B1 16-02-2000 [2000/07]
Date of grant — 16-02-2000 [2000/07]

Application numbers and filing date
EP19950304930 (95304930.1)
Date of filing — 14-07-1995 [1996/05]

Date of publication of search report
Date of publication of search report — 31-01-1996 [1996/05]

Priority number, priority date
US19940281331 27-07-1994 [1996/05]

Classification (IPC) and bulletin number
H04N5/262, G02B13/06 [1996/05]

Designated states
CH , DE , FR , GB , IT , LI , NL , SE [1996/05]

English title
Method and apparatus for hemispheric imaging [1996/05]

French title
Procédé et dispositif pour prise de vues hémisphériques [1996/05]

German title
Verfahren und Vorrichtung zur hemisphärischen Bildaufnahme [1996/05]

Designated states, applicant name, address
FOR ALL DESIGNATED STATES
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FOR ALL DESIGNATED STATES
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Filing language
EN

Procedure language
EN

Publicati n language
B1 — EN [2000/07]

L cati n of file and fax number f r file inspection requests
Application is treated in (/fax-nr) — MUNICH/(+49-89) 23994465

Examination procedure
request for examination — 28-05-1996 [1996/30]
Examination report(s) A.96(2), R.51(2)
date dispatch/time-limit/reply — 22-04-1998/M06/22-10-1998
communication R.51(4)
dispatched — 04-05-1999
- approval (yes or no) — yes

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printing 21-08-1999/21-08-1999

Opposition procedure

no opposition filed, time-limit expired on 17-11-2000 [2001/05]

Renewal fees

Renewal fee A.86 (patent year / paid)
03/16-07-1997
04/17-07-1998
05/20-07-1999

Lapsed, data supplied by contracting states

CH/16-02-2000
LI/16-02-2000
NL/16-02-2000
SE/16-05-2000 [2003/08]
[
CH/16-02-2000

LI/16-02-2000

SE/16-05-2000 [2001/09]
]
[
CH/16-02-2000

LI/16-02-2000 [2000/52]
]

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EP0574325 A [A];
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[A] PROCEEDINGS OF THE SPIE, APPLICATIONS OF DIGITAL IMAGE PROCESSING XV, vol. 1771, July 1992 SAN DIEGO, CA, USA, pages 106-112, GILBERT ET AL. 'Endoscopic inspection and measurement';
[A] PROCEEDINGS OF THE SPIE, APPLICATIONS OF DIGITAL IMAGE PROCESSING XV, vol. 1771, July 1992 SAN DIEGO, CA, USA, pages 567-573, GREGUSS ET AL. 'PALIMADAR: a PAL-optic based imaging modul for allround data acquisition and recording';
[A] PATENT ABSTRACTS OF JAPAN vol. 13 no. 425 (M-873) ,21 September 1989 & JP-A-01 163079 (NIPPON SHEET GLASS CO LTD) 27 June 1989,

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[End of Data]

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22-05-2003 11:45:44

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Method and apparatus for hemispheric imaging

Patent Number:	EP0695085
Publication date:	1996-01-31
Inventor(s):	BAKER ROBERT GROVER (US); KETTLER KEVIN (US); FLATTERY FREEDENBURG CANDACE J (US SUAREZ GUSTAVO ARMANDO (US); UPLINGER KENNETH ALLEN (US)
Applicant(s):	IBM (US)
Requested Patent:	EP0695085, B1
Application Number:	EP19950304930 19950714
Priority Number (s):	US19940281331 19940727
IPC Classification:	H04N5/262; G02B13/06
EC Classification:	G02B6/04, H04N7/14A2, H04N7/15, G02B3/00G, G02B6/06, G02B13/06, H04N5/262T
Equivalents:	BR9502919, CA2152314, DE69515087D, DE69515087T, JP2001091825, JP3103008B2, JP8055215, US5508734
Cited Documents:	WO9221208; WO8903076; EP0574325; EP0547635; US4832472; JP1163079

Abstract

A system for electronic imaging of a hemispheric field of view includes a camera for receiving optical images of the field of vie and for producing output data corresponding to the optical images. The camera includes an optical assembly for producing images throughout a hemispheric field of view for optical conveyance to an imaging device or photographic film. The optical system assembly has lens components that selectively emphasize the peripheral content of the hemispheric field of view. An electronic imaging device within the camera or a film-to-digital data conversion system provides digitized output signals to inp image memory or electronic storage devices. A transform processor selectively accesses and processes the digitized output signals from the input image memory according to user-defined criteria and stores the signals in output image memory. The signals in the output image memory can then be displayed according to the user-defined criteria.

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(19) Europäisches Patentamt
European Patent Office
Office uropéen des brevets

(11) EP 1 004 915 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
31.05.2000 Bulletin 2000/22

(51) Int. Cl.7: **G02B 13/06**

(21) Application number: 99304759.6

(22) Date of filing: 17.06.1999

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 25.11.1998 JP 35075198

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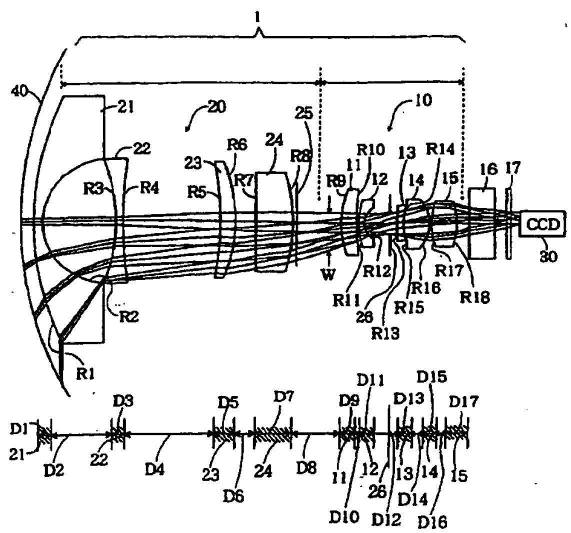
(54) Image pick-up device, image display device and information recording medium comprising a fisheye lens

(57) An image is picked up by a camera (2) comprising a fisheye lens (1) having a relationship of $h = n \cdot f \cdot \tan(\theta/m)$, wherein h is the height of an image of a subject at a certain point, f is the focal distance of the fisheye lens, θ if a field angle, m has a value of $1.6 \leq m \leq 3$, and n has a value of $m-0.4 \leq n \leq m + 0.4$, and the image data of which is output from the camera (2), is converted into a plane image by an image data processing unit (3), and this converted image is then output to a monitor unit (4). Preferably, n and m both equal 2.

Fig. 2



EP 1 004 915 A1

Description

[0001] The present invention relates to an image pick-up device comprising a fisheye lens, an image display device and an information recording medium, all of which can obtain a high-quality converted image when an image picked up by the fisheye lens is converted into a plane image.

[0002] A monitoring system using a camera which enables product examination at a plant or construction work at a construction site to be monitored from a remote place has recently been developed. In this monitoring system, depending on what is monitored, capability of monitoring a wide range at a limited number of cameras is desired. To realize this, the development of a monitoring system comprising a fisheye lens which can pick up an image of all the directions of the field of view around the optical axis at a field angle of at least 90° in each direction with respect to the optical axis is under way.

[0003] Use of this fisheye lens makes it possible to obtain an image of all the space with a single camera. That is, the space is regarded as a single sphere, a camera is installed at the center of the sphere, an image of half of the sphere is picked up by the fisheye lens, the camera is turned at an angle of 180° from that position, an image of the other half of the sphere in the opposite direction is picked up, and the two images are combined together to obtain an image of all the directions of the field of view in the space of 360°, that is, the sphere. This image is converted into a plane image.

[0004] As the monitoring system comprising a fisheye lens of the prior art, there is a system disclosed by Japanese Patent Application Laid-open No. Hei6-501585 (to be referred to as "prior art" hereinafter), for example. Although this prior art makes it possible to pick up an image of all the directions of the field of view, the lens used in the prior art is a fisheye lens having a relationship of $h = f \cdot \theta$ (wherein h is the height of an image of a subject at a certain point obtained by the fisheye lens, f is the focal distance of the fisheye lens and θ is a field angle). This is obvious from the fact that Nikon's 8-mm f/2.8 lens is used as the fisheye lens in the above Japanese Patent Application Laid-open No. Hei6-501585. Conventional fisheye lenses generally have a relationship of $h = f \cdot \theta$ and Nikon's 8-mm f/2.8 fisheye lens has the above relationship of $h = f \cdot \theta$.

[0005] The method of picking up an image by a fisheye lens having this relationship of $h = f \cdot \theta$ and converting the image into a plane image is called "equidistant projection". Since an image picked up by a fisheye lens having the above characteristics has a small volume of image data on its peripheral portion (field angle of around 90° with respect to the optical axis of the fisheye lens), when the image is converted into a plane image, there are many missing portions of image data on the peripheral portion of the image and the missing portions must be interpolated. In addition, the image picked up by the fisheye lens having the above characteristics involves such a problem that the peripheral portion of the image is distorted.

[0006] An object of the present invention is to provide an image pick-up device comprising a fisheye lens, an image display device and an information recording medium, which minimize missing portions of image data by extracting a large volume of image data at a field angle of around 90° with respect to the optical axis of the fisheye lens to reduce interpolating of the missing portions and can obtain a natural plane image when images of all the directions of the field of view around the optical axis are picked up at a field angle of at least 90° with respect to the optical axis and are converted into plane images.

[0007] Various other objects, advantages and features of the present invention will become readily apparent to those of ordinary skill in the art, and the novel features will be particularly pointed out in the appended claims.

[0008] To attain the above object, according to a first aspect of the present invention, there is provided an image pick-up device comprising a fisheye lens for picking up an image of all the directions of the field of view around the optical axis of the fisheye lens at a field angle of at least 90° in each direction with respect to the optical axis, wherein the fisheye lens has a relationship of $h = nf \cdot \tan(\theta/m)$ (wherein h is the height of an image of a subject at a certain point obtained by the fisheye lens, f is the focal distance of the fisheye lens, $1.6 \leq m \leq 3$, $m-0.4 \leq n \leq m+0.4$, and θ is a field angle).

[0009] According to a second aspect of the present invention, the fisheye lens is constructed by a master lens provided on an existing image pick-up device and by an attachment lens to be attached to the master lens.

[0010] Further, according to a third aspect of the present invention, there is provided an image display device comprising an image data processing unit for converting an image obtained by the image pick-up device of the first or second aspect of the present invention into a plane image and a display unit for displaying the converted plane image.

[0011] According to a fourth aspect of the present invention, there is provided an information recording medium that records a program having at least the step of converting an image obtained by a fisheye lens having a relationship of $h = nf \cdot \tan(\theta/m)$ (wherein h is the height of an image of a subject at a certain point, f is the focal distance of the fisheye lens, θ is a field angle, $1.6 \leq m \leq 3$. and $m-0.4 \leq n \leq m+0.4$) into a plane image, the step of displaying a predetermined portion of the converted plane image on a display unit and the step of changing continuously the predetermined portion with instruction means.

[0012] One of the fisheye lens used in the present invention has the relationship of $h = 2f \cdot \tan(\theta/2)$. Compared with an ordinary fisheye lens having a relationship of $h = f \cdot \theta$, an image at a peripheral portion (field angle of around 90° with respect to the optical axis of the fisheye lens) is enlarged and missing portions of image data on the peripheral portion can be minimized with the fisheye lens in accordance with the present invention. With this, when a picked-up image is to be converted into a plane image, the interpolating of image data can be reduced, thereby making it possible to obtain a more natural plane image.

[0013] The fisheye lens according to the present invention may be constructed by attaching an attachment lens to a master lens provided on an existing camera so that the fisheye lens can be attached to almost all the existing cameras. In addition, only the attachment lens is newly produced, thereby making it possible to reduce costs.

[0014] Further, the image display device for displaying a plane image converted from an image picked up by the image pick-up device having the above fisheye lens on a display unit makes the displayed image easy to be seen, thereby improving the value of the device. When the information recording medium recording the above steps is read by a computer and the program is executed, a more natural plane image can be displayed on the display unit and the displayed portion can be freely shifted within the range of the image picked up by the image pick-up device.

[0015] Embodiments of the invention will now be described, by way of example, with reference to the drawings, wherein like reference numerals denote like elements and parts, in which:

Fig. 1 is a schematic structural diagram of an image processing system using an image pick-up device comprising a fisheye lens according to the present invention;

Figs. 2 are a structural diagram of the fisheye lens shown in Fig. 1 and a corresponding diagram schematically showing lens intervals (lens intervals and lens thicknesses);

Fig. 3(A) is a diagram showing the relationship between field angle θ and image height h with respect to fisheye lenses having relationships of $h = f \cdot \theta$, $h = 2f \cdot \sin(\theta/2)$, $h = f \cdot \sin\theta$, $h = f \cdot \tan\theta$, $h=3f \cdot \tan(\theta/3)$, $h=2f \cdot (\tan \theta/1.6)$ and one of the fisheye lenses of the present invention having a relationship of $h = 2f \cdot \tan(\theta/2)$;

Fig. 3(B) is a diagram showing the relationship between field angle θ and image height h with respect to fisheye lenses having relationships of $h=2f \cdot \tan(\theta/1.6)$, $h= 2.4f \cdot \tan(\theta/2)$, $h = 3.4f \cdot \tan(\theta/3)$, $h = 1.2f \cdot \tan(\theta/1.6)$, $h = 1.6f \cdot \tan(\theta/2)$ and $h = f \cdot \theta$.

Figs. 4(A) to 4(D) are views illustrating, in concentric circles each centering around the optical axis of each fisheye lens shown in Fig. 3, changes of image heights when the field angle is changed in 10° with respect to the optical axis of each fisheye lens;

Fig. 5 is a diagram for explaining a method of polar-coordinate converting a hemispherical image obtained by a fisheye lens;

Fig. 6 is a diagram for explaining a method of obtaining the position of an image formation point on the surface of CCD image pick-up elements in the polar coordinate conversion of Fig. 5;

Fig. 7 is a flow chart for explaining the steps of processing an image using the image processing system of Fig. 1;

Figs. 8(A) and 8(B) are diagrams showing another application example of the image pick-up device of the present invention, wherein Fig. 8(A) is a schematic diagram showing the side thereof and Fig. 8(B) is a diagram when seen from a direction indicated by an arrow B in Fig. 8(A);

Figs. 9(A) and 9(B) are diagrams showing still another application example of the image pick-up device of the present invention, wherein Fig. 9(A) is a schematic diagram showing the side thereof and Fig. 9(B) is a diagram when seen from a direction indicated by an arrow B in Fig. 9(A); and

Fig. 10 is a diagram showing another example of an image processing system utilizing the image pick-up device comprising a fisheye lens of the present invention.

[0016] Preferred embodiments of the present invention will be described hereinafter with reference to Figs. 1 to 10.

[0017] Fig. 1 schematically shows an image processing system utilizing an image pick-up device comprising a fisheye lens of the present invention. This image processing system comprises a camera (such as a video camera) 2 that is an image pick-up device equipped with a fisheye lens 1, an image data processing unit 3 for processing image data from the camera 2, and a monitor unit 4 for displaying an image processed by the image data processing unit 3. The image data processing unit 3 has a CPU, memory means and the like and performs various processing using image data output from the camera 2. In the case of the present invention, the image data processing unit 3 also converts an image picked up by the fisheye lens 1 into a plane image.

[0018] As shown in Fig. 2, the fisheye lens 1 used in this embodiment roughly consists of a lens unit (called master lens unit) 10 provided on the camera 2 and a lens unit (called attachment lens unit) 20 that can be attached to and detached from the master lens unit 10. The fisheye lens 1 of the present invention functions as a fisheye lens when the attachment lens unit 20 is attached to the master lens unit 10.

[0019] The attachment lens unit 20 consists of a first lens 21, a second lens 22, a third lens 23, a fourth lens 24 and a plate 25. The master lens unit 10 consists of a fifth lens 11, a sixth lens 12, a seventh lens 13, an eighth lens 14, a ninth lens 15 and a diaphragm 26 interposed between the sixth lens 12 and the seventh lens 13.

[0020] The curvature R (diameter of the curved surface of the lens) of each lens and interval D (lens thickness or lens interval) in this embodiment are as follows. That is, beginning with the curvature R1 of the left curved surface of the first lens 21 on the leftmost side of Figs. 2, in turn, the curvatures R1 and R2 of the first lens 21 are 40.0 mm and 9.0 mm, the curvatures R3 and R4 of the second lens 22 are -26.0 mm and 80.0 mm, the curvatures R5 and R6 of the third lens 23 are -36.0 mm and -20.0 mm, and the curvatures R7 and R8 of the fourth lens 24 are -81.0 mm and -27.0 mm, respectively.

[0021] Further, the curvatures R9 and R10 of the fifth lens 11 are 14.0 mm and 68.0 mm, the curvatures R11 and R12 of the sixth lens 12 are 9.0 mm and 3.0 mm, the curvatures R13 and R14 of the seventh lens 13 are 0.0 mm and -8.0 mm, the curvatures R15 and R16 of the eighth lens 14 are 10.0 mm and -6.0 mm, and the curvatures R17 and R18 of the ninth lens 15 are 11.0 mm and -9.0 mm, respectively.

[0022] Meanwhile, the thickness D1 of the first lens 21 on the leftmost side of Figs. 2 is 1.2 mm, the interval D2 between the first lens 21 and the second lens 22 is 10.00 mm, and the thickness D3 of the second lens 22 is 1.2 mm. The interval D4 between the second lens 22 and the third lens 23 is 14.0 mm, the thickness D5 of the third lens 23 is 2.0 mm, the interval D6 between the third lens 23 and the fourth lens 24 is 3.0 mm, and the thickness D7 of the fourth lens 24 is 5.0 mm.

[0023] Further, the interval D8 between the fourth lens 24 and the fifth lens 11 is 7.0 mm, the thickness D9 of the fifth lens 11 is 2.0 mm, the interval D10 between the fifth lens 11 and the sixth lens 12 is 0.3 mm, and the thickness D11 of the sixth lens 12 is 0.8 mm. The seventh lens 13, the eighth lens 14 and the ninth lens 15 can be moved in the direction of the optical axis to change magnification, and the intervals between adjacent lenses to be described hereinafter are maximum values thereof. The interval D12 between the diaphragm 26 and the seventh lens 13 is 4.0 mm, the thickness D13 of the seventh lens 13 is 1.0 mm, the interval D14 of the seventh lens 13 and the eighth lens 14 is 1.0 mm, and the thickness D15 of the eighth lens 14 is 4.0 mm.

[0024] The interval D16 between the eighth lens 14 and the ninth lens 15 is 2.0 mm, and the thickness D17 of the ninth lens is 4.0 mm. Parallel plates 16 and 17 are arranged on the right side in Figs. 2 of the ninth lens 15.

[0025] In this arrangement, light incident upon the first lens 21 passes through the first to fourth lenses 21 to 24, further through the fifth to ninth lenses 11 to 15 and is input into CCD image pick-up elements 30 in the camera 2. In this attachment lens unit 20, parallel rays input into the first lens 21 are output from the fourth lens 24 as parallel rays. Therefore, this attachment lens unit 20 can be attached to almost all the cameras. The width of the parallel pencil of rays output from the fourth lens 24 of the attachment lens unit 20 (shown by "w" in the figure) is set to ½ or less the effective diameter of the master lens 10 of the camera to which the attachment lens unit 20 is attached. In Fig. 2, the spherical surface 40 at the front of the first lens 21 represents a virtual subject surface of the picked up image.

[0026] As described above, the present invention is characterized in that a desired fisheye lens 1 is constructed by the master lens unit 10 and the attachment lens unit 20 and has a relationship of $h = 2f \cdot \tan(\theta/2)$ (wherein h is the height of an image of a subject at a certain position, f is the focal distance of the fisheye lens and θ is a field angle). It is noted that although the preferred embodiment of the present invention has the above-indicated relationship, the present invention also embodies fisheye lenses having the relationship of $h = n \cdot f \cdot \tan(\theta/m)$, where m has the value of $1.6 \leq m \leq 3$, and n has the value of $m - 0.4 \leq n \leq m + 0.4$. Also, the present invention contemplates such a relationship when m equals n. Also, the relationship $h = 1.2f \cdot \tan(\theta/m)$, $m \geq 1.6$ also is embodied by the present invention. However, for purposes of discussion herein, m and n both equal to 2.

[0027] The fisheye lens that has been generally used in the prior art has a relationship of $h = f \cdot \theta$ as described above. These functions are used to map a spherical image as a polar-coordinate converted image. The relationship, other than that, may be $h = 2f \cdot \sin(\theta/2)$, $h = 2f \cdot \sin\theta$ or $h = f \cdot \tan\theta$.

[0028] Fig. 3(A) is a diagram showing relationships between field angle θ and image height h when fisheye lenses having relationships of $h = 2f \cdot \tan(\theta/2)$, $h = f \cdot \theta$, $h = f \cdot \sin(\theta/2)$, $h = f \cdot \sin\theta$ and $h = f \cdot \tan\theta$, etc. are used. Here, θ = 90° shows a field angle with respect to the optical axis (the field angle of the optical axis is 0°).

[0029] In Fig. 3(A), a curve C1 shows the relationship between field angle θ and image height h when the fisheye lens of the present invention having the relationship of $h = 2f \cdot \tan(\theta/2)$ is used, and a curve C2 shows the relationship between field angle θ and image height h when a fisheye lens having the relationship of $h = f \cdot \theta$ is used. A curve C3 shows the relationship between field angle θ and image height h when a fisheye lens having the relationship of $h = 2f \cdot \sin(\theta/2)$ is used, a curve C4 shows the relationship between field angle θ and image height h when a fisheye lens having the relationship of $h = 2f \cdot \sin\theta$ is used, and a curve C5 shows the relationship between field angle θ and image height h when a fisheye lens having the relationship of $h = f \cdot \tan\theta$ is used. A curve C1' shows the relationship of $h = 3f \cdot \tan(\theta/3)$ and a curve C" shows the relationship of $h = 2f \cdot \tan(\theta/1.6)$.

[0030] Fig. 3(B), is a diagram showing the relationship between field angle θ and image height when fisheye lenses having relationships of $h = 2f \cdot \tan(\theta/1.6)$, $h = 2.4f \cdot \tan(\theta/2)$, $h = 3.4f \cdot \tan(\theta/3)$, $h = 1.2f \cdot \tan(\theta/1.6)$, $h = 1.6f \cdot \tan(\theta/2)$ and $h = f \cdot \theta$. All of these fisheye lenses, except $h = f \cdot \theta$, are embodied by the present invention.

[0031] As is evident from Fig. 3, an increase in image height h at a field angle θ of about 90° is largest when the fisheye lens having the relationship of $h = f \cdot \tan\theta$ is used and is second largest when the fisheye lens having the relationship of $h = 2f \cdot \tan(\theta/2)$ is used. Changes in image height h with respect to changes in field angle θ become linear when the fisheye lens having the relationship of $h = f \cdot \theta$ is used and further an increase in image height h tends to be smaller as the field angle becomes closer to 90° when the fisheye lenses having the relationships of $h = 2f \cdot \sin(\theta/2)$ and $h = f \cdot \sin\theta$ are used.

[0032] An increase in image height becomes larger toward the peripheral portion (field angle of 90°) when the fisheye lens having the relationship of $h = f \cdot \tan\theta$ is used and more image data can be obtained. However, at a field angle θ of 90°, tanθ becomes infinite. Since the fisheye lens is required to obtain an image of all the directions of the field of view around the optical axis at a field angle of at least 90° with respect to the optical axis, it can be said that the fisheye lens having the relationship of $h = f \cdot \tan\theta$ is not suitable.

[0033] Therefore, the fisheye lenses having relationships of $h = 2f \cdot \tan(\theta/2)$, $h = f \cdot \theta$, $h = 2f \cdot \sin(\theta/2)$ and $h = f \cdot \sin\theta$ may be used. Figs. 4(A) to 4(D) show, in concentric circles each centering around the optical axis of each fisheye lens, image heights h when the field angle θ is changed in 10° with respect to the optical axis of each fisheye lens. Fig. 4(A) shows the image height in the fisheye lens having the relationship of $h = 2f \cdot \tan(\theta/2)$, Fig. 4(B) shows the image height in the fisheye lens having the relationship of $h = f \cdot \theta$, Fig. 4(C) shows the image height in the fisheye lens having the relationship of $h = 2f \cdot \sin(\theta/2)$, and Fig. 4(D) shows the image height in the fisheye lens having the relationship of $h = f \cdot \sin\theta$. In Figs. 4(A) to 4(D), h_o represents the height of an image M_o near the optical axis of each fisheye lens and h_e represents the height of an image M_e at a field angle of around 90°.

[0034] As is understood from Figs. 4(A) to 4(D), image height at a field angle of around 90° when the fisheye lens having the relationship of $h = 2f \cdot \sin(\theta/2)$ or the fisheye lens having the relationship of $h = f \cdot \sin\theta$ is used is smaller than image height near the optical axis and only a small volume of image data can be obtained. The image height h_e of an image M_e at a peripheral portion of the fisheye lens that has been generally used and has the relationship of $h = f \cdot \theta$ is the same as the image height h_o of an image M_o near the optical axis and the image is distorted.

[0035] From these facts, it can be said that the fisheye lenses having relationships of $h = 2f \cdot \sin(\theta/2)$ and $h = f \cdot \sin\theta$ are not preferred in view that how large volume of data can be obtained at a field angle of 90° or therearound. Even with the fisheye lens that has been generally used and has the relationship of $h = f \cdot \theta$ is not satisfactory.

[0036] In contrast to that, the image height h_e of the image M_e at a peripheral portion of the fisheye lens 1 having the relationship of $h = 2f \cdot \tan(\theta/2)$ in accordance with the present invention is enlarged and larger than the image height h_o of the image M_o near the optical axis, a larger volume of image data can be obtained in comparison with the conventional fisheye lens, and the obtained image is not distorted.

[0037] When a single spherical image obtained by combining two hemispherical images of all the directions of the field of view around the optical axis of the fisheye lens 1, which are picked up at a field angle of 90° with respect to the optical axis is converted into a plane image by the image data processing unit 3, it is necessary to interpolate missing image data on the peripheral portion (field angle of around 90° with respect to the optical axis) of the image. According to the present invention, since an image at the peripheral portion is enlarged and a large volume of data on the peripheral portion can be extracted, the volume of image data to be interpolated can be greatly reduced, when compared with the conventional system.

[0038] An image of all the directions of the field of view around the optical axis is picked up at a field angle of at least 90° with respect to the optical axis and is polar-coordinate converted into a plane image in the following manner.

[0039] An X, Y and Z coordinate system as shown in Fig. 5 is imagined in subject space. At this point, the optical axis of the fisheye lens 1 is made Z axis. The coordinates of a certain point p are represented as (X1, Y1, Z1) and the elevation angle of the point p from the origin O of the coordinates with respect to the XZ plane is represented by θ. The elevation angle of the point p from the position of Z1 on the Z axis with respect to the XZ plane is represented by ϕ.

[0040] When an x and y coordinate system having the optical axis (Z axis) as an origin o is imagined on the surface of CCD image pick-up elements 30 as shown in Fig. 6 and the focal distance of the fisheye lens 1 is represented by f, the image formation point (p') for the point p is located as shown in Fig. 6. In Fig. 6, π is added to ϕ because an image formed at the point p' is inverted vertically and horizontally with respect to the image of the subject surface (point p). The optical axis in Fig. 6 is present in a direction perpendicular to the paper from the origin o of the x and y coordinates.

[0041] The position of the point p' is expressed as polar coordinates with a length (h) between the origin o and the point p' and an angle $\phi + \pi$ formed by op' and the x axis. When the polar coordinates are expressed on the x and y rectangular coordinates, the position (x1, y1) on the x and y rectangular coordinates are expressed as follows.

$$x1 = h \cdot \cos(\phi + \pi) \quad (1)$$

$$y1 = h \cdot \sin(\phi + \pi) \quad (2)$$

In addition, the image height h of the point p' is represented by $h = 2f \cdot \tan(\theta/2)$, hence, when $h = 2f \cdot \tan(\theta/2)$ is substituted into the above expressions (1) and (2), the coordinates (x1, y1) of the image formation point p' on the surface of the CCD image pick-up elements 30 are as follows.

$$x1 = 2f \cdot \tan(\theta/2) \cdot \cos(\phi+\pi) \quad (3)$$

$$y1 = 2f \cdot \tan(\theta/2) \cdot \sin(\phi+\pi) \quad (4)$$

As a result, they are expressed as follows.

$$x1 = -2f \cdot \tan(\theta/2) \cdot \cos\phi \quad (5)$$

$$y1 = -2f \cdot \tan(\theta/2) \cdot \sin\phi \quad (6)$$

In the above expressions, θ and ϕ are defined as follows.

$$\theta = \tan^{-1} (X1^2 + Y1^2 / Z1)$$

$$\phi = \tan^{-1} (Y1/X1)$$

[0042] Thus, the position of the point p' on the surface of CCD image pick-up elements 30 can be obtained for the point p on the surface of the subject.

[0043] Thereafter, a description is subsequently given, with reference to Fig. 7, of steps required when the sphere (all directions) is photographed by the camera 2 comprising the fisheye lens 1 and an image thereof is displayed on the monitor unit 4 that is the display unit.

[0044] Briefly the steps S1 to S7 are as follows:

S1 photographing a hemisphere with a camera 2 equipped with a fisheye lens

S2 photographing the other hemisphere with the camera 2 equipped with a fisheye lens

S3 combining two images that are polar-coordinate displayed and converting the combined image into a plane image on the surface of the CCD image pick-up elements 30 as a polar-coordinate converted image.

[0045] The above two images are then combined together and the combined image is converted into a plane image by the image data processing unit 3 (step S3). At this point, an area corresponding to a connection portion between these hemispheres must be corrected. Since the polar-coordinate converted image obtained by the fisheye lens 1 has a large volume of information on a peripheral portion, the processing of combining these images is easy. Thereafter, a predetermined portion of the thus obtained plane image is extracted and displayed on the monitor unit 4 (step S4).

[0046] A user shifts the screen with instruction means such as a mouse when the user likes to change the displayed predetermined portion. This shifting can be made continuously in any direction of 360° around the portion displayed on the monitor unit 4 (step S5).

[0047] The above steps are for picking up an image of a sphere in all the directions of 360°. When only a single hemisphere is photographed, the same steps are taken. However, step S2 is unnecessary and the processing of combining two images in step S3 is also unnecessary.

[0048] In the present invention, since the volume of information on the peripheral portion of an image obtained by the fisheye lens 1 is large, that is, an image at the peripheral portion is enlarged, it is convenient when the present invention is used for the examination of a product. For example, when the inner surface 52 of a cylindrical body 51 is photographed at the condition that the optical axis of the fisheye lens 1 of the present invention is aligned with the central axis of the cylindrical body 51 as shown in Figs. 8(A) and 8(B), a peripheral portion of an image can be extracted as an image having a larger volume of information than a central portion in the present invention. Therefore, it is easy to find that a scratch has been generated in the inner surface 52. Consequently, this can be used for the examination of a pipe-like body such as a water pipe or gas pipe and further for the monitoring of a crack that has been generated in the wall surface of a tunnel or the like.

[0049] It can also be used for the examination of the connection condition of a small part such as an IC. That is, when a part 71 is fixed to a substrate 74 by a solder 73 on its both sides 72 and 72 as shown in Figs. 9(A) and 9(B), the soldering state of the part must be checked from its side direction in the prior art. However, when another part 75 is existent in a side direction, the solder 73 on the part 75 side cannot be seen through a camera, thereby making automatic examination difficult. On the other hand, even when the fisheye lens 1 is installed right over the part 71 as shown in Fig. 9(A), the side direction of the part 71 can be sufficiently photographed by the camera 2 comprising the fisheye lens 1 of the present invention, thereby enabling automatic examination with the camera 2.

[0050] Although each foregoing embodiment is an example of a preferred embodiment of the invention, it is to be understood that the invention is not limited thereto and that various changes and modifications may be made in the invention. For example, the fisheye lens may be constructed by the attachment lens unit 20 alone without the master lens 10, or contrariwise may be constructed by an integrated unit of the master lens unit 10 and the attachment lens unit 20. Also, the construction and numerical values of the fisheye lens 1 shown in the above embodiment are just examples and a fisheye lens having other construction and numerical values may be used.

[0051] Further, as the system comprising the fisheye lens 1 of the present invention, an image processing system 81 shown in Fig. 10 may be used. This image processing system 81 is mainly constructed with a camera 2 equipped with a fisheye lens 1 and an image data processing unit/monitor 5 connected to the camera 2 by a cable. The image data processing unit/monitor 5 is a personal computer equipped with a monitor, and a key board 5a and a mouse 5b are connected to the computer as instruction means.

[0052] Also, this image data processing unit/monitor 5 has a hard disk (not shown) in that the contents of an information recording medium (floppy disk) 6 recording a program for executing the steps S3, S4 and S5 shown in Fig. 7 are to be installed. By installing this program in the image data processing unit/monitor 5, the image data processing unit/monitor 5 carries out the same function as the image data processing unit 3 which has been described in the foregoing.

[0053] Image pick-up data may be transferred from the camera 2 to the image data processing unit/monitor 5 by a memory card such as a flash card or wireless communication such as infrared communication, besides a cable. Further, the program may be installed not from the floppy disk 6 but other recording medium such as a CD-ROM, or transferred from other storage unit over a network. When the program is transferred over a network, the storage unit of a transmitter or the hard disk (storage unit) of the image data processing unit/monitor 5 serves as the information recording medium of the present invention.

[0054] As having been described above, in the image pick-up device comprising the fisheye lens according to the first aspect of the present invention, the fisheye lens has the relationship of $h = nf \cdot \tan(\theta/m)$ (wherein h is an image height, f is a focal distance, and θ is a field angle). With this, compared with the ordinary fisheye lens having the relationship of $h = f \cdot \theta$ (wherein h is an image height, f is a focal distance, and θ is a field angle), an image at a peripheral portion (field angle of around 90° with respect to the optical axis of the fisheye lens) is enlarged and the volume of information is large, thereby making it possible to minimize the missing portions of image data on the peripheral portion. When the picked-up image is to be converted into a plane image, interpolating of image data can be thereby minimized and a more natural plane image can be obtained.

[0055] Also, according to the second aspect of the present invention, by attaching the attachment lens different from the master lens provided on the existing image pick-up device (camera) to the master lens, the fisheye lens is constructed by this master lens and the attachment lens. Therefore, the fisheye lens can be attached to almost all the existing image pick-up devices (cameras) and further, only the attachment lens is newly produced, thereby reducing costs.

[0056] Further, according to the third aspect of the present invention, the image display device can convert a spherical image into a plane image with ease and can display a more natural plane image. In addition, according to the fourth aspect of the present invention, when the program recorded in the information recording medium is read and executed by a computer, a more natural plane image can be formed.

Claims

1. An image pick-up device, comprising:

   a fisheye lens for picking up an image of all directions of a field of view around an optical axis of said fisheye lens at a field angle of at least 90° in each direction with respect to the optical axis
   the fisheye lens having a relationship of $h = n \cdot f \cdot \tan(\theta/m)$, h being a height of an image of a subject at a predetermined point obtained by the fisheye lens, f being a focal distance of the fisheye lens, θ being a field angle, m having a value of $1.6 \leq m \leq 3$, and n having a value of $m - 0.4 \leq n < m + 0.4$.

2. The image pick-up device of Claim 1, wherein the fisheye lens is constructed by a master lens provided on an existing image pick-up device and an attachment lens to be attached to the master lens.

3. An image display device, comprising:

   an image data processing unit for converting an image obtained by the image pick-up device of Claim 1 into a plane image; and
   a display unit for displaying the converted plane image.

4. The image display device of Claim 7, further comprising a fisheye lens for picking up an image of all directions of a field of view around an optical axis of said fisheye lens at a field angle of at least 90° in each direction with respect to the optical axis, the fisheye lens having a relationship of $h = n \cdot f \cdot \tan(\theta/m)$, h being a height of an image of a subject at a predetermined point obtained by the fisheye lens, f being a focal distance of the fish-

eye lens, θ being a field angle, m having a value of $1.6 \leq m \leq 3$, and n having a value of $m-0.4 \leq n \leq m+0.4$

wherein said image data processing unit receives the image picked up by said fisheye lens.

5. A method of converting into a plane image an image generated by a fisheye lens comprising the steps of:

   converting into a plane image an image obtained by a fisheye lens having a relationship of $h = n \cdot f \cdot \tan(\theta/m)$, h being a height of an image of a subject at a predetermined point obtained by the fisheye lens, f being a focal distance of the fisheye lens, θ being a field angle, m having a value of $1.6 \leq m \leq 3$, and n having a value of $m-0.4 \leq n \leq m+0.4$;
   displaying a predetermined portion of the converted plane image on a display unit; and
   changing continuously the predetermined portion with instruction means.

6. The image pick-up device of claim 1, image display device of claim 3 or method of claim 5 wherein m and n are substantially equal.

7. The image pick-up device of claim 1, image display device of claim 3 or method of claim 5 wherein m and n both substantially equal 2.

8. The image pick-up device of claim 1, image display device of claim 3 or method of claim 5 wherein m and n both equal 2 such that the fisheye lens has a relationship of $h = 2f \cdot \tan(\theta/2)$.

9. A recording medium having recorded thereon a program for implementing the method of any of claims 5 to 8.

10. An optical system for attachment to an optical device to form an image pick-up device as claimed in any of claims 1 to 2 or 6 to 8.

11. An image pick-up device, comprising:

   a fisheye lens for picking up an image of all directions of a field of view around an optical axis of said fisheye lens at a field angle of at least 90° in each direction with respect to the optical axis
   the fisheye lens having a relationship of $h = 1.2f \cdot \tan(\theta/m)$, h being a height of an image of a subject at a predetermined point obtained by the fisheye lens, f being a focal distance of the fisheye lens, θ being a field angle, and m having a value of $m \leq 1.6$.

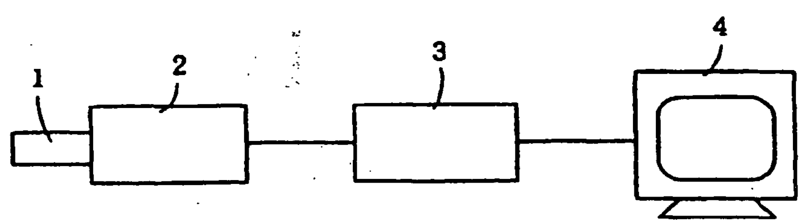
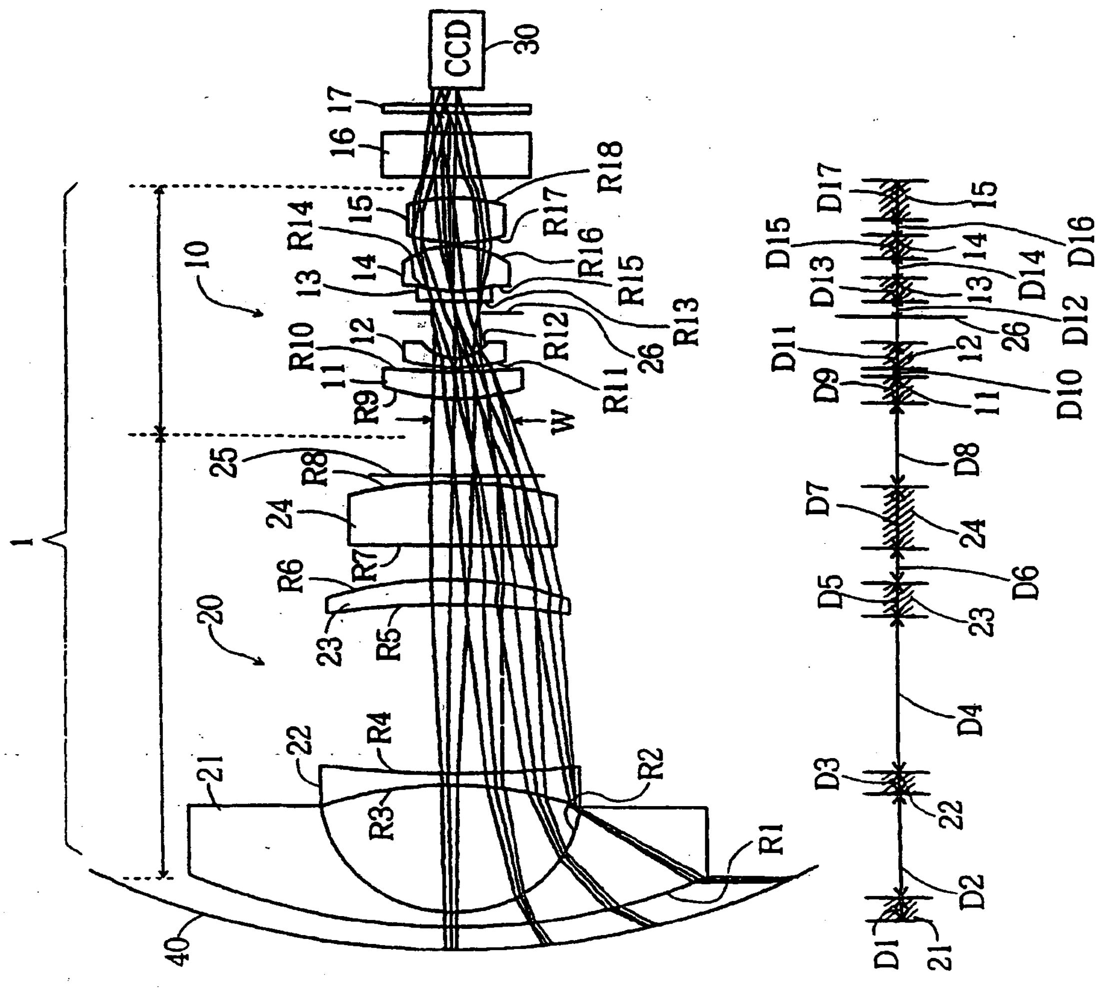


Fig. 1


CCD
30
16
17
1
10
20
40
W
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
11
12
13
14
15
21
22
23
24
25
26
D1
D2
D3
D4
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D12
D13
D14
D15
D16
D17

Fig. 2

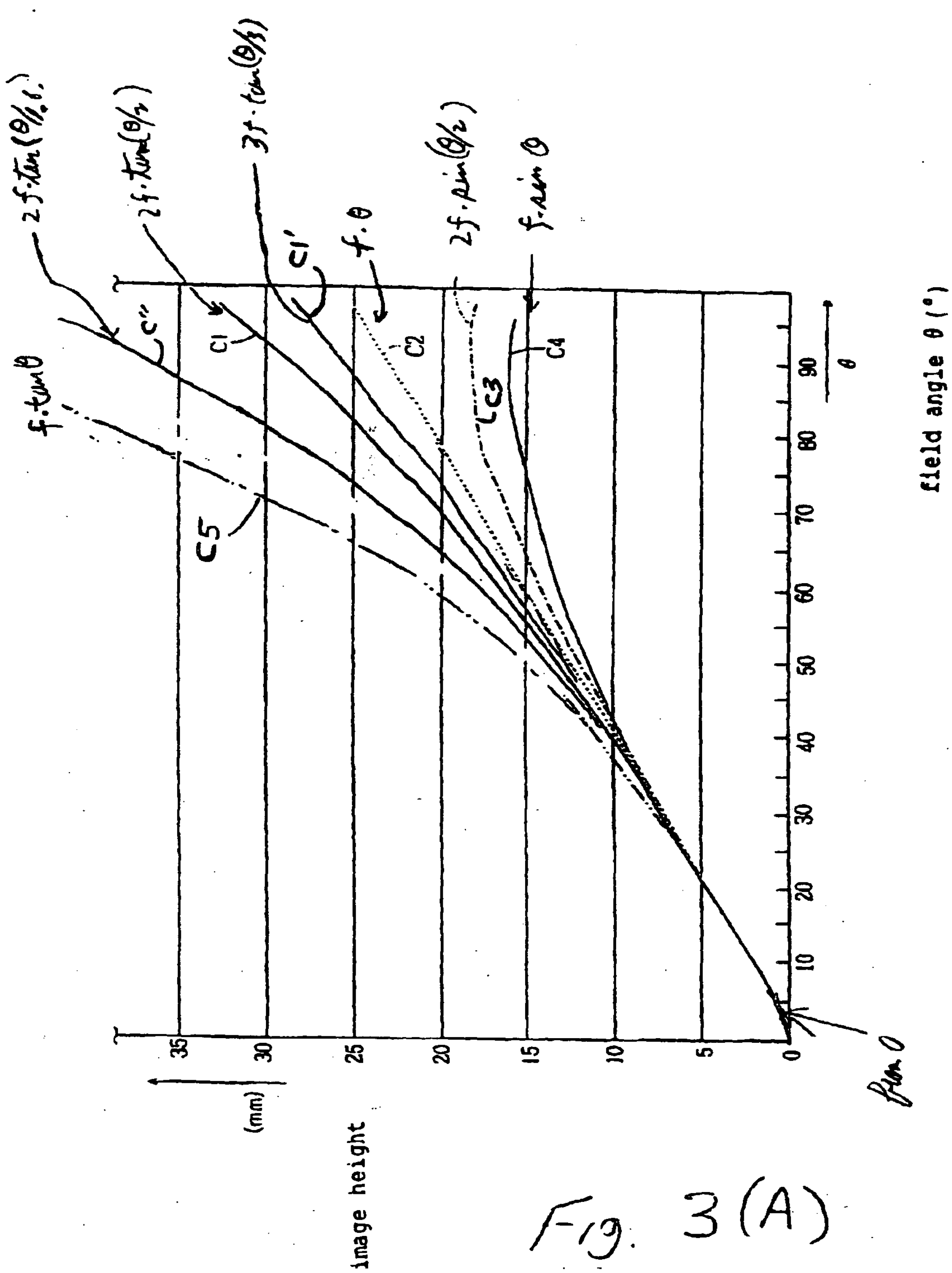

f·tanθ
2f·tan(θ/2)
3f·tan(θ/3)
f·θ
2f·sin(θ/2)
f·sin θ
C''
C1
C'
C2
C3
C4
C5
0 5 10 15 20 25 30 35
(mm)
image height
0 10 20 30 40 50 60 70 80 90
field angle θ (°)

Fig. 3(A)

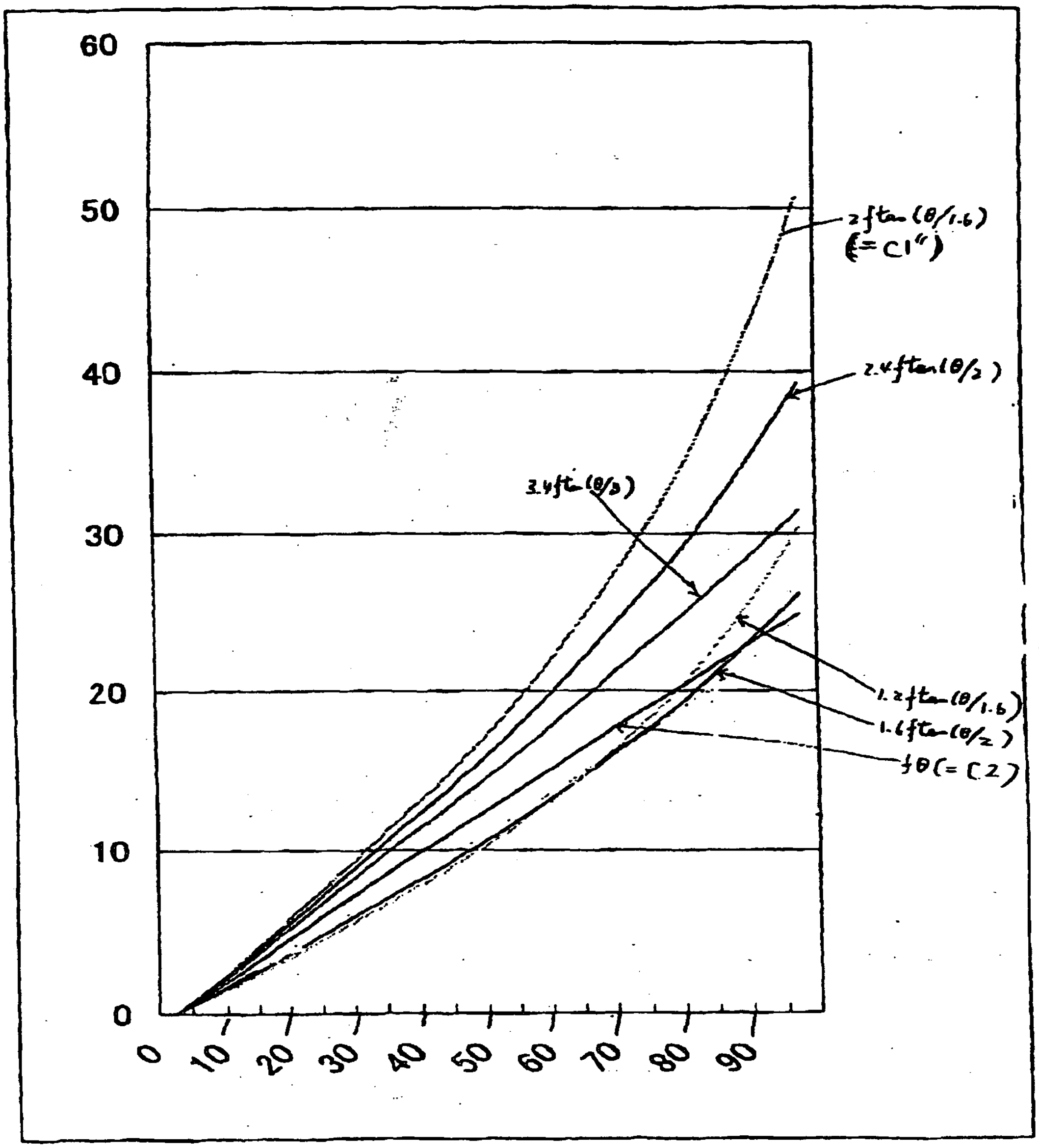

60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
2ftan(θ/1.6) (=C1")
2.4ftan(θ/2)
3.4ftan(θ/3)
1.2ftan(θ/1.6)
1.6ftan(θ/2)
fθ(=C2)

Fig. 3(B)

Fig. 4

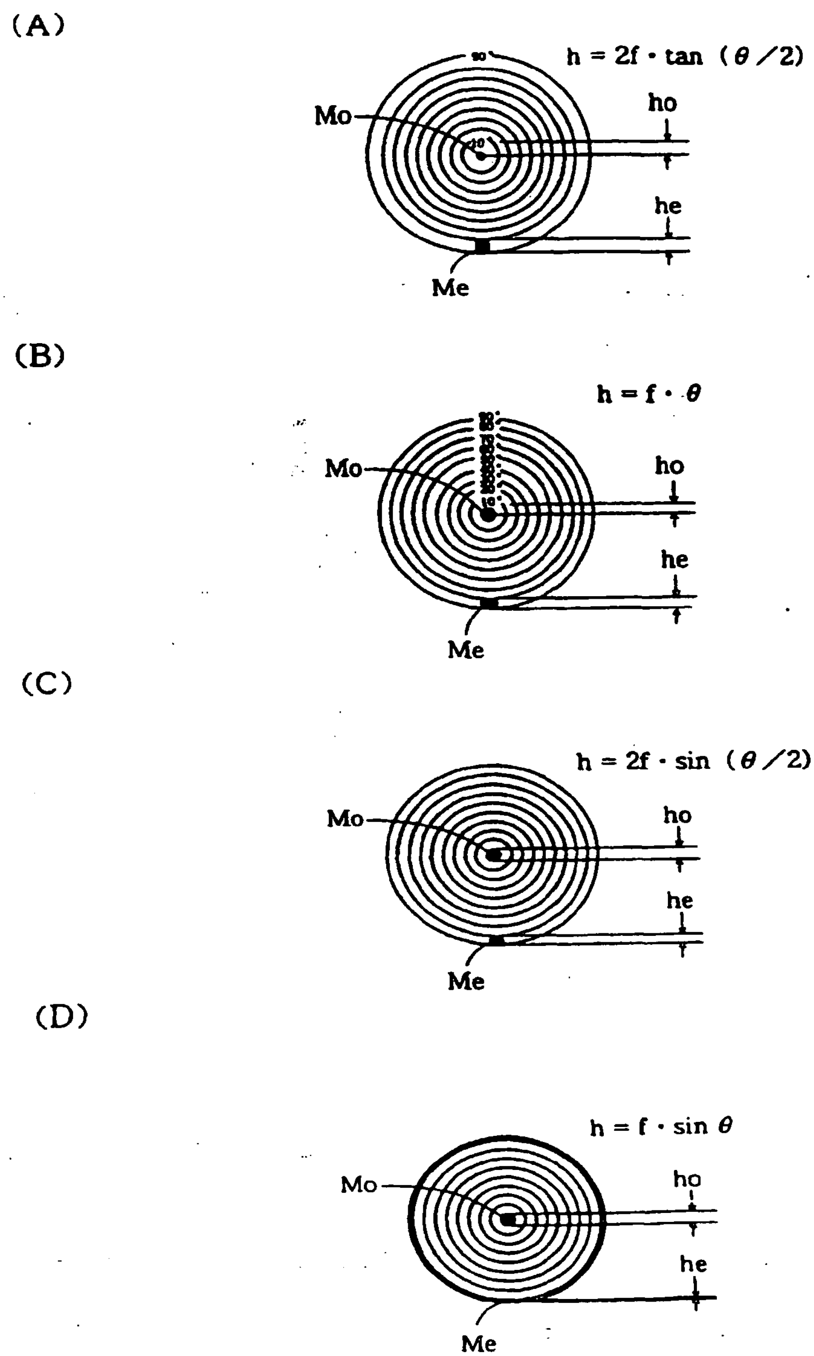

(A)
h = 2f · tan (θ／2)
Mo
ho
he
Me
(B)
h = f · θ
Mo
ho
he
Me
(C)
h = 2f · sin (θ／2)
Mo
ho
he
Me
(D)
h = f · sin θ
Mo
ho
he
Me

Fig. 5

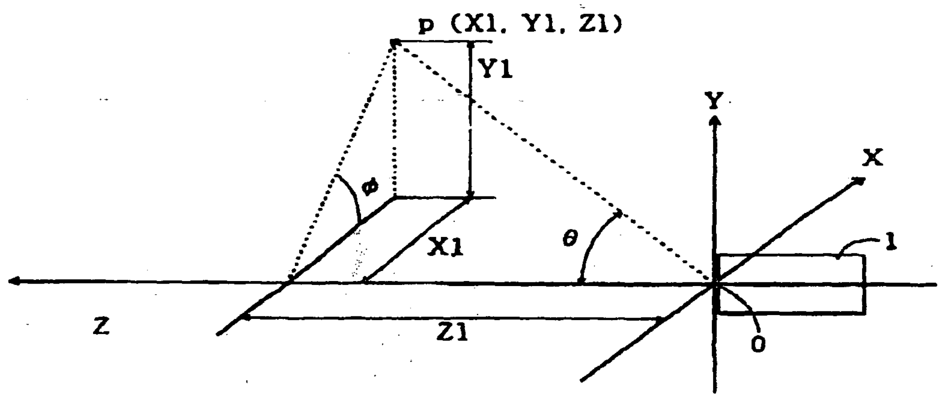


Fig. 6

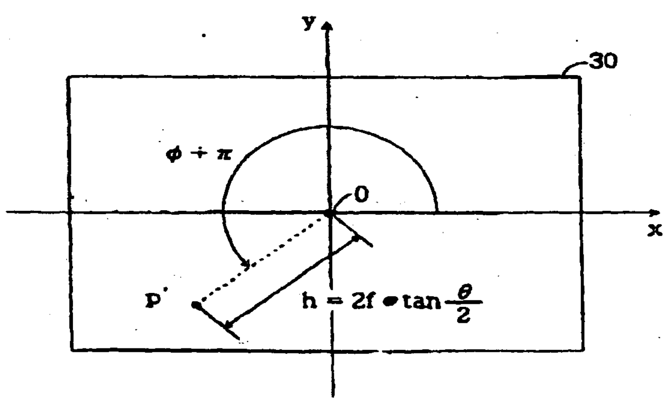


Fig. 7

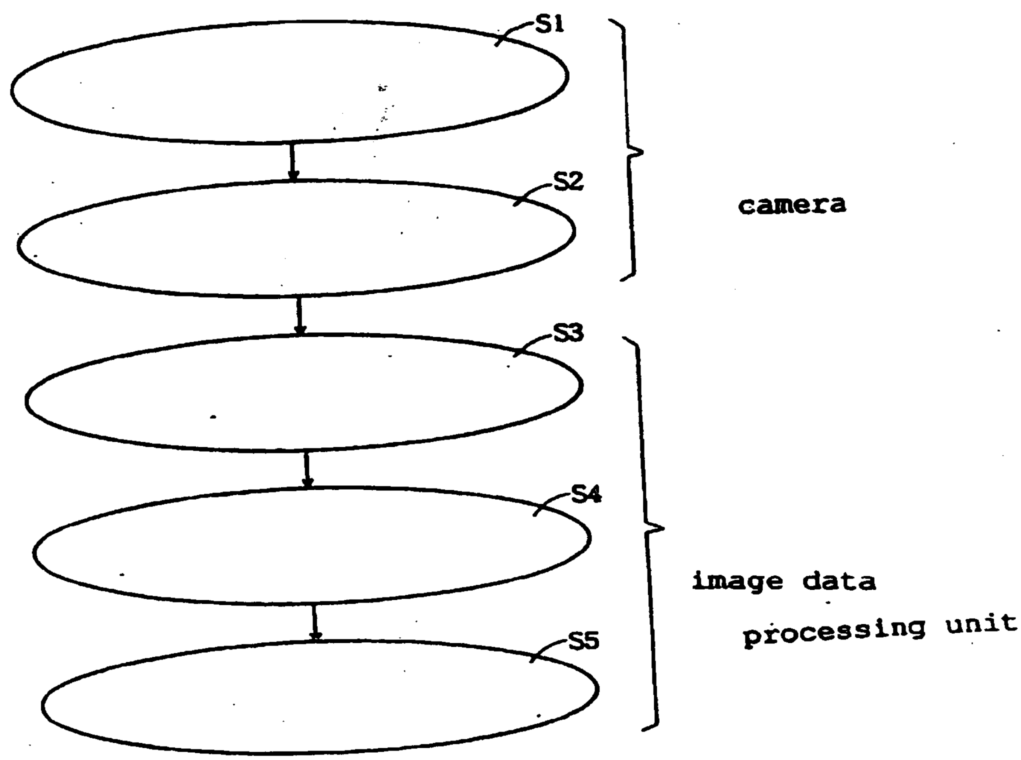


Fig. 8

(A) (B)

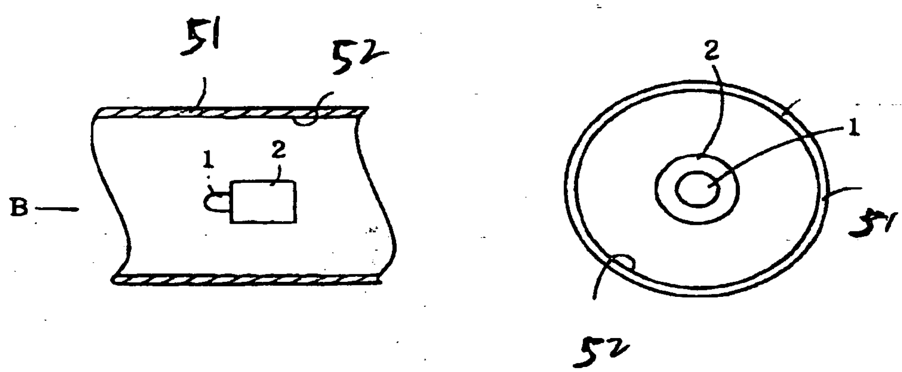


Fig. 9

(A) (B)

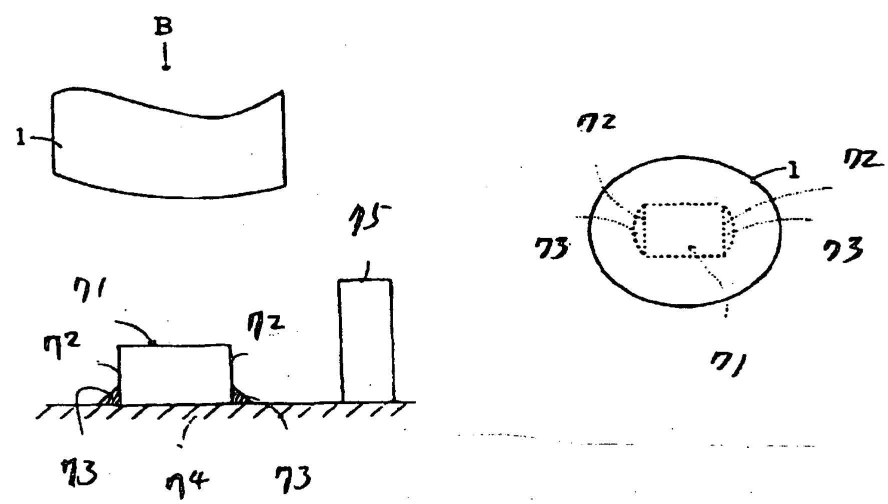
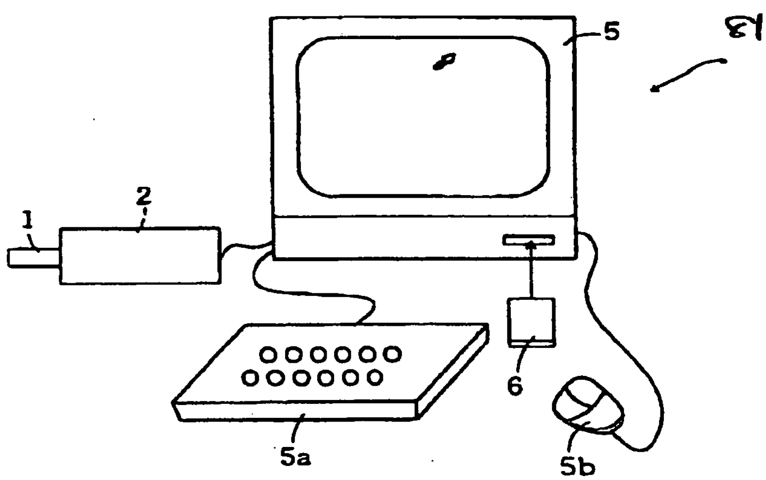


Fig. 10



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 99 30 4759

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	US 4 908 705 A (WIGHT RALPH) 13 March 1990 (1990-03-13) * column 11, line 15 - column 13, line 11; figure 3 *	1-11	G02B13/06
A	US 3 953 111 A (FISHER RALPH W ET AL) 27 April 1976 (1976-04-27) * column 2, line 56 - column 6, line 54; figures 1-6 *	1-11	
A	US 4 412 726 A (HORIMOTO MITSUAKI) 1 November 1983 (1983-11-01) * column 3, line 8 - column 6, line 13; figures 1,5; table 1 *	1-11	
A	US 5 686 957 A (BAKER ROBERT G) 11 November 1997 (1997-11-11) * column 10, line 37 - column 12, line 55; figures 2,3BA,3BB *	1-11	
E	US 5 999 660 A (BARR ALAN H ET AL) 7 December 1999 (1999-12-07) * column 7, line 34 - line 61; claims 8-12; figures 9,10 *	1,4,5,8, 11	TECHNICAL FIELDS SEARCHED (Int.Cl.7): G02B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	23 February 2000	THEOPISTOU, P

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
O : non-written disclosure
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T : theory or principle underlying the invention
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L : document cited for other reasons

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EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 99 30 4759

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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23-02-2000

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4908705 A	13-03-1990	NONE	
US 3953111 A	27-04-1976	NONE	
US 4412726 A	01-11-1983	JP 1587772 C	19-11-1990
		JP 2014684 B	09-04-1990
		JP 56101116 A	13-08-1981
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		EP 0695085 A	31-01-1996
		JP 8055215 A	27-02-1996
US 5999660 A	07-12-1999	NONE	

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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APPLICATION NUMBER	FILING OR 371 (c) DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET NUMBER
10/706,513	11/12/2003	Jean-Claude Artonne	10000-25US (100137/US/WO)

CONFIRMATION NO. 8287

FORMALITIES LETTER

OC000000011906029

000570
AKIN GUMP STRAUSS HAUER & FELD L.L.P.
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Date Mailed: 02/17/2004

NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION

FILED UNDER 37 CFR 1.53(b)

Filing Date Granted

Items Required To Avoid Abandonment:

An application number and filing date have been accorded to this application. The item(s) indicated below, however, are missing. Applicant is given **TWO MONTHS** from the date of this Notice within which to file all required items and pay any fees required below to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

- The oath or declaration is missing.
  A properly signed oath or declaration in compliance with 37 CFR 1.63, identifying the application by the above Application Number and Filing Date, is required.
- To avoid abandonment, a late filing fee or oath or declaration surcharge as set forth in 37 CFR 1.16(e) of $130 for a non-small entity, must be submitted with the missing items identified in this letter.

SUMMARY OF FEES DUE:

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P Phuong

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PART 3 - OFFICE COPY

Attorney Docket No.: 10000-250US
Your Ref. No.: 100137 US/WO

DECLARATION AND POWER OF ATTORNEY
(Related Application)

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

Method for capturing and displaying a variable-resolution digital panoramic image

the specification of which is attached hereto and/or was filed on November 12, 2003 as Application No. 10/706,513

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to herein.

I acknowledge the duty to disclose information which is material to patentability in accordance with Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d), of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

FOREIGN PRIORITY APPLICATION(S)

			Priority claimed
01 06261	FR	11/05/2001	[X] Yes [ ] No
(Number)	(Country)	(Day/Month/Year filed)	
			Priority Claimed
			[ ] Yes [ ] No.
(Number)	(Country)	(Day/month/year filed)	

I hereby claim the benefit under Title 35, United States Code §119(e) of any United States provisional patent application(s) listed below and have also identified below any United States provisional patent application(s) having a filing date before that of the application on which priority is claimed.

PROVISIONAL PRIORITY PATENT APPLICATION

		Priority Claimed
		[ ] Yes [ ] No
(Application No.)	(Filing Date)	
		Priority Claimed
		[ ] Yes [ ] No
(Application No.)	(Filing Date)	

I hereby claim the benefit under Title 35, United States Code, Section 120, of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application or in the prior U.S. provisional application in the manner provided by the first paragraph of Title 35, United States Code, Section 112, I acknowledge the duty to disclose information material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56, which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

PCT/FR02/01588	10/05/2002	Pending
(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)

And I hereby appoint the registered attorneys and agents associated with **AKIN, GUMP, STRAUSS, HAUER & FELD, L.L.P., Customer No. 000570**, as my attorneys or agents with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

Address all correspondence to **Customer No. 000570, namely, AKIN, GUMP, STRAUSS, HAUER & FELD, L.L.P.,** One Commerce Square, 2005 Market Street, Suite 2200, Philadelphia, Pennsylvania 19103. Please direct all communications and telephone calls to at (215) 965-

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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R E P U B L I Q U E F R A N Ç A I S E

01 02261

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Fait à Paris, le 29 OCT. 2003

Pour le Directeur général de l'Institut
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Le Chef du Département des brevets

Martine PLANCHE

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cerfa N° 11354*01

Code de la propriété intellectuelle - Livre VI

REQUÊTE EN DÉLIVRANCE 1/2

Cet imprimé est à remplir lisiblement à l'encre noire DB 540 W /260899

Réservé à l'INPI REMISE DES PIÈCES DATE 11 MAI 2001 LIEU 13 INPI MARSEILLE N° D'ENREGISTREMENT NATIONAL ATTRIBUÉ PAR L'INPI 0106261 DATE DE DÉPÔT ATTRIBUÉE PAR L'INPI 11 MAI 2001	**1** NOM ET ADRESSE DU DEMANDEUR OU DU MANDATAIRE À QUI LA CORRESPONDANCE DOIT ÊTRE ADRESSÉE OMNIPAT MARCHAND André 24 Place des Martyrs de la Résistance 13100 AIX EN PROVENCE
Vos références pour ce dossier *(facultatif)* 100137 FR	

Confirmation d'un dépôt par télécopie ☐ N° attribué par l'INPI à la télécopie

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Transformation d'une demande de brevet européen *Demande de brevet initiale*	☐ N°	Date __/__/__

3 TITRE DE L'INVENTION (200 caractères ou espaces maximum)

Procédé d'obtention et d'affichage d'une image panoramique numérique à résolution variable

4 DÉCLARATION DE PRIORITÉ OU REQUÊTE DU BÉNÉFICE DE LA DATE DE DÉPÔT D'UNE DEMANDE ANTÉRIEURE FRANÇAISE	
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Prénom		André
Cabinet ou Société		OMNIPAT
N °de pouvoir permanent et/ou de lien contractuel		
Adresse	Rue	24 Place des Martyrs de la Résistance
	Code postal et ville	13100 AIX EN PROVENCE
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N° de télécopie *(facultatif)*		04.42.99.06.69.
Adresse électronique *(facultatif)*		
7 INVENTEUR (S)		
Les inventeurs sont les demandeurs		☐ Oui ☒ Non **Dans ce cas fournir une désignation d'inventeur(s) séparée**
8 RAPPORT DE RECHERCHE		**Uniquement pour une demande de brevet (y compris division et transformation)**
Établissement immédiat ou établissement différé		☒ ☐
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PROCEDE DE CAPTURE ET D'AFFICHAGE D'UNE IMAGE PANORAMIQUE NUMERIQUE A RESOLUTION VARIABLE

La présente invention concerne l'obtention d'images panoramiques numériques et l'affichage d'images panoramiques sur des écrans d'ordinateurs.

La figure 1 représente un dispositif classique permettant de réaliser une image panoramique numérique et de la présenter sur un écran d'ordinateur. Le dispositif comprend un appareil de prise de vue numérique 1 équipé d'un objectif panoramique 2 de type "fish-eye", ayant un angle d'ouverture de l'ordre de 180°. L'appareil 1 est connecté à un calculateur 5, par exemple un micro-ordinateur, pourvu d'un écran 6. La connexion au micro-ordinateur 5 peut être permanente, par exemple lorsque l'appareil 1 est une caméra vidéo numérique, ou temporaire, par exemple lorsque l'appareil 1 est un appareil photographique numérique pourvu d'une mémoire d'images, la connexion étant alors faite au moment où des fichiers image doivent être transférés dans le micro-ordinateur.

La figure 2 représente schématiquement l'aspect d'une image panoramique 3 obtenue au moyen de l'objectif panoramique 2. L'aspect rond de l'image est caractéristique de la symétrie axiale des objectifs panoramiques et l'image présente des bords sombres 4 qui seront supprimés ultérieurement. Cette image panoramique numérique est délivrée par l'appareil 1 sous forme d'un fichier informatique contenant des points image codés RVBA agencés dans une table à deux dimensions, "R" étant le pixel rouge d'un point image, "V" le pixel vert, "B" le pixel bleu, et "A" le paramètre Alpha ou transparence, les paramètres R, V, B, A étant généralement codés sous 8 bits.

Le fichier image est transféré dans le micro-ordinateur 5 qui transforme l'image initiale en une image numérique à trois dimensions, puis présente à l'utilisateur un secteur de l'image à trois dimensions dans une fenêtre d'affichage 7 occupant tout ou partie de l'écran 6.

La figure 3 illustre schématiquement des étapes classiques de transformation de l'image panoramique à deux dimensions en une image panoramique offrant un effet de perspective réaliste. Après suppression des bords noirs de l'image, le micro-ordinateur dispose d'un ensemble de points image formant un disque image 10 de centre O et d'axes OX et OY. Les points image du disque image sont transférés dans un espace à trois dimensions défini par un repère orthogonal d'axes O'X'Y'Z, l'axe O'Z étant perpendiculaire au plan du disque image. Le transfert est assuré par une fonction mathématique mise en oeuvre par un algorithme exécuté par le micro-ordinateur, et conduit à l'obtention d'un ensemble de points image référencés dans le repère O'X'Y'Z. Ces points image sont par exemple codés en coordonnées sphériques RVBA(φ,θ), φ étant la latitude et θ la longitude d'un point image, les angles φ et θ étant codés sur 4 à 8 octets (norme IEEE). Ces points image forment une demi-sphère 11 lorsque l'objectif panoramique utilisé présente une ouverture de 180°, sinon une portion de demi-sphère. Le micro-ordinateur dispose ainsi d'une image virtuelle en forme de demi-sphère dont un secteur 12, correspondant à la fenêtre d'affichage 7, est présenté sur l'écran (fig. 1) en considérant que l'observateur se trouve sur le point central O' du système d'axes O'X'Y'Z, qui définit avec le centre O" du secteur d'image 12, une direction O'O" appelée "position du regard".

Afin d'éviter que le secteur d'image affiché 12 présente des déformations géométriques désagréables pour l'observateur, les objectifs panoramiques classiques doivent présenter une fonction de répartition des points image en fonction de l'angle de champ des points objet d'un panorama qui soit la plus linéaire possible. Ainsi, si l'on considère deux points A', B' situés sur un même méridien de la demi-sphère 11, et les points correspondants A, B sur le disque image 10, le rapport entre les angles (A'O'Z) et (B'O'Z) doit être égal au rapport entre les distances OA et OB sur le disque image.

En raison de cette propriété de linéarité d'un objectif panoramique classique, des points image correspondant à des points objet ayant un angle de champ identique forment sur le disque image 10 des cercles concentriques C10, C20... C90, comme cela est représenté en figure 4A. On désigne classiquement par "angle de champ d'un point objet" l'angle que présente un rayon lumineux incident passant par le point objet considéré et par le centre du panorama photographié, relativement à l'axe optique de l'objectif. L'angle de champ d'un point objet peut être compris entre 0 et 90° pour un objectif ayant une ouverture de 180°. Ainsi, le cercle C10 est formé par les points image correspondant à des points objet ayant un angle de champ de 10°, le cercle C20 est formé par des points image correspondant à des points objet ayant un angle de champ de 20°, etc., le cercle C90 étant formé par les points image ayant un angle de champ de 90°.

La figure 4B représente l'allure de la fonction de répartition Fdc d'un objectif panoramique classique, qui détermine la distance relative *dr* d'un point image par rapport au centre du disque image en fonction de l'angle de champ α du point objet correspondant. La distance relative *dr* est comprise entre 0 et 1 et est égale à la distance du point image par rapport au centre de l'image divisée par le rayon du disque image. La forme idéale de la fonction Fdc est une droite de pente K :

$$dr = Fdc(\alpha) = K\alpha$$

dans laquelle la constante K est égale à 0,111 degré$^{-1}$ (1/90°).

Cette technique d'affichage sur un écran d'ordinateur d'un secteur d'image numérique panoramique présente divers avantages, notamment la possibilité "d'explorer" l'image panoramique en faisant glisser le secteur d'image présenté à l'écran vers la gauche, la droite, le haut ou le bas, jusqu'à atteindre les limites de l'image panoramique. Cette technique permet également d'effectuer des rotations complètes de l'image lorsque deux images numériques complémentaires ont été prises et fournies au micro-ordinateur, ce dernier reconstituant alors une sphère panoramique complète par assemblage de deux demi-sphères. Un autre avantage offert par la présentation d'une image panoramique sur écran est de permettre à l'observateur d'effectuer des grossissements ou zooms sur des parties de l'image. Les zooms sont effectués de façon numérique, par rétrécissement du secteur d'image affiché et dilatation de la répartition des points image sur les pixels de l'écran.

Divers exemples d'images panoramiques interactives peuvent être trouvés sur le Web. On pourra notamment se reporter au site central "http://www.panoguide.com" ("the guide to panoramas and panoramic photography") qui donne un aperçu exhaustif de l'ensemble des produits à la disposition du public pour réaliser de telles images. Des logiciels permettant de transformer des photographies panoramiques numériques en images panoramiques interactives sont proposés au public sous forme de programmes téléchargeables ou de CD-ROM disponibles dans le commerce.

Malgré les divers avantages qu'offre cette technique d'affichage d'images numériques, les grossissements numériques présentent l'inconvénient d'être limités par la résolution du capteur d'image utilisé lors de la prise d'image initiale et la résolution d'un capteur d'image est généralement très inférieure à celle d'une photographie classique. Ainsi, lorsque le grossissement augmente, la granulosité de l'image apparaît car on arrive aux limites de la résolution du capteur d'image.

Pour pallier cet inconvénient, il est connu de procéder à des interpolations de pixels afin de retarder l'apparition des pavés de couleur qui trahissent les limites de la résolution du capteur. Toutefois, cette méthode ne fait qu'améliorer l'aspect du secteur d'image grossi et ne permet aucunement d'apporter un surcroît de définition. Une autre solution, évidente, est de prévoir un capteur d'image présentant une résolution élevée, supérieure à la résolution nécessaire pour la présentation d'un secteur d'image sans grossissement, de sorte qu'il reste une marge de définition pour les zooms. Cette solution est toutefois coûteuse car le prix de revient d'un capteur d'image augmente rapidement avec le nombre de pixel par unité de surface.

Afin d'améliorer la qualité des grossissements, certaines tentatives ont été faites en modifiant les propriétés optiques des objectifs panoramiques eux-mêmes. Ainsi, le brevet US 5710661 enseigne de capturer une image panoramique avec deux objectifs imbriqués grâce à un jeu de miroirs. Un premier jeu de miroir permet d'offrir une vue d'ensemble, et un miroir central mobile permet d'offrir une vue en détail sur une zone déterminée du panoramique. Toutefois cette solution n'offre pas la même souplesse que les zooms numériques, notamment lorsque l'image n'est pas affichée en temps réel, l'observateur n'ayant plus la possibilité de choisir la portion d'image qu'il veut agrandir une fois la photographie réalisée.

Ainsi, la présente invention vise un procédé permettant de contourner les limites physiques des capteurs d'image et d'améliorer la définition offerte par des grossissements numériques portant sur certaines parties d'une image panoramique numérique, sans qu'il soit nécessaire d'augmenter le nombre de pixels par unité de surface d'un capteur d'image ni de prévoir un système de grossissement optique imbriqué dans un objectif panoramique.

Pour atteindre cet objectif, la présente invention se fonde sur la constatation selon laquelle, dans de nombreuses applications, seules certaines zones d'une image panoramique présentent un intérêt pratique et sont susceptibles d'être dilatées par l'observateur au moyen d'un zoom numérique. Ainsi, dans des applications comme la vidéosurveillance, la vidéoconférence, la visioconférence, une caméra panoramique peut être installée contre un mur ou au plafond et l'on n'a généralement aucun intérêt à faire des grossissements sur les zones de l'image panoramique correspondant au mur ou au plafond. De même, dans le cadre d'une vidéoconférence faite au moyen d'une caméra panoramique, la zone la plus intéressante est généralement située à un endroit spécifique qui est situé vers le centre de l'image (dans le cas d'une utilisation individuelle) ou sur les bords de l'image (dans le cas d'une utilisation collective ou visioconférence). Par ailleurs, dans le domaine des loisirs, la plupart des images panoramiques comprennent des parties moins intéressantes que d'autres, par exemple les parties représentant le ciel ou un plafond, la partie la plus utile se trouvant généralement au voisinage du centre de l'image.

Ainsi, la présente invention se base sur le postulat selon lequel une image panoramique présente des zones peu utiles qui peuvent souffrir une définition passable au profit d'autres zones de l'image.

Sur le fondement de ce postulat, l'idée de la présente invention est de réaliser des photographies panoramiques au moyen d'un objectif panoramique qui n'est pas linéaire, qui dilate certaines zones de l'image et comprime d'autres zones de l'image. L'effet technique obtenu est que les zones dilatées de l'image couvrent un nombre de pixels du capteur d'image plus important que si elles n'étaient pas dilatées, et bénéficient par conséquent d'une meilleure définition. En choisissant un objectif assurant une dilatation des zones les plus utiles d'une image (qui dépendent de l'application visée), on bénéficie d'une excellente définition dans les ces zones et d'une définition médiocre dans les zones de moindre importance.

Ainsi, la présente invention propose un procédé de capture d'une image panoramique numérique, par projection d'un panorama sur un capteur d'image au moyen d'un objectif panoramique, dans lequel l'objectif panoramique présente une fonction de répartition de points image qui n'est pas linéaire relativement à l'angle de champ de points objet du panorama, la fonction de répartition présentant une divergence maximale d'au moins ±10% par rapport à une fonction de répartition linéaire, de telle sorte que l'image panoramique obtenue présente au moins une zone sensiblement dilatée et au moins une zone sensiblement comprimée.

Selon un mode de réalisation, l'objectif présente une fonction de répartition non linéaire qui est symétrique relativement à l'axe optique de l'objectif, la position d'un point image relativement au centre de l'image étant fonction de l'angle de champ du point objet correspondant.

Selon un mode de réalisation, l'objectif dilate le centre de l'image et comprime les bords de l'image.

Selon un mode de réalisation, l'objectif dilate les bords de l'image et comprime le centre de l'image.

Selon un mode de réalisation, l'objectif comprime le centre de l'image et les bords de l'image, et dilate une zone intermédiaire de l'image se trouvant entre le centre et les bords de l'image.

Selon un mode de réalisation, l'objectif comprend un jeu de lentilles formant apodiseur.

Selon un mode de réalisation, le jeu de lentilles formant apodiseur comprend au moins une lentille asphérique.

Selon un mode de réalisation, le jeu de lentilles formant apodiseur comprend au moins une lentille diffractive.

Selon un mode de réalisation, l'objectif comprend un jeu de miroirs comprenant au moins un miroir déformant.

La présente invention concerne également un procédé d'affichage d'une image panoramique initiale obtenue conformément au procédé décrit ci-dessus, comprenant une étape de correction de la non-linéarité de l'image initiale, faite au moyen d'une fonction réciproque de la fonction de répartition non linéaire de l'objectif ou au moyen de la fonction de répartition non linéaire.

Selon un mode de réalisation, l'étape de correction comprend une étape de transformation de l'image initiale en une image numérique corrigée comprenant un nombre de points image supérieur au nombre de pixels que comprend le capteur d'image.

Selon un mode de réalisation, le procédé comprend une étape de calcul, au moyen de la fonction réciproque de la fonction de répartition, de la taille de l'image corrigée, de manière que l'image corrigée ait une résolution équivalente à la zone la plus dilatée de l'image initiale, et une étape consistant à parcourir chaque point image de l'image corrigée, à chercher la position d'un point jumeau du point image sur l'image initiale et à attribuer la couleur du point jumeau au point image de l'image corrigée

Selon un mode de réalisation, l'image initiale et l'image corrigée comprennent un disque image.

Selon un mode de réalisation, le procédé comprend une étape de transfert des points image de l'image corrigée dans un espace à trois dimensions et une étape de présentation sur un moyen d'affichage d'un secteur de l'image à trois dimensions obtenue.

Selon un mode de réalisation, le procédé comprend une étape de détermination de la couleur de points image d'une fenêtre d'affichage, par projection des points image de la fenêtre d'affichage sur l'image initiale au moyen de la fonction de répartition non linéaire, et attribution à chaque point image de la fenêtre d'affichage de la couleur d'un point image le plus proche sur l'image initiale.

Selon un mode de réalisation, la projection des points image de la fenêtre d'affichage sur l'image initiale comprend une étape de projection des points image de la fenêtre d'affichage sur une sphère ou une portion de sphère, une étape de détermination de l'angle par rapport au centre de la sphère ou de la portion de sphère de chaque point image projeté, et une étape de projection sur l'image initiale de chaque point image projeté sur la sphère ou la portion de sphère, la projection étant faite au moyen de la fonction de répartition non linéaire en considérant l'angle de champ que présente chaque point à projeter par rapport au centre de la sphère ou de la portion de sphère.

La présente invention concerne également un objectif panoramique comprenant des moyens optiques pour projeter un panorama dans un plan image de l'objectif, l'objectif panoramique présentant une fonction de répartition de points image qui n'est pas linéaire relativement à l'angle de champ de points objet du panorama, la fonction de répartition présentant une divergence maximale d'au moins ±10% par rapport à une fonction de répartition linéaire, de telle sorte qu'une image panoramique obtenue au moyen de l'objectif comprend au moins une zone sensiblement dilatée et au moins une zone sensiblement comprimée.

Selon un mode de réalisation, l'objectif panoramique présente une fonction de répartition non linéaire qui est symétrique relativement à l'axe optique de l'objectif, la position d'un point image relativement au centre d'une image obtenue étant fonction de l'angle de champ du point objet correspondant.

Selon un mode de réalisation, l'objectif panoramique dilate le centre d'une image et comprime les bords de l'image.

Selon un mode de réalisation, l'objectif panoramique dilate les bords d'une image et comprime le centre de l'image.

Selon un mode de réalisation, l'objectif panoramique comprime le centre d'une image et les bords de l'image, et dilate une zone intermédiaire de l'image se trouvant entre le centre et les bords de l'image.

Selon un mode de réalisation, l'objectif panoramique comprend un jeu de lentilles formant apodiseur.

Selon un mode de réalisation, le jeu de lentilles formant apodiseur comprend au moins une lentille asphérique.

Selon un mode de réalisation, le jeu de lentilles formant apodiseur comprend au moins une lentille diffractive.

Selon un mode de réalisation, l'objectif panoramique comprend des lentilles en polyméthacrylate.

Selon un mode de réalisation, l'objectif panoramique comprend un jeu de miroirs comprenant au moins un miroir déformant.

Ces objets, caractéristiques et avantages ainsi que d'autres de la présente invention seront exposés plus en détail dans la description suivante du procédé selon l'invention et d'exemples de réalisation d'objectifs panoramiques non linéaires selon l'invention, faite à titre non limitatif en relation avec les figures jointes parmi lesquelles :

- la figure 1 précédemment décrite représente un système d'affichage sur un écran d'une image panoramique numérique,
- la figure 2 précédemment décrite représente une image panoramique avant son traitement par un ordinateur,
- la figure 3 précédemment décrite illustre un procédé classique de transformation d'une image panoramique à deux dimensions en une image panoramique numérique à trois dimensions,
- les figures 4A et 4B précédemment décrites illustrent la linéarité d'un objectif panoramique classique,
- les figures 5 et 6 illustrent un aspect du procédé selon l'invention et représentent respectivement une répartition de points image obtenue avec un objectif panoramique classique et une répartition de points image obtenue avec un objectif panoramique non linéaire selon l'invention,
- les figures 7A et 7B illustrent un premier exemple de non-linéarité d'un objectif panoramique selon l'invention,
- la figure 8 illustre un second exemple de non-linéarité d'un objectif panoramique selon l'invention,
- la figure 9 illustre un troisième exemple de non-linéarité d'un objectif panoramique selon l'invention,
- la figure 10 représente un système d'affichage d'une image panoramique numérique au moyen duquel est mis en œuvre un procédé de correction selon l'invention de l'image panoramique,
- la figure 11 illustre schématiquement un premier mode de réalisation du procédé de correction selon l'invention,
- la figure 12 est un organigramme décrivant un procédé d'affichage d'une image panoramique incorporant le premier procédé de correction selon l'invention,
- la figure 13 illustre schématiquement un second mode de réalisation du procédé de correction selon l'invention,
- la figure 14 est un organigramme décrivant un procédé d'affichage d'une image panoramique incorporant le second procédé de correction selon l'invention,
- la figure 15 est une vue en coupe d'un premier mode de réalisation d'un objectif panoramique non linéaire selon l'invention,

- la figure 16 est une vue éclatée en coupe d'un système de lentilles présent dans l'objectif panoramique de la figure 15,
- la figure 17 est une vue de profil d'une lentille présente dans l'objectif panoramique de la figure 15, et
- la figure 18 est le schéma d'un second mode de réalisation d'un objectif panoramique non linéaire selon l'invention.

I - Description du procédé selon l'invention

I.1 - Compression/dilation d'une image initiale

Principe général de l'invention

La figure 5 représente schématiquement un système classique de prise de vues panoramiques, comprenant un objectif panoramique 15 d'axe optique OZ et un capteur d'image numérique 17 agencé dans le plan image de l'objectif 15. On considère ici quatre points objet a, b, c, d appartenant à un panorama PM se trouvant en face de l'objectif et présentant respectivement des angles d'incidence α1, α2, -α2, -α1. Comme cela a été indiqué au préambule, l'angle de champ d'un point objet est l'angle que présente relativement à l'axe optique OZ de l'objectif un rayon lumineux incident passant par le point objet considéré et par le centre du panorama PM, repéré par un point "p" sur la figure. Dans cet exemple, l'angle α1 est égal à deux fois l'angle α2. Sur le capteur d'image 17, des points image a', b', c', d' correspondant aux points objet a, b, c, d se trouvent à des distances du centre de l'image égales respectivement à d1, d2, -d2, -d1. Comme la répartition des points image en fonction de l'angle de champ des points objet est linéaire avec un objectif panoramique classique, les distances d1 et d2 sont liées par la relation suivante:

$$d1/\alpha1 = d2/\alpha2$$

L'angle α1 étant ici égal à 2α2, il vient que :

$$d1 = 2d2$$

Comme cela est bien connu de l'homme de l'art, le terme "linéarité" désigne ici un rapport de proportionnalité entre la distance d'un point image mesurée relativement au centre de l'image et l'angle de champ du point objet correspondant. La notion de "linéarité" en matière d'objectifs panoramiques est donc différente de celle qui prévaut dans le domaine de l'optique paraxiale (au voisinage de l'axe optique) lorsque les conditions de Gauss sont remplies.

La figure 6 représente un système de prise de vue du même type que le précédent, mais dans lequel l'objectif panoramique classique 15 est remplacé par un objectif 18 selon l'invention, le capteur d'image 17 étant agencé dans le plan image de l'objectif 15. On considère à nouveau la projection sur le capteur d'image 17 des points objet a, b, c, d présentant des angles d'incidence α1, α2, -α2 et -α1 relativement à l'axe OZ de l'objectif et au centre "p" du panorama. Sur le capteur d'image 17, les points image correspondants a", b", c", d" se trouvent à des distances du centre de l'image respectivement égales à d1', d2', -d2', -d1'.

Selon l'invention, l'objectif 18 présente une fonction de répartition des points image qui n'est pas linéaire et le rapport des distances d1', d2', -d2', -d1' n'est pas égale au rapport des angles d'incidence α1, α2, -α2, -α1. Sur l'exemple représenté, la distance d2' est nettement supérieure à d1'/2, de sorte que la partie centrale de l'image panoramique projetée sur le capteur d'image 17, qui correspond à un angle solide 2α2 centré sur l'axe optique OZ, occupe une surface plus importante sur le capteur d'image 17 que la surface qu'elle occupe en figure 5 avec l'objectif panoramique classique (zone hachurée). Cette partie centrale de l'image panoramique est ainsi projetée sur le capteur d'image avec dilatation de sa surface, par rapport à la surface qu'elle occuperait si l'objectif était linaire. Il en résulte que le nombre de pixel du capteur d'image couvert par cette partie de l'image est plus important que dans l'art antérieur et que la définition obtenue est améliorée. En contrepartie, la partie de l'image délimitée par deux cercles passant respectivement par les points a", d" et par les points b", c" est comprimée relativement à la partie correspondante en figure 5, et la définition sur les bords de l'image est inférieure à celle que l'on obtient avec un objectif linéaire classique, au bénéfice de la partie centrale de l'image.

En appliquant ce principe selon l'invention, qui consiste à dilater une partie de l'image et compresser une autre partie de l'image, il vient que l'on peut choisir la partie à dilater et la partie à compresser en fonction de l'application visée, en réalisant plusieurs types d'objectifs non linéaires et en choisissant un objectif convenant à l'application visée. Selon l'application visée, la partie la plus utile d'une image panoramique peut se trouver au centre de l'image, en bordure de l'image, dans une zone intermédiaire située entre le centre et le bord de l'image, etc.

Exemples de fonctions de répartition selon l'invention

Les figures 7A et 7B, 8 et 9 illustrent trois exemples de fonctions de répartition non linaires selon l'invention.

La fonction de répartition illustrée sur les figures 7A et 7B correspond à l'exemple de la figure 6, à savoir un objectif panoramique assurant une dilatation de l'image au centre. La figure 7A représente des cercles concentriques équidistants C10, C20... C90 présents sur un disque image, chaque cercle étant formé par des points image correspondant à des points objet ayant le même angle de champ. Le cercle C10 est formé par les points image correspondant à des points objet ayant un angle de champ de 10°, le cercle C20 est formé par des points image correspondant à des points objet ayant un angle de champ de 20°, etc.. En comparant la figure 7A avec la figure 4A décrite au préambule, il apparaît que les cercles C10 et C20 sont plus éloignés du centre de l'image et plus éloignés l'un de l'autre que les cercles C10 et C20 obtenus avec un objectif classique, tandis que les cercles C30 à C90 sont plus proches les uns des autres. Une telle image panoramique présente ainsi une zone dilatée au centre et une zone comprimée en bordure du disque image.

La figure 4B représente la courbe de la fonction de répartition Fd1 correspondante. La fonction de répartition linéaire classique, d'expression Fdc = Kα et en forme de droite de pente K, est également représentée en tant que point de repère (la constante K étant égale à 1/90 pour un objectif ayant une ouverture de 180°, soit une pente de 0,111 degré$^{-1}$). L'angle de champ α des points objet est représenté en abscisse et est compris entre 0 et 90°. La distance relative *dr* d'un point image par rapport au centre du disque image est représentée sur l'axe des ordonnées et est comprise entre 0 et 1. On voit que la courbe de la fonction Fd1 présente une pente plus forte que la droite Fdc pour des angles α compris entre 0 et 20°, puis une pente plus faible au-delà des 20° et jusqu'à 90°. Une forte pente signifie une dilatation de l'image et une faible pente signifie une compression de l'image.

Il apparaît sur cet exemple que la courbe Fd1 présente un point de divergence maximale Pd à l'angle α = 20°. On entend par "point de divergence maximale" le point image Pd(α) où l'on observe le plus grand écart en distance relative *dr* par rapport à un point correspondant Pdl(α) sur la droite de répartition linaire Kα. Dans cet exemple, le point Pd(α=20°) présente une distance relative *dr* égale à 0,5 relativement au centre de l'image tandis que le point correspondant Pdl(α=20°) sur la courbe linaire Fdc présente une distance relative *dr* de 0,222. La divergence maximale DIVmax de la fonction de répartition Fd1 selon l'invention peut être calculée par une formule du type :

$$DIVmax\% = [[dr(Pd) - dr(Pdl)]/[dr(Pdl)]]*100$$

soit :

$$DIVmax\% = [[dr(Pd) - K*\alpha(Pd)]/[K*\alpha(Pd)]]*100$$

Dans laquelle *dr*(Pd) est la distance relative par rapport au centre du point de divergence maximale Pd, *dr*(Pdl) est la distance relative par rapport au centre du point correspondant sur la droite de répartition linéaire Fdc,

α(Pd) étant l'abscisse du point Pd soit l'angle de champ du point objet correspondant.

Dans l'exemple considéré ici, la divergence maximale est donc égale à +125%. Cette valeur de divergence maximale selon l'invention est nettement supérieure à celle due aux erreurs de conception éventuelles ou aux erreurs de fabrication d'un objectif panoramique classique, qui est de quelques pour-cent. De façon générale, un objectif non linéaire selon l'invention présente une divergence maximale de l'ordre de 10% au moins, pour obtenir une dilatation des parties utiles de l'image qui se traduise par un net accroissement du nombre de pixels du capteur d'image couvert par les parties utiles et une amélioration sensible de la définition obtenue.

On définit également, selon l'invention, un taux moyen de dilatation/compression TX d'une partie de l'image comprise entre deux cercles passant par des points Pd1 et Pd2. Ce taux moyen de dilatation/compression TX est le rapport entre la surface délimitée par les deux cercles passant par les points Pd1, Pd2 et la surface délimitée par deux cercles passant par des points Pdl1, Pdl2 de même abscisse appartenant à la fonction de répartition linéaire Fdc. Le taux TX peut être déterminé par une formule du type :

$$TX = [dr(Pd1)^2 - dr(Pd2)^2] / [(dr(Pdl1))^2 - (dr(Pdl2))^2]$$

soit :

$$TX = [dr(Pd1)^2 - dr(Pd2)^2] / [K^2[(\alpha(Pd1))^2 - (\alpha(Pd2))^2]]$$

Un taux TX supérieur à 1 indique une dilatation de la partie d'image considérée tandis qu'un taux TX inférieur à 1 indique une compression de la partie d'image considérée. Dans l'exemple de fonction Fd1 considéré ici, le taux moyen de dilatation/compression TX de la partie centrale de l'image, délimitée par le cercle C20, est égal à 5,07, soit une dilatation moyenne par un facteur 5 de la partie centrale de l'image et par conséquent une amélioration de 500% de la définition obtenue pour un nombre de pixels constant du capteur d'image.

La figure 8 représente un autre exemple de fonction de répartition Fd2 selon l'invention, présentant ici un point de divergence maximale Pd à l'angle α=70°, ayant une distance relative par rapport au centre de l'image de 0,3. La divergence maximale de la courbe Fd2 est ici de -61,4 %, et le taux moyen de dilatation/compression TX de la partie centrale de l'image délimitée par le cercle C70 (non représenté) est de 0,15, soit une compression moyenne par un facteur de 0,15 de la partie centrale de l'image. La partie dilatée de l'image se trouve ainsi ici sur le bord de l'image, entre le cercle C70 et le cercle C90, et présente un taux moyen de dilatation/compression de 2,3. Ainsi, un disque image obtenu avec un objectif panoramique ayant une fonction de répartition conforme à la fonction Fd2, présente une zone à haute définition sur ses bords, se prêtant bien aux grossissements numériques, et une zone à faible définition dans sa partie centrale.

La figure 9 représente un troisième exemple de fonction de répartition Fd3 selon l'invention, présentant un premier point de divergence maximale Pd1 (α=30°, *dr*=0,1) et un second point de divergence maximale Pd2 (α=70°, *dr*=0,9). On observe donc deux divergences maximales, l'une négative et égale à -70%, l'autre positive et égale à 15,8%. On observe également une zone d'image comprimée entre le centre O de l'image et le cercle C30 passant par le point Pd1, une zone d'image dilatée entre le cercle C30 et le cercle C70 passant par le point Pd2, et une zone d'image comprimée entre le cercle C70 et le cercle C90 formant le bord du disque image. Les taux moyens de dilatation/compression TX(0,C30), TX(C30, C70), TX(C70, C90) pour chacune de ces zones sont respectivement égaux à 0,09, 1,6 et 0,48. Un disque image obtenu avec un objectif panoramique ayant une fonction de répartition conforme à la fonction Fd3, présente dans sa partie intermédiaire une zone à haute définition, se prêtant bien aux grossissements numériques, et deux zones à faible définition dans sa partie centrale et sur ses bords.

I.2 - Correction de la non-linéarité de l'image initiale

On a décrit dans ce qui précède un premier aspect de l'invention, selon lequel on prévoit une répartition non linéaire de points image sur une image numérique afin d'améliorer la définition de l'image dans des zones dilatées, par augmentation du nombre de pixels du capteur d'image couvert par les zones dilatées. Avant de décrire des exemples de réalisation d'objectifs panoramiques non linéaires selon l'invention, on décrira un deuxième aspect de l'invention qui consiste à corriger la non-linéarité du disque image obtenu afin de présenter à l'observateur une image dépourvue de déformation optique.

Ce deuxième aspect de l'invention est mis en œuvre au stade du traitement par ordinateur de l'image initiale, pour la présentation d'une image panoramique interactive sur un écran. Les moyens de mise en œuvre du procédé de l'invention sont illustrés en figure 10 et sont en soi classiques. On distingue un appareil de prise de vue numérique 20 équipé d'un objectif panoramique non linéaire 21 et connecté à un micro-ordinateur 22 comprenant un écran 23. Les images numériques IMi prises au moyen de l'appareil 20 sont transférées au micro-ordinateur pour être traitées et affichées sur l'écran 23, dans une fenêtre d'affichage 24. Un programme de traitement comprenant un algorithme de transformation et d'affichage des images est préalablement chargé dans le micro-ordinateur, par exemple au moyen d'un CD-ROM 25 ou par téléchargement via le réseau Internet. L'appareil 20 peut être un appareil photographique numérique ou une caméra vidéo numérique et la connexion au micro-ordinateur peu être permanente ou non. Dans le cas d'une caméra vidéo, le micro-ordinateur reçoit un flux d'images qu'il traite en temps réel pour les afficher sur l'écran.

Dans ce contexte, le procédé de correction selon l'invention peut être exécuté selon deux modes de réalisation. Un premier mode de réalisation consiste à effectuer une correction de l'image initiale au moyen d'une fonction Fd^{-1} qui est la fonction réciproque de la fonction de répartition Fd selon l'invention. La fonction de répartition Fd étant connue et déterminée au moment de la conception de l'objectif non linéaire, il est aisé d'en déduire la fonction réciproque Fd^{-1}. Cette étape de correction permet d'obtenir une image corrigée dans laquelle les non linéarités dues à l'objectif selon l'invention sont supprimées. L'image corrigée est équivalente à une image prise au moyen d'un objectif panoramique classique et peut ensuite être traitée par tout logiciel d'affichage classique disponible dans le commerce, prévu pour transférer les points image d'un disque image dans un espace à trois dimensions et pour procéder à l'affichage interactif d'un secteur de l'image obtenue.

La seconde variante du procédé consiste à faire intervenir la fonction de répartition Fd dans un algorithme d'affichage d'image travaillant à rebours, c'est-à-dire définissant en temps réel la couleur des pixels d'une fenêtre d'affichage à partir des points image du disque image.

Premier mode de réalisation du procédé de correction

La figure 11 illustre le premier mode de réalisation du procédé selon l'invention. On suppose ici que l'on dispose d'une image initiale Img1 comportant un disque image non linéaire ID1 de rayon R1, ayant par exemple une zone de dilatation au centre (cercles C10 et C20). On transforme l'image initiale Img1 en une image corrigée Img2 comportant un disque image linéaire ID2 de rayon R2. Le rayon R2 du disque image ID2 est supérieur au rayon R1 du disque image initial ID1 et le disque image ID2 présente une résolution égale ou sensiblement égale à la résolution offerte par la zone du disque image Img1 où se trouve la plus grande densité d'information (soit la zone où l'image est la plus dilatée). Il s'agit ici de la partie centrale de l'image délimitée par le cercle C20.

Les principales étapes de ce procédé sont les suivantes :

- on calcule dans un premier temps, au moyen de la fonction réciproque Fd^{-1}, la taille R2 du disque image linéarisé ID2 en considérant sur le disque image initial ID1 l'endroit où

l'image est la plus dilatée, de manière que l'image corrigée Img2 ait une résolution égale ou sensiblement égale à la résolution offerte par la zone de l'image Img1 où se trouve la plus grande densité d'information,
- on parcourt ensuite chaque pixel de l'image à calculer Img2, et on cherche la position de son point jumeau sur l'image Img1, puis
- on affecte au point de la nouvelle image Img2 la couleur du point correspondant sur l'image initiale Img1.

Ce procédé est mis en oeuvre au moyen d'un algorithme décrit ci-après (algorithme 1), dans lequel :
- A est l'angle d'ouverture de l'objectif,
- D est la distance d'un point image relativement au centre du disque image initial ID1,
- R1 est la taille en pixels du rayon du disque image initial ID1 (soit le nombre de pixels entre le centre et le bord du disque image) et
- R2 est la taille en pixels du rayon du disque image linéarisé ID2,
- I et J sont les coordonnées d'un point image dans l'image d'arrivée, le point de coordonnées (0,0) étant au centre de l'image,
- U et V sont les coordonnées d'un point jumeau dans l'image de départ, le point de coordonnées (0,0) étant au centre de l'image,
- "Angle_courant" et "Angle_précédent" sont des paramètres itératifs
- DAM est la différence angulaire minimale entre deux points objets correspondants à deux points image adjacents sur le disque image initial ID1 (soit la résolution maximale du disque image ID1 exprimée en différence d'angle).

Algorithme 1 :

[recherche de DAM]

1/ DAM = A/2

2/ Angle_courant = 0

3/ Pour D = 1 à R1 *[avec des incréments de 1]*

4/ Angle_précédent = Angle_courant

```
5/    Angle_courant = Fd⁻¹(D/R1)
6/    Si DAM > (Angle_courant - Angle_précédent) alors
7/          DAM = (Angle_courant - Angle_précédent)
8/    Fin si
9/ Fin pour
[détermination du rayon R2 du disque ID2]
10/ R2 = (A/2)/DAM
[calcul de la nouvelle image]
[parcours de chaque pixel de l'image à calculer Img2]
11/ Pour I =-R2 à +R2 [avec un incrément de 1]
12/  Pour J =-R2 à +R2 [avec un incrément de 1]
[recherche des coordonnées polaires (R',θ) du point jumeau
sur l'image Img1 à partir des coordonnées (R,θ) du point de
l'image Img2]
13/          R = √(I²+J²)
14/          Si R < R2 alors
15/                Si J < 0 alors
16/                      θ = arc cosinus(I/R)
17/                Sinon
18/                      θ = -arc cosinus(I/R)
19/                Fin si
[conversion du rayon R pour trouver le rayon R']
20/                R'=R*R1/R2
[retour aux coordonnées cartésiennes ]
21/                U = R'*cos(θ)
22/                V = R'*sin(θ)
[affectation de la couleur du point]
23/                Img2[I,J] = Img1[U,V]
24/          Sinon
[attribution de la couleur noire aux points en dehors du
disque image]
25/                Img2[I,J] = Noir
26/          Fin si
27/  Fin pour
28/ Fin pour
```

On notera que l'étape 14 permet d'éviter de calculer tous les points situés en dehors du disque image (on se trouve à l'extérieur du disque image quand R > R2). D'autre part, l'algorithme 1 peut être amélioré en effectuant a posteriori une interpolation bilinéaire sur l'image Img2, en soi bien connue de l'homme de l'art, afin de lisser l'image finale.

La figure 12 est un organigramme donnant un aperçu général des étapes d'un procédé de capture et de présentation interactive d'une image panoramique sur un écran. Cet organigramme est décrit par le tableau 1 figurant en Annexe, faisant partie intégrante de la description. Les étapes S1 et S2, respectivement d'acquisition de l'image et de transfert de l'image dans un calculateur, sont en soi classiques. L'étape de linéarisation du disque image S3 est exécutée conformément au procédé de l'invention, par exemple au moyen de l'algorithme décrit ci-dessus. L'étape S4, dite de "numérisation", est également classique. Cette étape consiste à transférer les points image du disque image corrigé Img2 dans un espace à trois dimensions d'axes Oxyz dans lequel les points image sont par exemple référencés en coordonnées sphériques. L'étape S5 est également classique, et consiste à afficher sur un écran un secteur de l'image à trois dimensions appelé fenêtre d'affichage. La fenêtre d'affichage est déplacée vers le haut ou vers le bas en fonction des actions de l'utilisateur, ou fait l'objet d'un grossissement sur demande de l'utilisateur. Lors d'un grossissement, on bénéficie d'une meilleure définition que dans l'art antérieur dans les zones correspondant aux parties dilatées de l'image initiale.

Second mode de réalisation du procédé de correction

Le deuxième mode de réalisation du procédé de correction selon l'invention est illustré en figure 13. De façon schématique, ce procédé consiste à projeter sur le disque image ID1 de l'image initiale Img1 les points image d'un secteur d'image correspondant à une fenêtre d'affichage DW. Ce procédé ne nécessite pas le calcul d'un disque image corrigé, contrairement au mode de réalisation précédent.

Les points image de la fenêtre d'affichage DW sont référencés E(i,j) dans le repère de la fenêtre d'affichage, exprimé en coordonnées de lignes i et en coordonnées de colonnes j. Les points E(i,j) sont tout d'abord projetés sur une portion de sphère HS de centre O et d'axes OX, OY, OZ, pour obtenir des points image P(px, py, pz) appartenant à la portion de sphère. Cette portion de sphère couvre un angle solide qui correspond à l'ouverture de l'objectif utilisé. On a considéré jusqu'à présent l'exemple d'un objectif panoramique ayant une ouverture de 180° et la portion de sphère HS considérée ici est donc une demi-sphère. Les points image P ainsi déterminés sont ensuite projetés sur le disque image Img1 au moyen de la fonction de répartition non linéaire Fd selon l'invention, ce qui nécessite le calcul préalable de l'angle de champ α des points P par rapport au centre O de la semi-sphère. Le centre O de la demi-sphère est l'équivalent virtuel du centre "p" du panorama, ayant servi de référence, dans ce qui précède, pour déterminer les angles d'incidence α des points objet et l'allure de la fonction Fd. La projection des points image P sur le disque image ID1 permet d'obtenir des points image p(pu, pv) sur le disque image, dans un repère de centre O' (correspondant au centre du disque image) et d'axes O'U et O'V. L'axe OZ dans le référentiel de la demi-sphère HS est perpendiculaire au plan du disque image ID1 et passe par le centre O' du disque image, de sorte que les axes O'Z et OZ sont confondus.

Comme cela apparaîtra clairement à l'homme de l'art, la correction de la non-linéarité du disque image est implicite ici puisque l'on va "chercher" sur le disque image ID1, au moyen de la fonction Fd, les points image p(pu, pv) correspondant aux points image E(i, j) de la fenêtre d'affichage DW.

Le procédé selon l'invention est mis en œuvre au moyen d'un algorithme décrit ci-après (algorithme 2), dans lequel :

- i et j sont les coordonnées d'un point E(i, j) de la fenêtre d'affichage,
- Imax et Jmax sont le nombre de colonnes et le nombre de lignes de la fenêtre d'affichage, correspondant aux dimensions en nombre de pixels de la fenêtre d'affichage

- Ex, Ey et Ez sont les coordonnées cartésiennes dans le repère OXYZ d'un point E(i,j) de la fenêtre d'affichage DW,
- Px, Py et Pz sont les coordonnées cartésiennes d'un point P sur la demi-sphère HS,
- pu et pv sont les coordonnées cartésiennes d'un point image p dans le repère O'UV du disque image,
- L est la taille du disque image, en nombre de pixels,
- M est le centre de la fenêtre d'affichage DW,
- la "direction regard" est la direction matérialisée par le point O et le centre de la fenêtre d'affichage M, la fenêtre d'affichage formant la base d'une pyramide de vision de l'observateur dont le sommet est le point O (position de l'observateur),
- θ0 et φ0 sont les longitudes et latitudes correspondant à la direction du regard depuis le point O vers le centre M de la fenêtre d'affichage,
- Pixel_Ecran[i,j] est la couleur (RVBA) d'un point E (i,j) de la fenêtre d'affichage DW,
- Pixel_Image[i,j] est la couleur du point P(i,j) de la demi-sphère HS correspondant au disque image, le point de coordonnées (0,0) étant situé au centre du disque image,
- R est le rayon de la demi-sphère HS (valeur arbitraire choisie de manière à améliorer la précision des calculs, R est par exemple choisi égal à 10000),
- α est l'angle par rapport au centre O d'un point image P situé sur la demi-sphère (représente l'angle de champ au moment de la prise de vue du point objet correspondant), et
- aux1, aux2 sont des variables intermédiaires,
- "Zoom" est une variable définissant le grossissement, ayant une valeur par défaut égale à R.
- "√" est la fonction racine carrée.

Algorithme 2 :

1/ Pour i=-Imax/2 à i=Imax/2 faire *[par incréments de 1]*

2/ Pour j=-Jmax/2 à j=Jmax/2 faire *[par incréments de 1]*

[calcul des coordonnées cartésiennes Ex, Ey, Ez du point E de la fenêtre d'affichage dans le système OXYZ]

3/ Ey = j*cos(φ0) - Zoom*sin(φ0)

```
4/          Ez = Zoom*cos(φ0) + j*sin(φ0)
5/          aux1 = Ez
6/          Ez = Ez*cos(θ0) - i*sin(θ0)
7/          Ex = i*cos(θ0) + aux1*sin(θ0)
[calcul des coordonnées du point P correspondant au point E]
8/          aux2 = R/√(Ex*Ex + Ey*Ey + Ez*Ez)
9/          Px = Ex*aux2
10/         Py = Ey*aux2
11/         Pz = Ez*aux2
[calcul des coordonnées du point p correspondant au point P,
dans le repère (O'UV), au moyen de la fonction Fd]
12/         X = Px/R
13/         Y = Py/R
14/         r = √(X*X + Y*Y)
15/         α = arcsinus(r)
16/         U = X/r
17/         V = Y/r
18/         pu = L*U*Fd(α)
19/         pv = L*V*Fd(α)
20/         Pixel_Ecran[i,j] = Pixel_Image[pu,pv]
21/   fin pour
22/ fin pour
```

Une demande de grossissement (zoom) par l'utilisateur conduit l'algorithme à modifier le paramètre "Zoom". Lorsque le paramètre "Zoom" est égal au rayon R de la demi-sphère, la fenêtre d'affichage DW est tangentielle à la demi-sphère (figure 13). Lorsque le paramètre "Zoom" est supérieur à R, la fenêtre DW s'éloigne de la demi-sphère (en suivant l'axe donné par la position du regard OM), ce qui correspond à un rétrécissement de la pyramide de vision et un grossissement du secteur d'image présenté dans la fenêtre DW. Le grossissement du secteur d'image présenté à l'observateur est donc égal au rapport du paramètre "Zoom" par le rayon R.

Lorsque les étapes 18 et 19 sont effectuées avec un paramètre "Zoom" supérieur à R, on gagne en définition dans les zones où l'image a été dilatée lors de la prise de vue car il existe toujours, tant que la limite de résolution n'est pas atteinte, deux pixels adjacents sur le disque image qui correspondent à deux pixels adjacents de la fenêtre d'affichage. Dans les zones comprimées de l'image, la recherche du pixel le plus proche au moyen des relations L*U*Fd(α) et L*V*Fd(α) conduit au contraire l'algorithme à trouver sur le disque image le même pixel image pour plusieurs pixels adjacents de la fenêtre d'affichage. Toutefois ces zones d'image comprimées bénéficiant d'une moindre définition sur le disque image, sont considérées comme secondaires pour l'application visée, conformément au postulat sur lequel se fonde la présente invention.

De façon générale, toute autre méthode de projection est susceptible d'être utilisée, l'étape essentielle selon l'invention étant de retrouver l'angle de champ α des points objet sur la demi-sphère, par rapport au centre de la demi-sphère, afin de faire intervenir dans les calculs la fonction de répartition Fd.

L'algorithme 2 est bien entendu applicable lorsque l'on dispose de deux disques image complémentaires, l'un correspondant à une photographie avant et l'autre à une photographie arrière d'un panorama à 360°, la deuxième photographie étant prise en faisant pivoter l'objectif panoramique de 180° autour d'un axe passant par le centre du panorama. On définit dans ce cas deux demi-sphères et deux points image appelés "Pixel_Image_Devant" et "Pixel_Image_Derriere" :

- Pixel_Image_Devant[i,j] : couleur d'un point E(i,j) sur la demi-sphère correspondant à la photo avant, le point de coordonnées (0,0), étant situé au centre du disque image,
- Pixel_Image_Derriere[i,j] : couleur d'un point E(i,j) sur la demi-sphère correspondant à la photo arrière, le point de coordonnées (0,0) étant situé au centre du disque image.

Les étapes 18 et suivantes de l'algorithme 2 sont alors modifiées ainsi :

```
18/  pu = L*U*Fd(α)
19/  pv = L*V*Fd(α)
20/  Si Pz >= 0 alors
```

```
Pixel_Ecran[i,j] = Pixel_Image_Devant[pu,pv]
Sinon Pixel_Ecran[i,j] = Pixel_Image_Derriere[L-pu,pv]
Fin si
fin pour
fin pour
```

La figure 14 est un organigramme donnant un aperçu général des étapes d'un procédé de capture et de présentation interactive d'une image panoramique sur un écran. Cet organigramme est décrit par le tableau 2 figurant en Annexe, faisant partie intégrante de la description. On y retrouve les étapes d'acquisition S1 et de transfert S2 décrites plus haut. L'étape S2 est suivie d'une étape d'affichage interactif S3' faite conformément au procédé qui vient d'être décrit, incorporant implicitement une correction des non-linéarités du disque image grâce à l'utilisation de la fonction de répartition Fd pour retrouver sur le disque image les points correspondants aux pixels de la fenêtre d'affichage.

II - Exemples de réalisation d'un objectif panoramique non linéaire selon l'invention

Un objectif de la présente invention est ici de prévoir un objectif panoramique présentant une fonction de répartition Fd non linéaire, qui soit d'une structure simple et d'un faible prix de revient. On décrira dans ce qui suit deux exemples de réalisation d'objectifs panoramiques non linéaires selon l'invention, le premier étant un objectif de type direct et le second de type indirect, c'est-à-dire utilisant des miroirs.

Premier mode de réalisation

Les apodiseurs sont des systèmes optiques bien connus de l'homme de l'art, utilisés pour modifier la répartition énergétique (quantité de lumière) au niveau de la pupille d'une source de lumière. Ils sont notamment utilisés pour uniformiser l'énergie dans un faisceau laser ou encore, dans le domaine de la photographie, pour limiter la diffraction de la lumière à travers les lentilles. Il est également connu d'utiliser un apodiseur en tant que filtre, pour couvrir l'ouverture d'un instrument optique afin de supprimer les anneaux secondaires d'une figure de diffraction. Lorsque l'on veut séparer les images de deux sources ponctuelles voisines, ces anneaux secondaires sont gênants et réduisent la résolution. On peut alors "apodiser", c'est-à-dire supprimer ces anneaux secondaires en plaçant un filtre adéquat dans le plan de la pupille.

Ici, l'idée de l'invention est d'utiliser un apodiseur dans un but différent : le principe de l'apodiseur est utilisé pour contrôler la répartition angulaire d'un objectif panoramique et obtenir la non-linéarité recherchée.

La figure 15 représente par une vue en coupe un exemple de réalisation d'un objectif non linéaire 30 selon l'invention. La fonction de répartition Fd obtenue au moyen de l'objectif 30 est la fonction Fd1 décrite plus haut en relation avec la figure 7B, l'objectif 30 assurant ainsi une dilation de l'image au centre.

L'objectif 30 comprend un système de lentilles qui est également représenté en figure 16 par une vue éclatée. On distingue un groupe optique divergent formé par des lentilles L1, L2, L3, un groupe optique convergent formé par des lentilles L4, L5, L6, L7, un diaphragme D1 étant agencé entre les lentilles L6 et L7.

Des pièces B1 à B4 et des pièces I3 à I6 sont prévues pour maintenir les lentilles. La pièce B1 forme le corps de l'objectif et comprend une cavité cylindrique dans laquelle sont agencées les lentilles L2 à L6. La pièce B2 est vissée sur le corps B1 et permet de fixer la lentille frontale L1 contre la face avant de la pièce B1, la face arrière de la lentille L1 étant au contact de la face avant de la lentille L2. Les pièces B3 et B4 sont fixées par des vis (non représentées) contre la partie arrière du corps B1. La pièce B3 maintient le diaphragme D1 et comprend une cavité de réception de la lentille arrière L7. La pièce B4 plaque la lentille L7 dans la pièce B3 et comporte un manchon arrière F1 pourvu d'un filetage permettant de fixer un capteur d'image, par exemple un capteur CCD. Les pièces I3 à I6 sont des intercalaires permettant d'ajuster avec précision les distances entre les lentilles L2 à L6 à l'intérieur du corps B1.

Le groupe optique divergent L1, L2, L3 définit l'angle de champ de l'objectif 30, ici de 180°. La lentille frontale L1 est un ménisque divergent en PMMA à face avant asphérique et face arrière concave. Rappelons que le PMMA ou polyméthacrylate est un verre organique à faible prix de revient, appartenant à la catégorie des matières plastiques. La lentille L2 est de type plan-concave et est en borosilicate BK7 (verre minéral optique standard). Sa face avant (face plane) est plaquée contre une partie plate de la face arrière de la lentille L1, qui s'étend à la périphérie de la partie concave (partie utile) de la face arrière de la lentille L1. La lentille L3 est également de type plan-concave et est en BK7. Sa face concave est orientée vers l'avant, en regard de la face arrière de la lentille L2.

Le groupe optique convergent L4, L5, L6, L7 forme un apodiseur au sens de la présente invention et détermine la fonction de répartition Fd non linéaire, qui est obtenue ici au moyen de lentilles asphériques et d'une lentille diffractive.

La lentille L4 est de type plan-concave et est en PMMA. Sa face avant concave est asphérique. La lentille L5 est de type plan-convexe et est en BK7, sa face plane étant orientée vers l'avant. La lentille L6 est un ménisque en PMMA ayant une face avant concave et asphérique et une face arrière convexe diffractive. Cette face arrière diffractive présente un réseau de diffraction constitué de zones diffractives circulaires centrées sur l'axe optique de la lentille, dont le profil est représenté en figure 17. Enfin, la lentille arrière L7 est de type biconvexe et est en BK7. Elle focalise le flux lumineux sur le plan image, à l'emplacement prévu pour le capteur d'image.

Les faces avant asphériques des lentilles L1, L4 et L6 sont déterminées au moyen d'une formule du type :

$$z(r) = [(C*r^2)/(1 + \sqrt{}(1-(1+k)*C^2*r^2)] + A_1r^2 + A_2r^4 + A_3r^6 + A_4r^8 + A_5r^{10}$$

dans laquelle :
"k" est une constante de conicité,
"A1", "A2", "A3", "A4", "A5" sont des constantes d'ajustement du coefficient de conicité en fonction de la position,
"z" est la forme de la surface,
"r" est le rayon au centre, et
"C" est le rayon de courbure.

La face arrière diffractive de la lentille L6 permet de réduire le nombre de lentilles nécessaire à la réalisation de l'objectif 30. Dans le présent mode de réalisation, elle permet par exemple d'éviter la prévision d'au moins trois lentilles complexes supplémentaires. Elle est déterminée au moyen d'une formule du type :

$$\varphi(r) = \alpha 1 \ (r/R0)^2 + \alpha 2 \ (r/R0)^4$$

dans laquelle :
"r" est la distance par rapport au centre de la lentille d'un point considéré, se trouvant à la surface de la lentille,
α1 et α2 sont des constantes définissant le déphasage de la surface d'onde,
"R0" est une constante permettant de normaliser r, et
"φ" est le déphasage introduit par la surface diffractive au point considéré.

Les lentilles en PMMA L1, L4 et L6 sont fabriquées grâce à un procédé dit de "diamond turning" bien connu de l'homme de l'art, qui consiste à fraiser la surface des lentilles en suivant un maillage de points.

L'angle solide de propagation des rayons lumineux dans chaque lentille est repéré sur la figure 15 par des traits noirs. Les rayons lumineux traversent le groupe optique L1, L2, L3, passent à travers l'apodiseur L4, L5, L6, L7 tout en étant diaphragmés par D1.

La détermination des paramètres définissant les faces asphériques mentionnées ci-dessus, la formule du réseau de diffraction de la lentille L6, le calcul des diamètres des lentilles et des distances entre les lentilles, sont à la portée de l'homme de l'art en utilisant les outils classiques de conception de lentille assistée par ordinateur.

Second mode de réalisation

La figure 18 représente schématiquement un objectif 40 non linéaire utilisant un miroir déformant. L'objectif 40 comprend en entrée un groupe optique divergent constitué par exemple par les trois lentilles L1, L2, L3 décrites ci-dessus, définissant l'angle de champ de l'objectif. En regard du groupe optique se trouve un miroir plan M1 qui renvoie le faisceau lumineux sur un miroir déformant M2 de forme concave asphérique. Le faisceau réfléchi par le miroir M2 est envoyé sur un capteur d'image 43.

Dans un tel mode de réalisation, les irrégularités de sphéricité que présente la partie concave du miroir déterminent la fonction de répartition angulaire Fd recherchée pour l'application visée (déformation au centre, sur les bords...). Le résultat obtenu est équivalent à celui du système optique décrit plus haut. L'obtention de la fonction de répartition Fd est à la portée de l'homme de l'art grâce aux outils de conception de lentilles assistée par ordinateur qui permettent, outre la conception de lentilles, la conception et la mise au point de surfaces réfléchissantes.

Une variante de ce mode de réalisation consiste à prévoir plusieurs miroirs déformants afin de combiner des déformations ou de simplifier des déformations complexes en caractérisant un type de déformation par miroir, ce qui présente l'avantage de faciliter les travaux d'ingénierie.

Encore une autre variante consiste à utiliser un ou plusieurs miroirs déformables pour réaliser un système optique dit "adaptatif". Les miroirs déformables comprennent une couche de micro-pistons piézoélectriques couverte par une couche réfléchissante. Chaque piston piézoélectrique est activé individuellement, de sorte que l'on contrôle les déformations du miroir en plusieurs points afin d'obtenir la forme désirée. Un tel dispositif peut être piloté par un circuit intégré comprenant dans sa mémoire plusieurs configurations des micro-pistons, afin d'obtenir une fonction de répartition Fd ajustable en fonction de l'utilisation visée, ce qui évite de prévoir plusieurs objectifs.

De façon générale, les optiques adaptatives sont en soi connues de l'homme de l'art et utilisées dans les télescopes de haute précision afin de corriger les défauts optiques des lentilles ou des déformations atmosphériques. Les miroirs déformables existent également dans le domaine des disques optiques, si l'on se réfère par exemple aux brevets US 5 880 896 et US 57 45 278.

Ainsi, ici également, on utilise des moyens en soi connus à des fins différentes, non pas pour corriger une lentille mais pour obtenir au contraire une fonction de répartition angulaire non linéaire.

La présente invention est bien entendu susceptible de diverses autres variantes de réalisation. Notamment, bien que l'on ait décrit dans ce qui précède des objectifs panoramiques non linéaires à symétrie axiale relativement à l'axe optique, dans lesquels la position d'un point image est uniquement fonction de l'angle de champ relativement à cet axe du point objet correspondant (ce qui donne une distribution de points en cercles concentriques, comme vu plus haut), il entre dans le cadre de la présente invention de prévoir des objectifs dont la non-linéarité n'est pas symétrique relativement à l'axe optique, de sorte que les parties dilatées de l'image peuvent, dans ce cas, n'être pas calées sur le centre de l'image.

ANNEXE (faisant partie intégrante de la description)

Tableau 1

S1 - Acquisition - Prise d'une image panoramique au moyen d'un appareil photographique numérique ou d'une caméra vidéo numérique équipé(e) d'un objectif panoramique ayant fonction de répartition Fd non linéaire
S2 - Transfert du fichier image dans un calculateur - Transfert du fichier image (disque image) dans un micro-ordinateur - Stockage en mémoire de masse (optionnel)
S3 -Linéarisation du disque image - Transfert des points image du disque image initial dans un second disque image virtuel comprenant plus de points image que le disque image initial, au moyen de la fonction Fd^{-1} ⇒ Obtention d'un disque image linéaire
S4 - Numérisation - Transfert des points image du second disque image dans un système d'axes OXYZ en coordonnées sphériques ⇒ Obtention d'une image panoramique en demi-sphère
S5 - Affichage Interactif - Détermination des points image d'un secteur d'image à afficher - Affichage du secteur d'image sur une fenêtre d'affichage - Détection des actions de l'utilisateur sur un pointeur d'écran ou tout autre moyen de commande, - Détection des actions de l'utilisateur sur des touches de grossissement d'image, - Modification du secteur affiché (glissement du secteur d'image affiché à la surface de la demi-sphère et/ou rétrécissement/dilatation du secteur d'image affiché)

Tableau 2

S1 - Acquisition - Prise d'une image panoramique au moyen d'un appareil photographique numérique ou d'une caméra vidéo numérique équipé(e) d'un objectif panoramique ayant fonction de répartition Fd non linéaire
S2 - Transfert du fichier image dans un calculateur - Transfert du fichier image (disque image) dans un micro-ordinateur - Stockage en mémoire de masse (optionnel)
S3' - Affichage interactif avec correction implicite de la non-linéarité de l'image initiale A - Détermination de la couleur des points E(i, j) d'un secteur d'image à afficher à partir des points p(pu, pv) du disque image : 1 - détermination des coordonnées Ex, Ey, Ez dans le repère OXYZ de chaque point E(i, j) du secteur à afficher, 2 - détermination des coordonnées Px, Py, Pz de points P de la demi-sphère correspondant aux points E(i, j), 3 - calcul des coordonnées, dans le repère O'UV du disque image, de points p(pu, pv) correspondants aux points P de la demi-sphère, au moyen de la fonction Fd, B - Présentation du secteur d'image dans une fenêtre d'affichage, C - Détection des actions de l'utilisateur sur un pointeur d'écran ou tout autre moyen de commande D - Détection des actions de l'utilisateur sur des touches de grossissement E - Modification du secteur d'image affiché (déplacement et/ou rétrécissement/grossissement du secteur d'image).

REVENDICATIONS

1. Procédé de capture d'une image panoramique numérique, par projection d'un panorama (PM) sur un capteur d'image (17) au moyen d'un objectif panoramique, caractérisé en ce que l'objectif panoramique (18, 30, 40) présente une fonction (Fd, Fd1, Fd2, Fd3) de répartition de points image (a"-d") qui n'est pas linéaire relativement à l'angle de champ de points objet (a-d) du panorama, la fonction de répartition présentant une divergence maximale d'au moins ±10% par rapport à une fonction de répartition linéaire (Fdc), de telle sorte que l'image panoramique obtenue présente au moins une zone (C10, C20) sensiblement dilatée et au moins une zone (C30-C90) sensiblement comprimée.

2. Procédé selon la revendication 1, dans lequel l'objectif présente une fonction de répartition non linéaire qui est symétrique relativement à l'axe optique de l'objectif, la position d'un point image relativement au centre de l'image étant fonction de l'angle de champ du point objet correspondant.

3. Procédé selon l'une des revendications 1 et 2, dans lequel l'objectif dilate le centre de l'image et comprime les bords de l'image.

4. Procédé selon l'une des revendications 1 et 2, dans lequel l'objectif dilate les bords de l'image et comprime le centre de l'image.

5. Procédé selon l'une des revendications 1 et 2, dans lequel l'objectif comprime le centre de l'image et les bords de l'image, et dilate une zone intermédiaire de l'image se trouvant entre le centre et les bords de l'image.

6. Procédé selon l'une des revendications 1 à 5, dans lequel l'objectif (30) comprend un jeu de lentilles (L4-L7) formant apodiseur.

REVENDICATIONS

1. Procédé de capture d'une image panoramique numérique, par projection d'un panorama (PM) sur un capteur d'image (17) au moyen d'un objectif panoramique, caractérisé en ce que l'objectif panoramique (18, 30, 40) comprend un jeu de lentilles (L4-L7) formant apodiseur et comportant au moins une lentille asphérique (L4, L6) et au moins une lentille diffractive (L6), agencées pour présenter une fonction (Fd, Fd1, Fd2, Fd3) de répartition de points image (a"-d") qui n'est pas linéaire relativement à l'angle de champ de points objet (a-d) du panorama, la fonction de répartition présentant une divergence maximale d'au moins ±10% par rapport à une fonction de répartition linéaire (Fdc), de telle sorte que l'image panoramique obtenue présente au moins une zone (C10, C20) sensiblement dilatée et au moins une zone (C30-C90) sensiblement comprimée.

2. Procédé selon la revendication 1, dans lequel l'objectif présente une fonction de répartition non linéaire qui est symétrique relativement à l'axe optique de l'objectif, la position d'un point image relativement au centre de l'image étant fonction de l'angle de champ du point objet correspondant.

3. Procédé selon l'une des revendications 1 et 2, dans lequel l'objectif dilate le centre de l'image et comprime les bords de l'image.

4. Procédé selon l'une des revendications 1 et 2, dans lequel l'objectif dilate les bords de l'image et comprime le centre de l'image.

5. Procédé selon l'une des revendications 1 et 2, dans lequel l'objectif comprime le centre de l'image et les bords de l'image, et dilate une zone intermédiaire de l'image se trouvant entre le centre et les bords de l'image.

7. Procédé selon la revendication 6, dans lequel le jeu de lentilles formant apodiseur comprend au moins une lentille asphérique (L4, L6).

8. Procédé selon la revendication 6, dans lequel le jeu de lentilles formant apodiseur comprend au moins une lentille diffractive (L6).

9. Procédé selon l'une des revendications 1 à 5, dans lequel l'objectif (40) comprend un jeu de miroirs (M1, M2) comprenant au moins un miroir déformant (M2).

10. Procédé d'affichage d'une image panoramique initiale (Img1) obtenue conformément au procédé selon l'une des revendications 1 à 9, caractérisé en ce qu'il comprend une étape (S3, S3') de correction de la non-linéarité de l'image initiale, faite au moyen d'une fonction (Fd^{-1}) réciproque de la fonction (Fd) de répartition non linéaire de l'objectif ou au moyen de la fonction (Fd) de répartition non linéaire.

11. Procédé selon la revendication 10, dans lequel l'étape de correction (S3) comprend une étape de transformation de l'image initiale (Img1) en une image numérique corrigée (Img1) comprenant un nombre de points image supérieur au nombre de pixels que comprend le capteur d'image (17).

12. Procédé selon la revendication 11, comprenant :
- une étape de calcul, au moyen de la fonction réciproque de la fonction de répartition, de la taille (R2) de l'image corrigée, de manière que l'image corrigée ait une résolution équivalente à la zone la plus dilatée de l'image initiale, et
- une étape consistant à parcourir chaque point image de l'image corrigée, à chercher la position d'un point jumeau du point image sur l'image initiale et à attribuer la couleur du point jumeau au point image de l'image corrigée

6. Procédé selon l'une des revendications 1 à 5, dans lequel l'objectif (40) comprend un jeu de miroirs (M1, M2) comprenant au moins un miroir déformant (M2).

7. Procédé d'affichage d'une image panoramique initiale (Img1) obtenue conformément au procédé selon l'une des revendications 1 à 6, comprenant une étape (S3, S3') de correction de la non-linéarité de l'image initiale, faite au moyen d'une fonction (Fd^{-1}) réciproque de la fonction (Fd) de répartition non linéaire de l'objectif ou au moyen de la fonction (Fd) de répartition non linéaire, caractérisé en ce que l'étape de correction (S3) comprend une étape de transformation de l'image initiale (Img1) en une image numérique corrigée (Img1) comprenant un nombre de points image supérieur au nombre de pixels que comprend le capteur d'image (17).

8. Procédé selon la revendication 7, comprenant :
- une étape de calcul, au moyen de la fonction réciproque de la fonction de répartition, de la taille (R2) de l'image corrigée, de manière que l'image corrigée ait une résolution équivalente à la zone la plus dilatée de l'image initiale, et
- une étape consistant à parcourir chaque point image de l'image corrigée, à chercher la position d'un point jumeau du point image sur l'image initiale et à attribuer la couleur du point jumeau au point image de l'image corrigée

9. Procédé selon l'une des revendications 7 et 8, dans lequel l'image initiale et l'image corrigée comprennent un disque image (ID1, ID2).

10. Procédé selon l'une des revendications 7 à 9, comprenant une étape (S4) de transfert des points image de l'image corrigée dans un espace à trois dimensions et une étape de présentation sur un moyen d'affichage d'un secteur de l'image à trois dimensions obtenue.

13. Procédé selon l'une des revendications 11 et 12, dans lequel l'image initiale et l'image corrigée comprennent un disque image (ID1, ID2).

14. Procédé selon l'une des revendications 11 à 13, comprenant une étape (S4) de transfert des points image de l'image corrigée dans un espace à trois dimensions et une étape de présentation sur un moyen d'affichage d'un secteur de l'image à trois dimensions obtenue.

15. Procédé selon la revendication 10, comprenant une étape (S3') de détermination de la couleur de points image d'une fenêtre d'affichage (DW), par projection des points image de la fenêtre d'affichage sur l'image initiale au moyen de la fonction de répartition non linéaire, et attribution à chaque point image de la fenêtre d'affichage de la couleur d'un point image le plus proche sur l'image initiale.

16. Procédé selon la revendication 15, dans lequel la projection des points image de la fenêtre d'affichage sur l'image initiale comprend :
- une étape de projection des points image de la fenêtre d'affichage sur une sphère (HS) ou une portion de sphère,
- une étape de détermination de l'angle (α) par rapport au centre (O) de la sphère ou de la portion de sphère de chaque point image projeté, et
- une étape de projection sur l'image initiale de chaque point image projeté sur la sphère ou la portion de sphère, la projection étant faite au moyen de la fonction de répartition non linéaire (Fd) en considérant l'angle de champ (α) que présente chaque point à projeter par rapport au centre de la sphère ou de la portion de sphère.

17. Objectif panoramique (30, 40) comprenant des moyens optiques pour projeter un panorama dans un plan image de l'objectif, caractérisé en ce qu'il présente une fonction (Fd, Fd1, Fd2, Fd3) de répartition de points image (a"-d")

11. Procédé selon la revendication 7, comprenant une étape (S3') de détermination de la couleur de points image d'une fenêtre d'affichage (DW), par projection des points image de la fenêtre d'affichage sur l'image initiale au moyen de la fonction de répartition non linéaire, et attribution à chaque point image de la fenêtre d'affichage de la couleur d'un point image le plus proche sur l'image initiale.

12. Procédé selon la revendication 11, dans lequel la projection des points image de la fenêtre d'affichage sur l'image initiale comprend :

- une étape de projection des points image de la fenêtre d'affichage sur une sphère (HS) ou une portion de sphère,
- une étape de détermination de l'angle (α) par rapport au centre (O) de la sphère ou de la portion de sphère de chaque point image projeté, et
- une étape de projection sur l'image initiale de chaque point image projeté sur la sphère ou la portion de sphère, la projection étant faite au moyen de la fonction de répartition non linéaire (Fd) en considérant l'angle de champ (α) que présente chaque point à projeter par rapport au centre de la sphère ou de la portion de sphère.

13. Objectif panoramique (30, 40) comprenant des moyens optiques pour projeter un panorama dans un plan image de l'objectif, caractérisé en ce qu'il comprend un jeu de lentilles (L4-L6) formant apodiseur et comportant au moins une lentille asphérique (L4, L6) et au moins une lentille diffractive (L6), et en ce qu'il présente une fonction (Fd, Fd1, Fd2, Fd3) de répartition de points image (a"-d") qui n'est pas linéaire relativement à l'angle de champ de points objet (a-d) du panorama, la fonction de répartition présentant une divergence maximale d'au moins ±10% par rapport à une fonction de répartition linéaire (Fdc), de telle sorte qu'une image panoramique obtenue au moyen de l'objectif comprend au moins une zone (C10, C20) sensiblement dilatée et au moins une zone (C30-C90) sensiblement comprimée.

qui n'est pas linéaire relativement à l'angle de champ de points objet (a-d) du panorama, la fonction de répartition présentant une divergence maximale d'au moins ±10% par rapport à une fonction de répartition linéaire (Fdc), de telle sorte qu'une image panoramique obtenue au moyen de l'objectif comprend au moins une zone (C10, C20) sensiblement dilatée et au moins une zone (C30-C90) sensiblement comprimée.

18. Objectif panoramique selon la revendication 17, présentant une fonction de répartition non linéaire qui est symétrique relativement à l'axe optique de l'objectif, la position d'un point image relativement au centre d'une image obtenue étant fonction de l'angle de champ du point objet correspondant.

19. Objectif panoramique selon l'une des revendications 17 et 18, caractérisé en ce qu'il dilate le centre d'une image et comprime les bords de l'image.

20. Objectif panoramique selon l'une des revendications 17 et 18, caractérisé en ce qu'il dilate les bords d'une image et comprime le centre de l'image.

21. Objectif panoramique selon l'une des revendications 17 et 18, caractérisé en ce qu'il comprime le centre d'une image et les bords de l'image, et dilate une zone intermédiaire de l'image se trouvant entre le centre et les bords de l'image.

22. Objectif panoramique selon l'une des revendications 17 à 21, comprenant un jeu de lentilles (L4-L6) formant apodiseur.

23. Objectif panoramique selon la revendication 22, dans lequel le jeu de lentilles formant apodiseur comprend au moins une lentille asphérique (L4, L6).

14. Objectif panoramique selon la revendication 13, présentant une fonction de répartition non linéaire qui est symétrique relativement à l'axe optique de l'objectif, la position d'un point image relativement au centre d'une image obtenue étant fonction de l'angle de champ du point objet correspondant.

15. Objectif panoramique selon l'une des revendications 13 et 14, caractérisé en ce qu'il dilate le centre d'une image et comprime les bords de l'image.

16. Objectif panoramique selon l'une des revendications 13 et 14, caractérisé en ce qu'il dilate les bords d'une image et comprime le centre de l'image.

17. Objectif panoramique selon l'une des revendications 13 et 14, caractérisé en ce qu'il comprime le centre d'une image et les bords de l'image, et dilate une zone intermédiaire de l'image se trouvant entre le centre et les bords de l'image.

18. Objectif panoramique selon l'une des revendications 13 à 17, comprenant des lentilles en polyméthacrylate.

19. Objectif panoramique selon l'une des revendications 13 à 17, comprenant un jeu de miroirs (M1, M2) comprenant au moins un miroir déformant (M2).

24. Objectif panoramique selon l'une des revendications 22 et 23, dans lequel le jeu de lentilles formant apodiseur comprend au moins une lentille diffractive (L6).

25. Objectif panoramique selon l'une des revendications 22 à 24, comprenant des lentilles en polyméthacrylate.

26. Objectif panoramique selon l'une des revendications 17 à 21, comprenant un jeu de miroirs (M1, M2) comprenant au moins un miroir déformant (M2).

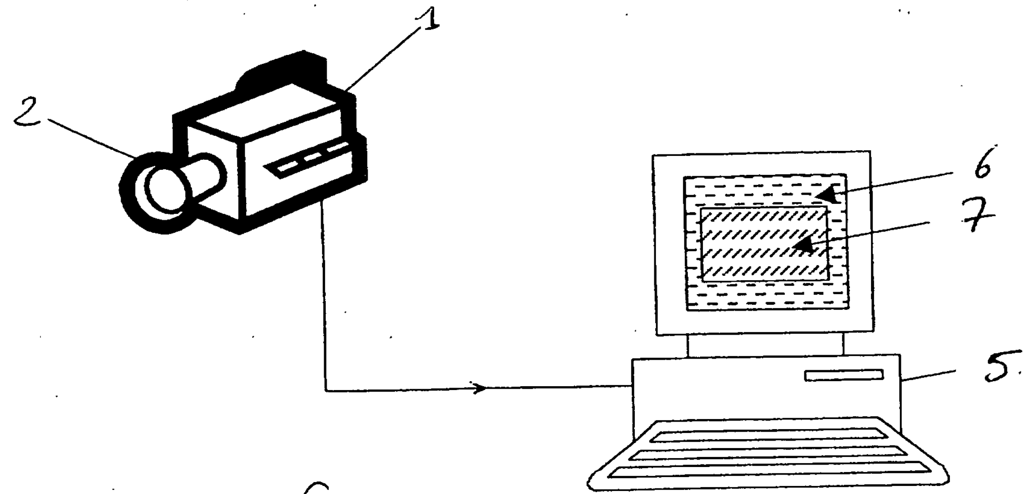


Fig. 1

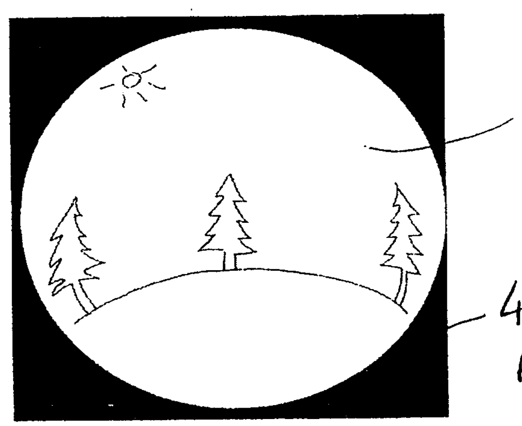


Fig. 2

DESSINS PROVISOIRES

Dessins Définitifs en cours d'élaboration

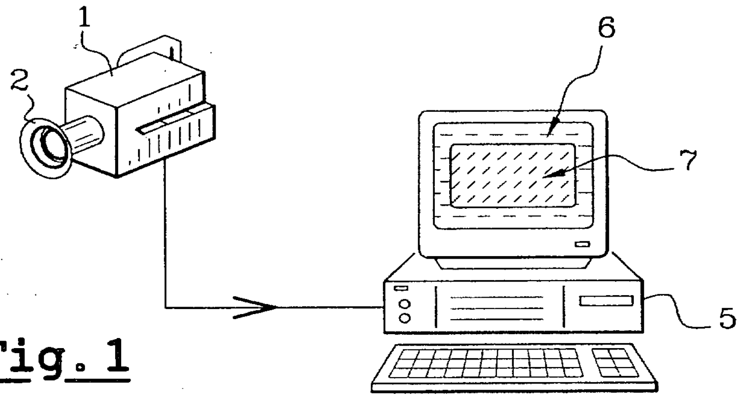


Fig. 1

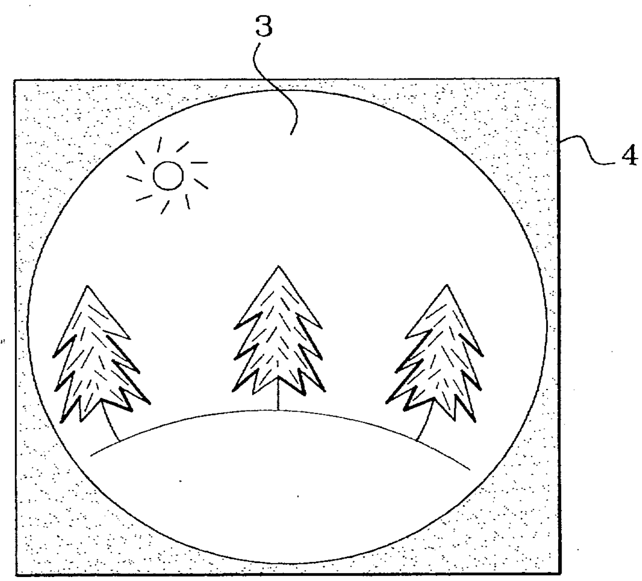


Fig. 2

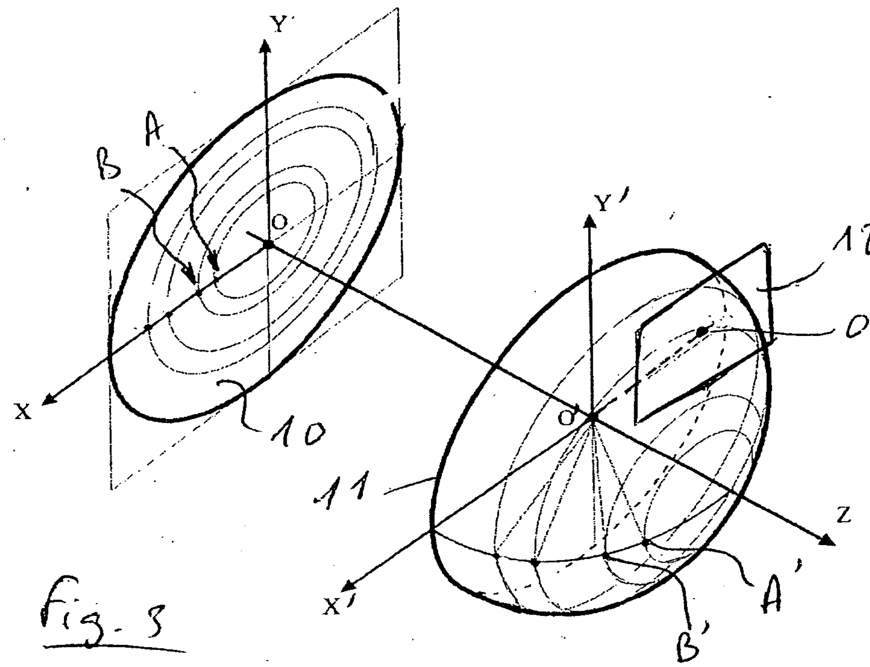


Fig. 3

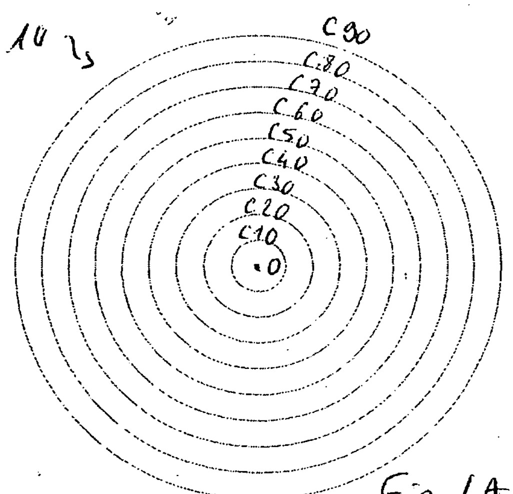


Fig. 4A

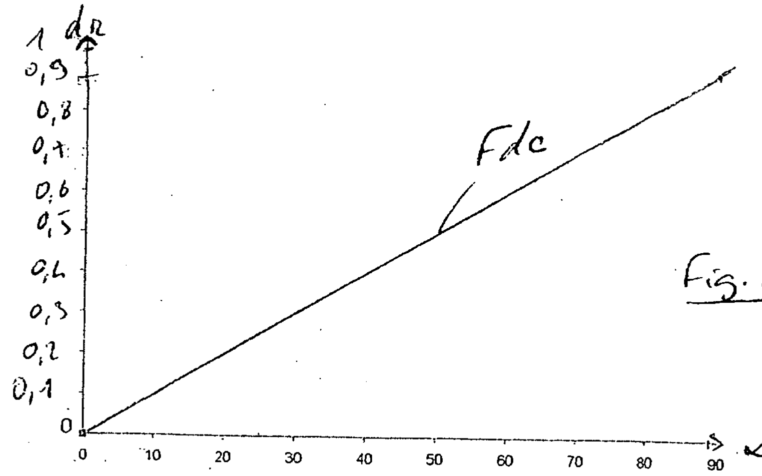


Fig. 4B

DESSINS PROVISOIRES

Dessins Définitifs en cours d'élaboration

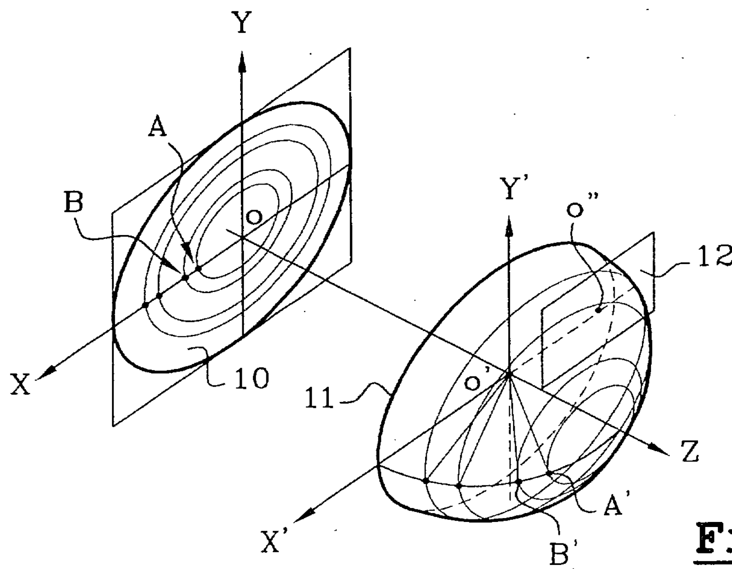


Fig. 3

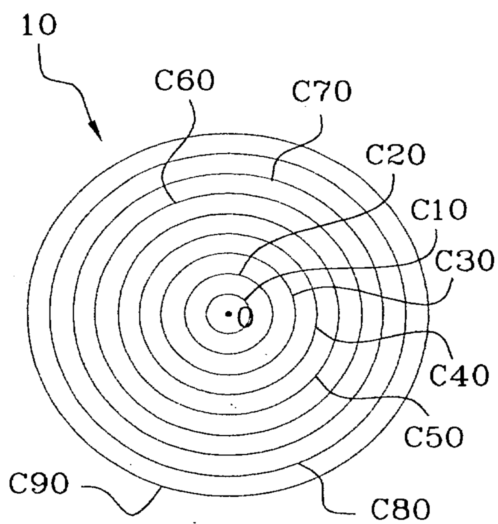


Fig. 4A

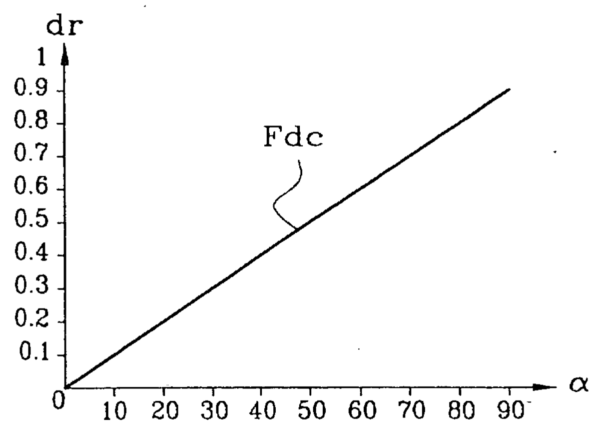


Fig. 4B

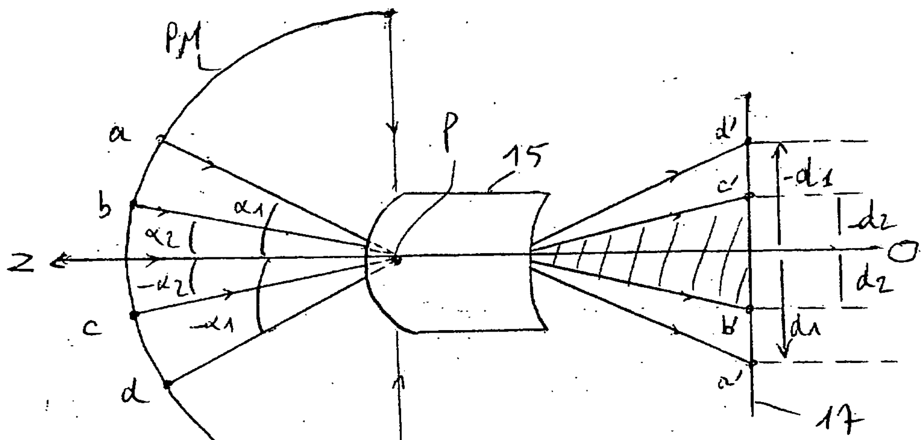


Fig.5

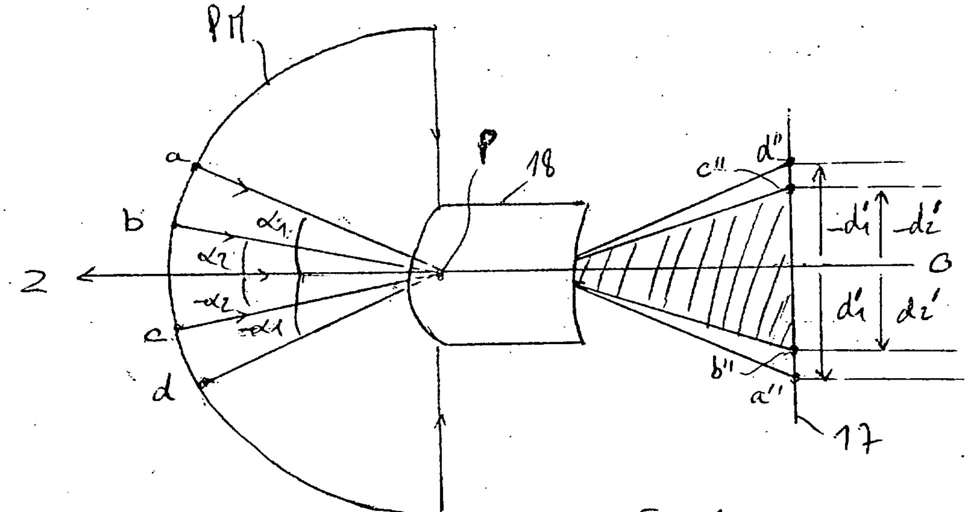


Fig.6

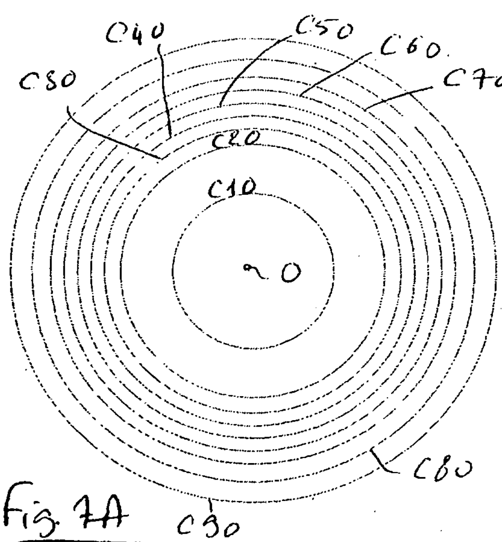


Fig.7A

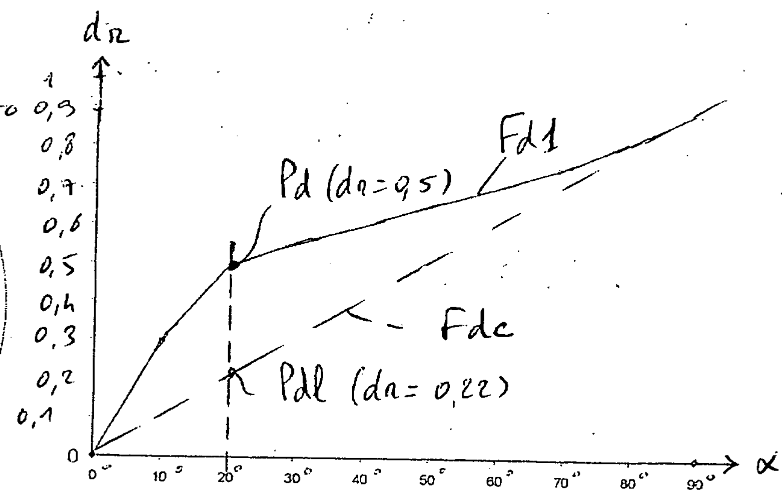


Fig.7B

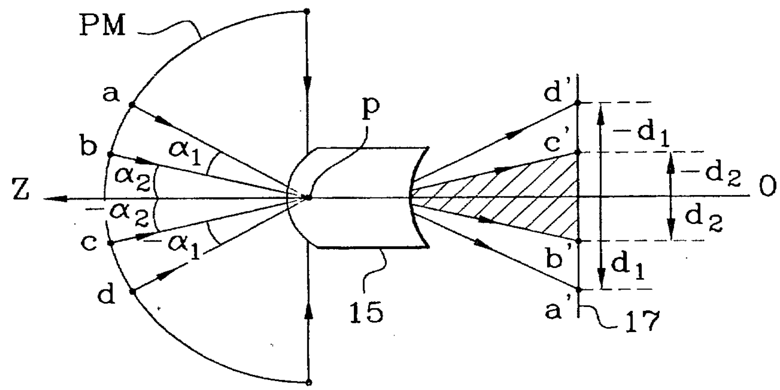


Fig. 5

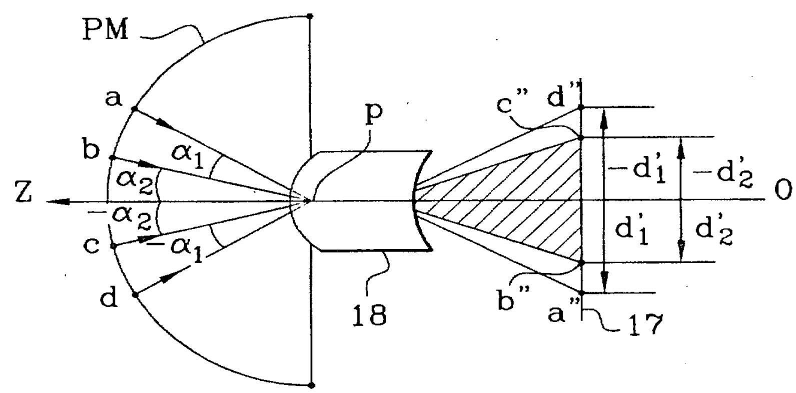


Fig. 6

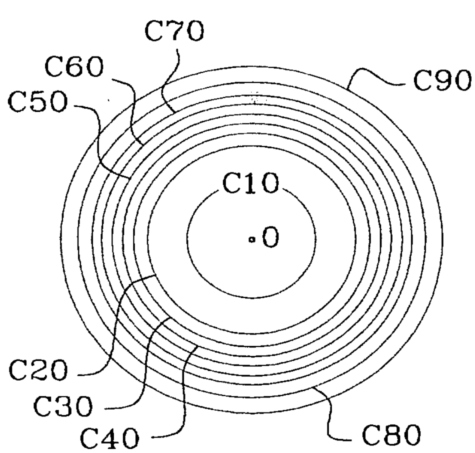


Fig. 7A

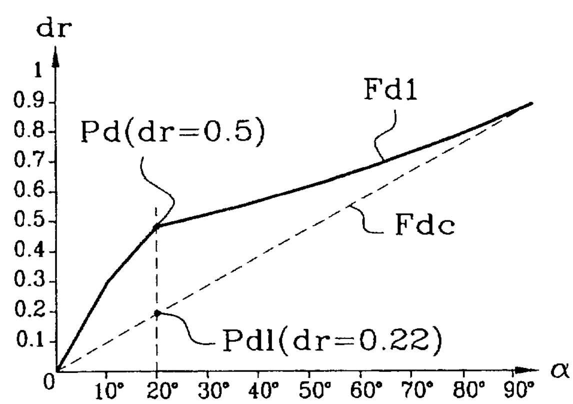


Fig. 7B

100 137 FR

4/11

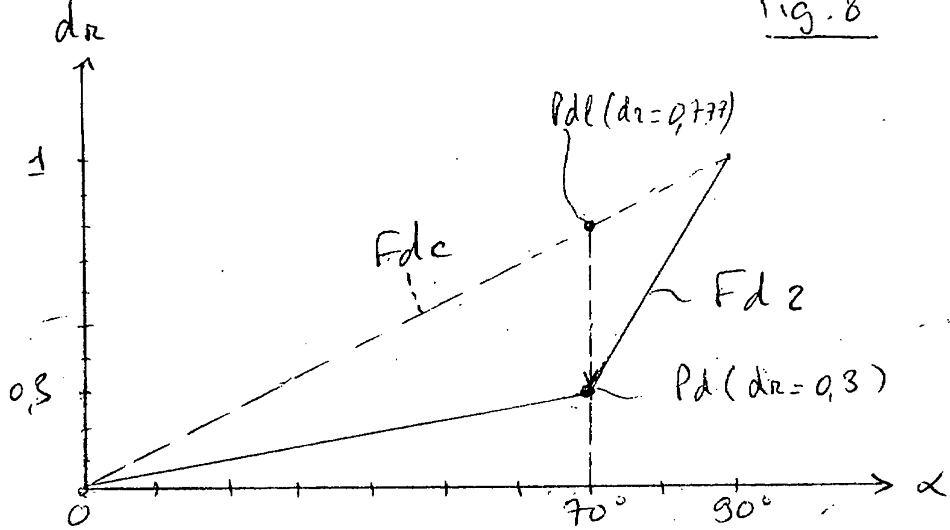


Fig. 8

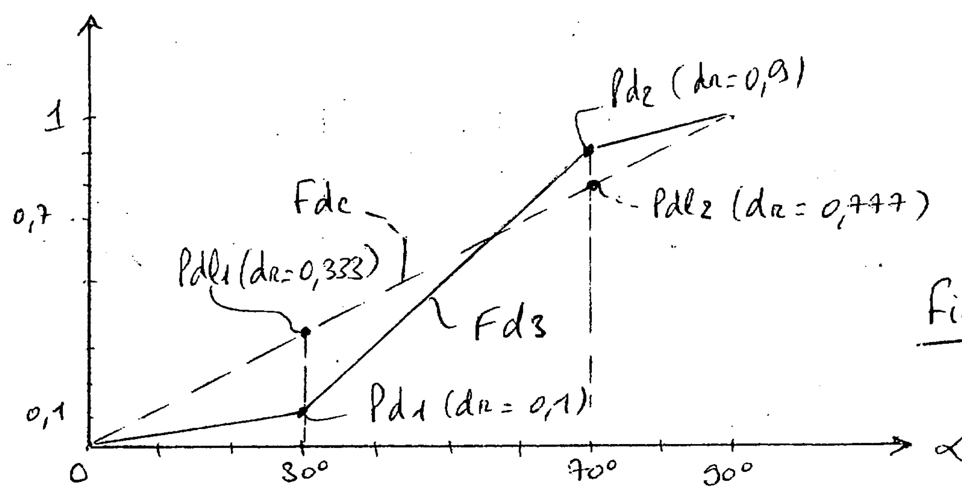
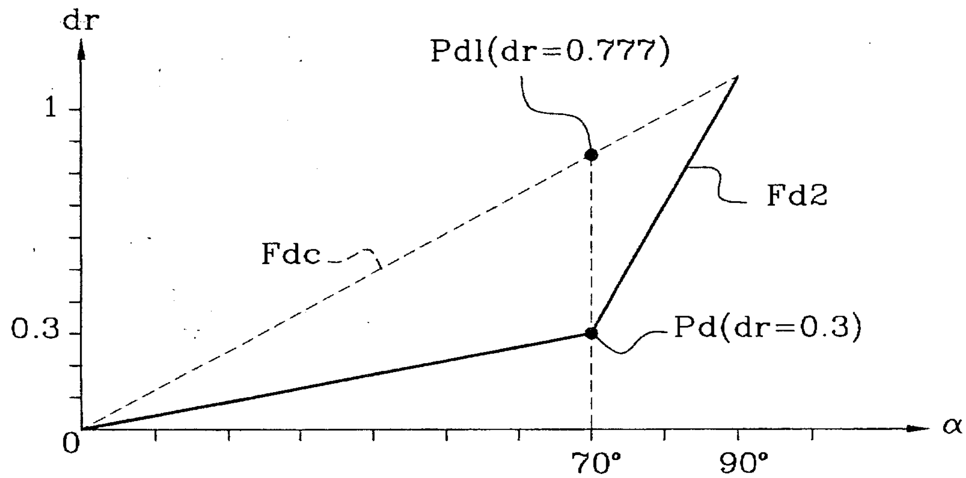


Fig. 9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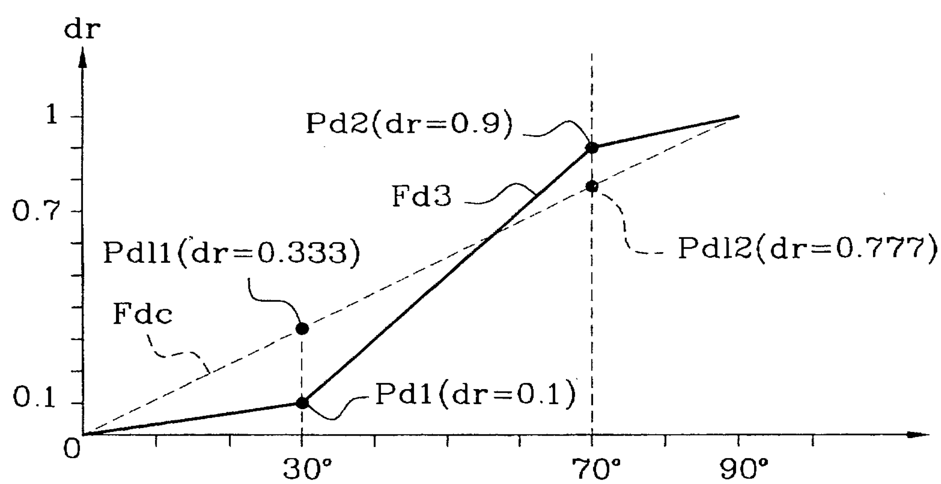
1
Fd2
Fdc
0.3
Pd(dr=0.3)
0
70°
90°
α

Fig. 8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Pdl1(dr=0.333)
Pdl2(dr=0.777)
Fdc
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Pd1(dr=0.1)
0
30°
70°
90°
α

Fig. 9

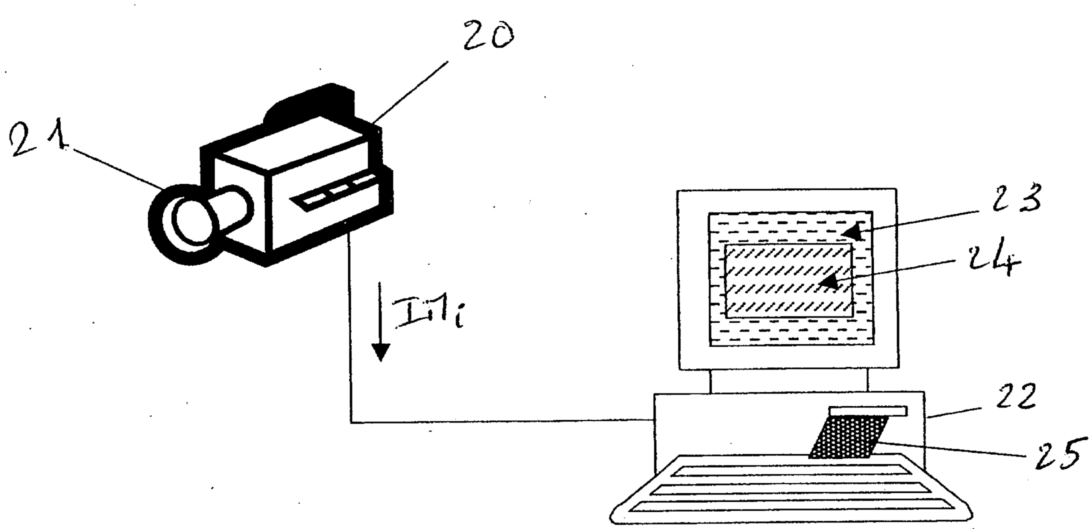


Fig. 10

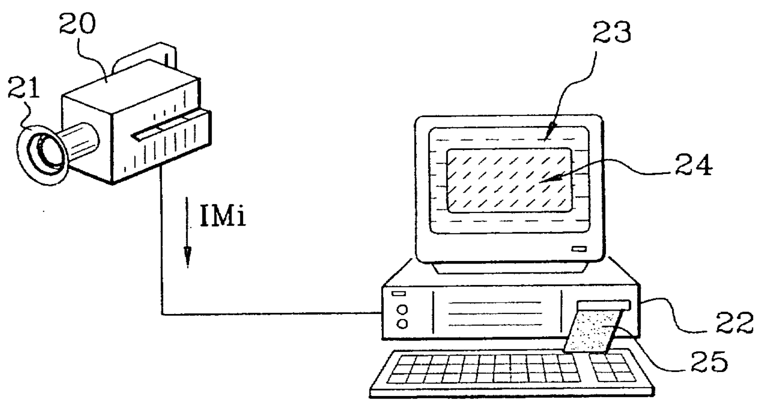
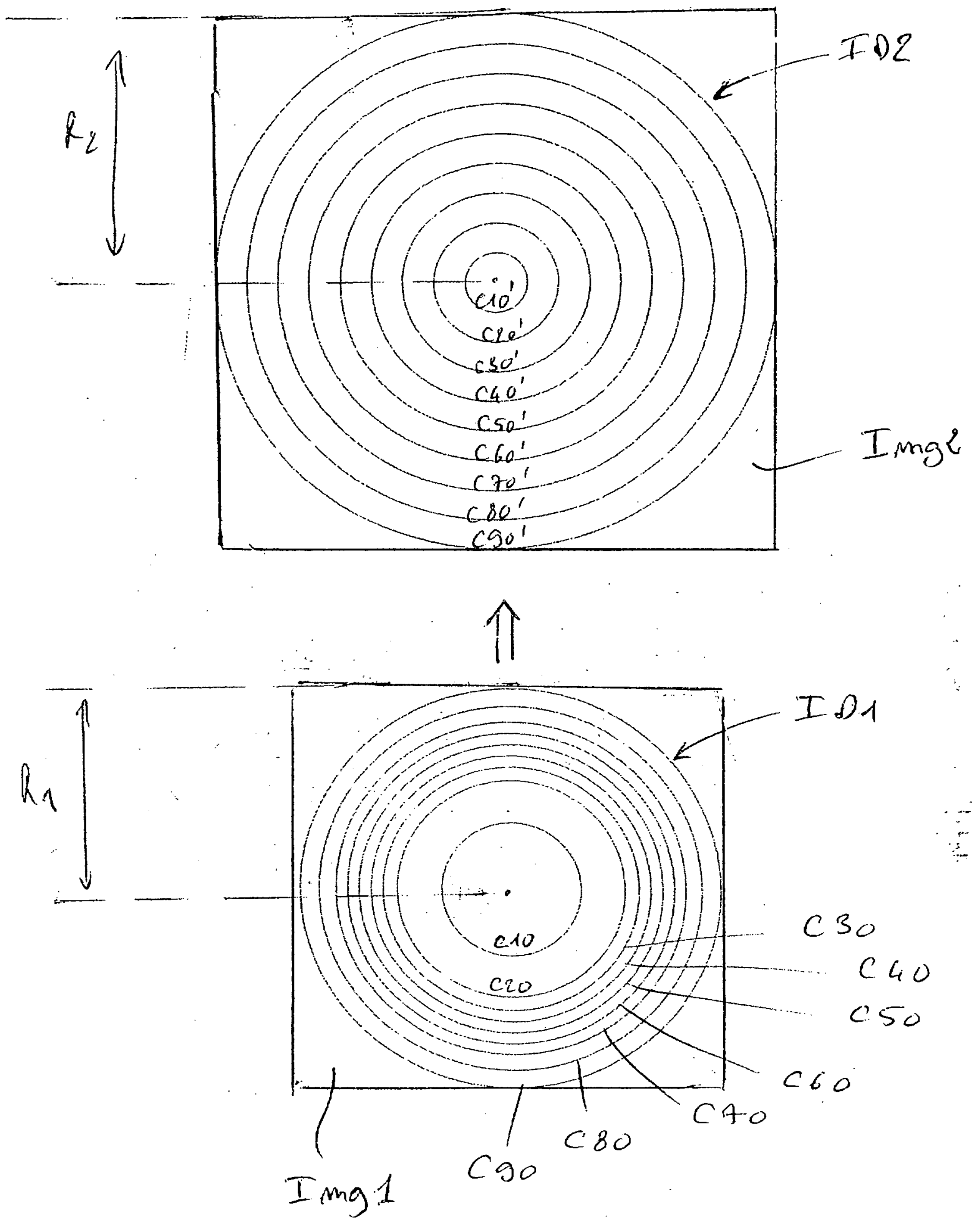


Fig. 10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Img2
ID1
R1
C10
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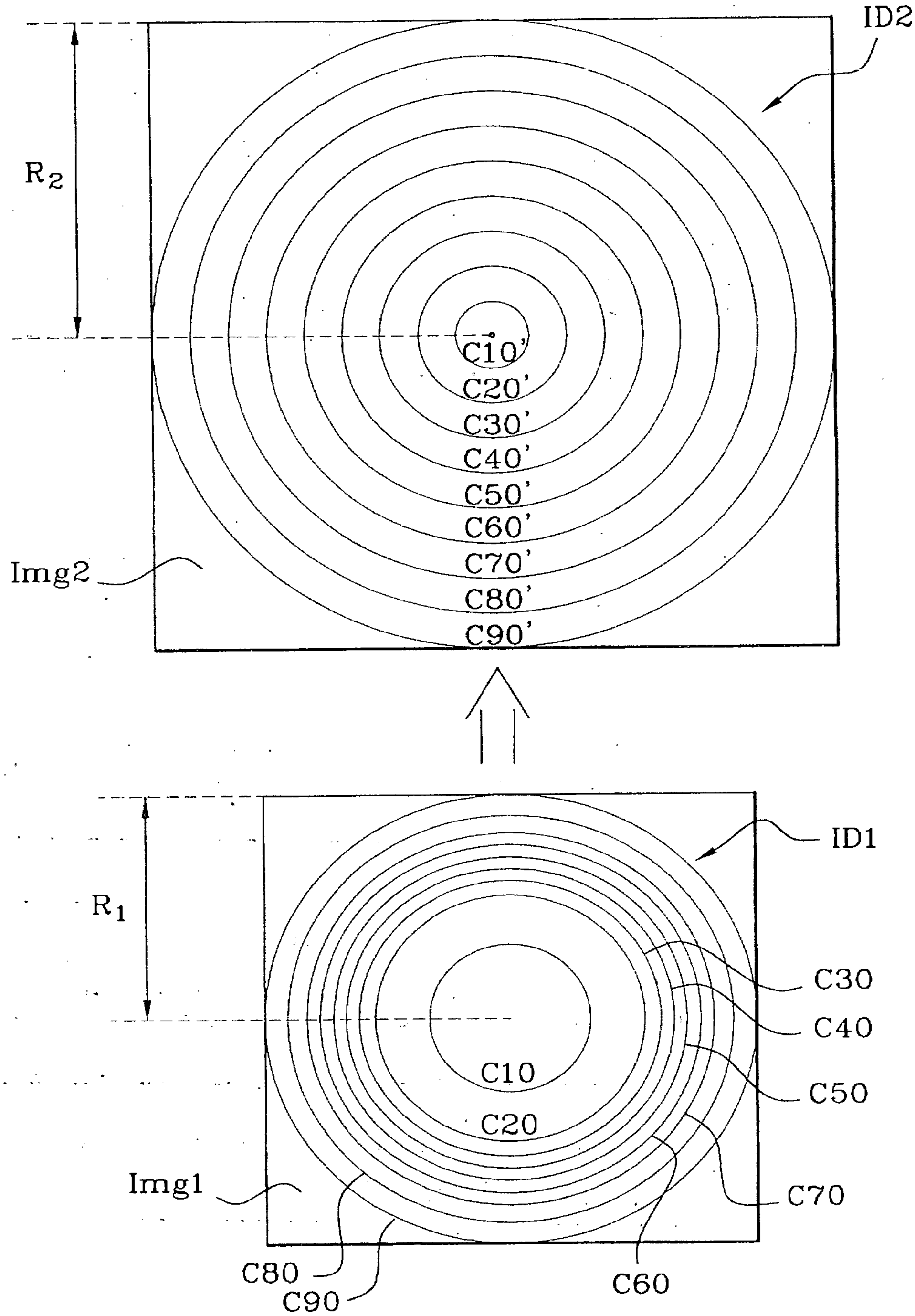
C40
C50
C60
C70
C80
C90
Img1

Fig. 11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R1
C30
C40
C50
C10
C20
C70
Img1
C80
C90
C60

Fig. 11

Fig. 12

S1 - Acquisition

- Prise d'une image panoramique au moyen d'un appareil photographique numérique ou d'une caméra vidéo numérique équipé(e) d'un objectif panoramique ayant fonction de répartition Fd non linéaire

S2 - Transfert du fichier image dans un calculateur

- Transfert du fichier image (disque image) dans un micro-ordinateur
- Stockage en mémoire de masse (optionnel)

S3 -Linéarisation du disque image

- Transfert des points image du disque image initial dans un second disque image virtuel comprenant plus de points image que le disque image initial, au moyen de la fonction Fd^{-1}

⇒ Obtention d'un disque image linéaire

S4 - Numérisation

- Transfert des points images du second disque image dans un système d'axes OXYZ en coordonnées sphériques ⇒ Obtention d'une image panoramique en demi-sphère

S5 - Affichage Interactif

- Détermination des points image d'un secteur d'image à afficher
- Affichage du secteur d'image sur une fenêtre d'affichage
- Détection des actions de l'utilisateur sur un pointeur d'écran ou tout autre moyen de commande,
- Détection des actions de l'utilisateur sur des touches de grossissement d'image,
- Modification du secteur affiché (glissement du secteur d'image affiché à la surface de la demi-sphère et/ou rétrécissement/dilatation du secteur d'image affiché)

Fig. 12

S1 - Acquisition

- Prise d'une image panoramique au moyen d'un appareil photographique numérique ou d'une caméra vidéo numérique équipé(e) d'un objectif panoramique ayant fonction de répartition Fd non linéaire

S2 - Transfert du fichier image dans un calculateur

- Transfert du fichier image (disque image) dans un micro-ordinateur
- Stockage en mémoire de masse (optionnel)

S3 -Linéarisation du disque image

- Transfert des points image du disque image initial dans un second disque image virtuel comprenant plus de points image que le disque image initial, au moyen de la fonction Fd^{-1}

Obtention d'un disque image linéaire

S4 - Numérisation

- Transfert des points images du second disque image dans un système d'axes OXYZ en coordonnées sphériques Obtention d'une image panoramique en demi-sphère

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- Affichage du secteur d'image sur une fenêtre d'affichage
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- Détection des actions de l'utilisateur sur des touches de grossissement d'image,
- Modification du secteur affiché (glissement du secteur d'image affiché à la surface de la demi-sphère et/ou rétrécissement/dilatation du secteur d'image affiché)

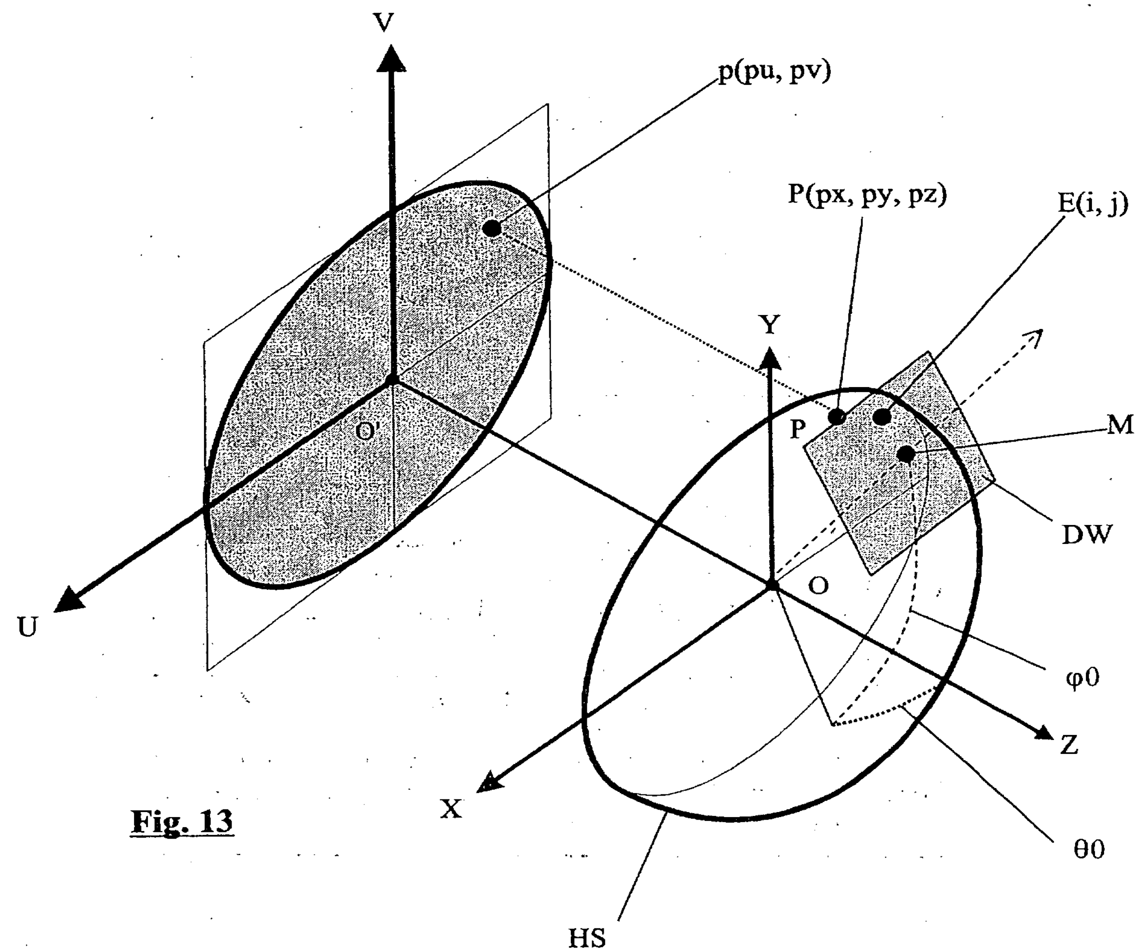


Fig. 13

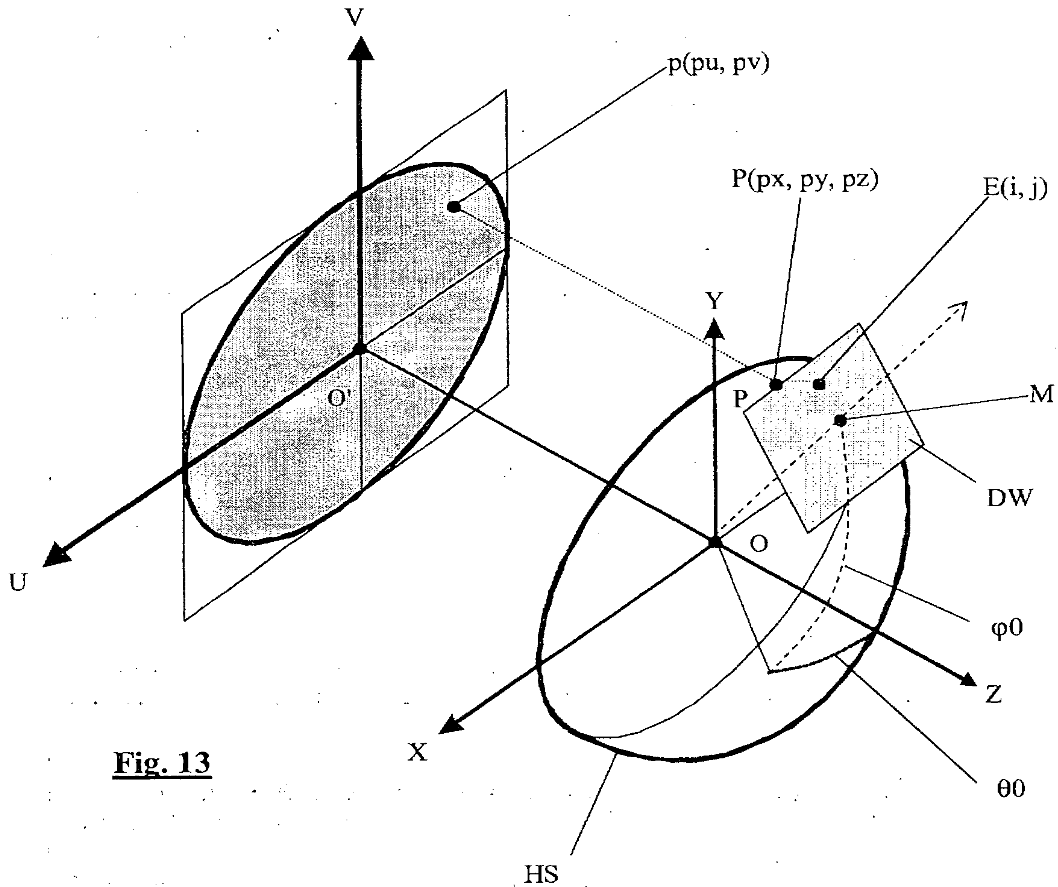


Fig. 13

Fig. 14

S1 - Acquisition

- Prise d'une image panoramique au moyen d'un appareil photographique numérique ou d'une caméra vidéo numérique équipé(e) d'un objectif panoramique ayant fonction de répartition Fd non linéaire

S2 - Transfert du fichier image dans un calculateur

- Transfert du fichier image (disque image) dans un micro-ordinateur
- Stockage en mémoire de masse (optionnel)

S3' - Affichage interactif avec correction implicite de la non-linéarité de l'image initiale

A - Détermination de la couleur des points E(i, j) d'un secteur d'image à afficher à partir des points p(pu, pv) du disque image :

1- détermination des coordonnées Ex, Ey, Ez dans le repère OXYZ de chaque point E(i, j) du secteur à afficher,
2- détermination des coordonnées Px, Py, Pz de points P de la demi-sphère correspondant aux points E(i, j),
3- calcul des coordonnées, dans le repère O'UV du disque image, des points p(pu, pv) correspondants aux points P de la demi-sphère, au moyen de la fonction Fd,

B - Présentation du secteur d'image dans une fenêtre d'affichage,
C - Détection des actions de l'utilisateur sur un pointeur d'écran ou tout autre moyen de commande
D - Détection des actions de l'utilisateur sur des touches de grossissement
E - Modification du secteur d'image affiché (déplacement et/ou rétrécissement/grossissement du secteur d'image)

Fig. 14

S1 - Acquisition

- Prise d'une image panoramique au moyen d'un appareil photographique numérique ou d'une caméra vidéo numérique équipé(e) d'un objectif panoramique ayant fonction de répartition Fd non linéaire

S2 - Transfert du fichier image dans un calculateur

- Transfert du fichier image (disque image) dans un micro-ordinateur
- Stockage en mémoire de masse (optionnel)

S3' - Affichage interactif avec correction implicite de la non-linéarité de l'image initiale

A - Détermination de la couleur des points E(i, j) d'un secteur d'image à afficher à partir des points p(pu, pv) du disque image :

1- détermination des coordonnées Ex, Ey, Ez dans le repère OXYZ de chaque point E(i, j) du secteur à afficher,
2- détermination des coordonnées Px, Py, Pz de points P de la demi-sphère correspondant aux points E(i, j),
3- calcul des coordonnées, dans le repère O'UV du disque image, des points p(pu, pv) correspondants aux points P de la demi-sphère, au moyen de la fonction Fd,

B - Présentation du secteur d'image dans une fenêtre d'affichage,
C - Détection des actions de l'utilisateur sur un pointeur d'écran ou tout autre moyen de commande
D - Détection des actions de l'utilisateur sur des touches de grossissement
E - Modification du secteur d'image affiché (déplacement et/ou rétrécissement/grossissement du secteur d'image)

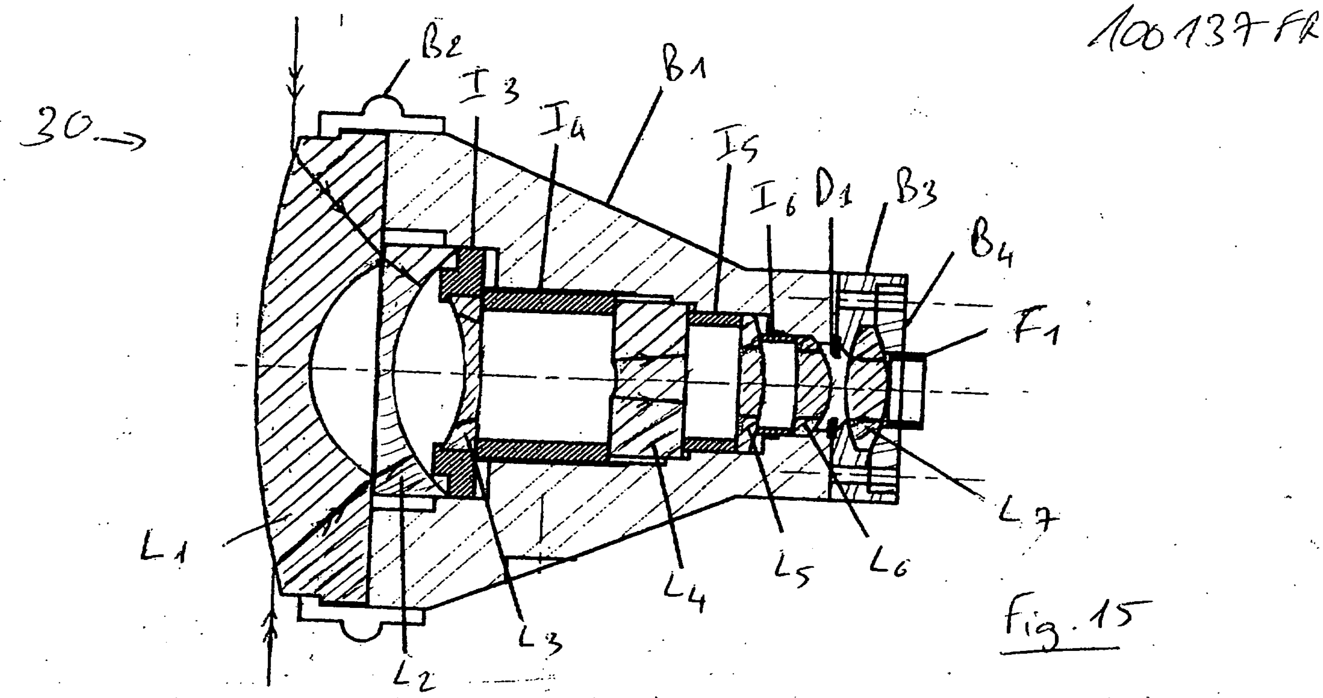


Fig. 15

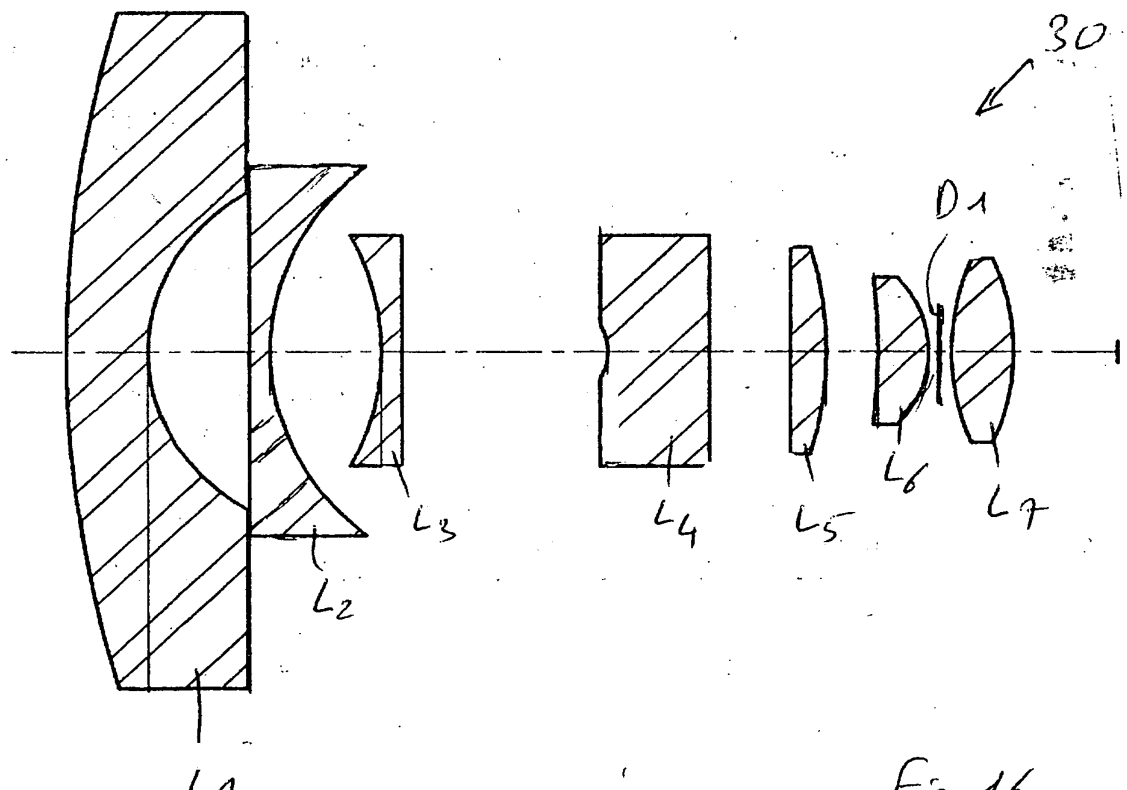
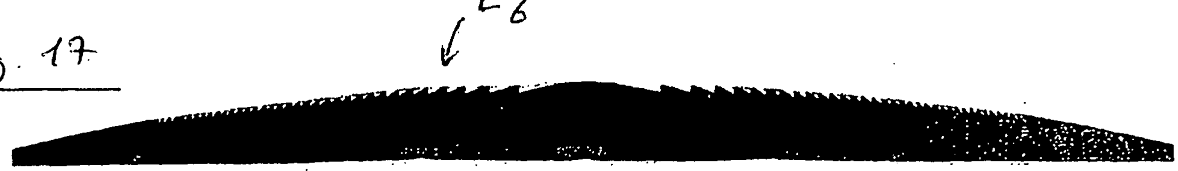


Fig. 16

Fig. 17



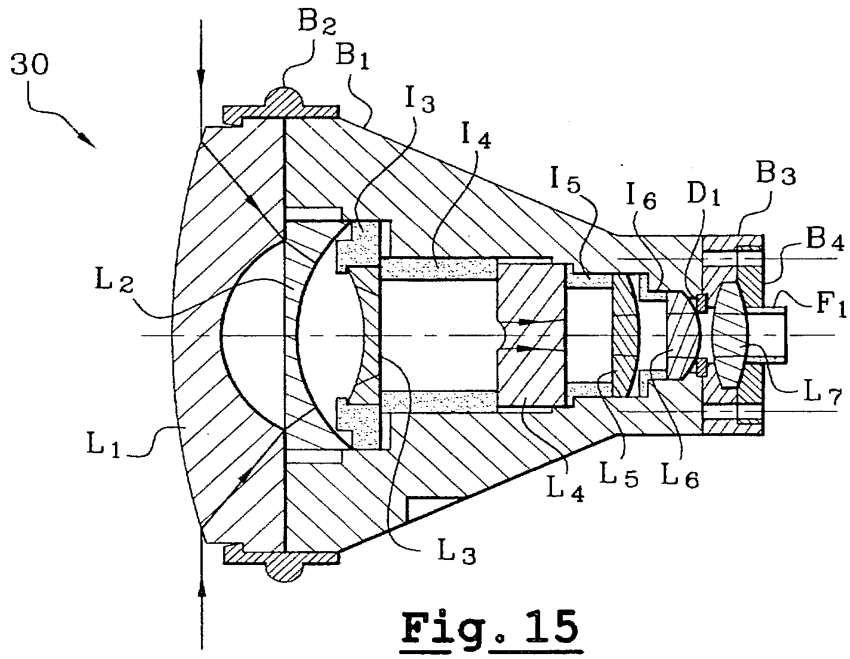


Fig. 15

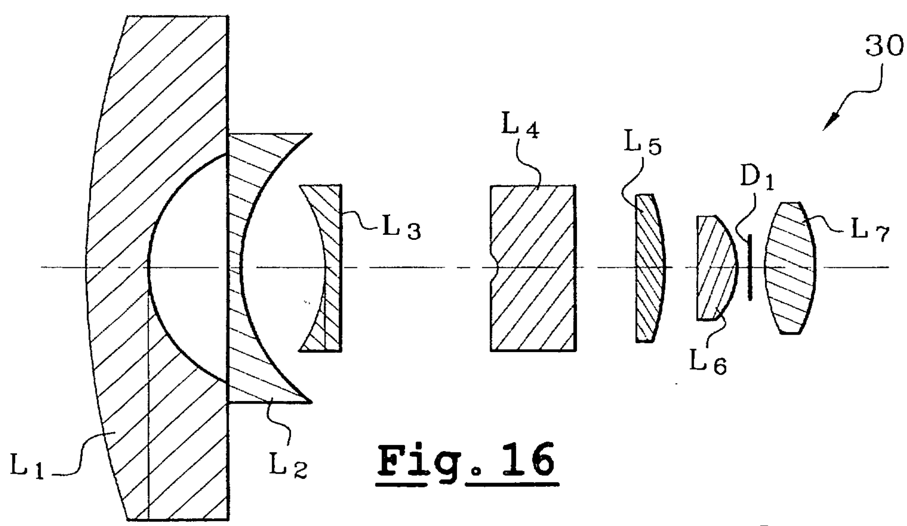


Fig. 16

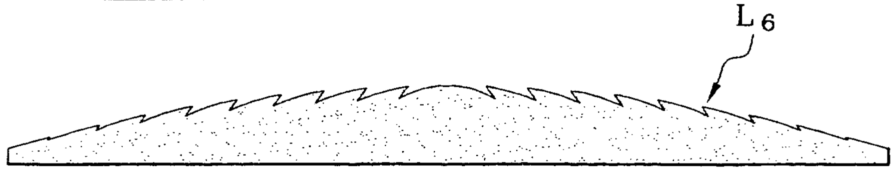


Fig. 17

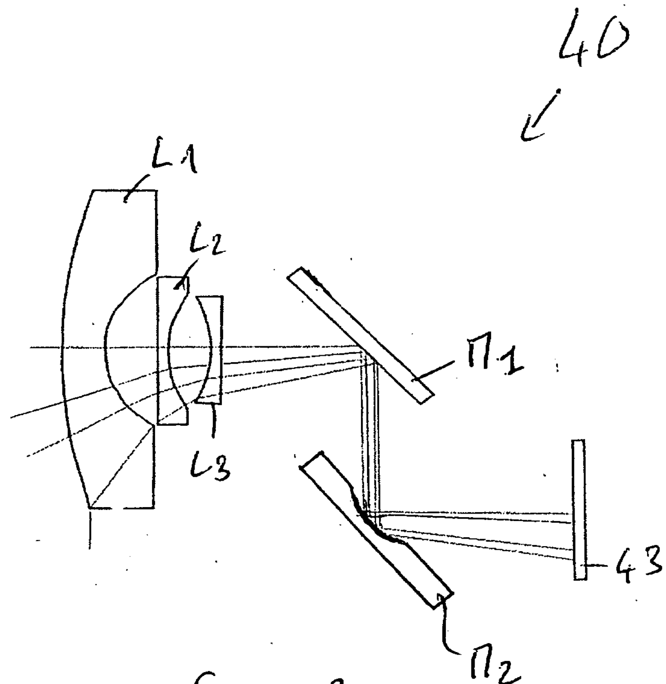


fig. 18

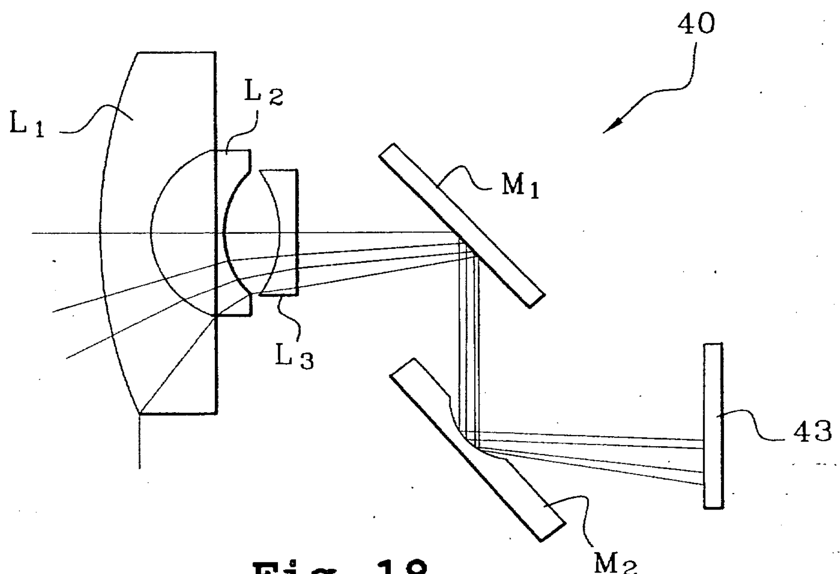


Fig. 18

reçue le 31/05/01

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Code de la propriété intellectuelle - Livre VI

cerfa N° 11 235*02

DÉSIGNATION D'INVENTEUR(S) Page N° 1../1..

(Si le demandeur n'est pas l'inventeur ou l'unique inventeur)

Cet imprimé est à remplir lisiblement à l'encre noire DB 113 W /260899

11 MAI 2001
13 INPI MARSEILLE

Vos références pour ce dossier *(facultatif)*	100137 FR
N° D'ENREGISTREMENT NATIONAL	0106261 — 01 06261

TITRE DE L'INVENTION (200 caractères ou espaces maximum)

Procédé d'obtention et d'affichage d'une image panoramique numérique à résolution variable

LE(S) DEMANDEUR(S) :

MARCHAND André
OMNIPAT
24, Place des Martyrs de la Résistance
13100 AIX EN PROVENCE

DESIGNE(NT) EN TANT QU'INVENTEUR(S) : (Indiquez en haut à droite «Page N° 1/1» S'il y a plus de trois inventeurs, utilisez un formulaire identique et numérotez chaque page en indiquant le nombre total de pages).

Nom		ARTONNE	
Prénoms		Jean-Claude	
Adresse	Rue	C/O OMNIPAT 24 Place des Martyrs de la Résistance	
	Code postal et ville	13100	AIX EN PROVENCE
Société d'appartenance *(facultatif)*			
Nom		MOUSTIER	
Prénoms		Christophe	
Adresse	Rue	C/O OMNIPAT 24 Place des Martyrs de la Résistance	
	Code postal et ville	13100	AIX EN PROVENCE
Société d'appartenance *(facultatif)*			
Nom		BLANC	
Prénoms		Benjamin	
Adresse	Rue	C/O OMNIPAT 24 Place des Martyrs de la Résistance	
	Code postal et ville	13100	AIX EN PROVENCE
Société d'appartenance *(facultatif)*			

DATE ET SIGNATURE(S) DU (DES) DEMANDEUR(S) OU DU MANDATAIRE (Nom et qualité du signataire) Aix en Provence, le 10 mai 2001 MARCHAND André - CPI N° 95 0303 OMNIPAT	[signature]

	Type	L #	Hits	Search Text	DBs
1	BRS	L1	562	panoram$6 near4 (lens or objective)	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB
2	BRS	L2	39	compress$8 and expand$8 and 1	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB

10/706,513

	Type	L #	Hits	Search Text	DBs
1	BRS	L1	757	panoram$6 near6 (lens or objective)	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB
2	BRS	L2	45	(compress$8 and expand$8) and 1	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB
3	BRS	L3	1061214	linear or nonlinear	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB
4	BRS	L4	16	2 and 3	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB
5	BRS	L5	50	(compress$8 and expan$8) and 1	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB
6	BRS	L6	5	5 not 2	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB
7	BRS	L7	2	3 and 6	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB
8	BRS	L8	13	((compress$8 near6 (area or portion or zone)) and (expan$8 near6 (area or portion or zone))) and 1	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB
9	BRS	L9	409	digit$6 near6 panoram$8	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB
10	BRS	L11	9	9 and 10	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB
11	BRS	L10	13	1 and 8	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB

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000570 7590 09/14/2004

AKIN GUMP STRAUSS HAUER & FELD L.L.P.
ONE COMMERCE SQUARE
2005 MARKET STREET, SUITE 2200
PHILADELPHIA, PA 19103-7013

EXAMINER	
SUGARMAN, SCOTT J	
ART UNIT	**PAPER NUMBER**
2873	

DATE MAILED: 09/14/2004

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/706,513	11/12/2003	Jean-Claude Artonne	10000-25US (100137/US/WO)	8287

TITLE OF INVENTION: METHOD FOR CAPTURING AND DISPLAYING A VARIABLE RESOLUTION DIGITAL PANORAMIC IMAGE

APPLN. TYPE	SMALL ENTITY	ISSUE FEE	PUBLICATION FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	$1330	$300	$1630	12/14/2004

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PTOL 85 (Rev 09/04) Approved for use through 04/30/2007

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/706,513	11/12/2003	Jean-Claude Artonne	10000-25US (100137/US/WO)	8287

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nonprovisional	NO	$1330	$300	$1630	12/14/2004

EXAMINER	ART UNIT	CLASS-SUBCLASS
SUGARMAN, SCOTT J	2873	359-725000

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   - ❑ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.
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Please check the appropriate assignee category or categories (will not be printed on the patent) : ❑ Individual ❑ Corporation or other private group entity ❑ Governm

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- ❑ b. Applicant is no longer claiming SMALL ENTITY status. See 37 CFR 1.27(g)(2).

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Authorized Signature ____________ Date ____________

Typed or printed name ____________ Registration No. ____________

This collection of information is required by 37 CFR 1.311. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to proc an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to comp this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P Box 1450, Alexandria, Virginia 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 14 Alexandria, Virginia 22313-1450.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/706,513	11/12/2003	Jean-Claude Artonne	10000-25US (100137/US/WO)	8287

000570 7590 09/14/2004

AKIN GUMP STRAUSS HAUER & FELD L.L.P.
ONE COMMERCE SQUARE
2005 MARKET STREET, SUITE 2200
PHILADELPHIA, PA 19103-7013

EXAMINER	
SUGARMAN, SCOTT J	

ART UNIT	PAPER NUMBER
2873	

DATE MAILED: 09/14/2004

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)
(application filed on or after May 29, 2000)

The Patent Term Adjustment to date is 0 day(s). If the issue fee is paid on the date that is three months after t mailing date of this notice and the patent issues on the Tuesday before the date that is 28 weeks (six and a ha months) after the mailing date of this notice, the Patent Term Adjustment will be 0 day(s).

If a Continued Prosecution Application (CPA) was filed in the above-identified application, the filing date th determines Patent Term Adjustment is the filing date of the most recent CPA.

Applicant will be able to obtain more detailed information by accessing the Patent Application Information Retriev (PAIR) WEB site (http://pair.uspto.gov).

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office Patent Legal Administration at (703) 305-1383. Questions relating to issue and publication fee payments should directed to the Customer Service Center of the Office of Patent Publication at (703) 305-8283.

PTOL 85 (Rev 09/04) Approved for use through 04/30/2007

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/706,513	11/12/2003	Jean-Claude Artonne	10000-25US (100137/US/WO)	8287

000570 7590 09/14/2004

AKIN GUMP STRAUSS HAUER & FELD L.L.P.
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2005 MARKET STREET, SUITE 2200
PHILADELPHIA, PA 19103-7013

EXAMINER	
SUGARMAN, SCOTT J	
ART UNIT	PAPER NUMBER
2873	

DATE MAILED: 09/14/2004

Notice of Fee Increase on October 1, 2004

If a reply to a "Notice of Allowance and Fee(s) Due" is filed in the Office on or after October 1, 2004, then t amount due will be higher than that set forth in the "Notice of Allowance and Fee(s) Due" because some fees w increase effective October 1, 2004. See Revision of Patent Fees for Fiscal Year 2005; Final Rule, 69 Fed. Reg. 5260 52606 (May 10, 2004).

The current fee schedule is accessible from WEB site (http://www.uspto.gov/main/howtofees.htm).

If the fee paid is the amount shown on the "Notice of Allowance and Fee(s) Due" but not the correct amount in vie of the fee increase, a "Notice of Pay Balance of Issue Fee" will be mailed to applicant. In order to avoid processi delays associated with mailing of a "Notice of Pay Balance of Issue Fee," if the response to the Notice of Allowan is to be filed on or after October 1, 2004 (or mailed with a certificate of mailing on or after October 1, 2004), t issue fee paid should be the fee that is required at the time the fee is paid. See Manual of Patent Examining Procedu (MPEP), Section 1306 (Eighth Edition, Rev. 2, May 2004). If the issue fee was previously paid, and the response the "Notice of Allowance and Fee(s) Due" includes a request to apply a previously-paid issue fee to the issue f now due, then the difference between the issue fee amount at the time the response is filed and the previously-pa issue fee should be paid. See MPEP Section 1308.01.

Effective October 1, 2004, 37 CFR 1.18 is amended by revising paragraphs (a) through (c) to read as set forth below

Section 1.18 Patent post allowance (including issue) fees.

(a) Issue fee for issuing each original or reissue patent,
except a design or plant patent:
By a small entity (Sec. 1.27(a))...................... $685.00
By other than a small entity......................... $1,370.00
(b) Issue fee for issuing a design patent:
By a small entity (Sec. 1.27(a))...................... $245.00
By other than a small entity............................ $490.00
(c) Issue fee for issuing a plant patent:
By a small entity (Sec. 1.27(a))...................... $330.00
By other than a small entity............................ $660.00

Questions relating to issue and publication fee payments should be directed to the Customer Service Center of t Office of Patent Publication at (703) 305-8283.

PTOL 85 (Rev 09/04) Approved for use through 04/30/2007

Notice of Allowability	Application No. 10/706,513	Applicant(s) ARTONNE ET AL.	
	Examiner Scott J. Sugarman	Art Unit 2873	

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address--

All claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice of Allowance (PTOL-85) or other appropriate communication will be mailed in due course. **THIS NOTICE OF ALLOWABILITY IS NOT A GRANT OF PATENT RIGHTS.** This application is subject to withdrawal from issue at the initiative of the Office or upon petition by the applicant. See 37 CFR 1.313 and MPEP 1308.

1. ☐ This communication is responsive to _____.
2. ☒ The allowed claim(s) is/are _1-26_.
3. ☒ The drawings filed on _12 November 2003_ are accepted by the Examiner.
4. ☒ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).
   a) ☒ All b) ☐ Some* c) ☐ None of the:
   1. ☒ Certified copies of the priority documents have been received.
   2. ☐ Certified copies of the priority documents have been received in Application No. _____ .
   3. ☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

   * Certified copies not received: _____.

Applicant has THREE MONTHS FROM THE "MAILING DATE" of this communication to file a reply complying with the requirements noted below. Failure to timely comply will result in ABANDONMENT of this application.
THIS THREE-MONTH PERIOD IS NOT EXTENDABLE.

5. ☐ A SUBSTITUTE OATH OR DECLARATION must be submitted. Note the attached EXAMINER'S AMENDMENT or NOTICE OF INFORMAL PATENT APPLICATION (PTO-152) which gives reason(s) why the oath or declaration is deficient.
6. ☒ CORRECTED DRAWINGS (as "replacement sheets") must be submitted.
   (a) ☐ including changes required by the Notice of Draftsperson's Patent Drawing Review (PTO-948) attached
   1) ☐ hereto or 2) ☐ to Paper No./Mail Date _____.
   (b) ☒ including changes required by the attached Examiner's ~~Amendment~~/ Comment or in the Office action of Paper No./Mail Date herewith.

   Identifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the drawings in the front (not the back) of each sheet. Replacement sheet(s) should be labeled as such in the header according to 37 CFR 1.121(d).
7. ☐ DEPOSIT OF and/or INFORMATION about the deposit of BIOLOGICAL MATERIAL must be submitted. Note the attached Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

Attachment(s)

1. ☒ Notice of References Cited (PTO-892)
2. ☐ Notice of Draftperson's Patent Drawing Review (PTO-948)
3. ☒ Information Disclosure Statements (PTO-1449 or PTO/SB/08), Paper No./Mail Date 11-12-03
4. ☐ Examiner's Comment Regarding Requirement for Deposit of Biological Material
5. ☐ Notice of Informal Patent Application (PTO-152)
6. ☐ Interview Summary (PTO-413), Paper No./Mail Date _____ .
7. ☒ Examiner's ~~Amendment~~/Comment
8. ☒ Examiner's Statement of Reasons for Allowance
9. ☐ Other _____.

DETAILED ACTION

Priority

Receipt is acknowledged of papers submitted under 35 U.S.C. 119(a)-(d), which papers have been placed of record in the file.

Examiner's Comments: Drawings

Figure 5 should be designated by a legend such as --Prior Art-- because only that which is old is illustrated. See MPEP § 608.02(g). Corrected drawings in compliance with 37 CFR 1.121(d) are required in reply to the Office action to avoid abandonment of the application. The replacement sheet(s) should be labeled "Replacement Sheet" in the page header (as per 37 CFR 1.121(d)) so as not to obstruct any portion of the drawing figures. If the changes are not accepted by the examiner, the applicant will be notified and informed of any required corrective action in the next Office action. The objection to the drawings will not be held in abeyance.

Allowable Subject Matter

Claims 1-26 are allowed.

The following is an examiner's statement of reasons for allowance:

The prior art taken either singularly or in combination fails to anticipate or fairly suggest the limitations of the independent claims, in such a manner that a rejection under 35 U.S.C. 102 or 103 would be proper. The prior art fails to teach a combination of all the claimed features as presented, for example, in independent claims 1 and 17, which include a panoramic objective lens having an image point distribution function that is not linear relative to the field angle of object points of the panorama, the distribution function having a maximum divergence of at least +/-10% compared to a linear distribution function, such that the panoramic image obtained has at least one substantially expanded zone and at least on substantially compressed zone.

Any comments considered necessary by applicant must be submitted no later than the payment of the issue fee and, to avoid processing delays, should preferably accompany the issue fee. Such submissions should be clearly labeled "Comments on Statement of Reasons for Allowance."

Conclusion

The prior art made of record and not relied upon is considered pertinent to applicant's disclosure. Charles (US 6,449,103) and (US 6,333,826) both teach a panoramic system, but do not teach the distinguishing limitations noted above. Note that Charles ('826) teaches that "...expansion of the image can be accomplished by adding pixels which repeat or interpolate the data of those immediately surrounding them..." and "...the expansion can be accompanied or replaced by progressive circumferential compression of the outer zones of the image..." (col. 45, lines 49-53). However, this is not accomplished with a lens having the distinguishing features.

Any inquiry concerning this communication or earlier communications from the examiner should be directed to Scott J. Sugarman whose telephone number is (571)272-2340.

The fax phone number for the organization where this application or proceeding is assigned is 703-872-9306.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free).

Scott J. Sugarman
Primary Examiner
Art Unit 2873

sjs
September 3, 2004

Form PTO/SB/08A	*Complete if Known*	
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	**Applicati n Number**	Not Yet Assigned
	Filing Dat	November 11, 2003
	First Named Invent r	Jean-Claude ARTONNE, et al.
(use as many sheets as necessary)	**Gr up Art Unit**	Not Yet Assigned
	Examin r Nam	Not Yet Assigned
Sheet 1 of 1	**Attorney Docket Number**	10000-25US (100137 US/WO)

U.S. PATENT DOCUMENTS

Exr Initials	U.S. Patent Document Number	Kind Code (if known)	Name of First Inventor of Cited Document	Date of Publication of Cited Document MM-YYYY
SJS	3,953,111		FISHER et al.	04-1976
SJS	5,880,896		ISHII et al.	03-1999
SJS	6,031,670		INOUE	02-2000

FOREIGN PATENT DOCUMENTS

Exr Initials	Foreign Patent Document Country Code	Number	Kind Code (if known)	Name of Applicant of Cited Document	Date of Publication of Cited Document MM-YYYY	T1
SJS	WO	00/42470	A1	The Australian National University	07-2000	X
SJS	EP	0 695 085	A1	International Business Machines Corporation	01-1996	X
SJS	EP	1 004 915	A1	Fit Corporation Rios Corporation	05-2000	X

OTHER PRIOR ART - NON PATENT LITERATURE DOCUMENTS

Exr Initials	Include Name of first Author (in CAPITAL LETTERS), title of the article (where appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), volume-issue number(s), page(s), date (in parentheses). If a book, also include publisher and city and/or county where published.	T1

Examiner Signature	S. J. Sugarman	Date Considered	9-2004

7086001 v1

Notice of References Cited	Application/Control No. 10/706,513	Applicant(s)/Patent Under Reexamination ARTONNE ET AL.	
	Examiner Scott J. Sugarman	Art Unit 2873	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-6,449,103 B1	09-2002	Charles, Jeffrey R.	359/725
*	B	US-6,333,826 B1	12-2001	Charles, Jeffrey R.	359/725
	C	US-			
	D	US-			
	E	US-			
	F	US-			
	G	US-			
	H	US-			
	I	US-			
	J	US-			
	K	US-			
	L	US-			
	M	US-			

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

U.S. Patent and Trademark Office
PTO-892 (Rev. 01-2001) **Notice of References Cited** Part of Paper No. 200409

Issue Classification	Application No. 10/706,513	Applicant(s) ARTONNE ET AL.
	Examiner Scott J. Sugarman	Art Unit 2873

ISSUE CLASSIFICATION

ORIGINAL		CROSS REFERENCE(S)							
CLASS	SUBCLASS	CLASS	SUBCLASS (ONE SUBCLASS PER BLOCK)						
359	725	359	718						

INTERNATIONAL CLASSIFICATION				
g	0	2	B	13/06
g	0	2	B	13/18
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				/

(Assistant Examiner) (Date)

[signature] 9/9/04
(Legal Instruments Examiner) (Date)

Scott J. Sugarman
Primary Examiner

[signature] 9/04
(Primary Examiner) (Date)

Total Claims Allowed: 26

O.G. Print Claim(s)	O.G. Print Fig.
17	11

☒ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original
1	1		31		61		91		121		151		181
2	2		32		62		92		122		152		182
3	3		33		63		93		123		153		183
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	29		59		89		119		149		179		209
	30		60		90		120		150		180		210

U.S. Patent and Trademark Office

Part of Paper No. 200409

Index of Claims

Application No.	Applicant(s)
10/706,513	ARTONNE ET AL.
Examiner	**Art Unit**
Scott J. Sugarman	2873

√	Rejected	–	(Through numeral) Cancelled	N	Non-Elected	A	Appeal
=	Allowed	+	Restricted	I	Interference	O	Objected

Claim		Date								
Final	Original	9/3/04								
1	1	=								
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BIBDATASHEET

Bib Data Sheet

CONFIRMATION NO. 8287

SERIAL NUMBER	FILING DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
10/706,513	11/12/2003 RULE	359	2873	10000-25US (100137/US/WO)

APPLICANTS

Jean-Claude Artonne, Montreal, CANADA;

Christophe Moustier, Marseille, FRANCE;
Benjamin Blanc, Montreal, CANADA;

** CONTINUING DATA *************************
This application is a CON of PCT/FR02/01588 05/10/2002

** FOREIGN APPLICATIONS ********************
FRANCE 01 06261 05/11/2001

IF REQUIRED, FOREIGN FILING LICENSE GRANTED
** 02/13/2004

	STATE OR COUNTRY	SHEETS DRAWING	TOTAL CLAIMS	INDEPENDENT CLAIMS
Foreign Priority claimed ☑ yes ☐ no 35 USC 119 (a-d) conditions met ☑ yes ☐ no ☐ Met after Allowance Verified and Acknowledged ______ Examiner's Signature Initials	CANADA	11	26	2

ADDRESS
000570
AKIN GUMP STRAUSS HAUER & FELD L.L.P.
ONE COMMERCE SQUARE
2005 MARKET STREET, SUITE 2200
PHILADELPHIA , PA
19103-7013

TITLE
Method for capturing and displaying a variable resolution digital panoramic image

FILING FEE RECEIVED		
1008	FEES: Authority has been given in Paper No. _________ to charge/credit DEPOSIT ACCOUNT No. _________ for following:	☐ All Fees ☐ 1.16 Fees (Filing) ☐ 1.17 Fees (Processing Ext. of time) ☐ 1.18 Fees (Issue) ☐ Other _______________

Search Notes

Application No.	Applicant(s)
10/706,513	ARTONNE ET AL.
Examiner	**Art Unit**
Scott J. Sugarman	2873

SEARCHED			
Class	Subclass	Date	Examiner
359	718, 719, 725, 728	9/3/2004	SJS

INTERFERENCE SEARCHED			
Class	Subclass	Date	Examiner
ABOVE TO DATE		9/3/2004	SJS

SEARCH NOTES (INCLUDING SEARCH STRATEGY)	DATE	EXMR
BRS EAST SEARCH ATTACHED	9/3/2004	SJS

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), to: Mail **Mail Stop ISSUE FEE, Commissioner for Patents, P.O. Box 1450, Alexandria, Virginia 22313-1450**

or Fax (703) 746-4000

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 5 should be completed wh appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Use Block 1 for any change of address)

000570 7590 09/14/2004

AKIN GUMP STRAUSS HAUER & FELD L.L.P.
ONE COMMERCE SQUARE
2005 MARKET STREET, SUITE 2200
PHILADELPHIA, PA 19103-7013

12/08/2004 SDENBOB2 00000016 10706513

01 FC:1501 1370.00 OP
02 FC:1504 300.00 OP
03 FC:8001 30.00 OP

Note: A certificate of mailing can only be used for domestic mailings of Fee(s) Transmittal. This certificate cannot be used for any other accompany papers. Each additional paper, such as an assignment or formal drawing, m have its own certificate of mailing or transmission.

Certificate of Mailing or Transmission

I hereby certify that this Fee(s) Transmittal is being deposited with the Un States Postal Service with sufficient postage for first class mail in an envel addressed to the Mail Stop ISSUE FEE address above, or being facsim transmitted to the USPTO (703) 746-4000, on the date indicated below.

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Donna Marks (Signat
12/6/04 (D

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/706,513	11/12/2003	Jean-Claude Artonne	10000-25US (100137/US/WO)	8287

TITLE OF INVENTION: METHOD FOR CAPTURING AND DISPLAYING A VARIABLE RESOLUTION DIGITAL PANORAMIC IMAGE

APPLN. TYPE	SMALL ENTITY	ISSUE FEE	PUBLICATION FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	~~$1330~~ $1370	$300	~~$1630~~ $1670	12/14/2004

EXAMINER	ART UNIT	CLASS-SUBCLASS
SUGARMAN, SCOTT J	2873	359-725000

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).
   - ☐ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.
   - ☐ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-02 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list
   (1) the names of up to 3 registered patent attorneys or agents OR, alternatively,
   (2) the name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.
   1. Akin Gump
   2. Strauss Hauer
   3. + Feld, LLP

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document has been filed recordation as set forth in 37 CFR 3.11. Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE: **6115187 Canada Inc.**

(B) RESIDENCE: (CITY and STATE OR COUNTRY): **Saint Laurent, Quebec, Canada**

Please check the appropriate assignee category or categories (will not be printed on the patent) : ☐ Individual ☒ Corporation or other private group entity ☐ Governm

4a. The following fee(s) are enclosed:
- ☒ Issue Fee
- ☒ Publication Fee (No small entity discount permitted)
- ☒ Advance Order - # of Copies 10

4b. Payment of Fee(s):
- ☒ A check in the amount of the fee(s) is enclosed.
- ☐ Payment by credit card. Form PTO-2038 is attached.
- ☒ The Director is hereby authorized by charge any discrepancy ~~the required fee(s), or credit any overpayment~~ Deposit Account Number 50-1017 (enclose an extra copy of this form). 010000-0025

5. **Change in Entity Status** (from status indicated above)
- ☐ a. Applicant claims SMALL ENTITY status. See 37 CFR 1.27.
- ☐ b. Applicant is no longer claiming SMALL ENTITY status. See 37 CFR 1.27(g)(2).

The Director of the USPTO is requested to apply the Issue Fee and Publication Fee (if any) or to re-apply any previously paid issue fee to the application identified above. NOTE: The Issue Fee and Publication Fee (if required) will not be accepted from anyone other than the applicant; a registered attorney or agent; or the assignee or other part interest as shown by the records of the United States Patent and Trademark Office.

Authorized Signature: John D. Simmons — Date: December 6, 2004

Typed or printed name: John D. Simmons — Registration No. 52,225

This collection of information is required by 37 CFR 1.311. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to proc an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to comp this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P Box 1450, Alexandria, Virginia 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 14 Alexandria, Virginia 22313-1450.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

I HEREBY CERTIFY THAT THIS CORRESPONDENCE IS BEING DEPOSITED WITH THE UNITED STATES POSTAL SERVICE AS FIRST CLASS MAIL IN AN ENVELOPE ADDRESSED TO: **COMMISSIONER FOR PATENTS, P.O. BOX 1450, ALEXANDRIA, VA 22313-1450** ON THE DATE INDICATED BELOW

BY Dora A. Marks DATE 12/6/04

MAIL STOP ISSUE FEE - DRAWINGS

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re:	Patent Application of Jean-Claude Artonne et al.	: **Attn: Official Draftsperson**
		: Group Art Unit 2873
Conf. No.:	8287	:
		: Allowed September 14, 2004
Appln. No.	10/706,513	:
Filed:	November 12, 2003	:
		: Attorney Docket
For:	METHOD FOR CAPTURING AND DISPLAYING A VARIABLE RSOLUTION DIGITAL PANORAMIC IMAGE	: No. 10000-25 (100137/US/WO)

TRANSMITTAL OF FORMAL DRAWINGS

In accordance with the Notice of Allowability accompanying the Notice of Allowance mailed September 14, 2004, enclosed is one (one) sheet of formal drawings, Figs. 5 through 7B, concerning the above-identified application.

It is respectfully submitted that the enclosed copies of formal drawings place this application in condition to be issued, the issue fee being paid concurrently herewith.

Respectfully submitted,

December 6, 2004
(Date)

By: John D. Simmons

JOHN D. SIMMONS
Registration No. 52,225
AKIN GUMP STRAUSS HAUER & FELD LLP
One Commerce Square
2005 Market Street, Suite 2200
Philadelphia, PA 19103-7013
Direct Dial: 215-965-1268
Facsimile: 215-965-1210
E-Mail: jsimmons@akingump.com

JDS:DCM
Enclosures

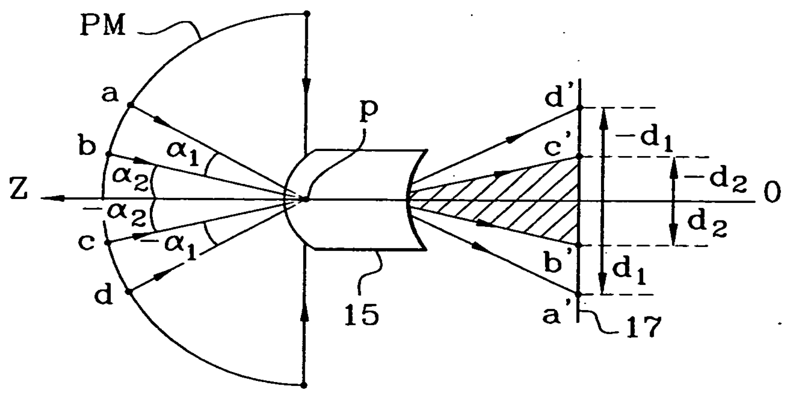

Fig. 5

PRIOR ART

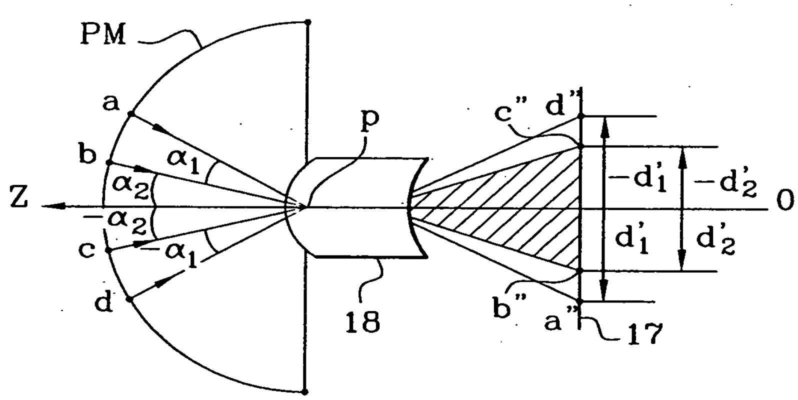

Fig. 6

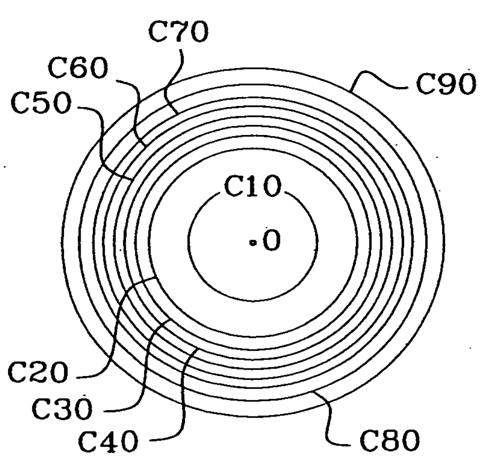

Fig. 7A

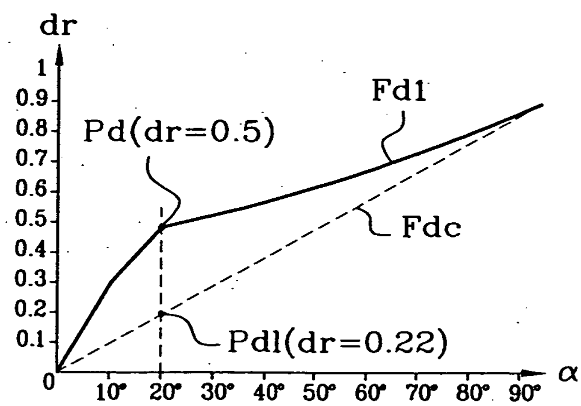

Fig. 7B

OIPE
MAR 2 5 2005

1FW Cof

I HEREBY CERTIFY THAT THIS CORRESPONDENCE IS BEING DEPOSITED WITH THE UNITED STATES POSTAL SERVICE AS FIRST CLASS MAIL IN AN ENVELOPE ADDRESSED TO: ATTN: DECISION AND CERTIFICATE OF CORRECTION BRANCH OF THE PATENT ISSUE DIVISION, COMMISSIONER FOR PATENTS, P.O. BOX 1450, ALEXANDRIA, VA 22313-1450, ON THE DATE INDICATED BELOW.

BY: Donna Marks DATE: 3/17/05

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re Patent of:	Jean-Claude Artonne et al.	
Patent No.:	6,844,990 B2	Issue Date: January 18, 2005
Appln. No.:	10/706,513	Filing Date: November 12, 2003
Title:	METHOD FOR CAPTURING AND DISPLAYING A VARIABLE RESOLUTION DIGITAL PANORAMIC IMAGE	Attorney Docket No.: 10000-25 (100137 US/WO)

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450
ATTN: Decision and Certificate of
Correction Branch of the Patent Issue Division

REQUEST FOR CERTIFICATE OF CORRECTION OF PATENT
FOR PTO MISTAKE (37 C.F.R. § 1.322(a))

Attached, in duplicate, is PTO/SB/44 (also Form PTO-1050), with at least one copy being suitable for printing.

It is submitted that the U.S. Patent and Trademark Office is responsible for the errors since the noted errors to the specification appear correctly in the application as filed. Accordingly, no fee should be charged to the patentees or their assignee for the correction.

Issuance of a Certificate of Correction is believed appropriate and is respectfully solicited.

Please send the Certificate to the undersigned.

Respectfully submitted,

March 17, 2005
(Date)

By: John D. Simmons
JOHN D. SIMMONS
Registration No. 52,225
AKIN, GUMP, STRAUSS, HAUER & FELD, LLP
One Commerce Square
2005 Market Street - Suite 2200
Philadelphia, PA 19103
Telephone: (215) 965-1268
Facsimile: (215) 965-1210
E-Mail: jsimmons@akingump.com

JDS/DCM
Enclosures

(Also Form PTO-1050)

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO : 6,844,990 B2

DATED : January 18, 2005

INVENTOR(S) : Jean-Claude Artonne et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification:

Column 2, line 34, "ax" should be replaced with -- α --;

Column 13, line 17 and column 14, line 65, "a" should be replaced with -- α --;

Column 16, line 62, the formula should read:

-- $z(r) = [(C*r^2)/(1 + \sqrt{}(1-(1+k)*C^2*r^2)] + A_1r^2 + A_2r^4 + A_3r^6 + A_4r^8 + A_5r^{10}$ --.

MAILING ADDRESS OF SENDER: John D. Simmons
Akin Gump Strauss Hauer & Feld, L.L.P.
One Commerce Square, Suite 2200
2005 Market Street
Philadelphia, PA 19103

PATENT NO. 6,844,990 B2

No. of additional copies

→

P15/REV02

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,844,990 B2

DATED : January 18, 2005

INVENTOR(S) : Jean-Claude Artonne et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 2,
Line 34, "ax" should be replaced with -- α --;

Column 13,
Line 17, "a" should be replaced with -- α --;

Column 14,
Line 65, "a" should be replaced with -- α --;

Column 16,
Line 62, the formula should read:

$$-- z(r) = [(C*r^2)/(1 + \sqrt{\ }(1-(1+k)*C^2*r^2)] + A_1r^2 + A_2r^4 + A_3r^6 + A_4r^8 + A_5r^{10} --.$$

Signed and Sealed this

Twenty-fourth Day of May, 2005

Jon W. Dudas

JON W. DUDAS

Director of the United States Patent and Trademark Office

AO 120 (Rev. 08/10)

TO: **Mail Stop 8 Director of the U.S. Patent and Trademark Office P.O. Box 1450 Alexandria, VA 22313-1450**	**REPORT ON THE FILING OR DETERMINATION OF AN ACTION REGARDING A PATENT OR TRADEMARK**

In Compliance with 35 U.S.C. § 290 and/or 15 U.S.C. § 1116 you are hereby advised that a court action has been filed in the U.S. District Court District of Delaware on the following

☐ Trademarks or ☑ Patents. (☐ the patent action involves 35 U.S.C. § 292.):

DOCKET NO.	DATE FILED 1/4/2016	U.S. DISTRICT COURT District of Delaware
PLAINTIFF 6115187 Canada, Inc., d/b/a Immervision, Inc.		DEFENDANT Samsung Techwin America, Samsung Techwin Co., Ltd., and KLM Marketing, LLC

PATENT OR TRADEMARK NO.	DATE OF PATENT OR TRADEMARK	HOLDER OF PATENT OR TRADEMARK
1 US 6,844,990 B2	1/18/2005	6115187 Canada Inc.
2		
3		
4		
5		

In the above—entitled case, the following patent(s)/ trademark(s) have been included:

DATE INCLUDED	INCLUDED BY ☐ Amendment ☐ Answer ☐ Cross Bill ☐ Other Pleading	
PATENT OR TRADEMARK NO.	DATE OF PATENT OR TRADEMARK	HOLDER OF PATENT OR TRADEMARK
1		
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5		

In the above—entitled case, the following decision has been rendered or judgement issued:

DECISION/JUDGEMENT

CLERK	(BY) DEPUTY CLERK	DATE

Copy 1—Upon initiation of action, mail this copy to Director Copy 3—Upon termination of action, mail this copy to Director
Copy 2—Upon filing document adding patent(s), mail this copy to Director Copy 4—Case file copy

PATENT ASSIGNMENT COVER SHEET

Electronic Version v1.1
Stylesheet Version v1.2

EPAS ID: PAT3955186

SUBMISSION TYPE:	NEW ASSIGNMENT
NATURE OF CONVEYANCE:	SECURITY INTEREST

CONVEYING PARTY DATA

Name	Execution Date
IMMERVISION INC.	07/06/2016

RECEIVING PARTY DATA

Name:	ACG 360 L.P.
Street Address:	426 SAINTE-HELENE STREET, SUITE 1
City:	MONTREAL
State/Country:	CANADA
Postal Code:	H2Y 2K7

PROPERTY NUMBERS Total: 12

Property Type	Number
Patent Number:	6895180
Patent Number:	6885817
Patent Number:	6844990
Patent Number:	6865028
Patent Number:	8016426
Application Number:	14668314
Patent Number:	9299127
Application Number:	14370268
Application Number:	62216105
Application Number:	62387409
Application Number:	62298795
Application Number:	62295725

CORRESPONDENCE DATA

Fax Number: (312)876-7934

Correspondence will be sent to the e-mail address first; if that is unsuccessful, it will be sent using a fax number, if provided; if that is unsuccessful, it will be sent via US Mail.

Phone: 312-876-8000
Email: patents.us@dentons.com, dianetatiana.filatov@dentons.com
Correspondent Name: DENTONS US LLP
Address Line 1: P.O. BOX 061080
Address Line 2: WACKER DRIVE STATION, WILLIS TOWER

Address Line 4:	CHICAGO, ILLINOIS 60606
ATTORNEY DOCKET NUMBER:	ACG360_R.TSIBULEVSKIY
NAME OF SUBMITTER:	ROMAN TSIBULEVSKIY
SIGNATURE:	/roman tsibulevskiy/
DATE SIGNED:	07/11/2016
	This document serves as an Oath/Declaration (37 CFR 1.63).

Total Attachments: 4
source=Notice of Security Interest in IP (USPTO) - ACG 360 and ImmerVision (2)#page1.tif
source=Notice of Security Interest in IP (USPTO) - ACG 360 and ImmerVision (2)#page2.tif
source=Notice of Security Interest in IP (USPTO) - ACG 360 and ImmerVision (2)#page3.tif
source=Notice of Security Interest in IP (USPTO) - ACG 360 and ImmerVision (2)#page4.tif

NOTICE OF SECURITY INTEREST IN INTELLECTUAL PROPERTY

TO: UNITED STATES PATENT AND TRADEMARK OFFICE
ACG 360 L.P.
DENTONS

WHEREAS IMMERVISION INC., a corporation incorporated under the federal laws of Canada (the "**Debtor**"), whose full address is 2020 Robert-Bourassa Boulevard, Suite 2320, Montréal, Québec H3A 2A5, is the owner of the registered patents and trademarks set forth in **Attachment 1** attached hereto (collectively, the "**Intellectual Property**");

AND WHEREAS ACG 360 L.P., a limited partnership created under the laws of Québec, whose full address is 426 Sainte-Hélène Street, suite 1, Montréal, Québec H2Y 2K7, represented by its general partner **ACG 360 GENERAL PARTNER INC.**, a corporation constituted under the laws of Québec, whose full address is 426 Sainte-Hélène Street, suite 1, Montréal, Québec H2Y 2K7 (the "**Creditor**") entered into, *inter alia*, a convertible loan agreement dated June 30, 2016 (the "**Convertible Loan Agreement**") and hypothec agreement with the Debtor dated June 30, 2016 (the "**Security Agreement**") by which the Debtor granted to the Creditor a security interest, hypothec and lien in all of its personal property, including the Intellectual Property;

NOW THEREFORE, for good and valuable consideration, the receipt and sufficiency of which are hereby acknowledged, and in accordance with the terms and obligations set forth in the Security Agreement, the Debtor hereby confirms the granting of a security interest, hypothec and lien in the Intellectual Property to the Creditor.

THE DEBTOR undertakes to immediately notify the Creditor in accordance with section 10 of the Convertible Loan Agreement of any new filing made in respect of patents and patent applications for the Debtor or any of its affiliates in the United States and to provide any related description, filing date, patent number or application number.

THE DEBTOR hereby certifies that the aforementioned information as it relates to the Debtor is true and accurate.

DATED: July 5, 2016.

[signature page follows]

IMMERVISION INC.

By: [signature]

Name: PASCALE NINI

Title: PRESIDENTE & CEO

APPIDAVIT OF WITNESS

I, Bernard Coles, domiciled at the following address :

564 ave Victoria, Westmount, Qc, Canada H3Y 2R6

solemnly declare and attest that I was present and saw the representative of 6115187 CANADA INC., who is personally known to me as the person named in the above *Notice of security interest in intellectual property*, sign and subscribe to this *Notice of security interest in intellectual property*.

Signature of the Witness : [signature]

Declared before me, this 6 day of July, 2010, in Montreal, Province of Quebec, Canada.

Commissioner for Oaths : [signature]

XAVIER MAGEAU
257 3423

Attachment I - Notice of Security Interest in Intellectual Property

ATTACHMENT 1

UNITED STATES PATENTS AND PATENT APPLICATIONS

	Description	Filing Date or 371 (c) Date	Patent number or Publication number (application number)
1.	Camera support device	August 13, 2003	6,895,180
2.	Method and device for orienting a digital panoramic image	August 14, 2003	6,885,817
3.	Method for capturing and displaying a variable resolution digital panoramic image	November 12, 2003	6,844,990
4.	Method for capturing a panoramic image by means of an image sensor rectangular in shape	January 20, 2004	6,865,028
5.	Method and device for projecting a panoramic image with a variable resolution	February 27, 2008	8,016,426
6.	Automated definition of system behavior or user experience by recording, sharing, and processing information associated with wide-angle image	March 25, 2015	2015/0281507 (14/668,314)
7.	Splitting of elliptical images	July 25, 2013	2014/0085303 (13/950,559) 9,299,127
8.	Panoramic camera	July 2, 2014	2014/0340473 A1 (14/370,268)
9.	Method for designing an optimization apparatus for a camera having a lens with non-uniform parameters to be imaged as a lens with uniform parameters	September 9, 2015	Unpublished provisional (62/216,105)
10.	Miniature Wide-Angle Imaging Lens	December 23,	Unpublished provisional

	Description	Filing Date or 371 (c) Date	Patent number or Publication number (application number)
		2015	application 62/387,409
11.	Miniature Wide-Angle Imaging Lens	February 23, 2016	Unpublished provisional application 62/298,795
12.	Image distortion transformation method and apparatus	February 16, 2016	Unpublished provisional application 62/295,725

LDB:6866023v2

AO 120 (Rev. 08/10)

TO: **Mail Stop 8** **Director of the U.S. Patent and Trademark Office** **P.O. Box 1450** **Alexandria, VA 22313-1450**	**REPORT ON THE FILING OR DETERMINATION OF AN ACTION REGARDING A PATENT OR TRADEMARK**

In Compliance with 35 U.S.C. § 290 and/or 15 U.S.C. § 1116 you are hereby advised that a court action has been filed in the U.S. District Court District of Delaware on the following

☐ Trademarks or ☑ Patents. (☐ the patent action involves 35 U.S.C. § 292.):

DOCKET NO.	DATE FILED	U.S. DISTRICT COURT
16-cv-2-SLR	1/4/2016	District of Delaware

PLAINTIFF	DEFENDANT
6115187 Canada, Inc., d/b/a Immervision, Inc.	Samsung Techwin America, Samsung Techwin Co., Ltd., and KLM Marketing, LLC

PATENT OR TRADEMARK NO.	DATE OF PATENT OR TRADEMARK	HOLDER OF PATENT OR TRADEMARK
1 US 6,844,990 B2	1/18/2005	6115187 Canada Inc.
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In the above—entitled case, the following patent(s)/ trademark(s) have been included:

DATE INCLUDED	INCLUDED BY ☐ Amendment ☐ Answer ☐ Cross Bill ☐ Other Pleading	
PATENT OR TRADEMARK NO.	**DATE OF PATENT OR TRADEMARK**	**HOLDER OF PATENT OR TRADEMARK**
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In the above—entitled case, the following decision has been rendered or judgement issued:

DECISION/JUDGEMENT
Notices of voluntary dismissal filed.

CLERK	(BY) DEPUTY CLERK	DATE
John A. Cerino	[signature]	8/3/2016

Copy 1—Upon initiation of action, mail this copy to Director Copy 3—Upon termination of action, mail this copy to Director
Copy 2—Upon filing document adding patent(s), mail this copy to Director Copy 4—Case file copy

AO 120 (Rev. 08/10)

TO: **Mail Stop 8 Director of the U.S. Patent and Trademark Office P.O. Box 1450 Alexandria, VA 22313-1450**	**REPORT ON THE FILING OR DETERMINATION OF AN ACTION REGARDING A PATENT OR TRADEMARK**

In Compliance with 35 U.S.C. § 290 and/or 15 U.S.C. § 1116 you are hereby advised that a court action has been filed in the U.S. District Court United States District Court, District of Delaware on the following

☐ Trademarks or ☑ Patents. (☐ the patent action involves 35 U.S.C. § 292.):

DOCKET NO.	DATE FILED	U.S. DISTRICT COURT
	10/19/2018	United States District Court, District of Delaware

PLAINTIFF	DEFENDANT
6115187 CANADA, INC., d/b/a IMMERVISION	LG ELECTRONICS U.S.A., INC. and LG ELECTRONICS, INC.

PATENT OR TRADEMARK NO.	DATE OF PATENT OR TRADEMARK	HOLDER OF PATENT OR TRADEMARK
1 6,844,990 B2	1/18/2005	Immervsion
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In the above—entitled case, the following patent(s)/ trademark(s) have been included:

DATE INCLUDED	INCLUDED BY ☐ Amendment ☐ Answer ☐ Cross Bill ☐ Other Pleading	
PATENT OR TRADEMARK NO.	**DATE OF PATENT OR TRADEMARK**	**HOLDER OF PATENT OR TRADEMARK**
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In the above—entitled case, the following decision has been rendered or judgement issued:

DECISION/JUDGEMENT

CLERK	(BY) DEPUTY CLERK	DATE

Copy 1—Upon initiation of action, mail this copy to Director Copy 3—Upon termination of action, mail this copy to Director
Copy 2—Upon filing document adding patent(s), mail this copy to Director Copy 4—Case file copy

AO 120 (Rev. 08/10)

TO: **Mail Stop 8 Director of the U.S. Patent and Trademark Office P.O. Box 1450 Alexandria, VA 22313-1450**	**REPORT ON THE FILING OR DETERMINATION OF AN ACTION REGARDING A PATENT OR TRADEMARK**

In Compliance with 35 U.S.C. § 290 and/or 15 U.S.C. § 1116 you are hereby advised that a court action has been filed in the U.S. District Court United States District Court, District of Delaware on the following

☐ Trademarks or ☑ Patents. (☐ the patent action involves 35 U.S.C. § 292.):

DOCKET NO.	DATE FILED 10/19/2018	U.S. DISTRICT COURT United States District Court, District of Delaware
PLAINTIFF 6115187 CANADA, INC., d/b/a IMMERVISION		DEFENDANT LG ELECTRONICS U.S.A., INC. and LG ELECTRONICS, INC.

PATENT OR TRADEMARK NO.	DATE OF PATENT OR TRADEMARK	HOLDER OF PATENT OR TRADEMARK
1 6,844,990 B2	1/18/2005	Immervsion
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3		
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In the above—entitled case, the following patent(s)/ trademark(s) have been included:

DATE INCLUDED	INCLUDED BY ☐ Amendment ☐ Answer ☐ Cross Bill ☐ Other Pleading	
PATENT OR TRADEMARK NO.	**DATE OF PATENT OR TRADEMARK**	**HOLDER OF PATENT OR TRADEMARK**
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In the above—entitled case, the following decision has been rendered or judgement issued:

DECISION/JUDGEMENT

CLERK	(BY) DEPUTY CLERK	DATE

Copy 1—Upon initiation of action, mail this copy to Director Copy 3—Upon termination of action, mail this copy to Director
Copy 2—Upon filing document adding patent(s), mail this copy to Director Copy 4—Case file copy

PATENT ASSIGNMENT COVER SHEET

Electronic Version v1.1
Stylesheet Version v1.2

EPAS ID: PAT5596456

SUBMISSION TYPE:	NEW ASSIGNMENT
NATURE OF CONVEYANCE:	SECURITY INTEREST

CONVEYING PARTY DATA

Name	Execution Date
IMMERVISION INC.	06/26/2019

RECEIVING PARTY DATA

Name:	BRIDGING FINANCE INC.
Street Address:	77 KING STREET WEST
Internal Address:	SUITE 2925
City:	TORONTO, ONTARIO
State/Country:	CANADA
Postal Code:	M5K 1K7

PROPERTY NUMBERS Total: 18

Property Type	Number
Application Number:	16432180
Application Number:	16243492
Application Number:	15384900
Application Number:	15656647
Application Number:	15656707
Application Number:	15903872
Application Number:	62859861
Patent Number:	9930326
Patent Number:	10204398
PCT Number:	IB1950169
Patent Number:	6895180
Patent Number:	6885817
Patent Number:	6844990
Patent Number:	6865028
Patent Number:	8016426
Application Number:	14668314
Patent Number:	9299127
Application Number:	14370268

CORRESPONDENCE DATA

Fax Number:

Correspondence will be sent to the e-mail address first; if that is unsuccessful, it will be sent using a fax number, if provided; if that is unsuccessful, it will be sent via US Mail.

Phone:	2159651330
Email:	abennett@panitchlaw.com
Correspondent Name:	JOHN D. SIMMONS
Address Line 1:	2001 MARKET STREET STE 2800
Address Line 4:	PHILADELPHIA, PENNSYLVANIA 19103

ATTORNEY DOCKET NUMBER:	688266.5002
NAME OF SUBMITTER:	JOHN D. SIMMONS
SIGNATURE:	/John D. Simmons/
DATE SIGNED:	06/28/2019
	This document serves as an Oath/Declaration (37 CFR 1.63).

Total Attachments: 7

source=Contract Confirmatory Security Agreement#page1.tif
source=Contract Confirmatory Security Agreement#page2.tif
source=Contract Confirmatory Security Agreement#page3.tif
source=Contract Confirmatory Security Agreement#page4.tif
source=Contract Confirmatory Security Agreement#page5.tif
source=Contract Confirmatory Security Agreement#page6.tif
source=Contract Confirmatory Security Agreement#page7.tif

CONFIRMATORY SECURITY AGREEMENT

WHEREAS IMMERVISION INC (the "**Grantor**"), having its registered office at 2320-2020 boul. Robert-Bourassa, Montréal, Quebec H3A 2A5 **(i)** is the registered owner of the US trademarks and trademark applications listed in Schedule "A" hereto and may, in the future, become the registered owner of additional US trademarks and trademark applications (collectively, the "**US Trademarks**"), and **(ii)** is the registered owner of the US patents and patent applications listed in Schedule "B" hereto and may, in the future, become the registered owner of additional US patents and patent applications (collectively, the "**US Patents**", and together with the US Trademarks, the "**Intellectual Property**");

WHEREAS Bridging Finance Inc. (the "**Creditor**"), having a place of business at 77 King Street West, Suite 2925, Toronto, Ontario M5K 1K7 and the Grantor entered into a deed of hypothec dated as of June 26, 2019 (the "**Deed of Hypothec**"), pursuant to which the Grantor granted to the Creditor a security in and to, among other things, the Intellectual Property;

WHEREAS the Grantor and the Creditor have perfected and rendered opposable to third parties the Deed of Hypothec in the Intellectual Property in accordance with the laws of the Provinces of Québec, Canada;

WHEREAS the Grantor and the Creditor are desirous of recording the Deed of Hypothec and the additional security created hereunder in the Intellectual Property with the United States Patent and Trademark Office;

NOW THEREFORE, the Grantor and the Creditor hereby confirm that the Grantor and the Creditor entered into the Deed of Hypothec, pursuant to which the Grantor granted to the Creditor a security in and to, among other things, the Intellectual Property.

AND, for good and valuable consideration, receipt of which is hereby acknowledged, the Grantor does hereby further grant to the Creditor a security interest in, and mortgage on, the Intellectual Property.

AND each party hereto does hereby further acknowledge and affirm that the rights and remedies of the Creditor with respect to the security interest in and mortgage on the Intellectual Property made and granted hereby are more fully set forth in the Deed of Hypothec, the terms and provisions of which are hereby incorporated herein by reference as if fully set forth herein.

THE PARTIES FURTHER AGREE that the Grantor shall record this Confirmatory Security Agreement with the United States Patent and Trademark Office, with respect to the US Trademarks and the US Patents.

IN WITNESS WHEREOF, the parties hereto have caused these presents to be executed as a sealed instrument on June 26 , 2019.

IMMERVISION INC.

Per: ______________________

Name: Pascale Nini
Title: President and CEO

BRIDGING FINANCE INC.

Per: ______________________

Name: Natasha Sharpe
Title: Chief Investment Officer

SCHEDULE A

TRADEMARKS

TRADEMARK	OWNER	TERRITORY	REGISTRATION NUMBER	CLASS	EXPIRY DATE
Immervision (word mark)	Immervision Inc.	United States of America	3542321	9	December 11, 2028
Immervision Enables (word mark)	Immervision Inc.	United States of America	3578319	9	February 26, 2029
Enabling Panoramic Technology (word mark)	Immervision Inc.	United States of America	3604788	9	October 15, 2019

308470.00009/104794256.1

SCHEDULE B

UNITED STATES PATENTS AND PATENT APPLICATIONS

	Description	Filing Date or 371 (c) Date	Patent number or Publication number (application number)
1.	Camera support device	August 13, 2003	6,895,180
2.	Method and device for orienting a digital panoramic image	August 14, 2003	6,885,817
3.	Method for capturing and displaying a variable resolution digital panoramic image	November 12, 2003	6,844,990
4.	Method for capturing a panoramic image by means of an image sensor rectangular in shape	January 20, 2004	6,865,028
5.	Method and device for projecting a panoramic image with a variable resolution	February 27, 2008	8,016,426
6.	Automated definition of system behaviour or user experience by recording, sharing, and processing information associated with wide-angle image	March 25, 2015	2015/0281507 (14/668,314)
7.	Splitting of elliptical images	July 25, 2013	9,299,127

308470.00009/104794256.1

	Description	Filing Date or 371 (c) Date	Patent number or Publication number (application number)
8.	Panoramic camera	July 2, 2014	2014/0340473 A1 (14/370,268)
9.	Method for designing an optimization apparatus for a camera having a lens with non-uniform parameters to be imaged as a lens with uniform parameters	September 9, 2015	9,930,326 unpublished provisional (62/216,105)
10.	Miniature Wide-Angle Imaging Lens	December 20, 2016	US *non-provisional* application US2017/0184813 US continuation 16/432,180
11.	Image distortion transformation method and apparatus	February 16, 2017	10,204,398
Families with ungranted patents applications			
12.	Method to Capture, Store, Distribute, Share, Stream and Display Panoramic Image or Video	July 21, 2017 July 21, 2017	US *non-provisional* application 15/656,647 US *non-provisional* application 15/656,707
13.	Wide angle Stereoscopic Vision With Cameras Having Different Parameters	February 23, 2018	US non-provisional application 15/903,872

308470.00009/104794256.1

	Description	Filing Date or 371 (c) Date	Patent number or Publication number (application number)
14.	Constant resolution continuous hybrid zoom system	January 9, 2019	US non-provisional application 16/243,492 PCT/IB2019/050169
15.	Method for Adaptive Dewarping Based on Context Segmentation Layers	June 11, 2019	US provisional application 62/859,861

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571-272-7822

Paper 6
Entered: May 13, 2020

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

LG ELECTRONICS INC.,
Petitioner,

v.

IMMERVISION, INC.,
Patent Owner.

IPR2020-00195
Patent 6,844,990 B2

Before KRISTINA M. KALAN, WESLEY B. DERRICK, and KIMBERLY MCGRAW, *Administrative Patent Judges.*

DERRICK, *Administrative Patent Judge.*

DECISION
Granting Institution of *Inter Partes* Review
35 U.S.C. § 314

I. INTRODUCTION

On November 27, 2019, LG Electronics Inc. ("Petitioner" or "LG Electronics") filed a Petition requesting an *inter partes* review of claim 21 ("the challenged claim") of U.S. Patent No. 6,844,990 B2 (Ex. 1001, "the '990 patent"). Paper 2 ("Pet."). ImmerVision, Inc. ("Patent Owner" or "ImmerVision") filed a Preliminary Response to the Petition. Paper 5 ("Prelim. Resp.").

We have authority to determine whether to institute an *inter partes* review. *See* 35 U.S.C. § 314(b) (2018); 37 C.F.R. § 42.4(a). To institute an *inter partes* review, we must determine that the information presented in the Petition shows that there is "a reasonable likelihood that the petitioner would prevail with respect to at least 1 of the claims challenged in the petition." 35 U.S.C. § 314(a). Applying that standard, for the reasons set forth below, we institute an *inter partes* review as to all grounds raised in the Petition.

II. BACKGROUND

A. Real Parties in Interest

Petitioner LG Electronics Inc. identifies LG Electronics U.S.A., Inc. and LG Innotek Co. Ltd. as additional real parties-in-interest. Pet. 2. Patent Owner ImmerVision, Inc., identifies itself as the real party-in-interest. Paper 4, 2. The parties do not raise any issue about real parties-in-interest.

B. Related Proceedings

The parties identify two pending district court cases involving the '990 patent as related matters: *ImmerVision, Inc. v. LG Electronics U.S.A.*, Case No. 1-18-cv-01630 (D. Del.) and *ImmerVision, Inc. v. LG Electronics U.S.A.*, Case No. 1-18-cv-01631 (D. Del.). Pet. 2; Paper 4, 2–3.

Petitioner concurrently filed another petition that challenges claim 5 of the '990 patent. *See LG Electronics Inc. v. Immervision, Inc.*, IPR2020-00179, Paper 2.

In addition, Petitioner states the '990 patent: (1) was the subject of *Ex Parte* Reexamination Control No. 90/013,410; (2) was challenged in an *inter partes* proceeding, *Panasonic System Networks Co., Ltd. v. 6115187 CANADA INC.*, IPR2014-01438; and (3) was the subject of three other district court cases, now closed. *See* Pet. 2–3; *see also Panasonic System Networks Co., Ltd. v. 6115187 CANADA INC.*, IPR2014-01438, Paper 11 (PTAB Nov. 26, 2014) (terminating proceeding prior to institution following settlement).

C. The '990 Patent (Ex. 1001)

The '990 patent is titled "Method for Capturing and Displaying a Variable Resolution Digital Panoramic Image" and issued on Jan. 18, 2005, from an application filed on Nov. 12, 2003. Ex. 1001, code (22), (45), (54). The application for the '990 patent is a continuation of application No. PCT/FR02/01588, filed on May 10, 2002, and claims priority to foreign application FR 01 06261, filed May 11, 2001. *Id.* at code (30), (63).

The '990 patent is directed to capturing a digital panoramic image that includes using a panoramic objective lens having "a distribution function of the image points that is not linear relative to the field angle of the object points of the panorama." Ex. 1001, Abstract. The image obtained using such a panoramic objective lens has at least one zone that is expanded and another zone that is compressed. *Id.* The patent further provides for correcting the non-linearity of the panoramic image initially obtained. *Id.*

The '990 patent was the subject of an *ex parte* reexamination. *Id.* at 25–27 (Ex Parte Reexamination Certificate (10588th)). The

Reexamination Request—Control No. 90/013,410—was filed November 26, 2014. *Id.* at 25; Ex. 1003, 328–339 ("Request by Patent Owner for *Ex Parte* Reexamination of U.S. Patent No. 6,844,990"). A preliminary amendment, *inter alia*, canceling certain claims and amending others was filed with the request for reexamination. *See* Pet. 17–18; Ex. 1003, 328–354. The preliminary amendment did not amend or cancel claim 17—the base claim for claim 21. Ex. 1001, 21:7–11; Ex. 1003, 342–343. The Patent Office granted Patent Owner's request for reexamination of the identified claims. Ex. 1003, 52–63. The Patent Office declined to reexamine claims 5, 8, 9, 12–14, 21, 24, and 26 on the basis that "the requester did not request reexamination of . . . and did not assert the existence of a substantial new question of patentability for those claims." *Id.* at 56 (citing 35 U.S.C. § 311(b)(2)). The Patent Office issued an Office Action on January 29, 2015, rejecting, *inter alia,* independent claim 17—the base claim for claim 21—as anticipated by Nagaoka (US 6,128,145 "Ex. 1004") and Baker (US 5,686,957 "Ex. 1005"), which are asserted in the present proceeding, and Fisher (US 3,953,111 "Ex. 1006"). *Id.* at 30, 32, 36–39. Patent Owner filed an Amendment on February 12, 2015, canceling, *inter alia,* claim 17 and amending certain other claims. *Id.* at 19–25. At the conclusion of the reexamination proceeding, the Patent Office issued an *Ex Parte* Reexamination Certificate cancelling claims 1, 6, 7, 17–20, 22, 23, and 25; determining claims 2–4, 10, and 15 to be patentable as amended; determining claims 11 and 16 dependent on an amended claim to be patentable; and adding and determining to be patentable new claims 27–47. Ex. 1001, 25–27; Ex. 1003, 1–3.

D. Claimed Subject Matter

Challenged claim 21 incorporates the limitations of cancelled claim 17, from which it depends. *See* MPEP § 2260.01 ("the content of the canceled base claim . . . [is] available to be read as part of the confirmed or allowed dependent claim"). Both claims are reproduced below.

> 17. A panoramic objective lens comprising:
>
> optical means for projecting a panorama into an image plane of the objective lens, the optical means having an image point distribution function that is not linear relative to the field angle of object points of the panorama, the distribution function having a maximum divergence of at least ±10% compared to a linear distribution function, such that a panoramic image obtained by means of the objective lens comprises at least one substantially expanded zone and at least one substantially compressed zone.

Ex. 1001, 20:51–61.

> 21. The panoramic objective lens according to claim 17, wherein the lens compresses the center of the image and the edges of the image, and expands an intermediate zone of the image located between the center and the edges of the image.

Ex. 1001, 21:7–11.

E. Evidence

Petitioner relies upon the following prior art references in the asserted grounds of unpatentability:

Reference	Date	Exhibit No.
US 5,861, 999 ("Tada")	Jan. 19, 1999, filed Aug. 21, 1997	1007
US 6,128,145 ("Nagaoka")	Oct. 3, 2000, filed Apr. 28, 1999	1004
US 5,686,957 ("Baker")	Nov. 11, 1997, filed Jun. 30, 1995	1005

Petitioner also relies on the Declaration of Russell Chipman, Ph.D. (Ex. 1008).

F. The Asserted Grounds of Unpatentability

Petitioner contends that the challenged claim is unpatentable based on the following grounds:

Claim(s) Challenged	35 U.S.C. §[1]	Reference(s)/Basis
21	103	Tada
21	103	Tada, Nagaoka
21	103	Tada, Baker

III. ANALYSIS

A. Level of Ordinary Skill in the Art

Petitioner contends that a person of ordinary skill in the art "would have had at least a bachelor's degree in Physics, Optical Engineering, and/or Electrical Engineering, and at least five years' experience in developing and designing optical products or systems and have familiarity with image processing algorithms and optical design software." Pet. 20 (citing Ex. 1008 ¶ 41).

Patent Owner neither disputes Petitioner's articulation of the level of ordinary skill in the art nor presents its own articulation of the level of skill in the art, stating that "[a]t this stage of the proceeding, . . . for purposes of [the] Preliminary Response, Patent Owner does not object to Petitioner's proposed skill level." Prelim. Resp. 16.

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[1] The Leahy-Smith America Invents Act ("AIA"), Pub. L. No. 112–29, 125 Stat. 284, 287–88 (2011), revised 35 U.S.C. § 103 effective March 16, 2013. Because the challenged patent was filed before March 16, 2013, we refer to the pre-AIA version of 35 U.S.C. § 103.

On this record, we have no reason to fault Petitioner's definition of the level of ordinary skill and, therefore, adopt it for the purposes of this Decision. We further note that the prior art itself demonstrates the level of skill in the art at the time of the invention. *See Okajima v. Bourdeau*, 261 F.3d 1350, 1355 (Fed. Cir. 2001) (explaining that "specific findings on the level of skill in the art . . . [are not required] 'where the prior art itself reflects an appropriate level and a need for testimony is not shown'" (quoting *Litton Indus. Prods., Inc. v. Solid State Sys. Corp.*, 755 F.2d 158, 163 (Fed. Cir. 1985))).

B. Claim Construction

1. Standard of Construction

For petitions filed on or after November 13, 2018, we apply the claim construction standard from *Phillips v. AWH Corp.*, 415 F.3d 1303 (Fed. Cir. 2005) (en banc). 37 C.F.R. § 42.100(b) (2019).

Claim terms are generally given their ordinary and customary meaning as would be understood by one with ordinary skill in the art in the context of the specification, the prosecution history, other claims, and even extrinsic evidence including expert and inventor testimony, dictionaries, and learned treatises, although extrinsic evidence is less significant than the intrinsic record. *Phillips*, 415 F.3d at 1312–1317. Usually, the specification is dispositive, and it is the single best guide to the meaning of a disputed term. *Id.* at 1315.

Only those claim terms that are in controversy need to be construed and only to the extent necessary to resolve the controversy. *Nidec Motor Corp. v. Zhongshan Broad Ocean Motor Co.*, 868 F.3d 1013, 1017 (Fed. Cir. 2017); *see also U.S. Surgical Corp. v. Ethicon, Inc.*, 103 F.3d 1554, 1568 (Fed. Cir. 1997) (holding claim construction is not necessary when it is not "directed to, or has been shown reasonably to affect, the determination of obviousness").

2. *Proposed Constructions*

Petitioner proposes constructions for eight claim terms. *See* Pet. 21–29. Petitioner contends that "'[p]anoramic objective lens' should be construed to mean a super-wide or ultra-wide angle objective lens." *Id.* at 21 (citing Ex. 1001, 1:18–20; Ex. 1008 ¶ 44). Petitioner contends that "[o]bject points of the panorama' should be construed as points of the object in the panorama being viewed by the lens." *Id.* at 25 (citing Ex. 1001, 7:2–5, Fig. 5; Ex. 1008 ¶ 52). Petitioner contends that "'[i]mage point' should be construed as a point of light projected by the lens onto an image plane, said light coming from the corresponding object point of a viewed object in the panorama." *Id.* at 26 (citing Ex. 1001, 7:11–14, Fig. 5; Ex. 1008 ¶ 52). Petitioner contends that "'[f]ield angle of object points' should be construed as the angles of incident light rays passing through the object points and through the center of the panorama photographed, relative to the optical axis of the objective lens." *Id.* at 26–27 (citing Ex. 1001, 2:18–22; Ex. 1008 ¶ 52). Petitioner contends that "maximum divergence" is defined by the '990 patent according to the formula "DIVmax %=[[dr(Pd)-dr(Pdl)]/[dr(Pdl)]]*100, in which dr(Pd) is the relative distance in relation to the center of the point of maximum divergence Pd, and dr(Pdl) is the relative distance in relation to the center of the corresponding point on the linear distribution line." *Id.* at 27 (citing Ex. 1001, 8:57-65; Ex. 1008 ¶ 57). Petitioner contends that "[e]xpanded zone' should be construed as the portion of the image point distribution function where the gradient is higher than the gradient of the linear distribution function." *Id.* at 27–28 (citing Ex. 1001, 8:38-43, Fig. 9; Ex. 1008 ¶ 63). Petitioner contends that "[c]ompressed zone' should be construed as the portion of the image point distribution function where the gradient is lower than the gradient of the linear distribution function." *Id.* at 28 (citing Ex. 1001, 8:38–43, Fig. 9; Ex. 1008 ¶ 63).

Petitioner also addresses the "optical means for projecting . . ." limitation of cancelled claim 17, contending that "this limitation should be construed as a means-plus-function limitation under § 112(6)," and then identifying the recited function and the structure from the specification for performing the function. *See id.* at 22–24. Petitioner contends that "the 'optical means for projecting . . ." should be construed as: 'a series of optical elements, e.g., as shown in Figs. 15, 16, and 18, and equivalents thereof'" for performing the claimed function." *Id.* at 24.

Patent Owner does not contest the proposed constructions of the claim terms at this stage of the proceeding, stating that "for purposes of this Preliminary Response, Patent Owner does not object to the definitions set out by Petitioner." Prelim. Resp. 16.

Based on the current record, and for the purpose of this decision, we adopt the constructions set forth by Petitioner, because these appear reasonable and are not contested. Any further construction, is not necessary at this time for the purpose of this decision.

C. Principles of Law

A claim is unpatentable under 35 U.S.C. § 103 if "the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains." *KSR Int'l Co. v. Teleflex Inc.*, 550 U.S. 398, 406 (2007). The question of obviousness is resolved on the basis of underlying factual determinations, including: (1) the scope and content of the prior art; (2) any differences between the claimed subject matter and the prior art; (3) the level of skill in the art; and (4) if in evidence, objective evidence of nonobviousness, i.e., secondary considerations. *See Graham v. John Deere Co.*, 383 U.S. 1, 17–18 (1966).

"In an [*inter partes* review], the petitioner has the burden from the onset to show with particularity why the patent it challenges is unpatentable." *Harmonic Inc. v. Avid Tech., Inc.*, 815 F.3d 1356, 1363 (Fed. Cir. 2016) (citing 35 U.S.C. § 312(a)(3) as "requiring *inter partes* review petitions to identify 'with particularity . . . the evidence that supports the grounds for the challenge to each claim'"); *cf. Intelligent Bio-Systems, Inc. v. Illumina Cambridge, Ltd.*, 821 F.3d 1359, 1369 (Fed. Cir. 2016) (quoting 35 U.S.C. § 312(a)(3)) (addressing "the requirement that the initial petition identify 'with particularity' the evidence that supports the grounds for the challenge to each claim'"). This burden never shifts to Patent Owner. *See Dynamic Drinkware, LLC v. Nat'l Graphics, Inc.*, 800 F.3d 1375, 1378 (Fed. Cir. 2015) (citing *Tech. Licensing Corp. v. Videotek, Inc.*, 545 F.3d 1316, 1326–27 (Fed. Cir. 2008)) (discussing the burden of proof in *inter partes* review). Furthermore, Petitioner cannot satisfy its burden of proving obviousness by employing "mere conclusory statements." *In re Magnum Oil Tools Int'l, Ltd.*, 829 F.3d 1364, 1380 (Fed. Cir. 2016).

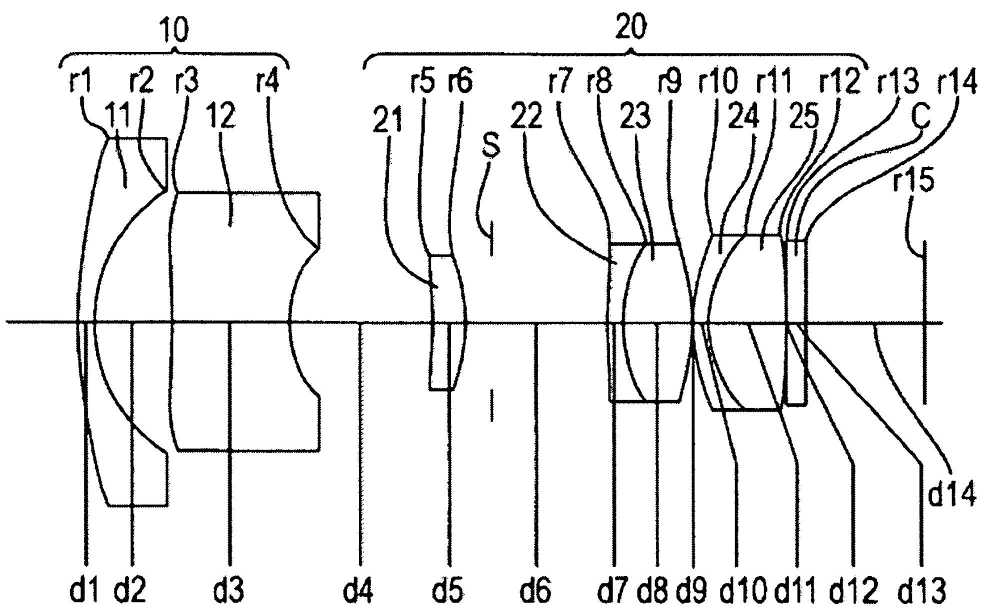
D. Asserted Obviousness over Tada

Petitioner challenges claim 21 as unpatentable for having been obvious over Tada. Pet. 29–52.

1. Tada (Ex. 1007)

Tada discloses a method for capturing a digital panoramic image, including by use of "a super wide angle lens system which can be used for a monitoring camera (CCTV) etc." Ex. 1007, 1:7–9. Tada states that "[i]t is an object . . . to provide a retrofocus type super wide angle lens system . . . [having] an angle of view of approximately 120° to 140°." *Id.* at 1:48–50. Tada identifies Figure 11 as "show[ing] a third embodiment of a super wide angle lens system." *Id.* at 8:59–64; Fig. 11. The third embodiment, as depicted in Figure 11 below, "is substantially the same as the second embodiment," depicted in Figure 6, which "is substantially the same as that of the first embodiment," depicted in Figure 1. *Id.* at 6:2–3, 7:36–43, 8:58–62.

FIG. 11



Tada's Figure 11 (reproduced above) depicts the lens arrangement of a super wide angle lens system. *Id.* at 3:44–46, Fig. 11. The depicted super wide angle lens system consists of front lens group 10 and rear lens group 20. *See id.* at 6:4–5 (identifying elements in reference to Figure 1). Figure 11 also depicts features of a CCD[2] (charge-coupled device) used to capture an image; element C refers to "a glass cover of the CCD" and "surface No. 15 refers to the image pickup surface of the CCD." *See id.* at 6:26–32 (identifying elements in reference to Figure 1). Tada's Figures 5 and 6 disclose numerical data regarding the third embodiment, including "[t]he surface figure, paraxial spherical amount and aspherical amount of surface No. 3." *Id.* at 8:63–9:57.

2. Analysis

Claim 21, which incorporates the limitations of cancelled claim 17 from which it depends, is directed to an improved panoramic objective lens. In general, claim 17 requires that the panoramic objective lens has optical means for projecting a panorama into an image plane of the objective lens, the optical means having an image point distribution function that is not linear to the field angle of the object points of the panorama, the image point distribution function having a maximum divergence that is at least ±10% compared to a linear distribution function, and that the panoramic image has at least one substantially expanded zone and at least one substantially compressed zone. *See* Ex. 1001, 20:51–61. Claim 21 further requires that "the lens compresses the center of the image and edges of the image, and expands an intermediate zone of the image located between the center and the edges of the image." *Id.* at 21:7–11.

a) Petitioner's Contentions

Petitioner contends that Tada discloses a panoramic objective lens that compresses the center of the image and edges of the image and expands an

[2] Although neither Tada nor the Petitioner define "CCD," we understand CCD to be a "charge-coupled device."

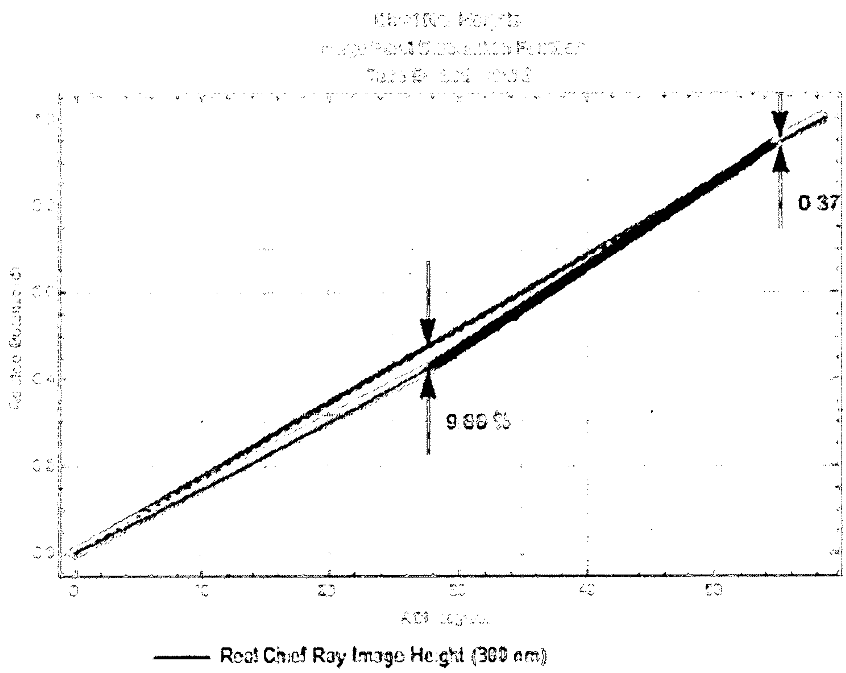
intermediate zone of the image located between the center and edges of the image. Pet. 33–42. Petitioner relies on Tada's third embodiment, as set forth in Figure 11 and Table 5, and calculations based on the disclosure for the distribution function of image points for different wavelengths of visible light. *Id.* at 35–42 (citing Ex. 1007, Fig. 11, Table 5). Petitioner further contends that the objective lens has a distribution function of image points that deviates from being linear to the field angle of the object points by an amount sufficient to meet the ±10% limitation of claim 17, and that, if not meeting the limitation outright, it would have been obvious to a person of ordinary skill in the art to modify the lens system to increase the maximum deviation in the expansion zone in order to increase the resolution of the acquired image. *Id.* at 42–51. Petitioner relies, in effect, on Tada's third embodiment rendering the objective lens with the ±10% deviation limitation *prima facie* obvious on the basis that it would have been expected to have the same properties and on the basis that the deviation amounts to nothing more than a result effective variable that is subject to routine optimization.

Petitioner addresses the limitations of base independent claim 17 and of claim 21 in turn.

Petitioner contends that Tada teaches the recited "panoramic objective lens" having "optical means for projecting a panorama into an image plane of the objective lens" in its disclosure of a super wide angle lens system for a monitoring CCTV camera, including the third embodiment depicted in Figure 11. *See id. at* 33–37 (citing Ex. 1007, 1:7–9, 1:48–50, 6:2–5, 6:26–32, 7:36–43, 8:58–64, Fig. 11; Ex. 1008 ¶¶ 44–45, 48). Petitioner also contends that its expert, Dr. Chipman, "reconstructed" the third embodiment using the information from Table 5. *Id.* at 35–37 (citing Ex. 1008 ¶ 48); *see* Ex. 1008 ¶ 46.

Petitioner contends that Tada teaches the recited "optical means having an image point distribution function that is not linear relative to the field angle of object points of the panorama." *See* Pet. 37–42 (citing Ex. 1007, 5:46–53, 8:59–64, 9:1–24 (Table 5), Fig. 11; Ex. 1008 ¶¶ 49–54). Petitioner relies on Dr. Chipman's testimony that Tada's disclosure of "schematic views of the lens arrangements, diagrams of the aberrations, astigmatism and distortion experienced by the particular lens systems disclosed, and tables of measurements of the lens" allows "one of ordinary skill in the art to reconstruct the exact lens systems described in Tada." *Id.* at 37; Ex. 1008 ¶ 49. In addition, Petitioner details the numerical data from Table 5 and contends that a person of ordinary skill in the art "at the relevant time period would have used a [computer] program . . . to mathematically calculate the characteristics of the lens system to test and show how it will function by providing plots of the various characteristics of the lens system." Pet. 38–39 (citing Ex. 1007, 5:46–53, 8:59–64, 9:1–24; Ex. 1008 ¶¶ 50–51). The data relied on includes W specified in Table 5 of Tada, the half angle field of view, indicating the angular extent from the optical axis of the lens of a scene that is imaged. *See id.* at 34–36, 39–41. The value for W in Table 5 is 58.5 degrees. Ex. 1007, 9:5.

As to calculating lens system characteristics, Petitioner and Petitioner's expert Dr. Chipman contend that a particular computer program—Code V software—"merely performs mathematical calculations applying well known principles of optics and physics" and that these well-known principles "have not changed in any material respects since at least the early 2000s." Pet. 39; Ex. 1008 ¶ 51. Petitioner and Dr. Chipman further contend that the Code V program "has been around since at least the mid-1960's and was capable of performing the analysis used herein by at least 1980." Pet. 39; Ex. 1008 ¶ 51. Petitioner relies on Dr. Chipman's calculations using the Code V software to model the lens system of Tada's third embodiment (depicted in Figure 11) using the information from Tada's Table 5. Pet. 39–42. Petitioner contends that a person of ordinary skill would have understood the recited lens system to be for use with a video camera and, thus, for the claim to be directed to visible light. *Id.* at 40 (citing Ex. 1008 ¶ 52). Petitioner details that Dr. Chipman, using the definitions of "object points of the panorama," "image point," and "field angle of object points," and the data from Table 5, "plotted the relative distance of image points produced by the lens system of the third embodiment of Tada in relation to the field angle of the corresponding object point" for six different wavelengths of light representative of visible light—violet (380 nm, 400 nm), blue (450 nm), yellow (587 nm), and red (700 nm, 740 nm)—using the Code V program. *Id.* at 39–40 (citing Ex. 1008 ¶ 52; Ex. 1012, 3 (American Heritage Dictionary of Science definition of "visible light")). Petitioner relies on these plots overlaid with a linear distribution and on the percent divergence calculated using the '990 patent's DIVmax equation to illustrate that "the image point distribution function is not linear relative to the field angle of object points of the panorama. *Id.* at 40–41 (citing Ex. 1008 ¶¶ 52–53; Ex. 1013 (Code V analysis of Tada's third embodiment)). The plot obtained for 380 nm illustrates the contended deviation.



Reproduced above from page 41 of the Petition, the plot of the lens prescription, based on Table 5 and Figure 11, for 380 nm wavelength light illustrates the deviation from a linear distribution. Petitioner highlights, in particular, that the slope of the image point distribution is less than that for a linear distribution over the lower object point field angles (orange) and the higher object point angles (green) and greater than that for a linear distribution over intermediate object point field angles (blue). *Id.* at 48–50. Petitioner contends that, "[a]s described in the '990 patent, a higher gradient of the image point distribution function compared to the linear distribution function indicates an expansion of the image and a lower gradient means a compression of the image." *Id.* at 49; Ex. 1001, 8:41–43; Ex. 1008 ¶ 63.

Thus, Petitioner contends that Tada teaches the recited "optical means having an image point distribution function that is not linear relative to the field angle of object points of the panorama."

Petitioner contends that Tada teaches, or renders obvious, "the distribution function having a maximum divergence of at least ±10% compared to a linear distribution function, such that the panoramic image obtained has at least one substantially expanded zone and at least one substantially compressed zone." *See* Pet. 42–51. Petitioner relies on two theories for the maximum divergence of at least ±10% compared to a linear distribution. First, Petitioner contends that the maximum divergence value of Tada's third embodiment itself establishes a *prima facie* case of obviousness because it is sufficiently close to ±10%. *See id.* at 42–46. Second, Petitioner contends that it would have been obvious to a person of ordinary skill in the art to modify Tada's third embodiment lens system to increase the maximum deviation in the expansion zone in order to increase the resolution of the acquired image, including as a matter of routine optimization. *Id.* at 46–48. As to the obtained panoramic image having "at least one substantially expanded zone and at least one substantially compressed zone," Petitioner relies, respectively, on the higher and lower gradients of portions of the plot of the lens prescription, discussed above. *Id.* at 48–51.

In arguing the disclosed maximum divergence value is sufficiently close to establish a *prima facie* case, Petitioner contends that the '990 patent does not attribute any special characteristic to the 10% value, but rather sets forth that it "is sufficient 'to obtain an expansion of the useful parts of the image . . . result[ing] in a clear increase in the number of pixels covered by the useful parts and a substantial improvement in the definition obtained.'" *Id.* at 42 (citing Ex. 1001, 9:7–12; Ex. 1008 ¶ 56). Petitioner further relies on the '990 patent "describ[ing] the 10% value as a mere approximation" and that "such a maximum divergence value 'on the order of 10% at least' merely needs to be higher than that due to the possible design errors in manufacturing errors . . . 'which is of a few percent.'" *Id.* (citing Ex. 1001, 9:2–6, 9:8; Ex. 1008 ¶ 56).

Petitioner contends that its calculated plots for various wavelengths demonstrates that the third embodiment of Tada's lens system meets, or renders obvious, the recited limitations as to the maximum divergence with respect to the linear distribution and the substantially expanded and compressed zones. *Id.* at 44–45. Petitioner relies on its calculations indicating, depending on the wavelength of visible light, a maximum divergence of -8.12% to -9.88% occurring at or near 25–28 degrees and of +0.37 to +1.44% occurring at or near 52–55 degrees. *Id.* at 43–44 (citing Ex. 1001, 8:57; Ex. 1008 ¶ 57). Petitioner highlights the maximum divergence of -9.88% at 27.6 degrees and of +0.37% at 55.2 degrees for a 380 nm wavelength (violet light) (*id.*) and that violet light suffices as the claims do not require that the visible light be of any particular wavelength (*id.* at 40, 44).

Petitioner contends, thus, that "Tada's 8.12% to 9.88% maximum divergence either is 'on the order of 10% or is at least sufficiently close to it such that there is no meaningful difference from 10% in the impact of the maximum divergence." *Id.* at 44–45 (citing Ex. 1008 ¶ 58). Petitioner further contends that, "[a]ccordingly, the disclosure in Tada renders [the at least ±10% divergence] limitation obvious because the maximum deviation is 'close enough' to the claimed maximum deviation 'such that one skilled in the art would have expected [it] to have the same properties.'" *Id.* at 45 (citing *In re Peterson*, 315 F.3d 1325, 1329 (Fed. Cir. 2003); *Titanium Metals Corp. of Am. v. Banner*, 778 F.2d 775, 778 F.2d 783 (Fed. Cir. 1985).

In arguing it would have been obvious to increase the maximum deviation, Petitioner contends that

> it would have been obvious for a [person of ordinary skill in the art] . . . to modify Tada's third embodiment lens system through routine experimentation to add an additional divergence of only 0.12% (for violet light) to this lens system's 9.88% maximum divergence (or up to 1.88% added to 8.12% for red light) to further expand the useful parts of the image and improve the definition in the already expanded zone of Tada's third embodiment.

Pet. 46. Petitioner relies on *In re Aller*, 220 F.2d 454, 456 (CCPA 1955), for the principle that "where the general conditions of a claim are disclosed in the prior art, it is not inventive to discover the optimum or workable ranges by routine experimentation." Pet. 47. In effect, Petitioner relies on Tada as disclosing a lens system, including its third embodiment, and argues that reaching a workable lens meeting the claim limitations requires nothing more than routine experimentation. Petitioner supports its contention by identifying that, in lens design, there are design tradeoffs, including image quality, which includes "the definition of the image captured in different zones of the field of view," and that "[d]epending on the application of the lens, it may be desirable that a particular zone have higher definition at the expense of lower definition in less important zones." *Id.* (citing Ex. 1008 ¶ 60). Petitioner further contends that "Tada's third embodiment shows a lens system with an intermediate zone of enhanced definition compared to the center and edges of the system" and highlights that further enhancement of the intermediate zone by adding a further "0.12-1.88% deviation . . . would have been well within the skill of a [person of ordinary skill in the art]" and that adding such further deviation "would have been undertaken as part of routine engineering optimization techniques with a reasonable expectation that it would have lead [sic] to further improved definition in the intermediate zone while maintaining acceptable image quality." *Id.* at 47–48 (citing Ex. 1008 ¶¶ 60–61).

As to claim 21 itself, Petitioner contends that Tada's third embodiment lens system of Figure 11 together with Table 5 meets the further limitation that "the lens compresses the center of the image and the edges of the image, and expands an intermediate zone of the image located between the center and the edges of the image." *Id.* at 52–57 (citing Ex. 1008 ¶¶ 63–64, 68–72). Petitioner relies, as discussed above, on the plots of the distribution function of Tada's third embodiment. Petitioner highlights that Tada's third embodiment lens system has a similarly shaped distribution function to that of Figure 9 of the '990 patent. *Id.* at 53–54 (citing Ex. 1001, Fig. 9; Ex. 1008 ¶ 69).

b) Patent Owner's Contentions and Our Conclusions

Patent Owner raises a number of arguments as to why Petitioner has not shown Tada renders claim 21 unpatentable. Prelim. Resp. 17–36. Patent Owner identifies some as applicable to all grounds. *Id.* at 17–29. Patent Owner identifies others as specific to the ground of obviousness over Tada alone. *Id.* at 30–36. We have considered the parties evidence and argument and determine that Petitioner has demonstrated a reasonable likelihood that it would prevail in establishing that claim 21 would have been obvious over Tada, notwithstanding Patent Owner's arguments to the contrary. We focus our analysis on the issues that are disputed by Patent Owner.

Patent Owner contends that Petitioner failed to establish that the Code V analysis "could have been done by a [person of ordinary skill in the art] . . . to recreate this same analysis *at the time of the invention.*" *Id.* at 19–20. Patent Owner argues that Dr. Chipman's declaration testimony is insufficient to establish that the Code V program was available, and capable of providing the necessary calculations, at the time of invention, and that there is no other evidence of record to support Petitioner's argument. *See id.* at 20–22 (citing Pet. 39; Ex. 1008 ¶¶ 46, 51–52). Patent Owner relies on the rule that "[e]xpert testimony that does not disclose the underlying facts or data on which the opinion is based is entitled to little or no weight." *Id.* at 21–22 (quoting 37 C.F.R. § 42.65).

Based on our review of the current record, we are persuaded Petitioner has sufficiently shown that Tada renders obvious the limitations of claim 21. Petitioner contends, with supporting testimony by Dr. Chipman, that a person skilled in the art at the relevant time period would have used a computer program, such as the "Code V" program to mathematically calculate the characteristics of the lens system. *See* Pet. 39; Ex. 1008 ¶ 51. Petitioner further asserts the "software merely performs mathematical calculations applying well known principals [sic] of optics and physics" (Pet. 39; Ex. 1008 ¶ 51), and Patent Owner provides no discernable basis for any change in the principles and the mathematical calculations necessary to apply those principles in the relevant time period (*see generally* Prelim. Resp.). Applying those would reasonably allow, as Dr. Chipman testifies, "a [person of ordinary skill in the art] at the relevant time period . . . to mathematically calculate the characteristics of the lens system to test and show how it will function by providing plots of the various characteristics of the lens system." Pet. 39; Ex. 1008 ¶ 51. We find Petitioner's arguments and evidence are sufficient at this stage of the proceeding. Patent Owner's arguments raise factual disputes that are best resolved upon a full record. Further, as to the unpatentability of claim 21 grounded on the maximum divergence of Tada's third embodiment sufficing to meet the ±10%, there is no need for the calculation if the limitation simply follows as a consequence of a lens system that is otherwise rendered obvious by Tada's third embodiment such that the limitation is met.

Patent Owner also contends that the use of Tada is based on impermissible hindsight. Prelim. Resp. 22–28. Patent Owner argues that the selection of Tada itself constitutes hindsight because "Tada does not provide any image point distribution function information for any of its lens systems or describe image heights as a function of object point field angles, let alone acknowledge these concepts in its text." *Id.* at 23. Patent Owner argues that selection of Tada as the base reference where "other prior art references explicitly discussing image point distribution functions exist," as demonstrated by the citation to Nagaoka and Baker, "can only be the result of ***impermissible hindsight***." *Id.* at 23–24.

Patent Owner's argument is grounded too narrowly on the point distribution function to be persuasive in this circumstance. As discussed above, Tada discloses a super wide angle lens system for capturing a digital panoramic image, including that of its third embodiment, one of only four particular embodiments it sets forth in its disclosure. *See generally* Ex. 1007. Patent Owner provides no cogent argument to rebut Petitioner's position that one of ordinary skill in the art would look to Tada for such a method of capturing a digital panoramic image and a suitable lens system, even if it is only one reference of many disclosing such systems. *See generally* Prelim. Resp.; Pet. 33–34, 36–37.

Patent Owner also contends that Petitioner's Code V analysis constitutes impermissible hindsight. Prelim. Resp. at 24–27. Patent Owner argues, in particular, that there is no evidence provided that a person of ordinary skill in the art would have sought to obtain Tada's image point distribution function data or to determine an image point distribution function for any of Tada's lens. *Id.* at 24–26. Patent Owner discounts Dr. Chipman's testimony because it refers generally to "lens characteristics" for what a person of ordinary skill in the art would have calculated, tested, or plotted, and the actual calculations were only undertaken by Dr. Chipman in 2019. *Id.* at 24–25 (citing Ex. 1008 ¶¶ 51–52). Patent Owner contends that "the only reason to analyze Tada in this fashion comes from impermissible hindsight reconstruction." *Id.* at 26. Patent Owner further argues that Petitioner's focus on the third embodiment alone constitutes impermissible hindsight, where there are three other lens system embodiments, and that "[i]t is impermissible . . . to pick and choose from any one reference only so much of it as will support a given position, to the exclusion of other parts necessary to the full appreciation of what such reference fairly suggests to one of ordinary skill in the art." *Id.* at 26–27 (citing Pet. 34; Ex. 1007, 6:1–33, 7:35–48, 8:55–67, 9:58–67; Ex. 1008 ¶¶ 52–53) (quoting *In re Hedges*, 783 F.2d 1038, 1041 (Fed. Cir. 1986)).

Based on our review of the present record, Petitioner has sufficiently established that a person of ordinary skill in the art at the relevant time period would have been able to calculate the characteristics of the lens system to discern how it will function, including by providing plots of various characteristics. Pet. 37, 39; Ex. 1008 ¶¶ 49, 51. Petitioner's argument, supported by the testimony by Dr. Chipman, is also sufficient to show at this stage of the proceeding that a person of ordinary skill in the art would have sought to determine (or calculate) the characteristics of Tada's lens systems to understand their function. *See* Pet. 39; Ex. 1008 ¶ 51. The specific issue raised by Patent Owner here is whether a person of ordinary skill in the art would have sought to obtain such information, and more particularly, would have sought to undertake the same analysis conducted by Dr. Chipman that Petitioner relies on for showing the image point distribution of Tada's third embodiment. *See* Prelim. Resp. 24–26. Patent Owner provides no cogent argument, however, that the image point distribution function, or an equivalent measure of a lens system's function, is not required to fully understand how the lens system will function, such that Petitioner's evidence is not sufficient. *Id.* Nor does Patent Owner provide any sound basis for Dr. Chipman's testimony not reasonably encompassing calculations that include, or are an equivalent measure to, the image point distribution, where he states that a person of skill in the art would have "mathematically calculate[d] the characteristics of the lens system." Ex. 1008 ¶ 51. We note here, again, that if the maximum divergence of Tada's third embodiment suffices to meet the respective claim limitation, and lens system and its use is otherwise obvious, there is a reasonable likelihood that the lens system and its use would be established to be unpatentable over Tada's third embodiment even if one of ordinary skill in the art would not have appreciated its image point distribution function. *Cf. In re Spada*, 911 F.2d 705, 709 (Fed. Cir. 1990) ("When the claimed compositions are not novel they are not rendered patentable by recitation of properties, whether or not these properties are shown or suggested in the prior art.").

Moreover, on this record, even if Tada's third embodiment is not preferred over the other embodiments, we determine that the disclosure is sufficient because each of the four embodiments constitutes a basis for what Tada explicitly discloses as useful for capturing a digital panoramic image. Prelim. Resp. 27–28. In sum, Tada appears to disclose what is suggested by each of the four embodiments, and Patent Owner fails to explain how a different image point distribution function for the other three embodiments would undercut that of the third embodiment, or Petitioner's reliance on it. *Id.*

Patent Owner contends that all grounds fall short on the basis that "[t]here is no reason to modify a prior art reference if the proposed modification would render the reference unsatisfactory for its intended purpose." *Id.* at 28–29. Patent Owner argues that "Tada presents a list of conditions that its lens system must satisfy else it will suffer from various deficiencies in the resulting image" and that "Petitioner never considered whether the modified version of Tada's third embodiment would meet each of the express conditions." *Id.* (citing Ex. 1007, 2:7–67, 4:48–5:38). Patent Owner argues, in particular, that "Petitioner did not discuss whether the required changes would keep the lens system within the condition ranges that Tada requires for a satisfactory image" and that it is not enough, in this circumstance, for Petitioner to rely on "increasing the maximum divergence in Tada's third example embodiment . . . [as being] mere 'routine engineering optimization' . . . [that] would maintain 'acceptable' image quality." *Id.* at 29.

Patent Owner's argument is not persuasive of any shortcoming in Petitioner's challenge. First, it is not clear that the conditions Patent Owner relies on are, in fact, required such that the lens would be unsatisfactory for Tada's purposes if they are not met. Tada discusses the cited parameters as conditions that are "preferably satisfie[d]" (Ex. 1007, 2:9, 2:50–51) and describes how failure to meet these leads only to reduced performance (*id.* at 4:48–5:38). Second, Patent Owner fails to set forth that these parameters would not be met with Tada as modified. Prelim. Resp. 28–29. Third, Patent Owner offers no cogent argument that such changes, as might be required, actually amount to anything more than "routine engineering optimization," but only argues that Petitioner failed to account for the changes in its analysis. *Id.* However close certain parameters in Tada may be to what may be considered unacceptable, on this record, Petitioner adequately shows that increasing the maximum divergence in Tada's third example embodiment would be a matter of routine engineering optimization.

Turning to arguments specific to the challenge based on Tada alone, Patent Owner contends that Petitioner's theory of obviousness based on the disclosure of maximum divergence values that are "close enough" to those claimed is legally incorrect (*id.* at 30–32) and that based on routine experimentation to modify Tada is conclusory and based on hindsight rather than evidence (*id.* at 32–36).

Patent Owner argues that Petitioner's reliance on *Peterson* and *Titanium Metals* as supporting the *prima facie* obviousness of ranges over non-overlapping prior art ranges is not well founded. Prelim. Resp. 30. Patent Owner contends that "Petitioner relied on *dicta* from cases where the claimed and prior art ranges all overlapped." *Id.* Patent Owner characterizes *Titanium Metals* as an overlapping range case on the basis that individual values in the prior art bounded individual values recited in the claims, stating that the claimed alloy "with a single point for each metal, . . . which fell *between the single amounts* disclosed by the prior art," such that "the claimed values overlapped with the prior art." *Id.* at 31. Patent Owner then contends that *In re Patel*, 566 Fed. Appx. 1005 (Fed. Cir. 2014) (non-precedential), is more applicable and that it "[r]eject[s] the *dicta* of *In re Peterson*, . . . [in] that proximity alone is not enough to render non-overlapping ranges obvious – there must be some 'teaching *in the prior art* that the end points of the prior art range are approximate, or can be flexibly applied.'" *Id.* at 31–32 (citing *Patel*, 556 Fed. Appx. at 1009–1010). Patent Owner further contends that "[n]o such prior art teaching exists here." *Id.* at 32.

In *Peterson*, the Federal Circuit expressly recognized "that a *prima facie* case of obviousness exists when the claimed range and the prior art range do not overlap but are close enough such that one skilled in the art would have expected them to have the same properties." *Peterson*, 315 F.3d at 1329 (citing *Titanium Metals*, 778 F.2d at 783). Further, *Titanium Metals* does not set forth that there was an overlapping range rendering the composition unpatentable, but rather that "[t]he proportions are so close that prima facie one skilled in the art would have expected them to have the same properties." *Titanium Metals*, 778 F.2d at 783. Patent Owner's reliance on the non-binding holding in *Patel* similarly falls short, as the Federal Circuit recognized that *Patel* "does not stand for the proposition . . . that a claimed range and prior art range must overlap . . . to find a *prima facie* case." *In re Brandt*, 886 F.3d 1171, 1177 (Fed. Cir. 2018). Still further, contrary to Patent Owner's reliance on *Patel* for the notion that there must be evidence *from the prior art* that the purported range is flexible, *Brandt* relies on "the claimed range and the prior art range abut[ting] one another" and Appellants' concession "that there [was] no meaningful distinction between the two ranges," as "the insignificance of the range difference between the claims and prior art [could] be gleaned from the '858 application itself." *Id.* at 1177–79. Here the '990 patent itself likewise supports Petitioner's position that there is no meaningful distinction between the maximum divergence values of Tada's third embodiment and the 10% value, as it is characterized as a mere approximation in the '990 patent itself. Pet. 42

(citing Ex. 1001, 9:2–12; Ex. 1008 ¶ 56); Ex. 1001, 9:7–8 ("a maximum divergence on the order of 10% at least").

On this record, we determine that Petitioner has sufficiently established a basis for a *prima facie* case for this limitation on the closeness of the maximum divergence of Tada's third embodiment to the recited maximum divergence of at least ±10% where the divergence is characterized as an approximation. *Cf. E.I. DuPont de Nemours & Co. v. Synvina C.V.*, 904 F.3d 996, 1006 (Fed. Cir. 2018) (applying the concept of *prima facie* obviousness based on overlapping ranges in the context of an *inter partes* review trial). The closeness of the values, including the -9.88% maximum deviation, to the recited "at least ±10%," depends in part on whether the trailing zero in 10% is significant. While not necessary to support our decision to institute *inter partes* review, as we determine a reasonable basis for doing so based on the values as expressly written, but characterized as an approximation, the parties may wish to address this issue in further briefing.

Patent Owner argues that Petitioner's reliance on modifying Tada's third embodiment as a matter of routine experimentation falls short, because the rationale merely presumes that a person of ordinary skill in the art would have found the allegedly expanded intermediate zone in Tada's third embodiment to be important and worth expanding through increasing the maximum divergence point. Prelim. Resp. 33 (citing Pet. 46–48). Patent Owner further argues that Petitioner's presumption that the intermediate zone is of primary importance overlooks that Tada's specification emphasizes the importance of resulting image edges. *Id.* at 33–34 (citing Ex. 1007, 1:11–27, 1:39–41, 1:48–2:6, 4:9–20, 5:3–7, 6:6–12). Patent Owner further argues that Petitioner also ignored examining Tada's third embodiment lens within the context in which it was identified, instead relying on a general assertion that "*[d]epending on the application* of the lens, it *may be* desirable that a particular zone have higher definition at the expense of lower definition in less important zone" without ever identifying the particular application. *Id.* at 34–35 (quoting Pet. 47; citing Pet. 46–48; Ex. 1007, 1:7–9) (alteration in original). Patent Owner further contends that, at best, all Petitioner establishes is that a person of ordinary skill in the art could have modified Tada in the fashion claimed, and not that they would have done so, and that this is insufficient to establish obviousness. *Id.* at 35 (citing *Belden Inc. v. Berk-Tek LLC*, 805 F.3d 1064, 1073 (Fed. Cir. 2015)). Patent Owner also argues that Dr. Chipman's declaration falls short of establishing a "reason to modify Tada." *Id.* at 35–36.

Based on our review of the current record, we are persuaded Petitioner has sufficiently articulated a reason with some rational underpinning to modify Tada to arrive at the subject matter of claim 21. Petitioner asserts the divergence is a result effective variable in the functioning of the lens system, or reflects such, in that deviation from a linear function results in compression or expansion of the projected image zone relative to the panorama being viewed. Pet. 46–48 (citing Ex. 1008 ¶¶ 59–61). Moreover, Petitioner and Dr. Chipman tie this to the definition of the image captured in different zones of the field of view. *Id.* (citing Ex. 1008 ¶ 60). For purposes of institution, the recited range is reasonably established as *prima facie* obvious as a matter of routine experimentation. *Id.* at 48; *see also Aller*, 220 F.2d at 456 ("[W]here the general conditions of a claim are disclosed in the prior art, it is not inventive to discover the optimum or workable ranges by routine experimentation.") (cited at Pet. 47).

Thus, what Patent Owner contends is not established by Petitioner, the particular importance of the intermediate zone and a particular teaching to further expand it, is not necessary under this obviousness theory set forth by Petitioner. Further, Patent Owner's emphasis on the contended failure by Petitioner to identify what would be an optimal lens system fails to address that workable ranges meeting the claim reasonably would be within the grasp of the skilled artisan through no more than routine experimentation. *See Aller*, 220 F.2d at 456; Pet. 46–48.

For the foregoing reasons, Petitioner has sufficiently demonstrated a reasonable likelihood that it would prevail in establishing the unpatentability of claim 21 as obvious over Tada.

Having determined that Petitioner has demonstrated a reasonable likelihood of success in proving that at least one claim of the '990 patent is unpatentable, we institute a review as to all challenged claims, i.e., claim 21, and all grounds raised in the Petition. *See SAS Inst., Inc. v. Iancu*, 138 S. Ct. 1348, 1359–60 (2018); USPTO, Guidance on the Impact of *SAS* on AIA Trial Proceedings (April 26, 2018), https://www.uspto.gov/patents-application-process/patent-trial-and-appeal-board/trials/guidance-impact-sas-aia-trial ("As required by [SAS], the PTAB will institute as to all claims or none," and "[a]t this time, if the PTAB institutes a trial, the PTAB will institute on all challenges raised in the petition."); PTAB Consolidated Trial Practice Guide (Nov. 2019) ("Consolidated Guide"), 5–6 (available at https://www.uspto.gov/TrialPracticeGuideConsolidated).

We offer the following views on the remaining grounds for the parties' consideration.

E. Asserted Obviousness over Tada in View of Nagaoka

Petitioner challenges claim 21 as unpatentable for having been obvious over the combined teachings of Tada and Nagaoka. Pet. 57–68.

Nagaoka is directed to a monitoring system using a camera having a fisheye lens. Ex. 1004, 1:6–10, 1:11–14. Nagaoka discloses a number of different fisheye lenses having a nonlinear distribution function of image points relative to the field angle of the object points of the panorama. *Id.*, Figs. 3A–3B.

Petitioner contends that Nagaoka teaches the limitations of claim 17 (Pet. 58–63 (citing Ex. 1004, 1:38–41, 1:50–57, 2:44–53, 5:28–29, Figs. 3A, 3B; Ex. 1008 ¶¶ 75–82)), and that Patent Owner "provided a clear and unambiguous admission in the reexamination that claim 17 is taught by Nagaoka" (*id.* at 58 (citing Ex. 1003, 245–46, 331)). Despite this, Petitioner largely relies on Tada as set forth above for the ground with Tada alone (*compare id.* at 63–65, *with id.* at 33–57) and further on Nagaoka for teaching the maximum deviation of at least ±10% (*id.* at 63–68).

Petitioner relies on Nagaoka's disclosure of a fisheye lens having a nonlinear distribution function, including two examples—$h=1.2f \cdot \tan(\theta/1.6)$ and $h=1.6f \cdot \tan(\theta/2)$. *Id.* at 59–63 (citing Ex. 1004, Fig. 3B). Petitioner calculates "a plot of the relative distance of an image point in relation to the center of the image according to the field angle of the corresponding object point" for these functions "with a focal length of $f=1$" and overlays these with a linear distribution to demonstrate that the lens having the function $h=1.2f \cdot \tan(\theta/1.6)$ has a maximum divergence -24.19% and a lens having the function $h=1.6f \cdot \tan(\theta/2)$ has a maximum divergence of at least -14.76%. *Id.* at 61–63 (citing Ex. 1008 ¶¶ 79–82).

Petitioner contends that it would have been obvious to combine Tada with the teachings of Nagaoka, as "Tada and Nagaoka are in the same field of endeavor, e.g., super wide angle lenses and imaging lenses." *Id.* at 63 (citing Ex. 1007, 1:6–9, 6:29–33, 7:36–44, 8:59–64; Ex. 1004, Fig. 2, 3:36–

40, 4:66–5:2, 7:11–16, 7:31–35, 7:50–52, 7:60–67; Ex. 1008 ¶ 83). Petitioner further contends that "Nagaoka teaches the use of non-linear curves for fisheye lens[es] to increase the resolution of an area of interest, which in Nagaoka is at the edge or periphery of the image." *Id.* at 66 (citing Ex. 1008 ¶ 88); *see id.* at 65–66 (citing Ex. 1004, 1:50–57, 1:61–2:4, 2:43–53, 6:53–65, 9:30–44; Ex. 1008 ¶ 87).

Petitioner contends that "[i]n Tada's third embodiment, the area of interest is the intermediate zone," and that a person of ordinary skill in the art "with the teachings of Nagaoka would have been motivated to increase the maximum deviation of the lens in Tada from approximately between 8.12 and 9.88% to at least ±10% in order to increase the resolution in Tada's area of interest, *i.e.*, the intermediate zone of the image." Pet. 66 (citing Ex. 1008 ¶ 88). In effect, Petitioner relies on the fact that the intermediate zone in Tada's third embodiment has enhanced definition compared to the center and edges of the system as indicating that it is the area of interest. *Id.* at 64 (citing Ex. 1008 ¶ 85).

As discussed above, Patent Owner argues that Petitioner cites no underlying facts or data in support of the idea that the expanded intermediate zone in Tada's third embodiment is important. Prelim. Resp. 33 (citing Pet. 46–48). Patent Owner further argues that Nagaoka teaches away from use of an "objective lens [that] compresses . . . the edges of the image, and expands an intermediate zone of the image located between the center and the edges of the image" (claim 21) in that "Nagaoka explicitly teaches that enhancement or expansion is needed at the *peripheral* portion (as opposed to a central or intermediate portion) due to image distortion and 'many missing portions of image data' there which 'must be interpolated.'" *Id.* at 38 (citing Ex. 1004, 1:48–60); *see id.* (citing Ex. 1004, 1:61–2:4, 6:30–52, 6:60–65).

Patent Owner's general arguments appear more cogent here than when applied to the ground based on Tada alone. Petitioner's further reasoning here relies on the intermediate expanded zone of Tada's third embodiment being a particular area of interest, and then on further expansion of that based on the teachings of Nagaoka. Pet. 64 (citing Ex. 1008 ¶ 85), 66 (citing Ex. 1008 ¶ 88). As such, this further reasoning requires a sufficient showing that a person of ordinary skill in the art would have recognized the importance of the expanded intermediate zone, a showing that Patent Owner contends Petitioner has not made. Prelim. Resp. 33 (citing Pet. 46–48). Patent Owner's arguments that Nagaoka teaches away may also have some merit because of Nagaoka's apparent focus on enhancement or expansion of the image at the peripheral portion. *Id.* at 38 (citing Ex. 1004, 1:48–2:4, 6:30–52, 6:60–65).

F. Asserted Obviousness over Tada in View of Baker

Petitioner challenges claim 21 as unpatentable for having been obvious over the combined teachings of Tada and Baker. Pet. 68–77.

Baker is directed to a videoconference system using a lens system that provides a panoramic display. Ex. 1005, Abstract. Baker discloses wide angle lenses that have "a fairly significant portion of the imaging surface dedicated to the peripheral field [of the field of view], and consequently less of the surface dedicated to the central field" than "typical with commercially available wide-angle, fish-eye, or other conventional lenses." *Id.* at 11:47–48, 12:30–32.

Petitioner contends that Baker teaches the limitations of claim 17 (Pet. 68–72 (citing Ex. 1005, 6:48–56, 8:32–36, 12:6–11; Ex. 1008 ¶¶ 92, 94–96)) and that Patent Owner "provided a clear and unambiguous admission in the reexamination that claim 17 is taught by Baker" (*id.* at 68–

69 (citing Ex. 1003, 331); *see also id.* at 71–72 (citing Ex. 1003, 240), 76–77 (citing Ex. 1003 at 19, 37, 239–41)). Despite this, Petitioner largely relies on Tada as set forth above for the ground with Tada alone (*compare id.* at 72–74, *with id.* at 33–57) and further on Baker for teaching the maximum deviation of at least ±10% (*id.* at 74–76).

Petitioner relies on Baker's disclosure of a fisheye lens having a nonlinear distribution function, and on a plot of such a lens showing its nonlinearity. *Id.* at 69–71 (citing Ex. 1005, 6:48–56, 8:32–36, 12:6–11; Ex. 1008 ¶¶ 92, 94–96). Petitioner relies on Baker's disclosure that "using a 'hemispherical gradient index unit with a wide field multi-element lens' such that 'the portion of the camera dedicated to the periphery is increased, thereby increasing the relative resolution of information detectable by the imaging device sensing elements'" (*id.* at 69 (citing Ex. 1005, 12:6–11)) and its statement that "'[t]o maximize data collection and resolution for analysis and/or display . . . , it is desirable to maximize the dedication of the available image detection area to this peripheral field portion'" (*id.* (citing Ex. 1005, 8:32–36)). Petitioner also relies on the testimony of Dr. Chipman "that these goals are achieved by use of a non-linear function." *Id.* at 69–70 (citing Ex. 1008 ¶ 92). Petitioner relies particularly on a plot it contends "corresponds to the description of the lens in Baker" and "would have a maximum deviation of **15.1%**." *Id.* at 70–71 (citing Ex. 1008 ¶ 95).

Petitioner contends that it would have been obvious to combine Tada with the teachings of Baker, because "Tada and Baker are in the same field of endeavor, *e.g.*, wide angle lenses and imaging lenses." Pet. 72 (citing Ex. 1007, 1:6–9, 6:29–33, 7:36–44, 8:59–64; Ex. 1005, 13:11–17; Ex. 1008 ¶ 97). Petitioner further contends Baker provides motivation for one of skill in the art to increase the maximum deviation in its teachings and disclosure of a non-linear lens "designed to capture and enhance the peripheral content of a hemispheric scene." *Id.* at 74–75 (citing Ex. 1005, 2:59–61, 2:65–3:3, 6:44–48, 8:32–36, 8:60–62, 10:38–41, 12:48–55, Fig. 3BA; Ex. 1008 ¶¶ 101, 103). In sum, Petitioner contends that "Baker teaches the use of non-linear curves for fisheye lens [sic] to increase the resolution of an area of interest, which in Baker is the periphery of the lens system" and that "Baker also teaches that the area of interest can vary based on the needs of the application." *Id.* at 75 (citing Ex. 1008 ¶ 103).

Petitioner contends that "[i]n Tada's third embodiment, the area of interest is the intermediate zone, rather than the edge or periphery of the image" and that a person of ordinary skill in the art "with the teachings of Baker would have been motivated to increase the maximum deviation of the lens in Tada from approximately between 8.12 and 9.88% to at least ±10% in order to increase the resolution in Tada's area of interest, i.e., the intermediate zone of the image." Pet. 75–76 (citing Ex. 1008 ¶ 103). In effect, Petitioner again relies on the fact that the intermediate zone in Tada's third embodiment has enhanced definition compared to the center and edges of the system as indicating that it is the area of interest. *Id.* at 72–73 (citing Ex. 1008 ¶ 99).

As discussed above, Patent Owner argues that Petitioner cites no underlying facts or data in support of the idea that the expanded intermediate zone in Tada's third embodiment is important. Prelim. Resp. 33 (citing Pet. 46–48), 40 (citing Pet. 67–69 [sic, 72–74]). Patent Owner further argues that Baker teaches away from use of an "objective lens [that] compresses . . . the edges of the image, and expands an intermediate zone of the image located between the center and the edges of the image" (claim 21) in that "Baker, as a whole, teaches that it is important to enhance or expand the periphery of an image based on degradation experienced from conventional lenses." *Id.* at 40–41 (citing Ex. 1005, 3:60–4:14, 10:38–12:55). Patent Owner further faults Petitioner's reliance on a selective quote from a more complete citation as support for Baker teaching that the enhanced field of view can be anything other than the peripheral region. Prelim. Resp. 41–42 (citing Pet. 75; Ex. 1005, 12:33–51).

For similar reasons as with the combination of Tada and Nagaoka, Patent Owner's general arguments appear more cogent here than when applied to the ground based on Tada alone. As with the combination of Tada and Nagaoka, Petitioner's further reasoning here relies on the intermediate expanded zone of Tada's third embodiment being a particular area of interest (Pet. 72–73 (citing Ex. 1008 ¶ 99), 75–76 (citing Ex. 1008 ¶ 103)), and then on further expansion of that based on the teachings of a further reference, here, Baker (*id.* at 74–75 (citing Ex. 1005, 2:59–61, 2:65–3:3, 6:44–48, 8:32–36, 8:60–62, 10:38–41, 12:48–55, Fig. 3BA; Ex. 1008 ¶¶ 101, 103)). And again, Patent Owner contends that Petitioner has not made a sufficient showing that a person of ordinary skill in the art would have recognized the importance of the expanded intermediate zone. Prelim. Resp. 33 (citing Pet. 46–48), 40 (citing Pet. 67–69 [sic, 72–74]). Patent Owner's arguments that Baker teaches away may also have some merit because of Baker's apparent focus on enhancement or expansion of the periphery of an image. *Id.* at 40–41 (citing Ex. 1005, 3:60–4:14, 10:38–12:55).

IV. CONCLUSION

For the reasons set forth above, we determine that Petitioner has demonstrated a reasonable likelihood of prevailing with respect to the one challenged claim of the '990 patent. Thus, we institute an *inter partes* review on the one challenged claim and on all grounds presented in the Petition.

V. ORDER

Accordingly, it is:

ORDERED that pursuant to 35 U.S.C. § 314(a), an *inter partes* review is hereby instituted as to claim 21 of the '990 patent with respect to the grounds set forth in the Petition; and

FURTHER ORDERED that pursuant to 35 U.S.C. § 314(c) and 37 C.F.R. § 42.4, notice is hereby given of the institution of a trial commencing on the entry date of this decision.

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Paper 6
Entered: May 13, 2020

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

LG ELECTRONICS INC.,
Petitioner,

v.

IMMERVISION, INC.,
Patent Owner.

IPR2020-00179
Patent 6,844,990 B2

Before KRISTINA M. KALAN, WESLEY B. DERRICK, and KIMBERLY McGRAW, *Administrative Patent Judges.*

DERRICK, *Administrative Patent Judge.*

DECISION
Granting Institution of *Inter Partes* Review
35 U.S.C. § 314

I. INTRODUCTION

On November 27, 2019, LG Electronics Inc. ("Petitioner" or "LG Electronics") filed a Petition requesting an *inter partes* review of claim 5 ("the challenged claim") of U.S. Patent No. 6,844,990 B2 (Ex. 1001, "the '990 patent"). Paper 2 ("Pet."). ImmerVision, Inc. ("Patent Owner" or "ImmerVision") filed a Preliminary Response to the Petition. Paper 5 ("Prelim. Resp.").

We have authority to determine whether to institute an *inter partes* review. *See* 35 U.S.C. § 314(b) (2018); 37 C.F.R. § 42.4(a). To institute an *inter partes* review, we must determine that the information presented in the Petition shows that there is "a reasonable likelihood that the petitioner would prevail with respect to at least 1 of the claims challenged in the petition." 35 U.S.C. § 314(a). Applying that standard, for the reasons set forth below, we institute an *inter partes* review as to all grounds raised in the Petition.

II. BACKGROUND

A. Real Parties in Interest

Petitioner LG Electronics Inc. identifies LG Electronics U.S.A., Inc. and LG Innotek Co. Ltd. as additional real parties-in-interest. Pet. 2. Patent Owner ImmerVision, Inc., identifies itself as the real party-in-interest. Paper 4, 2. The parties do not raise any issue about real parties-in-interest.

B. Related Proceedings

The parties identify two pending district court cases involving the '990 patent as related matters: *ImmerVision, Inc. v. LG Electronics U.S.A.*, Case No. 1-18-cv-01630 (D. Del.) and *ImmerVision, Inc. v. LG Electronics U.S.A.*, Case No. 1-18-cv-01631 (D. Del.). Pet. 2; Paper 4, 2–3.

Petitioner concurrently filed another petition that challenges claim 21 of the '990 patent. *See LG Electronics Inc. v. Immervision, Inc.*, IPR2020-00195, Paper 2.

In addition, Petitioner states the '990 patent: (1) was the subject of *Ex Parte* Reexamination Control No. 90/013,410; (2) was challenged in an *inter partes* proceeding, *Panasonic System Networks Co., Ltd. v. 6115187 CANADA INC.*, IPR2014-01438; and (3) was the subject of three other district court cases, now closed. *See* Pet. 2–3; *see also Panasonic System Networks Co., Ltd. v. 6115187 CANADA INC.*, IPR2014-01438, Paper 11 (PTAB Nov. 26, 2014) (terminating proceeding prior to institution following settlement).

C. The '990 Patent (Ex. 1001)

The '990 patent is titled "Method for Capturing and Displaying a Variable Resolution Digital Panoramic Image" and issued on Jan. 18, 2005, from an application filed on Nov. 12, 2003. Ex. 1001, code (22), (45), (54). The application for the '990 patent is a continuation of application No. PCT/FR02/01588, filed on May 10, 2002, and claims priority to foreign application FR 01 06261, filed May 11, 2001. *Id.* at code (30), (63).

The '990 patent is directed to capturing a digital panoramic image that includes using a panoramic objective lens having "a distribution function of the image points that is not linear relative to the field angle of the object points of the panorama." *Id.*, Abstract. The image obtained using such a panoramic objective lens has at least one zone that is expanded and another zone that is compressed. *Id.* The patent further provides for correcting the non-linearity of the panoramic image initially obtained. *Id.*

The '990 patent was the subject of an *ex parte* reexamination. *Id.* at 25–27 (Ex Parte Reexamination Certificate (10588th)). The

Reexamination Request—Control No. 90/013,410—was filed November 26, 2014. *Id.* at 25; Ex. 1003, 328–339 ("Request by Patent Owner for *Ex Parte* Reexamination of U.S. Patent No. 6,844,990"). Patent Owner cancelled, *inter alia*, claim 1 by way of preliminary amendment that accompanied its request for *ex parte* reexamination of claims 1–4, 6, 7, 10, 11, 15–20, 22, 23, and 25. *See* Pet. 17–18; Ex. 1003, 330, 341. The Patent Office granted Patent Owner's request for reexamination of the identified claims. Ex. 1003, 52–63. The Patent Office declined to reexamine claims 5, 8, 9, 12–14, 21, 24, and 26 on the basis that "the requester did not request reexamination of . . . and did not assert the existence of a substantial new question of patentability for those claims." *Id.* at 56 (citing 35 U.S.C. § 311(b)(2)). At the conclusion of the proceeding, the Patent Office issued an *Ex Parte* Reexamination Certificate cancelling claims 1, 6, 7, 17–20, 22, 23, and 25; determining claims 2–4, 10, and 15 to be patentable as amended; determining claims 11 and 16 dependent on an amended claim to be patentable; and adding and determining to be patentable new claims 27–47. Ex. 1001, 25–27; Ex. 1003, 1–3.

D. Claimed Subject Matter

Challenged claim 5 incorporates the limitations of cancelled claim 1, from which it depends. *See* MPEP § 2260.01 ("the content of the canceled base claim . . . [is] available to be read as part of the confirmed or allowed dependent claim"). Both claims are reproduced below.

> 1. A method for capturing a digital panoramic image, by projecting a panorama onto an image sensor by means of a panoramic objective lens, the panoramic objective lens having an image point distribution function that is not linear relative to the field angle of object points of the panorama, the distribution function having a maximum divergence of at least ±10% compared to a linear distribution function, such that the

> panoramic image obtained has at least one substantially compressed zone.

Ex. 1001, 19:28–37.

> 5. The method according to claim 1, wherein the objective lens compresses the center of the image and the edges of the image and expands an intermediate zone of the image located between the center and the edges of the image.

Ex. 1001, 19:49–52.

E. Evidence

Petitioner relies upon the following prior art references in the asserted grounds of unpatentability:

Reference	Date	Exhibit No.
US 5,861, 999 ("Tada")	Jan. 19, 1999, filed Aug. 21, 1997	1007
US 6,128,145 ("Nagaoka")	Oct. 3, 2000, filed Apr. 28, 1999	1004
US 5,686,957 ("Baker")	Nov. 11, 1997, filed Jun. 30, 1995	1005

Petitioner also relies on the Declaration of Russell Chipman, Ph.D. (Ex. 1008).

F. The Asserted Grounds of Unpatentability

Petitioner contends that the challenged claim is unpatentable based on the following grounds:

Claim(s) Challenged	**35 U.S.C. §[1]**	**Reference(s)/Basis**
5	103	Tada

[1] The Leahy-Smith America Invents Act ("AIA"), Pub. L. No. 112–29, 125 Stat. 284, 287–88 (2011), revised 35 U.S.C. § 103 effective March 16, 2013. Because the challenged patent was filed before March 16, 2013, we refer to the pre-AIA version of 35 U.S.C. § 103.

Claim(s) Challenged	35 U.S.C. §[1]	Reference(s)/Basis
5	103	Tada, Nagaoka
5	103	Tada, Baker

III. ANALYSIS

A. Level of Ordinary Skill in the Art

Petitioner contends that a person of ordinary skill in the art "would have had at least a bachelor's degree in Physics, Optical Engineering, and/or Electrical Engineering and at least five years' experience in developing and designing optical products or systems and have familiarity with image processing algorithms and optical design software." Pet. 20 (citing Ex. 1008 ¶ 41).

Patent Owner neither disputes Petitioner's articulation of the level of ordinary skill in the art nor presents its own articulation of the level of skill in the art, stating that "[a]t this stage of the proceeding, . . . for purposes of [the] Preliminary Response, Patent Owner does not object to Petitioner's proposed skill level." Prelim. Resp. 16.

On this record, we have no reason to fault Petitioner's definition of the level of ordinary skill and, therefore, adopt it for the purposes of this Decision. We further note that the prior art itself demonstrates the level of skill in the art at the time of the invention. *See Okajima v. Bourdeau*, 261 F.3d 1350, 1355 (Fed. Cir. 2001) (explaining that "specific findings on the level of skill in the art . . . [are not required] 'where the prior art itself reflects an appropriate level and a need for testimony is not shown'" (quoting *Litton Indus. Prods., Inc. v. Solid State Sys. Corp.*, 755 F.2d 158, 163 (Fed. Cir. 1985))).

B. Claim Construction

1. Standard of Construction

For petitions filed on or after November 13, 2018, we apply the claim construction standard from *Phillips v. AWH Corp.*, 415 F.3d 1303 (Fed. Cir. 2005) (en banc). 37 C.F.R. § 42.100(b) (2019).

Claim terms are generally given their ordinary and customary meaning as would be understood by one with ordinary skill in the art in the context of the specification, the prosecution history, other claims, and even extrinsic evidence including expert and inventor testimony, dictionaries, and learned treatises, although extrinsic evidence is less significant than the intrinsic record. *Phillips*, 415 F.3d at 1312–1317. Usually, the specification is dispositive, and it is the single best guide to the meaning of a disputed term. *Id.* at 1315.

Only those claim terms that are in controversy need to be construed and only to the extent necessary to resolve the controversy. *Nidec Motor Corp. v. Zhongshan Broad Ocean Motor Co.*, 868 F.3d 1013, 1017 (Fed. Cir. 2017); *see also U.S. Surgical Corp. v. Ethicon, Inc.*, 103 F.3d 1554, 1568 (Fed. Cir. 1997) (holding claim construction is not necessary when it is not "directed to, or has been shown reasonably to affect, the determination of obviousness").

2. Proposed Constructions

Petitioner proposes constructions for seven claim terms. *See* Pet. 21–25. Petitioner contends that "'[p]anoramic objective lens' should be construed to mean a super-wide or ultra-wide angle objective lens." *Id.* at 21 (citing Ex. 1001, 1:18–20; Ex. 1008 ¶ 44). Petitioner contends that "[o]bject points of the panorama' should be construed as points of the object in the panorama being viewed by the lens." *Id.* at 21–22 (citing Ex. 1001, 7:2–5,

Fig. 5; Ex. 1008 ¶ 52). Petitioner contends that "'[i]mage point' should be construed as a point of light projected by the lens onto an image plane, said light coming from the corresponding object point of a viewed object in the panorama." *Id.* at 22 (citing Ex. 1001, 7:11–14, Fig. 5; Ex. 1008 ¶ 52). Petitioner contends that "'[f]ield angle of object points' should be construed as the angles of incident light rays passing through the object points and through the center of the panorama photographed, relative to the optical axis of the objective lens." *Id.* at 23 (citing Ex. 1001, 2:18–22; Ex. 1008 ¶ 52). Petitioner contends that "maximum divergence" is defined by the '990 patent according to the formula "DIVmax %=[[dr(Pd)-dr(Pdl)]/[dr(Pdl)]]*100, in which dr(Pd) is the relative distance in relation to the center of the point of maximum divergence Pd, and dr(Pdl) is the relative distance in relation to the center of the corresponding point on the linear distribution line." *Id.* at 23–24 (citing Ex. 1001, 8:57–65; Ex. 1008 ¶ 57). Petitioner contends that "[e]xpanded zone' should be construed as the portion of the image point distribution function where the gradient is higher than the gradient of the linear distribution function." *Id.* at 24 (citing Ex. 1001, 8:38–43, Fig. 9; Ex. 1008 ¶ 63). Petitioner contends that "[c]ompressed zone' should be construed as the portion of the image point distribution function where the gradient is lower than the gradient of the linear distribution function." *Id.* at 24–25 (citing Ex. 1001, 8:38–43, Fig. 9; Ex. 1008 ¶ 63).

Patent Owner does not contest the proposed constructions of the claim terms at this stage of the proceeding, stating that "for purposes of this Preliminary Response, Patent Owner does not object to the definitions set out by Petitioner." Prelim. Resp. 16.

Based on the current record, and for the purpose of this decision, we adopt the constructions set forth by Petitioner, because these appear reasonable and are not contested. Any further construction is not necessary at this time for the purpose of this decision.

C. Principles of Law

A claim is unpatentable under 35 U.S.C. § 103 if "the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains." *KSR Int'l Co. v. Teleflex Inc.*, 550 U.S. 398, 406 (2007). The question of obviousness is resolved on the basis of underlying factual determinations, including: (1) the scope and content of the prior art; (2) any differences between the claimed subject matter and the prior art; (3) the level of skill in the art; and (4) if in evidence, objective evidence of nonobviousness, i.e., secondary considerations. *See Graham v. John Deere Co.*, 383 U.S. 1, 17–18 (1966).

"In an [*inter partes* review], the petitioner has the burden from the onset to show with particularity why the patent it challenges is unpatentable." *Harmonic Inc. v. Avid Tech., Inc.*, 815 F.3d 1356, 1363 (Fed. Cir. 2016) (citing 35 U.S.C. § 312(a)(3) as "requiring *inter partes* review petitions to identify 'with particularity . . . the evidence that supports the grounds for the challenge to each claim'"); *cf. Intelligent Bio-Systems, Inc. v. Illumina Cambridge, Ltd.*, 821 F.3d 1359, 1369 (Fed. Cir. 2016) (quoting 35 U.S.C. § 312(a)(3)) (addressing "the requirement that the initial petition identify 'with particularity' the evidence that supports the grounds for the challenge to each claim'"). This burden never shifts to Patent Owner. *See Dynamic Drinkware, LLC v. Nat'l Graphics, Inc.*, 800 F.3d 1375, 1378

(Fed. Cir. 2015) (citing *Tech. Licensing Corp. v. Videotek, Inc.*, 545 F.3d 1316, 1326–27 (Fed. Cir. 2008)) (discussing the burden of proof in *inter partes* review). Furthermore, Petitioner cannot satisfy its burden of proving obviousness by employing "mere conclusory statements." *In re Magnum Oil Tools Int'l, Ltd.*, 829 F.3d 1364, 1380 (Fed. Cir. 2016).

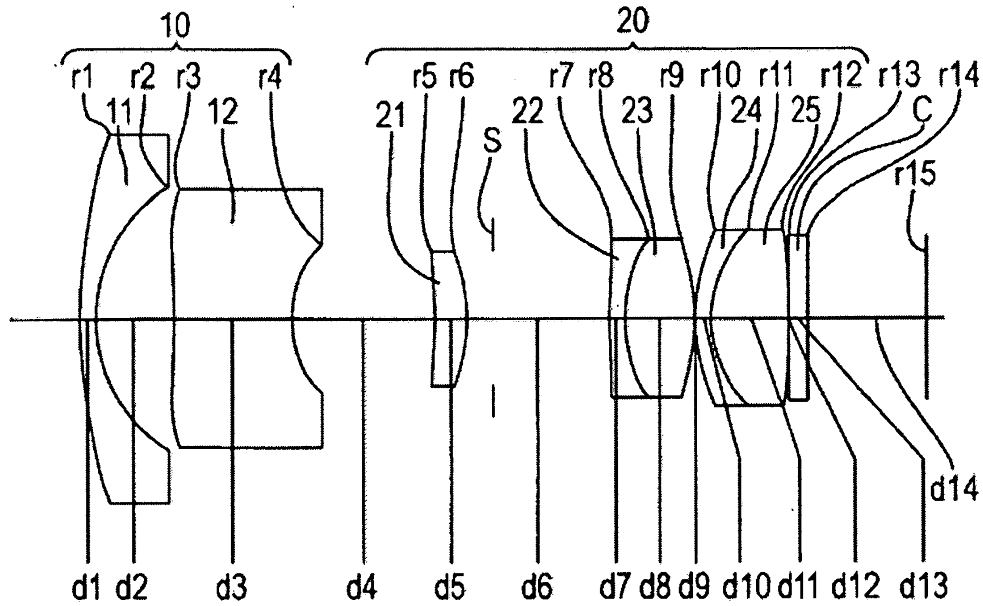
D. Asserted Obviousness over Tada

Petitioner challenges claim 5 as unpatentable for having been obvious over Tada. Pet. 29–52.

1. Tada (Ex. 1007)

Tada discloses a method for capturing a digital panoramic image, including by use of "a super wide angle lens system which can be used for a monitoring camera (CCTV) etc." Ex. 1007, 1:7–9. Tada states that "[i]t is an object . . . to provide a retrofocus type super wide angle lens system . . . [having] an angle of view of approximately 120° to 140°." *Id.* at 1:48–50. Tada identifies Figure 11 as "show[ing] a third embodiment of a super wide angle lens system." *Id.* at 8:59–64; Fig. 11. The third embodiment, as depicted in Figure 11 below, "is substantially the same as the second embodiment," depicted in Figure 6, which "is substantially the same as that of the first embodiment," depicted in Figure 1. *Id.* at 6:2–3, 7:36–43, 8:58–62.

FIG. 11



Tada's Figure 11 (reproduced above) depicts the lens arrangement of a super wide angle lens system. *Id.* at 3:44–46, Fig. 11. The depicted super wide angle lens system consists of front lens group 10 and rear lens group 20. *See id.* at 6:4–5 (identifying elements in reference to Figure 1). Figure 11 also depicts features of a CCD[2] (charge-coupled device) used to capture an image; element C refers to "a glass cover of the CCD" and "surface No. 15 refers to the image pickup surface of the CCD." *See id.* at 6:26–32 (identifying elements in reference to Figure 1). Tada's Figures 5 and 6 disclose numerical data regarding the third embodiment, including "[t]he surface figure, paraxial spherical amount and aspherical amount of surface No. 3." *Id.* at 8:63–9:57.

[2] Although neither Tada nor the Petitioner define "CCD," we understand CCD to be a "charge-coupled device."

2. Analysis

Claim 5, which incorporates the limitations of cancelled claim 1 from which it depends, is directed to a method of capturing a digital panoramic image by use of a panoramic objective lens to project a panorama onto an image sensor. In general, claim 1 requires that the panoramic objective lens used to capture the image has a distribution function of the image points that is not linear to the field angle of the object points of the panorama, having a maximum divergence that is at least ±10% compared to a linear distribution function. Ex. 1001, 19:28–37. Claim 5 further requires that "the objective lens compresses the center of the image and edges of the image and expands an intermediate zone of the image located between the center and the edges of the image." *Id.* at 19:49–52.

a) Petitioner's Contentions

Petitioner contends that Tada discloses a method of capturing a digital panoramic image using a panoramic objective lens that compresses the center of the image and edges of the image and expands an intermediate zone of the image located between the center and edges of the image. Pet. 29–37. Petitioner relies on Tada's third embodiment, as set forth in Figure 11 and Table 5, and calculations based on the disclosure for the distribution function of image points for different wavelengths of visible light. *Id.* at 31–37 (citing Ex. 1007, Fig. 11, Table 5). Petitioner further contends that the objective lens has a distribution function of image points that deviates from being linear to the field angle of the object points by an amount sufficient to meet the ±10% limitation of claim 1, and that, if not meeting the limitation outright, that it would have been obvious to a person of ordinary skill in the art to modify the lens system to increase the maximum deviation in the expansion zone in order to increase the resolution of the acquired image. *Id.* at 37–46. Petitioner relies, in effect, on Tada's third embodiment rendering the objective lens with the ±10% deviation limitation *prima facie* obvious on the basis that it would have been expected to have the same properties, and on the basis that the deviation amounts to nothing more than a result effective variable that is subject to routine optimization. *Id.*

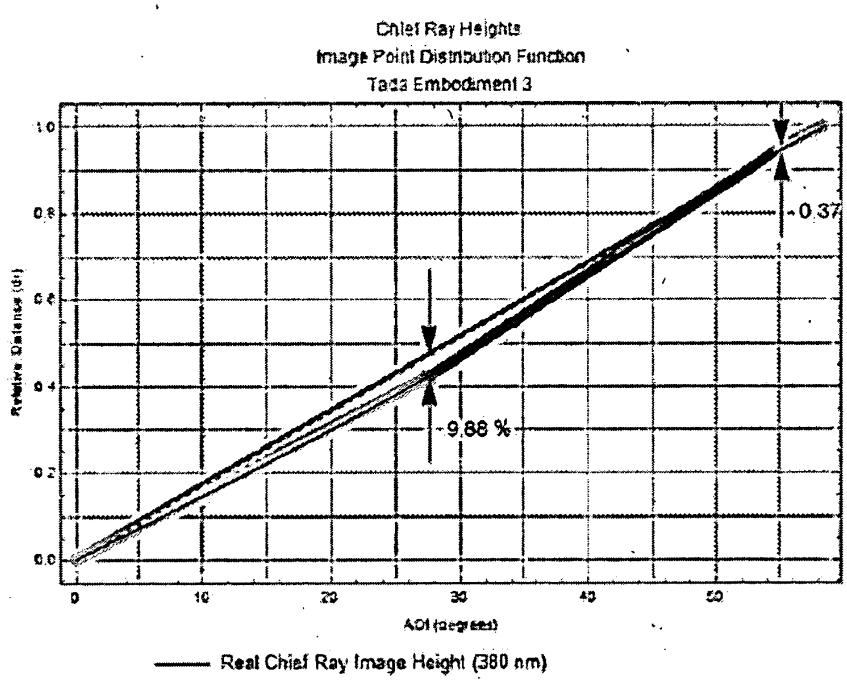
Petitioner addresses the limitations of base independent claim 1 and of claim 5 in turn.

Petitioner contends that Tada teaches the recited "method for capturing a digital panoramic image by projecting a panorama onto an image sensor by means of a panoramic objective lens" in its disclosure of a super wide angle lens system for a monitoring CCTV camera, including the third embodiment depicted in Figure 11. *See id.* at 29–32 (citing Ex. 1007, 1:7–9, 1:48–50, 6:2–5, 6:26–32, 7:36–43, 8:58–64, Fig. 11; Ex. 1008 ¶¶ 44–45, 47). Petitioner also contends that its expert, Dr. Chipman, "reconstructed" the third embodiment depicted in Figure 11 using the information from Table 5. *Id.* at 31–32 (citing Ex. 1008 ¶ 47); *see* Ex. 1008 ¶ 46.

Petitioner contends that Tada teaches the recited "panoramic objective lens having an image point distribution function that is not linear relative to the field angle of object points of the panorama." *See* Pet. 32–37 (citing Ex. 1007, 5:46–53, 9:1–24 (Table 5), Fig. 11; Ex. 1008 ¶¶ 49–54). Petitioner relies on Dr. Chipman's testimony that Tada's disclosure of "schematic views of the lens arrangements, diagrams of the aberrations, astigmatism and distortion experienced by the particular lens systems disclosed, and tables of measurements of the lens" allows "one of ordinary skill in the art to reconstruct the exact lens systems described in Tada." *Id.* at 32; Ex. 1008 ¶ 49. In addition, Petitioner details the numerical data from

Table 5, and contends that a person of ordinary skill in the art "at the relevant time period would have used a [computer] program . . . to mathematically calculate the characteristics of the lens system to test and show how it will function by providing plots of the various characteristics of the lens system." Pet. 33–34 (citing Ex. 1007, 5:46–53, 8:59–64, 9:1–24; Ex. 1008 ¶¶ 50–51). The data relied on includes W specified in Table 5 of Tada, the half angle field of view, indicating the angular extent from the optical axis of the lens of a scene that is imaged. *See id.* at 30–31, 35–36. The value for W in Table 5 is 58.5 degrees. Ex. 1007, 9:5.

As to calculating lens system characteristics, Petitioner and Petitioner's expert Dr. Chipman contend that a particular computer program—Code V software—"merely performs mathematical calculations applying well known principles of optics and physics" and that these well-known principles "have not changed in any material respects since at least the early 2000s." Pet. 34; Ex. 1008 ¶ 51. Petitioner and Dr. Chipman further contend that the Code V program "has been around since at least the mid-1960's and was capable of performing the analysis used herein by at least 1980." Pet. 34; Ex. 1008 ¶ 51. Petitioner relies on Dr. Chipman's calculations using the Code V software to model the lens system of Tada's third embodiment (depicted in Figure 11) using the information from Tada's Table 5. Pet. 34–37. Petitioner contends that a person of ordinary skill would have understood the recited lens system to be for use with a video camera and, thus, for the claim to be directed to visible light. *Id.* at 35 (citing Ex. 1008 ¶ 52). Petitioner details that Dr. Chipman, using the definitions of "object points of the panorama," "image point," and "field angle of object points," and the data from Table 5, "plotted the relative distance of image points produced by the lens system of the third embodiment of Tada in relation to the field angle of the corresponding object point" for six different wavelengths of light representative of visible light—violet (380 nm, 400 nm), blue (450 nm), yellow (587 nm), and red (700 nm, 740 nm)—using the Code V program. *Id.* at 34–35 (citing Ex. 1008 ¶ 52; Ex. 1012, 3 (American Heritage Dictionary of Science definition of "visible light")). Petitioner relies on these plots overlaid with a linear distribution and on the percent divergence calculated using the '990 patent's DIVmax equation to illustrate that "the image point distribution function is not linear relative to the field angle of object points of the panorama. *Id.* at 35–36 (citing Ex. 1008 ¶¶ 52–53; Ex. 1013 (Code V analysis of Tada's third embodiment)). The plot obtained for 380 nm illustrates the contended deviation.



Reproduced above from page 36 of the Petition, the plot of the lens prescription, based on Table 5 and Figure 11, for 380 nm wavelength light illustrates the deviation from a linear distribution. Petitioner highlights, in particular, that the slope of the image point distribution is less than that for a linear distribution over the lower object point field angles (orange) and the higher object point angles (green) and greater than that for a linear distribution over intermediate object point field angles (blue). *Id.* at 43–45. Petitioner contends that, "[a]s described in the '990 patent, a higher gradient of the image point distribution function compared to the linear distribution function indicates an expansion of the image and a lower gradient means a compression of the image." *Id.* at 44; Ex. 1001, 8:41–43; Ex. 1008 ¶ 63.

Thus, Petitioner contends that Tada teaches the recited "panoramic objective lens having an image point distribution function that is not linear relative to the field angle of object points of the panorama."

Petitioner contends that Tada teaches, or renders obvious, "the distribution function having a maximum divergence of at least ±10% compared to a linear distribution function, such that the panoramic image obtained has at least one substantially expanded zone and at least one substantially compressed zone." *See* Pet. 37–46. Petitioner relies on two theories for the maximum divergence of at least ±10% compared to a linear distribution. First, Petitioner contends that the maximum divergence value of Tada's third embodiment itself establishes a *prima facie* case of obviousness because it is sufficiently close to ±10%. *See id.* at 37–41. Second, Petitioner contends that it would have been obvious to a person of ordinary skill in the art to modify Tada's third embodiment lens system to increase the maximum deviation in the expansion zone in order to increase the resolution of the acquired image, including as a matter of routine optimization. *Id.* at 41–43. As to the obtained panoramic image having "at least one substantially expanded zone and at least one substantially compressed zone," Petitioner relies, respectively, on the higher and lower gradients of portions of the plot of the lens prescription, discussed above. *Id.* at 43–46.

In arguing the disclosed maximum divergence value is sufficiently close to establish a *prima facie* case, Petitioner contends that the ’990 patent does not attribute any special characteristic to the 10% value, but rather sets forth that it “is sufficient ‘to obtain an expansion of the useful parts of the image . . . result[ing] in a clear increase in the number of pixels covered by the useful parts and a substantial improvement in the definition obtained.’” *Id.* at 37 (citing Ex. 1001, 9:7–12; Ex. 1008 ¶ 56). Petitioner further relies on the ’990 patent “describ[ing] the 10% value as a mere approximation” and that “such a maximum divergence value ‘on the order of 10% at least’ merely needs to be higher than that due to the possible design errors in manufacturing errors . . . ‘which is of a few percent.’” *Id.* (citing Ex. 1001, 9:2–6, 9:8; Ex. 1008 ¶ 56).

Petitioner contends that its calculated plots for various wavelengths demonstrates that the third embodiment of Tada’s lens system meets, or renders obvious, the recited limitations as to the maximum divergence with respect to the linear distribution and the substantially expanded and compressed zones. *Id.* at 39–40. Petitioner relies on its calculations indicating, depending on the wavelength of visible light, a maximum divergence of -8.12% to -9.88% occurring at or near 25–28 degrees and of +0.37 to +1.44% occurring at or near 52–55 degrees. *Id.* at 38–39 (citing Ex. 1001, 8:57; Ex. 1008 ¶ 57). Petitioner highlights the maximum divergence of -9.88% at 27.6 degrees and of +0.37% at 55.2 degrees for a 380 nm wavelength (violet light) (*id.*) and that violet light suffices as the claims do not require that the visible light be of any particular wavelength (*id.* at 35, 38).

Petitioner contends, thus, that "Tada's 8.12% to 9.88% maximum divergence either is 'on the order of 10% or is at least sufficiently close to it such that there is no meaningful difference from 10% in the impact of the maximum divergence." *Id.* at 39–40 (citing Ex. 1008 ¶ 58). Petitioner further contends that, "[a]ccordingly, the disclosure in Tada renders [the at least ±10% divergence] limitation obvious because the maximum deviation is 'close enough' to the claimed maximum deviation 'such that one skilled in the art would have expected [it] to have the same properties.'" *Id.* at 40 (citing *In re Peterson*, 315 F.3d 1325, 1329 (Fed. Cir. 2003); *Titanium Metals Corp. of Am. v. Banner*, 778 F.2d 775, 778 F.2d 783 (Fed. Cir. 1985).

In arguing it would have been obvious to increase the maximum deviation, Petitioner contends that

> it would have been obvious for a [person of ordinary skill in the art] . . . to modify Tada's third embodiment lens system through routine experimentation to add an additional divergence of only 0.12% (for violet light) to this lens system's 9.88% maximum divergence (or up to 1.88% added to 8.12% for red light) to further expand the useful parts of the image and improve the definition in the already expanded zone of Tada's third embodiment.

Pet. 41. Petitioner relies on *In re Aller*, 220 F.2d 454, 456 (CCPA 1955), for the principle that "where the general conditions of a claim are disclosed in the prior art, it is not inventive to discover the optimum or workable ranges by routine experimentation." Pet. 42. In effect, Petitioner relies on Tada as disclosing a lens system, including its third embodiment, and argues that reaching a workable lens meeting the claim limitations requires nothing more than routine experimentation. Petitioner supports its contention by identifying that, in lens design, there are design tradeoffs, including image quality, which includes "the definition of the image captured in different zones of the field of view," and that "[d]epending on the application of the lens, it may be desirable that a particular zone have higher definition at the expense of lower definition in less important zones." *Id.* (citing Ex. 1008 ¶ 60). Petitioner further contends that "Tada's third embodiment shows a lens system with an intermediate zone of enhanced definition compared to the center and edges of the system" and highlights that further enhancement of the intermediate zone by adding a further "0.12-1.88% deviation . . . would have been well within the skill of a [person of ordinary skill in the art]" and that adding such further deviation "would have been undertaken as part of routine engineering optimization techniques with a reasonable expectation that it would have lead [sic] to further improved definition in the intermediate zone while maintaining acceptable image quality." *Id.* at 42–43 (citing Ex. 1008 ¶¶ 60–61).

As to claim 5 itself, Petitioner contends that Tada's third embodiment lens system of Figure 11 together with Table 5 meets the further limitation that "the objective lens compresses the center of the image and the edges of the image and expands an intermediate zone of the image located between the center and the edges of the image." *Id.* at 47–52 (citing Ex. 1008 ¶¶ 63–64, 68–72). Petitioner relies, as discussed above, on the plots of the distribution function of Tada's third embodiment. Petitioner highlights that Tada's third embodiment lens system has a similarly shaped distribution function to that of Figure 9 of the '990 patent. *Id.* at 48–49 (citing Ex. 1001, Fig. 9; Ex. 1008 ¶ 69).

b) Patent Owner's Contentions and Our Conclusions

Patent Owner raises a number of arguments as to why Petitioner has not shown Tada renders claim 5 unpatentable. Prelim. Resp. 17–36. Patent Owner identifies some as applicable to all grounds. *Id.* at 17–29. Patent

Owner identifies others as specific to the ground of obviousness over Tada alone. *Id.* at 30–36. We have considered the parties' evidence and argument and determine that Petitioner has demonstrated a reasonable likelihood that it would prevail in establishing that claim 5 would have been obvious over Tada, notwithstanding Patent Owner's arguments to the contrary. We focus our analysis on the issues that are disputed by Patent Owner.

Patent Owner contends that "Petitioner failed to establish that the Code V analysis could have been done by a [person of ordinary skill in the art] . . . to recreate this same analysis *at the time of the invention*." *Id.* at 19–20. Patent Owner argues that Dr. Chipman's declaration testimony is insufficient to establish that the Code V program was available, and capable of providing the necessary calculations, at the time of invention, and that there is no other evidence of record to support Petitioner's argument. *See id.* at 20–22 (citing Pet. 34; Ex. 1008 ¶¶ 46, 51–52). Patent Owner relies on the rule that "[e]xpert testimony that does not disclose the underlying facts or data on which the opinion is based is entitled to little or no weight." *Id.* at 21–22 (quoting 37 C.F.R. § 42.65).

Based on our review of the current record, we are persuaded Petitioner has sufficiently shown that Tada renders obvious the limitations of claim 5. Petitioner contends, with supporting testimony by Dr. Chipman, that a person skilled in the art at the relevant time period would have used a computer program, such as the "Code V" program to mathematically calculate the characteristics of the lens system. *See* Pet. 34; Ex. 1008 ¶ 51. Petitioner further asserts the "software merely performs mathematical calculations applying well known principals [sic] of optics and physics" (Pet. 34; Ex. 1008 ¶ 51), and Patent Owner provides no discernable basis for any change in the principles and the mathematical calculations necessary to apply those principles in the relevant time period (*see generally* Prelim. Resp.). Applying those would reasonably allow, as Dr. Chipman testifies, "a [person of ordinary skill in the art] at the relevant time period . . . to mathematically calculate the characteristics of the lens system to test and show how it will function by providing plots of the various characteristics of the lens system." Pet. 34; Ex. 1008 ¶ 51. We find Petitioner's arguments and evidence are sufficient at this stage of the proceeding. Patent Owner's arguments raise factual disputes that are best resolved upon a full record. Further, as to the unpatentability of claim 5 grounded on the maximum divergence of Tada's third embodiment sufficing to meet the ±10%, there is no need for the calculation if the limitation simply follows as a consequence of a lens system that is otherwise rendered obvious by Tada's third embodiment such that the limitation is met.

Patent Owner also contends that the use of Tada is based on impermissible hindsight. Prelim. Resp. 22–28. Patent Owner argues that the selection of Tada itself constitutes hindsight because "Tada does not provide any image point distribution function information for any of its lens systems or describe image heights as a function of object point field angles, let alone acknowledge these concepts in its text." *Id.* at 23. Patent Owner argues that selection of Tada as the base reference where "other prior art references explicitly discussing image point distribution functions exist," as demonstrated by the citation to Nagaoka and Baker, "can only be the result of ***impermissible hindsight.***" *Id.* at 23–24.

Patent Owner's argument is grounded too narrowly on the point distribution function to be persuasive in this circumstance. As discussed above, Tada discloses a method for capturing a digital panoramic image using a super wide angle lens system, including that of its third embodiment, one of only four particular embodiments it sets forth in its disclosure. *See generally* Ex. 1007. Patent Owner provides no cogent argument to rebut Petitioner's position that one of ordinary skill in the art would look to Tada for such a method of capturing a digital panoramic image and a suitable lens system, even if it is only one reference of many disclosing such systems. *See generally* Prelim. Resp.; Pet. 29–30, 32.

Patent Owner also contends that Petitioner's Code V analysis constitutes impermissible hindsight. Prelim. Resp. 24–27. Patent Owner argues, in particular, that there is no evidence provided that a person of ordinary skill in the art would have sought to obtain Tada's image point distribution function data or to determine an image point distribution function for any of Tada's lens. *Id.* at 24–26. Patent Owner discounts Dr. Chipman's testimony because it refers generally to "lens characteristics" for what a person of ordinary skill in the art would have calculated, tested, or plotted, and the actual calculations were only undertaken by Dr. Chipman in 2019. *Id.* at 24–25 (citing Ex. 1008 ¶¶ 51–52). Patent Owner contends that "the only reason to analyze Tada in this fashion comes from impermissible hindsight reconstruction." *Id.* at 26. Patent Owner further argues that Petitioner's focus on the third embodiment alone constitutes impermissible hindsight, where there are three other lens system embodiments, and that "[i]t is impermissible . . . to pick and choose from any one reference only so much of it as will support a given position, to the exclusion of other parts necessary to the full appreciation of what such reference fairly suggests to one of ordinary skill in the art." *Id.* at 26–27 (citing Pet. 30; Ex. 1007, 6:1–33, 7:35–48, 8:55–67, 9:58–67; Ex. 1008 ¶¶ 52–53) (quoting *In re Hedges*, 783 F.2d 1038, 1041 (Fed. Cir. 1986)).

Based on our review of the present record, Petitioner has sufficiently established that a person of ordinary skill in the art at the relevant time period would have been able to calculate the characteristics of the lens system to discern how it will function, including by providing plots of various characteristics. Pet. 32, 34; Ex. 1008 ¶¶ 49, 51. Petitioner's argument, supported by the testimony by Dr. Chipman, is also sufficient to show at this stage of the proceeding that a person of ordinary skill in the art would have sought to determine (or calculate) the characteristics of Tada's lens systems to understand their function. *See* Pet. 34; Ex. 1008 ¶ 51. The specific issue raised by Patent Owner here is whether a person of ordinary skill in the art would have sought to obtain such information, and more particularly, would have sought to undertake the same analysis conducted by Dr. Chipman that Petitioner relies on for showing the image point distribution of Tada's third embodiment. *See* Prelim. Resp. 24–26. Patent Owner provides no cogent argument, however, that the image point distribution function, or an equivalent measure of a lens system's function, is not required to fully understand how the lens system will function, such that Petitioner's evidence is not sufficient. *Id.* Nor does Patent Owner provide any sound basis for Dr. Chipman's testimony not reasonably encompassing calculations that include, or are an equivalent measure to, the image point distribution, where he states that a person of skill in the art would have "mathematically calculate[d] the characteristics of the lens system." Ex. 1008 ¶ 51. We note here, again, that if the maximum divergence of Tada's third embodiment suffices to meet the respective claim limitation, and lens system and its use is otherwise obvious, there is a reasonable likelihood that the lens system and its use would be established to be unpatentable over Tada's third embodiment even if one of ordinary skill in the art would not have appreciated its image point distribution function. *Cf. In re Spada*, 911 F.2d 705, 709 (Fed. Cir. 1990) ("When the claimed compositions are not novel they are not rendered patentable by recitation of properties, whether or not these properties are shown or suggested in the prior art.").

Moreover, on this record, even if Tada's third embodiment is not preferred over the other embodiments, we determine that the disclosure is sufficient because each of the four embodiments constitutes a basis for what Tada explicitly discloses as useful for capturing a digital panoramic image. Prelim. Resp. 27–28. In sum, Tada appears to disclose what is suggested by each of the four embodiments, and Patent Owner fails to explain how a different image point distribution function for the other three embodiments would undercut that of the third embodiment, or Petitioner's reliance on it. *Id.*

Patent Owner contends that all grounds fall short on the basis that "[t]here is no reason to modify a prior art reference if the proposed modification would render the reference unsatisfactory for its intended purpose." *Id.* at 28–29. Patent Owner argues that "Tada presents a list of conditions that its lens system must satisfy else it will suffer from various deficiencies in the resulting image" and that "Petitioner never considered whether the modified version of Tada's third embodiment would meet each of the express conditions." *Id.* (citing Ex. 1007, 2:7–67, 4:48–5:38). Patent Owner argues, in particular, that "Petitioner did not discuss whether the required changes would keep the lens system within the condition ranges that Tada requires for a satisfactory image" and that it is not enough, in this circumstance, for Petitioner to rely on "increasing the maximum divergence in Tada's third example embodiment . . . [as being] mere 'routine engineering optimization' . . . [that] would maintain 'acceptable' image quality." *Id.* at 29.

Patent Owner's argument is not persuasive of any shortcoming in Petitioner's challenge. First, it is not clear that the conditions Patent Owner relies on are, in fact, required such that the lens would be unsatisfactory for Tada's purposes if they are not met. Tada discusses the cited parameters as conditions that are "preferably satisfie[d]" (Ex. 1007, 2:9, 2:50–51) and describes how failure to meet these leads only to reduced performance (*id.* at 4:48–5:38). Second, Patent Owner fails to set forth that these parameters would not be met with Tada as modified. Prelim. Resp. 28–29. Third, Patent Owner offers no cogent argument that such changes, as might be required, actually amount to anything more than "routine engineering optimization," but only argues that Petitioner failed to account for the changes in its analysis. *Id.* However close certain parameters in Tada may be to what may be considered unacceptable, on this record, Petitioner adequately shows that increasing the maximum divergence in Tada's third example embodiment would be a matter of routine engineering optimization.

Turning to arguments specific to the challenge based on Tada alone, Patent Owner contends that Petitioner's theory of obviousness based on the disclosure of maximum divergence values that are "close enough" to those claimed is legally incorrect (*id.* at 30–32) and that based on routine experimentation to modify Tada is conclusory and based on hindsight rather than evidence (*id.* at 32–36).

Patent Owner argues that Petitioner's reliance on *Peterson* and *Titanium Metals* as supporting the *prima facie* obviousness of ranges over non-overlapping prior art ranges is not well founded. Prelim. Resp. 30. Patent Owner contends that "Petitioner relied on *dicta* from cases where the claimed and prior art ranges all overlapped." *Id.* Patent Owner characterizes *Titanium Metals* as an overlapping range case on the basis that individual values in the prior art bounded individual values recited in the claims, stating that the claimed alloy "with a single point for each metal, . . . which fell *between the single amounts* disclosed by the prior art," such that "the claimed values overlapped with the prior art." *Id.* at 31. Patent Owner then contends that *In re Patel*, 566 Fed. Appx. 1005 (Fed. Cir. 2014) (non-precedential), is more applicable and that it "[r]eject[s] the *dicta* of *In re Peterson*, . . . [in] that proximity alone is not enough to render non-overlapping ranges obvious – there must be some 'teaching *in the prior art* that the end points of the prior art range are approximate, or can be flexibly applied.'" *Id.* at 31–32 (citing *Patel*, 556 Fed. Appx. at 1009–1010). Patent Owner further contends that "[n]o such prior art teaching exists here." *Id.* at 32.

In *Peterson*, the Federal Circuit expressly recognized "that a *prima facie* case of obviousness exists when the claimed range and the prior art range do not overlap but are close enough such that one skilled in the art would have expected them to have the same properties." *Peterson*, 315 F.3d at 1329 (citing *Titanium Metals*, 778 F.2d at 783). Further, *Titanium Metals* does not set forth that there was an overlapping range rendering the composition unpatentable, but rather that "[t]he proportions are so close that prima facie one skilled in the art would have expected them to have the same properties." *Titanium Metals*, 778 F.2d at 783. Patent Owner's reliance on the non-binding holding in *Patel* similarly falls short, as the Federal Circuit recognized that *Patel* "does not stand for the proposition . . . that a claimed range and prior art range must overlap . . . to find a *prima facie* case." *In re Brandt*, 886 F.3d 1171, 1177 (Fed. Cir. 2018). Still further, contrary to

Patent Owner's reliance on *Patel* for the notion that there must be evidence *from the prior art* that the purported range is flexible, *Brandt* relies on "the claimed range and the prior art range abut[ting] one another" and Appellants' concession "that there [was] no meaningful distinction between the two ranges," as "the insignificance of the range difference between the claims and prior art [could] be gleaned from the '858 application itself." *Id.* at 1177–79. Here the '990 patent itself likewise supports Petitioner's position that there is no meaningful distinction between the maximum divergence values of Tada's third embodiment and the 10% value, as it is characterized as a mere approximation in the '990 patent itself. Pet. 37 (citing Ex. 1001, 9:2–12; Ex. 1008 ¶ 56); Ex. 1001, 9:7–8 ("a maximum divergence on the order of 10% at least").

On this record, we determine that Petitioner has sufficiently established a basis for a *prima facie* case for this limitation on the closeness of the maximum divergence of Tada's third embodiment to the recited maximum divergence of at least ±10% where the divergence is characterized as an approximation. *Cf. E.I. DuPont de Nemours & Co. v. Synvina C.V.*, 904 F.3d 996, 1006 (Fed. Cir. 2018) (applying the concept of *prima facie* obviousness based on overlapping ranges in the context of an *inter partes* review trial). The closeness of the values, including the -9.88% maximum deviation, to the recited "at least ±10%," depends in part on whether the trailing zero in 10% is significant. While not necessary to support our decision to institute *inter partes* review, as we determine a reasonable basis for doing so based on the values as expressly written, but characterized as an approximation, the parties may wish to address this issue in further briefing.

Patent Owner argues that Petitioner's reliance on modifying Tada's third embodiment as a matter of routine experimentation falls short, because the rationale merely presumes that a person of ordinary skill in the art would have found the allegedly expanded intermediate zone in Tada's third embodiment to be important and worth expanding through increasing the maximum divergence point. Prelim. Resp. 33 (citing Pet. 41–43). Patent Owner further argues that Petitioner's presumption that the intermediate zone is of primary importance overlooks that Tada's specification emphasizes the importance of resulting image edges. *Id.* at 33–34 (citing Ex. 1007, 1:11–27, 1:39–41, 1:48–2:6, 4:9–20, 5:3–7, 6:6–12). Patent Owner further argues that Petitioner also ignored examining Tada's third embodiment lens within the context in which it was identified, instead relying on a general assertion that "*[d]epending on the application* of the lens, it *may be* desirable that a particular zone have higher definition at the expense of lower definition in less important zone" without ever identifying the particular application. *Id.* at 34–35 (quoting Pet. 42; citing Pet. 41–43; Ex. 1007, 1:7–9) (alteration in original). Patent Owner further contends that, at best, all Petitioner establishes is that a person of ordinary skill in the art could have modified Tada in the fashion claimed, and not that they would have done so, and that this is insufficient to establish obviousness. *Id.* at 35 (citing *Belden Inc. v. Berk-Tek LLC*, 805 F.3d 1064, 1073 (Fed. Cir. 2015)). Patent Owner also argues that Dr. Chipman's declaration falls short of establishing a "reason to modify Tada." *Id.* at 35–36.

Based on our review of the current record, we are persuaded Petitioner has sufficiently articulated a reason with some rational underpinning to modify Tada to arrive at the subject matter of claim 5. Petitioner asserts the divergence is a result effective variable in the functioning of the lens system, or reflects such, in that deviation from a linear function results in compression or expansion of the projected image zone relative to the panorama being viewed. Pet. 41–43 (citing Ex. 1008 ¶¶ 59–61). Moreover, Petitioner and Dr. Chipman tie this to the definition of the image captured in different zones of the field of view. *Id.* (citing Ex. 1008 ¶ 60). For purposes of institution, the recited range is reasonably established as *prima facie* obvious as a matter of routine experimentation. *Id.* at 43; *see also Aller*, 220 F.2d at 456 ("[W]here the general conditions of a claim are disclosed in the prior art, it is not inventive to discover the optimum or workable ranges by routine experimentation.") (cited at Pet. 42).

Thus, what Patent Owner contends is not established by Petitioner, the particular importance of the intermediate zone and a particular teaching to further expand it, is not necessary under this obviousness theory set forth by Petitioner. Further, Patent Owner's emphasis on the contended failure by Petitioner to identify what would be an optimal lens system fails to address that workable ranges meeting the claim reasonably would be within the grasp of the skilled artisan through no more than routine experimentation. *See Aller*, 220 F.2d at 456; Pet. 41–43.

For the foregoing reasons, Petitioner has sufficiently demonstrated a reasonable likelihood that it would prevail in establishing the unpatentability of claim 5 as obvious over Tada.

Having determined that Petitioner has demonstrated a reasonable likelihood of success in proving that at least one claim of the '990 patent is unpatentable, we institute a review as to all challenged claims, i.e., claim 5, and all grounds raised in the Petition. *See SAS Inst., Inc. v. Iancu*, 138 S. Ct. 1348, 1359–60 (2018); USPTO, Guidance on the Impact of *SAS* on AIA Trial Proceedings (April 26, 2018), https://www.uspto.gov/patents-application-process/patent-trial-and-appeal-board/trials/guidance-impact-sas-aia-trial ("As required by [SAS], the PTAB will institute as to all claims or none," and "[a]t this time, if the PTAB institutes a trial, the PTAB will institute on all challenges raised in the petition."); PTAB Consolidated Trial Practice Guide (Nov. 2019) ("Consolidated Guide"), 5–6 (available at https://www.uspto.gov/TrialPracticeGuideConsolidated).

We offer the following views on the remaining grounds for the parties' consideration.

E. Asserted Obviousness over Tada in View of Nagaoka

Petitioner challenges claim 5 as unpatentable for having been obvious over the combined teachings of Tada and Nagaoka. Pet. 52–63.

Nagaoka is directed to a monitoring system using a camera having a fisheye lens. Ex. 1004, 1:6–10, 1:11–14. Nagaoka discloses a number of different fisheye lenses having a nonlinear distribution function of image points relative to the field angle of the object points of the panorama. *Id.*, Figs. 3A–3B.

Petitioner contends that Nagaoka teaches the limitations of claim 1 (Pet. 53–58 (citing Ex. 1004, 1:38–41, 1:50–57, 2:44–53, 5:28–29, Figs. 3A, 3B; Ex. 1008 ¶¶ 75–82)), and that Patent Owner "provided a clear and unambiguous admission in the reexamination that claim 1 is taught by Nagaoka" (*id.* at 53 (citing Ex. 1003, 244, 331)). Despite this, Petitioner largely relies on Tada as set forth above for the ground with Tada alone (*compare id.* at 58–60, *with id.* at 29–52) and further on Nagaoka for teaching the maximum deviation of at least ±10% (*id.* at 58–62).

Petitioner relies on Nagaoka's disclosure of a fisheye lens having a nonlinear distribution function, including two examples—$h=1.2f \cdot \tan(\theta/1.6)$ and $h=1.6f \cdot \tan(\theta/2)$. *Id.* at 54–58 (citing Ex. 1004, Fig. 3B). Petitioner calculates "a plot of the relative distance of an image point in relation to the center of the image according to the field angle of the corresponding object point" for these functions "with a focal length of f=1" and overlays these with a linear distribution to demonstrate that the lens having the function h=1.2f·tan(θ/1.6) has a maximum divergence -24.19% and a lens having the function h=1.6f·tan(θ/2) has a maximum divergence of at least -14.76%. *Id.* at 56–58 (citing Ex. 1008 ¶¶ 79–82).

Petitioner contends that it would have been obvious to combine Tada with the teachings of Nagaoka, as "Tada and Nagaoka are in the same field of endeavor, e.g., super wide angle lenses and imaging lenses." *Id.* at 58 (citing Ex. 1007, 1:6–9, 6:29–33, 7:36–44, 8:59–64; Ex. 1004, Fig. 2, 3:36–40, 4:66–5:2, 7:11–16, 7:31–35, 7:50–52, 7:60–67; Ex. 1008 ¶ 83). Petitioner further contends that "Nagaoka teaches the use of non-linear curves for fisheye lens[es] to increase the resolution of an area of interest, which in Nagaoka is at the edge or periphery of the image." *Id.* at 61 (citing Ex. 1008 ¶ 88); *see id.* at 60–61 (citing Ex. 1004, 1:50–57, 1:61–2:4, 2:43–53, 6:53–65, 9:30–44; Ex. 1008 ¶ 87).

Petitioner contends that "[i]n Tada's third embodiment, the area of interest is the intermediate zone," and that a person of ordinary skill in the art "with the teachings of Nagaoka would have been motivated to increase the maximum deviation of the lens in Tada from approximately between 8.12 and 9.88% to at least ±10% in order to increase the resolution in Tada's area of interest, *i.e.*, the intermediate zone of the image." Pet. 61 (citing Ex. 1008 ¶ 88). In effect, Petitioner relies on the fact that the intermediate zone in Tada's third embodiment has enhanced definition compared to the center and edges of the system as indicating that it is the area of interest. *Id.* at 59 (citing Ex. 1008 ¶ 85).

As discussed above, Patent Owner argues that Petitioner cites no underlying facts or data in support of the idea that the expanded intermediate zone in Tada's third embodiment is important. Prelim. Resp. 33 (citing Pet. 41–43). Patent Owner further argues that Nagaoka teaches away from use of an "objective lens [that] compresses . . . the edges of the image and expands an intermediate zone of the image located between the center and the edges of the image" (claim 5) in that "Nagaoka explicitly teaches that enhancement or expansion is needed at the *peripheral* portion (as opposed to a central or intermediate portion) due to image distortion and 'many missing portions of image data' there which 'must be interpolated.'" *Id.* at 38 (citing Ex. 1004, 1:48–60); *see id.* (citing Ex. 1004, 1:61–2:4, 6:30–52, 6:60–65).

Patent Owner's general arguments appear more cogent here than when applied to the ground based on Tada alone. Petitioner's further reasoning here relies on the intermediate expanded zone of Tada's third embodiment being a particular area of interest, and then on further expansion of that based on the teachings of Nagaoka. Pet. 59 (citing Ex. 1008 ¶ 85), 61 (citing Ex. 1008 ¶ 88) As such, this further reasoning requires a sufficient showing that a person of ordinary skill in the art would have recognized the importance of the expanded intermediate zone, a showing that Patent Owner contends Petitioner has not made. Prelim. Resp. 33 (citing Pet. 41–43). Patent Owner's arguments that Nagaoka teaches away may also have some merit because of Nagaoka's apparent focus on enhancement or expansion of the image at the peripheral portion. *Id.* at 38 (citing Ex. 1004, 1:48–2:4, 6:30–52, 6:60–65).

F. Asserted Obviousness over Tada in View of Baker

Petitioner challenges claim 5 as unpatentable for having been obvious over the combined teachings of Tada and Baker. Pet. 63–72.

Baker is directed to a videoconference system using a lens system that provides a panoramic display. Ex. 1005, Abstract. Baker discloses wide angle lenses that have "a fairly significant portion of the imaging surface dedicated to the peripheral field [of the field of view], and consequently less of the surface dedicated to the central field" than "typical with commercially available wide-angle, fish-eye, or other conventional lenses." *Id.* at 11:47–48, 12:30–32.

Petitioner contends that Baker teaches the limitations of claim 1 (Pet. 63–67 (citing Ex. 1005, 6:48–56, 8:32–36, 12:6–11; Ex. 1008 ¶¶ 92, 94–96)), and that Patent Owner "provided a clear and unambiguous admission in the reexamination that claim 1 is taught by Baker" (*id.* at 63–64 (citing Ex. 1003, 331); *see also id.* at 66–67 (citing Ex. 1003, 237), Petitioner largely relies on Tada as set forth above for the ground with Tada alone (*compare id.* at 67–69, *with id.* at 29–52) and further on Baker for teaching the maximum deviation of at least ±10% (*id.* at 69–71).

Petitioner relies on Baker's disclosure of a fisheye lens having a nonlinear distribution function, and on a plot of such a lens showing its nonlinearity. *Id.* at 64–66 (citing Ex. 1005, 6:48–56, 8:32–36, 12:6–11; Ex. 1008 ¶¶ 92, 94–96). Petitioner relies on Baker's disclosure that "using a 'hemispherical gradient index unit with a wide field multi-element lens' such that 'the portion of the camera dedicated to the periphery is increased, thereby increasing the relative resolution of information detectable by the imaging device sensing elements'" (*id.* at 64 (citing Ex. 1005, 12:6–11)) and its statement that "[t]o maximize data collection and resolution for analysis and/or display . . . , it is desirable to maximize the dedication of the available image detection area to this peripheral field portion" (*id.* at 64–65 (citing Ex. 1005, 8:32–36)). Petitioner also relies on the testimony of Dr. Chipman "that these goals are achieved by use of a non-linear function." *Id.* at 65 (citing Ex. 1008 ¶ 92). Petitioner relies particularly on a plot it contends "corresponds to the description of the lens in Baker" and "would have a maximum deviation of **15.1%**." *Id.* at 65–66 (citing Ex. 1008 ¶ 95).

Petitioner contends that it would have been obvious to combine Tada with the teachings of Baker, as "Tada and Baker are in the same field of endeavor, e.g., wide angle lenses and imaging lenses." Pet. 67 (citing Ex. 1007, 1:6–9, 6:29–33, 7:36–44, 8:59–64; Ex. 1005, 13:11–17; Ex. 1008 ¶ 97). Petitioner further contends Baker provides further motivation for one of skill in the art to increase the maximum deviation in its teachings and disclosure of a non-linear lens "designed to capture and enhance the peripheral content of a hemispheric scene." *Id.* at 69–70 (citing Ex. 1005, 2:59–61, 2:65–3:3, 6:44–48, 8:32–36, 8:60–62, 10:38–41, 12:48–55, Fig. 3BA; Ex. 1008 ¶¶ 101, 103). In sum, Petitioner contends that "Baker teaches the use of non-linear curves for fisheye lens [sic] to increase the resolution of an area of interest, which in Baker is the periphery of the lens system" and that "Baker also teaches that the area of interest can vary based on the needs of the application." *Id.* at 70 (citing Ex. 1008 ¶ 103).

Petitioner contends that "[i]n Tada's third embodiment, the area of interest is the intermediate zone, rather than the edge or periphery of the image" and that a person of ordinary skill in the art "with the teachings of Baker would have been motivated to increase the maximum deviation of the lens in Tada from approximately between 8.12 and 9.88% to at least ±10% in order to increase the resolution in Tada's area of interest, *i.e.*, the intermediate zone of the image." Pet. 70–71 (citing Ex. 1008 ¶ 103). In effect, Petitioner again relies on the fact that the intermediate zone in Tada's third embodiment has enhanced definition compared to the center and edges of the system as indicating that it is the area of interest. *Id.* at 67–68 (citing Ex. 1008 ¶ 99).

As discussed above, Patent Owner argues that Petitioner cites no underlying facts or data in support of the idea that the expanded intermediate zone in Tada's third embodiment is important. Prelim. Resp. 33 (citing Pet. 41–43), 40 (citing Pet. 67–69). Patent Owner further argues that Baker teaches away from use of an "objective lens [that] compresses . . . the edges of the image and expands an intermediate zone of the image located between the center and the edges of the image" (claim 5) in that "Baker, as a whole, teaches that it is important to enhance or expand the periphery of an image based on degradation experienced from conventional lenses." *Id.* at 40–41 (citing Ex. 1005, 3:60–4:14, 10:38–12:55). Patent Owner further faults Petitioner's reliance on a selective quote from a more complete citation as support for Baker teaching that the enhanced field of view can be anything other than the peripheral region. Prelim. Resp. 41–42 (citing Pet. 70; Ex. 1005, 12:33–51).

For similar reasons as with the combination of Tada and Nagaoka, Patent Owner's general arguments appear more cogent here than when applied to the ground based on Tada alone. As with the combination of Tada and Nagaoka, Petitioner's further reasoning here relies on the intermediate expanded zone of Tada's third embodiment being a particular area of interest (Pet. 67–68 (citing Ex. 1008 ¶ 99), 70–71 (citing Ex. 1008 ¶ 103)), and then on further expansion of that based on the teachings of a further reference, here, Baker (*id.* at 69–70 (citing Ex. 1005, 2:59–61, 2:65–3:3, 6:44–48, 8:32–36, 8:60–62, 10:38–41, 12:48–55, Fig. 3BA; Ex. 1008 ¶¶ 101, 103)). And again, Patent Owner contends that Petitioner has not made a sufficient showing that a person of ordinary skill in the art would have recognized the importance of the expanded intermediate zone. Prelim. Resp. 33 (citing Pet. 41–43), 40 (citing Pet. 67–69). Patent Owner's arguments that Baker teaches away may also have some merit because of Baker's apparent focus on enhancement or expansion of the periphery of an image. *Id.* at 40–41 (citing Ex. 1005, 3:60–4:14, 10:38–12:55).

IV. CONCLUSION

For the reasons set forth above, we determine that Petitioner has demonstrated a reasonable likelihood of prevailing with respect to the one challenged claim of the '990 patent. Thus, we institute an *inter partes* review on the one challenged claim and on all grounds presented in the Petition.

V. ORDER

Accordingly, it is:

ORDERED that pursuant to 35 U.S.C. § 314(a), an *inter partes* review is hereby instituted as to claim 5 of the '990 patent with respect to the grounds set forth in the Petition; and

FURTHER ORDERED that pursuant to 35 U.S.C. § 314(c) and 37 C.F.R. § 42.4, notice is hereby given of the institution of a trial commencing on the entry date of this decision.

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Paper 26
Date: May 11, 2021

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

LG ELECTRONICS INC.,
Petitioner,

v.

IMMERVISION, INC.,
Patent Owner.

IPR2020-00195
Patent 6,844,990 B2

Before KRISTINA M. KALAN, WESLEY B. DERRICK, and KIMBERLY MCGRAW, *Administrative Patent Judges.*

DERRICK, *Administrative Patent Judge.*

JUDGMENT
Final Written Decision
Determining No Challenged Claims Unpatentable
35 U.S.C. § 318(a)

I. INTRODUCTION

In this *inter partes* review, LG Electronics Inc. ("Petitioner") challenges the patentability of claim 21 of U.S. Patent No. 6,844,990 B2 (Ex. 1001, "the '990 patent"), owned by ImmerVision, Inc. ("Patent Owner").

We have jurisdiction to hear this *inter partes* review under 35 U.S.C. § 6. This Final Written Decision is issued pursuant to 35 U.S.C. § 318(a) and 37 C.F.R. § 42.73. For the reasons discussed herein, Petitioner has not shown, by a preponderance of the evidence, that claim 21 of the '990 patent is unpatentable.

A. Procedural History

On November 27, 2019, Petitioner requested an *inter partes* review of claim 21 of the '990 patent. Paper 2 ("Pet."). Patent Owner filed a Preliminary Response. Paper 5 ("Prelim. Resp."). On May 13, 2020, we instituted an *inter partes* review of the challenged claim on all grounds raised in the Petition. Paper 6 ("Dec."). Following institution, Patent Owner filed a Patent Owner Response (Paper 12, "PO Resp."), Petitioner filed a Reply to the Patent Owner Response (Paper 16, "Pet. Reply"), and Patent Owner filed a Sur-Reply to Petitioner's Reply (Paper 17, "PO Sur-Reply).

Petitioner relies on the declaration testimony of Russell Chipman, Ph.D. (Exs. 1008, 1017, 1019) to support the Petition. Patent Owner took cross-examination via deposition of Dr. Chipman (Ex. 2002). Patent Owner relies on the declaration testimony of David Aikens (Ex. 2009). Petitioner took cross-examination via deposition of Mr. Aikens (Ex. 1018).

Oral hearing was requested by both parties. Papers 18, 19. We heard argument on February 8, 2021, and a transcript of the hearing has been entered into the record. Paper 25 ("Tr.").

B. Real Parties-in-Interest

Petitioner LG Electronics Inc. identifies LG Electronics U.S.A., Inc. and LG Innotek Co. Ltd. as additional real parties-in-interest. Pet. 2. Patent Owner ImmerVision, Inc., identifies itself as the real party-in-interest. Paper 4, 2. The parties do not raise any issues about real parties-in-interest.

C. Related Proceedings

The parties identify two pending district court cases involving the '990 patent: *ImmerVision, Inc. v. LG Electronics U.S.A.*, No. 1-18-cv-01630 (D. Del.) and *ImmerVision, Inc. v. LG Electronics U.S.A.*, No. 1-18-cv-01631 (D. Del.). Pet. 2; Paper 4, 2–3. The '990 patent is also the subject of an *inter partes* review in IPR2020-00179. *See* IPR2020-00179, Paper 6.

In addition, the '990 patent: (1) was the subject of *Ex Parte* Reexamination Control No. 90/013,410; (2) was challenged in an *inter partes* proceeding, *Panasonic System Networks Co., Ltd. v. 6115187 Canada Inc.*, IPR2014-01438; and (3) was the subject of three other district court cases that are no longer pending. *See* Pet. 2–3; *see also Panasonic System Networks Co., Ltd. v. 6115187 Canada Inc.*, IPR2014-01438, Paper 11 (PTAB Nov. 26, 2014) (terminating proceeding prior to institution following settlement).

D. The '990 Patent (Ex. 1001)

The '990 patent is titled "Method for Capturing and Displaying a Variable Resolution Digital Panoramic Image" and issued on January 18, 2005, from an application filed on November 12, 2003. Ex. 1001, codes (22), (45), (54). The application for the '990 patent is a continuation of application No. PCT/FR02/01588, filed on May 10, 2002, and claims priority to foreign application FR 01 06261, filed May 11, 2001. *Id.* at codes (30), (63).

The ’990 patent relates to capturing a digital panoramic image that includes using a panoramic objective lens having “a distribution function of the image points that is not linear relative to the field angle [α] of the object points of the panorama,” where the “distribution function Fdc . . . determines the relative distance dr of an image point in relation to the center of the image disk according to the field angle α of the corresponding object point.” *Id.* at code (57), 2:30–34 (as corrected by Jan. 18, 2005, Cert. of Correction). The image obtained using such a panoramic objective lens has at least one zone that is expanded and another zone that is compressed. *Id.* at code (57). The ’990 patent further explains that an image zone is “expanded” when it covers a greater number of pixels on an image sensor than it would with a linear distribution lens. *Id.* at 3:66–4:10. The ’990 patent also provides that an “expanded” zone and “compressed” zone can be illustrated by comparison to a linear distribution function, with a slope greater than that of the linear distribution indicating an expanded zone and a lesser slope indicating a compressed zone. *Id.* at 9:13–35; *see also id.* at 2:30–42 (describing how “Figure 4B represents the shape of the distribution function Fdc of a classical objective lens,” of ideal form, “a straight line of gradient K . . . in which the constant K is equal to 0.111 $degree^{-1}$ (1/90°)”). Figure 9, reproduced below, depicts an image point distribution of a lens having a compressed zone between α=0° and α=30°, an expanded zone between α=30° and α=70°, and a compressed zone between α=70° and α=90°.

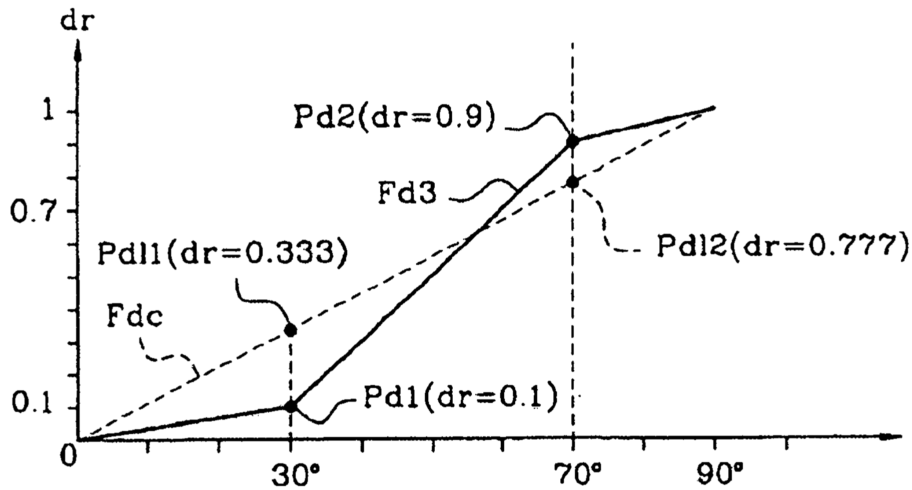


Fig. 9

Id., Fig. 9 (depicting plot of a non-linear distribution function of a panoramic objective lens). The patent further provides for correcting the non-linearity of the panoramic image initially obtained when using such lens. *Id.* at code (57).

The '990 patent was the subject of an *ex parte* reexamination. *Id.* at 25–27 (Ex Parte Reexamination Certificate (10588th)). The Reexamination Request—Control No. 90/013,410—was filed November 26, 2014. *Id.* at 25; Ex. 1003, 328–339 ("Request by Patent Owner for *Ex Parte* Reexamination of U.S. Patent No. 6,844,990"). Patent Owner requested an *ex parte* reexamination of claims 1–4, 6, 7, 10, 11, 15–20, 22, 23, and 25, which request was granted. Pet. 17–18; Ex. 1003, 52–63, 330, 341. The Patent Office issued an Office Action on January 29, 2015, rejecting independent claim 17—the base claim for claim 21. Ex. 1003, 30, 36–39. Patent Owner filed an Amendment on February 12, 2015, canceling claim 17. *Id.* at 19.

E. The Challenged Claim

Challenged claim 21 incorporates the limitations of cancelled claim 17, from which it depends. *See* MPEP § 2260.01 ("the content of the canceled base claim . . . [is] available to be read as part of the confirmed or allowed dependent claim"). Both claims are reproduced below.

> 17. A panoramic objective lens comprising:
>
> optical means for projecting a panorama into an image plane of the objective lens, the optical means having an image point distribution function that is not linear relative to the field angle of object points of the panorama, the distribution function having a maximum divergence of at least ±10% compared to a linear distribution function, such that a panoramic image obtained by means of the objective lens comprises at least one substantially expanded zone and at least one substantially compressed zone.

Ex. 1001, 20:51–61.

> 21. The panoramic objective lens according to claim 17, wherein the lens compresses the center of the image and the edges of the image, and expands an intermediate zone of the image located between the center and the edges of the image.

Id. at 21:7–11.

F. Instituted Grounds of Unpatentability at Issue

We instituted trial on all grounds of unpatentability proposed by Petitioner, as shown below:

Claim Challenged	35 U.S.C. §[1]	Reference(s)/Basis
21	103	Tada[2]
21	103	Tada, Nagaoka[3]
21	103	Tada, Baker[4]

II. ANALYSIS

A. Principles of Law

A claim is unpatentable under § 103 if "the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains." *KSR Int'l Co. v. Teleflex Inc.*, 550 U.S. 398, 406 (2007). The question of obviousness is resolved on the basis of underlying factual determinations, including: (1) the scope and content of the prior art; (2) any differences between the claimed subject matter and the prior art; (3) the level of skill in the art; and (4) when in evidence, objective evidence of nonobviousness, i.e., secondary considerations. *See Graham v. John Deere Co.*, 383 U.S. 1, 17–18 (1966).

[1] The Leahy-Smith America Invents Act ("AIA"), Pub. L. No. 112–29, 125 Stat. 284, 287–88 (2011), revised 35 U.S.C. § 103 effective March 16, 2013. Because the challenged patent was filed before March 16, 2013, we refer to the pre-AIA version of 35 U.S.C. § 103.
[2] US 5,861,999, issued January 19, 1999 (Ex. 1007).
[3] US 6,128,145, issued October 3, 2000 (Ex. 1004).
[4] US 5,686,957, issued November 11, 1997 (Ex. 1005).

Regarding the scope and content of the prior art, "[w]hat a reference teaches is a question of fact." *In re Beattie*, 914 F.2d 1309, 1311 (Fed. Cir. 1992). A reference is prior art for what it discloses, even if it is in error, unless the error is an "obvious error," in which case "it cannot be said to describe or suggest [what is disclosed in error] to those in the art." *In re Yale*, 434 F.2d 666, 668–69 (CCPA 1970) (holding that an error in the statement of a chemical formula would have been obvious to one of ordinary skill in the art and thus would not have put them in possession of the compound because they would have disregarded it as an error or replaced it with the correct chemical formula); *see also In re Clark*, 420 F. App'x 994, 998 (Fed. Cir. 2011) (nonprecedential) (holding that "absent an obvious error on the face of a reference, a reference is prior art for what it discloses" and that the Board did not err in relying on such a disclosure where there was "nothing in the . . . publication indicating that the [relied-on] statements . . . were in error.").

Additionally, the obviousness inquiry typically requires an analysis of "whether there was an apparent reason to combine the known elements in the fashion claimed by the patent at issue." *KSR*, 550 U.S. at 418 (citing *In re Kahn*, 441 F.3d 977, 988 (Fed. Cir. 2006) (requiring "articulated reasoning with some rational underpinning to support the legal conclusion of obviousness")); *see In re Warsaw Orthopedic, Inc.*, 832 F.3d 1327, 1333 (Fed. Cir. 2016) (citing *DyStar Textilfarben GmbH & Co. Deutschland KG v. C.H. Patrick Co.*, 464 F.3d 1356, 1360 (Fed. Cir. 2006)).

The Petition guides the proceeding. *See Koninklijke Philips N.V. v. Google LLC*, 948 F.3d 1330, 1335–36 (Fed. Cir. 2020). Our reviewing court explains that "[f]rom the outset, we see that Congress chose to structure a process in which it's the petitioner, . . . who gets to define the contours of the proceeding," and that "the statute envisions that a petitioner will seek an inter partes review of a particular kind—one guided by a petition describing each claim challenged and the grounds on which the challenge to each claim is based." *Id.* at 1335 (quoting *SAS Inst. Inc. v. Iancu*, 138 S. Ct. 1348, 1355 (2018) (internal quotations omitted)) (alterations in original). "[T]he petitioner's petition, not the Director's discretion is supposed to guide the life of the litigation," and that "the petitioner's contentions, not the Director's discretion, define the scope of the litigation all the way from institution through to conclusion." *Sirona Dental Sys. GmbH v. Institut Straumann AG*, 892 F.3d 1349, 1356 (Fed. Cir. 2018) (quoting *SAS*, 138 S. Ct. at 1356–57 (internal quotations omitted)).

To prevail, Petitioner must demonstrate by a preponderance of the evidence that the claims are unpatentable. 35 U.S.C. § 316(e); 37 C.F.R. § 42.1(d) (2019). "In an [*inter partes* review], the petitioner has the burden from the onset to show with particularity why the patent it challenges is unpatentable." *Harmonic Inc. v. Avid Tech., Inc.*, 815 F.3d 1356, 1363 (Fed. Cir. 2016) (citing 35 U.S.C. § 312(a)(3) (requiring *inter partes* review petitions to identify "with particularity . . . the evidence that supports the grounds for the challenge to each claim")). This burden never shifts to Patent Owner. *See Dynamic Drinkware, LLC v. National Graphics, Inc.*, 800 F.3d 1375, 1378 (Fed. Cir. 2015) (citing *Tech. Licensing Corp. v. Videotek, Inc.*, 545 F.3d 1316, 1326–27 (Fed. Cir. 2008)) (discussing the burden of proof in *inter partes* review).

B. Level of Ordinary Skill in the Art

In the Institution Decision, we adopted Petitioner's description of the level of ordinary skill in the art, not contested at that time by Patent Owner, and determined that a person of ordinary skill in the art "would have had at least a bachelor's degree in Physics, Optical Engineering, and/or Electrical Engineering, and at least five years' experience in developing and designing optical products or systems and have familiarity with image processing algorithms and optical design software." Dec. 6; Pet. 20 (citing Ex. 1008 ¶ 41).

Patent Owner neither disputes Petitioner's articulation of the level of ordinary skill in the art nor presents its own articulation of the level of skill in the art, stating that "for purposes of this Response, Patent Owner does not object to Petitioner's proposed skill level." PO Resp. 20.

On this record, we have no reason to fault Petitioner's definition of the level of ordinary skill. We further note that the prior art itself demonstrates the level of skill in the art at the time of the invention, and there is no apparent inconsistency with Petitioner's definition. *See Okajima v. Bourdeau*, 261 F.3d 1350, 1355 (Fed. Cir. 2001) (explaining that "specific findings on the level of skill in the art . . . [are not required] 'where the prior art itself reflects an appropriate level and a need for testimony is not shown'" (quoting *Litton Indus. Prods., Inc. v. Solid State Sys. Corp.*, 755 F.2d 158, 163 (Fed. Cir. 1985))). Accordingly, we adopt the level of ordinary skill set forth by Petitioner.

C. Claim Construction

We apply the same claim construction standard that would be used to construe the claim in a civil action under 35 U.S.C. § 282(b), following the standard articulated in *Phillips v. AWH Corp.*, 415 F.3d 1303 (Fed. Cir. 2005) (en banc). 37 C.F.R. § 42.100(b). Under *Phillips*, claim terms are afforded "their ordinary and customary meaning." *Phillips*, 415 F.3d at 1312. "[T]he ordinary and customary meaning of a claim term is the meaning that the term would have to a person of ordinary skill in the art in question at the time of the invention." *Id.* at 1313. Only those terms that are in controversy need be construed, and only to the extent necessary to resolve the controversy. *See Nidec Motor Corp. v. Zhongshan Broad Ocean Motor Co.*, 868 F.3d 1013, 1017 (Fed. Cir. 2017) (citing *Vivid Techs., Inc. v. Am. Sci. & Eng'g, Inc.*, 200 F.3d 795, 803 (Fed. Cir. 1999)).

Before institution, Petitioner proposed constructions for particular claim terms, which Patent Owner, for the purposes of its Preliminary Response, did not contest. Dec. 8–9. On that record, and for the purpose of the Institution Decision, we adopted the constructions set forth by Petitioner, because the constructions appeared reasonable and were not contested. *Id.* at 9.

Following institution, Patent Owner again neither disputes Petitioner's proposed constructions nor proposes its own, stating, "[w]hile not necessarily agreeing with the proposed constructions of those terms, ***solely*** for purposes of this Response, Patent Owner does not object to the constructions set out by Petitioner." PO Resp. 20.

Considering again the proposed constructions, on this record, we adopt the definitions set forth by Petitioner: (i) "panoramic objective lens" means "a super-wide or ultra-wide objective lens"; (ii) "object points of the panorama" are "points of the object in the panorama being viewed by the lens"; (iii) "image point" means "a point of light projected by the lens onto an image plane, said light coming from the corresponding object point of a viewed object in the panorama"; (iv) "field angle of object points" are "the angles of incident light rays passing through the object points and through the center of the panorama photographed, relative to the optical axis of the objective lens"; (v) "maximum divergence" is defined by the formula "DIVmax %=[[dr(Pd)-dr(Pdl)]/[dr(Pdl)]]*100, in which dr(Pd) is the relative distance in relation to the center of the point of maximum divergence Pd, and dr(Pdl) is the relative distance in relation to the center of the corresponding point on the linear distribution line"; (vi) "expanded zone" means "the portion of the image point distribution function where the gradient is higher than the gradient of the linear distribution function"; and (vii) "compressed zone" means "the portion of the image point distribution function where the gradient is lower than the gradient of the linear distribution function." Dec. 8–9 (citing Ex. 1001, 1:18–20, 2:18–22, 7:2–5, 7:11–14, 8:38–43, 8:57–65; Ex. 1008 ¶¶ 44, 52, 57, 63).

We likewise consider again the construction of the "optical means for projecting . . ." limitation of cancelled claim 17, and agree it is a means-plus-function limitation that should be construed, as Petitioner contends, as "'a series of optical elements, e.g., as shown in Figs. 15, 16, and 18, and equivalents thereof' for performing the claimed function." *Id.* at 9 (citing Prelim. Resp. 22–24).

We further determine that no additional claim construction is necessary to reach our decision in this case.

D. Asserted Obviousness over Tada

Petitioner challenges claim 21 as obvious over Tada. Pet. 33–57.

1. Overview of Tada (Ex. 1007)

Tada discloses a method for capturing a digital panoramic image, including by use of "a super wide angle lens system which can be used for a monitoring camera (CCTV) etc." Ex. 1007, 1:7–9. Tada states that "[i]t is an object . . . to provide a retrofocus type super wide angle lens system . . . [having] an angle of view of approximately 120° to 140°." *Id.* at 1:48–50. Tada identifies Figures 1, 6, 11, and 16 as schematic views "showing the lens arrangement" of a first, second, third, and fourth embodiment, respectively, "of a super wide angle lens system. *Id.* at 3:18–20, 3:32–34, 3:44–46, 3:57–59, Figs. 1, 6, 11, 16. The third embodiment, depicted in Figure 11, reproduced below, "is substantially the same as the second embodiment," depicted in Figure 6, which "is substantially the same as that of the first embodiment," depicted in Figure 1. *Id.* at 6:2–3, 7:36–43, 8:58–62.

FIG. 11

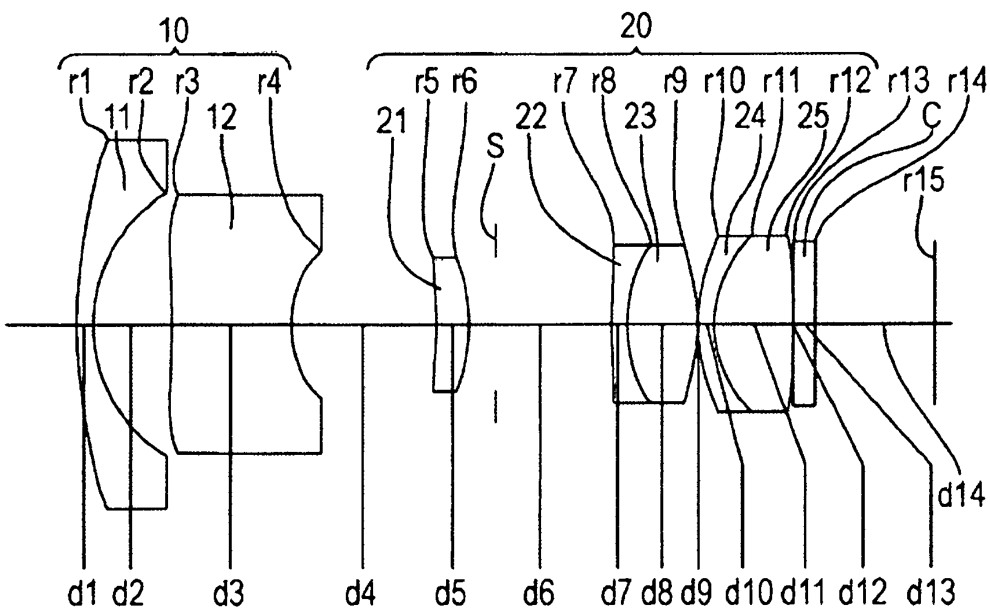


Figure 11 depicts the lens arrangement of a super wide angle lens system. *Id.* at 3:44–46, Fig. 11. The depicted super wide angle lens system consists of front lens group 10 and rear lens group 20. *See id.* at 6:4–5 (identifying elements in reference to Figure 1). Figure 11 also depicts features of a CCD[5] (charge-coupled device) used to capture an image; element C refers to

[5] Although neither Tada nor the Petitioner define "CCD," we understand CCD to be a "charge-coupled device." *See, e.g.*, Ex. 2001 ¶ 595.

"a glass cover of the CCD" and "surface No. 15 refers to the image pickup surface of the CCD." *See id.* at 6:26–32 (identifying elements in reference to Figure 1). Tada sets forth that its Figures 5 and 6 disclose numerical data regarding the third embodiment, including "[t]he surface figure, paraxial spherical amount and aspherical amount of surface No. 3." *Id.* at 8:63–9:57. Tada similarly sets forth that its Tables 1 and 2 disclose numerical data regarding the first embodiment (*id.* at 6:28–32, 6:36–7:29), Tables 3 and 4 disclose numerical data regarding the second embodiment (7:42–8:53), and Tables 7 and 8 disclose numerical data regarding the fourth embodiment (9:63–10:50). Tada also sets forth "[v]alues of the ratios defined in conditions (1) through (8) for the four embodiments" in its Table 9. *Id.* at 10:53–11:12.

2. *Analysis*

Claim 21, which incorporates the limitations of cancelled claim 17 from which it depends, is directed to an improved panoramic objective lens. In general, claim 17 requires that the panoramic objective lens has optical means for projecting a panorama into an image plane of the objective lens, the optical means having an image point distribution function that is not linear to the field angle of the object points of the panorama, having a maximum divergence that is at least ±10% compared to a linear distribution function. Ex. 1001, 20:51–67. Claim 21 further requires that "the lens compresses the center of the image and edges of the image, and expands an intermediate zone of the image located between the center and the edges of the image." *Id.* at 21:7–11.

a) Overview of Ground Based on Tada

Petitioner contends that Tada discloses the claimed panoramic objective lens in its "third embodiment of a super wide angle lens system" that compresses the center of the image and edges of the image and expands an intermediate zone of the image located between the center and edges of the image. Pet. 33–42; Pet. Reply 2–3, 10–19. Petitioner asserts that Tada's "Figure 11. . . shows a third embodiment of a super wide angle lens system" and that Table 5 provides for the "prescription of the third embodiment lens," i.e., "[n]umerical data regarding the third embodiment." Pet. 33–35, 37. Dr. Chipman testifies that he reconstructed the lens of Figure 11 using the numerical data information in Table 5. Ex. 1008 ¶ 46; *see also id.* ¶ 49 (stating Tada's disclosure of, *inter alia*, schematic views of the lens arrangements and tables of measurements of the lens allows one of ordinary skill in the art to reconstruct the exact lens system described in Tada). In particular, Dr. Chipman testifies that he input certain information from Table 5 (i.e., the FNO and W values, the values in the R, D, Nd, and vd columns, and the "aspherical data" information) into an "optical design program called Code V" and that Code V then generated a depiction of the lens system corresponding to the lens prescription in Table 5. *Id.* ¶ 46; *see also id.* ¶ 50 (stating numerical data regarding Tada's third embodiment is shown in Table 5). Dr. Chipman also testifies that he used the Code V program to calculate the characteristics of the lens system to test and show how it would function by providing plots of the various characteristics of the lens system. Ex. 1008 ¶ 51. Dr. Chipman also testifies that he plotted the image point distribution function for the lens system at six wavelengths, and that the function is not linear in any of them (*id.* ¶¶ 52–53), that the maximum deviation from a linear distribution function is at least 8.12% to 9.88%, depending on the wavelength (*id.* ¶¶ 57–58), and that the lens "compresses the center of the image and the edges of the image and expands an intermediate zone of the image located between the center and the edges of the image" (*id.* ¶ 68).

Petitioner relies on these calculations and plots of Tada's third embodiment lens system of Figure 11 with the prescription set forth in Table 5 to show that Tada's third embodiment meets the limitations of claim 21, and of claim 17 from which it depends. Pet. 35–57 (citing Ex. 1007, Fig. 11, Table 5); Pet. Reply 1–19. That is, Petitioner relies on the lens prescription set forth in Table 5 for the lens system depicted in Figure 11, and calculations of that lens system's properties showing it (1) "compresses the center of the image and the edges of the image, and expands an intermediate zone of the image located between the center and edges of the image," as required by claim 21, and (2) for it to have an image point distribution that is not linear relative to the field angle of object points of the panorama, having a maximum divergence that is at least ±10% compared to a linear distribution function, as required by independent claim 17 from which claim 21 depends. Pet. 35–57.

b) Patent Owner's Contention of Obvious Error in Tada

Patent Owner contends that Tada's third embodiment, as set forth in Table 5, has a readily apparent error (i.e., the aspherical data). PO Resp. 1–3. Patent Owner argues that the grounds of unpatentability set forth in the Petition fail because the disclosure including an apparent error should be disregarded or corrected, and it is only in relying on the disclosure in error that Petitioner arrives at a lens that compresses the center and edges and expands an intermediate zone of an image as required by claim 21. *Id.* at 1–3, 8–14, 24–40; PO Sur-Reply 1–7. Patent Owner relies on *Yale* for its holding that "[w]here a prior art reference contains 'an error obvious to one of ordinary skill in the art, it cannot be said to describe or suggest' the erroneous feature." *Yale*, 434 F.2d at 668–669. In identifying the error, Patent Owner contends that Tada's "ratios (2)–(4) in Table 9 should respectively match Table 5's A_4, A_6, and A_8, but do not." PO Resp. 13 (citing Ex. 2002, 47:22–50:24 (cross-examination testimony of Dr. Chipman); Ex. 2009 ¶ 69 (testimony of Mr. Aikens that identified "values do not match the values in Table 5 because Table 5 is in error")). Patent Owner's declarant Mr. Aikens also testifies on cross-examination that "[b]ecause the focal length is 1 [in each of the four embodiments], Table 9 rather conveniently gives you the aspheric coefficients for each of the four embodiments, and it matches correctly for 1, 2 and 4 and is totally wrong for 3." Ex. 1018, 136:11–15. Patent Owner also sets forth calculations by Mr. Aikens for Embodiment 3 using aspherical data information from Tada's Japanese priority application JP 06-201903[6], which Patent Owner contends is the correct lens prescription, and determines that the "compressed zone at the edge of the lens across the visible wavelength spectrum" is missing. PO Resp. 32–38 (citing Ex. 2009 ¶¶ 73, 88, 90–100). Patent Owner further contends that Petitioner failed to "explain why a [person of ordinary skill in the art] would have modified [the lens system according to the correct prescription] to include a compressed edge zone." *Id.* at 40 (emphasis omitted).

c) Petitioner's Argument There is No Obvious Error

In its Reply, Petitioner does not dispute that Dr. Chipman relies on the data in Tada's Table 5 to reconstruct a lens it contends satisfies all of the limitations of claim 21, including the "three zone" limitations that require

[6] The JP 09-201903 application was published as JP H10115778. Ex. 2007, 1; Ex. 2008, 2. Patent Owner provides an English language translation. Ex. 2008, 1–2.

compression of the center and edges and expansion of an intermediate zone of the image obtained by means of the lens (i.e., (1) a central compressed zone, (2) an intermediate expanded zone, and (3) a compressed edge zone). *See generally* Pet. Reply. Petitioner also does not dispute that if the purported error in Tada's Table 5 was corrected using the aspherical data from the Japanese priority application, that a lens reconstructed using the Japanese priority application data would not satisfy a limitation of claim 21 because the lens would not compress the edges of the produced image, and thus would not have a compressed edge zone. *Id.* Petitioner contends, rather, that the alleged error in the aspherical data in Tada's Table 5 is irrelevant because it was not apparent or obvious upon reading the reference. *Id.* at 3–10 (citing *Yale*, 434 F.2d at 669). Petitioner argues that Tada's Table 5, accordingly, should be considered as it reads, neither disregarding nor correcting its disclosure, and that Table 5 itself, as written, discloses and enables a lens meeting the requirements set forth for Tada's invention. *Id.*

Petitioner further argues that the error in Table 5 would not have been "readily apparent" because "there is nothing in Table 5 that would lead a [person of ordinary skill in the art] to believe that there is an error." *Id.* at 3. Petitioner contends that Table 5 "includes all of the information necessary to enable a complete lens" (*id.* at 4 (citing Ex. 1019 ¶¶ 5–8), 2), and that "[t]he lens of Table 5 as analyzed by Dr. Chipman discloses all of the elements . . . of claim 21" (*id.* at 3). Petitioner further contends that even if a person of ordinary skill in the art "were to check Table 5 with other parts of Tada, it would have taken many hours to conclude there was an error." *Id.* at 4 (citing Ex. 1018, 132:1–15, 136:5–137:12). To support its argument that the error would not have been readily apparent, Petitioner quotes testimony of Patent Owner's declarant Mr. Aikens that he "had figured out that something was wrong probably within two to three hours. Then modeling the other embodiments, that took time. And then continuing to try to understand how to recreate the surface, that took more time." *Id.* (quoting Ex. 1018, 137:8–12).

Petitioner argues that this case differs from those in which errors were determined to be "obvious on their face and detectable with little effort." *Id.* at 5. Specifically, Petitioner argues that "any purported 'error' in Table 5 of Tada" would not have been like the obvious error in *Yale*, and, thus, that this is not a case "such that a [person of ordinary skill in the art] would 'mentally disregard [the information in Table 5] as a misprint or mentally substitute [the information in Tables 6 and 9] in its place.'" *Id.* at 4–5 (citing *Yale*, 434 F.2d at 669). Petitioner relies on the court's reasoning in *Yale* "that the error was such that '[t]he public is not put in possession of the compound; thus it would not be obvious to use,'" and argues that here, in contrast, Tada puts the public in possession because "Table 5 'describes' the claimed invention" and "a [person of ordinary skill in the art] would have been able to make the Table 5 lens." *Id.* at 5–6 (citing *In re Elsner*, 381 F.3d 1125, 1128 (Fed. Cir. 2004); *Yale*, 434 F.2d at 669). Petitioner further contends that the "'error'. . . in Tada's Table 5 is more like the errors that courts have found do not rise to the level of being excluded." *Id.* at 7–8 (citing *In re Garfinkel*, 437 F.2d 1005, 1008 (CCPA 1971); *In re Borst*, 345 F.2d 851, 853 n.2 (CCPA 1965); *Clark*, 420 F.App'x at 998).

d) Analysis of Tada's Disclosure

On this record, we find that there is an obvious error on the face of Tada, in Table 5, and that this error cannot be relied on to support the grounds of unpatentability set forth by Petitioner.

As mentioned above, Tada sets forth numerical data for prescribing the lens systems of each of its first, second, third, and fourth embodiments in Tables 1, 3, 5, and 7, respectively. *See* Ex. 1007, 6:36–63 (Table 1), 7:50–8:25 (Table 3), 9:1–29 (Table 5), 10:1–29 (Table 7). These tables include values for aspherical data (coefficients) for surface No. 3 of the second lens element, with each table setting forth K (a conic constant), A4 (representing a fourth-order aspherical factor), A6 (representing a sixth-order aspherical factor), A8 (an eighth-order aspherical factor), and A10 (a tenth-order aspherical factor). *Id.* at 5:63–67, 6:59–61 (Table 1, first embodiment), 8:21–23 (Table 3, second embodiment), 9:25–27 (Table 5, third embodiment), 10:25–27 (Table 7, fourth embodiment).

Tada's Table 9 also sets forth "[v]alues of the ratios defined in conditions (1) through (8) for the four embodiments." *Id.* at 10:53–11:12. Of these, conditions (2), (3), and (4) specify the condition on the fourth-, sixth-, and eighth-order aspherical factors of the aspherical surface. *Id.* at 4:60–61, 5:3–5.

There is a readily apparent inconsistency in the aspherical coefficients A4, A6, and A8, in Tables 1, 3, 5, and 7, and of values for conditions (2), (3), and (4) for each of the four embodiments, in Table 9. The portion of each of Tables 1, 3, 5, and 7 setting forth the "Aspherical Data" for "Surface No. 3" is reproduced below, as is Table 9:

From Table 1 (Embodiment 1)

Aspherical Data:
No.3: K = 0.00, A4 = 0.41500×10^{-1}, A6 = -0.72169×10^{-2}, A8 = 0.10529×10^{-2}, A10 = 0.70513×10^{-4}

From Table 3 (Embodiment 2)

Aspherical Data:

No.3: K = 0.00, A4 = 0.30330×10^{-1}, A6 = -0.43125×10^{-2}, A8 = 0.46329×10^{-3}, A10 = -0.24092×10^{-4}

From Table 5 (Embodiment 3)

Aspherical Data:

No.3: K = 0.00, A4 = 0.30330×10^{-1}, A6 = -0.43125×10^{-2}, A8 = 0.46329×10^{-3}, A10 = -0.24092×10^{-4}

From Table 7 (Embodiment 4)

Aspherical Data:

No.3: K = 0.00, A4 = 0.88810×10^{-1}, A6 = -0.27110×10^{-1}, A8 = 0.79690×10^{-2}, A10 = -0.61180×10^{-3}

TABLE 9

	Embodiment 1	Embodiment 2
Condition (1)	−7.296	−6.981
Condition (2)	4.1500×10^{-2}	3.0330×10^{-2}
Condition (3)	-7.2169×10^{-3}	-4.3125×10^{-3}
Condition (4)	1.0529×10^{-3}	4.6329×10^{-4}
Condition (5)	2.549	2.907
Condition (6)	2.400	2.479
Condition (7)	529.729	25.228
Condition (8)	4.118	4.178

TABLE 9-continued

	Embodiment 3	Embodiment 4
Condition (1)	−8.060	−10.108
Condition (2)	2.0485×10^{-2}	8.8810×10^{-2}
Condition (3)	-2.5925×10^{-3}	-2.7110×10^{-2}
Condition (4)	2.4634×10^{-4}	7.9690×10^{-3}
Condition (5)	3.022	2.691
Condition (6)	2.425	2.512
Condition (7)	27.255	25.229
Condition (8)	4.229	4.543

The portions of Tables 1, 3, 5, and 7 set forth "aspherical data," and Table 9 sets forth values for conditions (1)–(8) for Embodiments 1–4. *Id.* at 6:59–61, 8:21–23, 9:25–27, 10:25–27, 10:57–11:12.

Comparison of aspherical coefficients A4, A6, and A8, in Tables 1, 3, 5, and 7, and of values for conditions (2), (3), and (4) for each of the four embodiments in Table 9 shows the inconsistency. The values of aspherical coefficients A4, A6, and A8 in Tables 1, 3, and 7, for Embodiments 1, 2, and 4, and the corresponding values for conditions (2), (3), and (4), for Embodiments 1, 2, and 4, are identical. *Compare id.* at 6:59–61, *with id.* at 10:57–62 (Embodiment 1); *compare id.* at 8:21–23, *with id.* at 10:57–62 (Embodiment 2); *compare id.* at 10:25–27, *with id.* at 11:2–8 (Embodiment 4). The values of aspherical coefficients A4, A6, and A8 in Table 5, however, differ from the corresponding values for conditions (2), (3), and (4) for Embodiment 3. *Compare id.* at 9:25–27, *with id.* at 11:2–8. This indicates that there is an error for Embodiment 3 in either Table 5 or in Table 9. Still looking only at the Tables, it is also apparent that the values set forth for aspherical coefficients, including A4, A6, and A8, of Embodiment 3 in Table 5 are identical to those for Embodiment 2 in Table 3. *Compare id.* at 8:21–25, *with id.* at 9:25–29. That these aspherical coefficients are identical is incongruous with the differences in the values of other data for the lens systems, including the radius of curvature (R) of lens surfaces and the distances between lens surfaces (D), prescribing these two lens systems. *Id.* at 5:48–49, 7:50–8:25 (Table 3), 9:1–29 (Table 5); *see also id.* at 6:36–63 (Table 1), 10:1–29 (Table 7).

The inconsistency between Tada's Table 5 and Table 9 makes it apparent that there is an error in Table 5's recitation of the aspherical coefficients. As discussed above, a comparison of the values for aspherical coefficients A4, A6, and A8 in Table 5 (Embodiment 3) and conditions (2), (3), and (4) for Embodiment 3 in Table 9 indicates that the data in one of Table 5 and Table 9 is in error. Mr. Aikens opines that "[b]ecause the focal length is 1 [in each of the four embodiments], Table 9 rather conveniently gives you the aspheric coefficients for each of the four embodiments, and it matches correctly for 1, 2 and 4 and is totally wrong for 3." Ex. 1018, 136:11–15; Pet. Reply 4 ((citing Ex. 1018, 136:5–137:12); *see also* PO Resp. 13 ("ratios (2)–(4) in Table 9 should respectively match Table 5's A_4, A_6, and A_8, but do not." (citing Ex. 2002, 47:22–50:24 (cross-examination testimony of Dr. Chipman)); Ex. 2009 ¶ 69 (testimony of Mr. Aikens that identified "values do not match the values in Table 5 because Table 5 is in error")). We are persuaded by Dr. Aikens' testimony that a person of ordinary skill in the art would readily ascertain, from the Specification alone, that the error is in the aspherical data in Table 5. Ex. 2009 ¶ 69. As discussed above, the aspherical data from Table 5 matches that in Table 3 and, if the error is in Table 5, this can be explained as a simple transcription error, inadvertently duplicating the aspherical data from Table 3. If the error as to Embodiment 3 is in Table 9, however, then the error is more difficult to explain in the context of the lens systems of Embodiments 1–4. As set forth in Tables 3 and 5, the aspherical coefficients, including A4, A6, and A8, are identical in Embodiments 2 and 3, despite these lens systems differing throughout with respect to the lens surface's radius of curvature (R) and distances between the lens surfaces (D). The lens systems of Embodiments 1 and 4 each also differ from every other embodiment with respect to the aspherical coefficients and the values of R and D.

Tada provides that "Japanese Patent Application Nos. 08-222394 . . . and 09-201903 . . . are expressly incorporated herein by reference in their entireties." Ex. 1007, 3:9–13; *see* PO Sur-Reply 6–7 (noting Tada expressly incorporates the Japanese priority application by reference, citing Ex. 2007 (JP H115778)). The cited Japanese priority application for Tada—JP 09-201903—also includes a Table 3 with the same data as within the body of Tada itself, including the aspherical data (Ex. 2007, 5–6 ¶ 29; Ex. 2008, 13–14 ¶ 29; Ex. 1007, 7:50–8:25), and a Table 9 with the same values for conditions (2), (3), and (4) of all four embodiments[7] (Ex. 2007, 9 ¶ 37; Ex. 2008, 20 ¶ 37; Ex. 1007, 10:56–11:12). Importantly, as to Table 5, the JP 09-201903 application has different values for "aspherical surface data," including for A4, A6, and A8, than those for "[a]spherical data" in Tada itself. *See* Ex. 2007, 7 ¶ 32; Ex. 2008, 16 ¶ 32; Ex. 1007, 10:25–29. Also, unlike in Tada itself, the values for A4, A6, and A8 in JP 09-201903 Table 5 are identical to the values for conditions (2), (3), and (4) for Embodiment 3. Ex. 2007, 7 ¶ 32, 9 ¶ 37; Ex. 2008, 16 ¶ 32, 20 ¶ 37; Ex. 1007, 9:25–27, 11:6–8. The correspondence of Tables 1, 3, 7, and 9 between the JP 09-201903 application and Tada itself is apparent, even prior to translation, as is the inconsistency as to the aspherical data for Table 5.

In sum, we find that one of ordinary skill in the art considering Tada would have reasonably considered the entire document, including the Japanese priority application incorporated by reference. Having done so, one of ordinary skill in the art would have readily ascertained that there was an error in the aspherical data of Table 5. The discrepancy between the data in Table 5 and Table 9 would have been apparent and obvious, because one of ordinary skill in the art would have appreciated that the values for

[7] We find no distinction in JP 09-201903 referring to Tada's "four embodiments" as "working examples."

aspherical data A4, A6, and A8 and for conditions (2), (3), and (4), respectively, should be identical, but were not identical, for Embodiment 3. Further, one of ordinary skill in the art also would have reasonably appreciated, considering the remainder of Tada's disclosure, the error to be in Table 5. The Japanese priority application incorporated by reference into Tada—JP 09-201903—confirms the error. All in all, we find it apparent that the discrepancy is grounded on a transcription error in the values for A4, A6, and A8 in Tada's Table 5, namely, inadvertent duplication of the values for the aspherical data in Table 3.

e) Analysis of Petitioner's Arguments Regarding Obvious Error

Petitioner's case-based arguments that the error was not an "obvious error" fall short. In *Yale*, the error was the listing of a particular compound, i.e., CF(3)CF(2)CHClBr, in a figure plotting characteristics of different compounds, which compound was not disclosed elsewhere in the reference, and where the value of a characteristic for the compound listed in error in that figure was identical to the value for a different compound, i.e., CF(3)CHClBr, disclosed in another figure.[8] *Yale*, 434 F.2d at 667. The court determined that "[a]ny number of these individually or cumulatively would, . . . alert one of ordinary skill in the art of the typographical error" and "that the one [the court] immediately noted was the inconsistency between Figs. 1 and 3 of [the reference]." *Id.* at 669. Petitioner argues that the error in Table 5 would not have been "readily apparent" because nothing

[8] The Appellant in *Yale* also contended an error would be apparent because, other than the compound listed in error, only known compounds were discussed in the article. *Yale*, 434 F.2d at 667. Also, the appellant in *Yale* submitted two letters, a letter sent to the author of the reference inquiring whether the compound was listed in error, and a letter in response that the listing was a typographical error. *Id.*

in Table 5 itself would lead a person of ordinary skill in the art to believe there was an error, but the circumstances here appear to be essentially the same as in *Yale*, where the court relied on an inconsistency between different portions of the disclosure. *Id.*

Petitioner further argues that Table 5 "includes all of the information necessary to enable a complete lens." Pet. Reply 3 (citing Ex. 1019 ¶¶ 5–8). The court in *Yale*, however, determined that one of ordinary skill in the art, recognizing a disclosure to be an obvious error, would simply disregard it and not even get so far as to consider whether they knew how to make it. *Yale*, 434 F.2d at 669.

Petitioner's reliance on *Elsner* in arguing that Tada put the public in possession of the invention because "Table 5 'describes' the claimed invention" and "a [person of ordinary skill in the art] would have been able to make the Table 5 lens" (Pet. Reply 5–6 (citing *Elsner*, 381 F.3d at 1128)) fails because, as discussed above, the issue is not whether the prior art disclosure is enabled, but rather whether it would be recognized as an obvious error and simply disregarded (*see Yale*, 434 F.2d at 669). Similarly, we give little weight to Dr. Chipman's testimony that the error would not have been readily apparent because Table 5 enables a person of ordinary skill in the art to make a complete lens because it is grounded on an incorrect understanding of the law. Ex. 1019 ¶¶ 5, 7–8; *cf. Integra Lifesciences I, Ltd. v. Merck KGaA*, 496 F.3d 1334, 1342 (Fed. Cir. 2007) (holding that "when an expert witness' statement of the law is incorrect, that view of the law cannot be relied upon to support the verdict."). As discussed above, the issue is not whether Table 5 enables the lens it describes, but rather whether the disclosure would be recognized as an obvious error. Dr. Chipman's expressed opinion grounded on an incorrect understanding that this is the law fails to support Petitioner's case.

Petitioner contends that even if a person of ordinary skill in the art "were to check Table 5 with other parts of Tada, it would have taken many hours to conclude there was an error." Pet. Reply 4 (citing Ex. 1018, 132:1–15, 136:5–137:12). Petitioner supports this contention with the testimony of Dr. Chipman (*id.* at 3 (citing Ex. 1019 ¶¶ 5–8)), including that "the purported error that Mr. Aikens alleges is not obvious on its face and detectable with little effort" that relies on the reasoning that "Mr. Aikens had to spend many hours, going through a convoluted process" (Ex. 1019 ¶ 6). The relevant question is whether the error was an obvious error to one of ordinary skill in the art, not whether Mr. Aikens happened to take a circuitous route to determine that the aspherical data in Table 5 was, in fact, in error. *Yale*, 434 F.2d at 669. As laid out above, we find that one of ordinary skill in the art considering Tada would have ascertained a discrepancy between the values of aspherical data A4, A6, and A8 in Table 5 and the corresponding values for conditions (2), (3), and (4) for embodiment 3 in Table 7, and discerned an error in Table 5 through no more than considering the disclosure of Tada as a whole.

The particular manner in which Mr. Aikens determined that there was an error in Table 5, as laid out in Patent Owner's Response, does not diminish that there is an obvious error in Tada within the meaning of *Yale*. Tada's disclosure indicates on its face that there is obvious, likely typographical, error apparent upon considering the values of aspherical data A4, A6, and A8 in Table 5, and the corresponding values for conditions (2), (3), and (4) for Embodiment 3 in Table 9, and that this is confirmed by the Japanese priority application incorporated by reference into Tada.

Dr. Chipman's testimony does not address how this discrepancy between the data in Table 5 and Table 9, and the disclosure incorporated by reference, would not be sufficient indication of an obvious error. Ex. 1019 ¶ 5–8. Accordingly, we give little weight to his testimony that the "purported 'error' in Table 5 of Tada would not have been an error obvious to one of ordinary skill in the art." *Id.* ¶ 6; *Velander v. Garner*, 348 F.3d 1359, 1371 (Fed. Cir. 2003) ("It is within the discretion of the trier of fact to give each item of evidence such weight as it feels appropriate."); *Ashland Oil, Inc. v. Delta Resins & Refractories, Inc.*, 776 F.2d 281, 294 (Fed. Cir. 1985) ("Lack of factual support for expert opinion going to factual determinations, however, may render the testimony of little probative value in a validity determination."). Indeed, Mr. Aikens' cross-examination testimony cited by Petitioner includes testimony that confirms that the presence of an error would have been immediately apparent because Mr. Aikens recognized that the values for conditions (2), (3), and (4) set forth in Table 9 do not match the aspheric coefficients for Embodiment 3 as defined in Table 5. *See* Ex. 1018, 136:11–15 ("Because the focal length is 1, Table 9 rather conveniently gives you the aspheric coefficients for each of the four embodiments, and it matches correctly for 1, 2 and 4 and is totally wrong for 3.").

Petitioner also argues that the alleged error in Tada's Table 5 is like the errors that the courts did not exclude in *Clark*, *Garfinkel*, or *Borst*. Pet. Reply 7–9. In *Clark*, the court found that reference incorrectly stated that a particular system used an FM transmitter and signal, but that nothing in the publication indicated that the statements were in error. *Clark*, 420 F. App'x at 998. Thus, while it is correct that "absent an obvious error on the face of the reference, a reference is prior art for what it discloses," here there is an "obvious error on the face of the reference," as discussed above. *Id.* In *Garfinkel*, the court did not disregard the teaching of a reference, despite the fact that an applicant had submitted an affidavit that a reference's teaching was in error, because "the error, if it exist[ed], was not apparent or obvious from reading the publication." *Garfinkel*, 437 F.2d at 1008; Pet. Reply 7–8. But here, again, the error is apparent and obvious from reading Tada. In *Borst*, the court found a prior art document to be enabling despite a possible error; Petitioner argues that, because Tada's disclosure of a lens in its Table 5 is enabling, the disclosed lens should be considered. Pet. Reply 8–9. As discussed above, however, the issue is not whether the disclosure is enabling, but rather whether there is an obvious error, such that the disclosure is simply disregarded. Even to the extent that *Borst* appears to indicate that there was an error in the disclosure of the relied-on reference in that case, there is no indication that it was an obvious error such that it informs the outcome where, as here, the error is an obvious error. *Borst*, 345 F.2d at 853 n.2 (noting that "Appellant does argue that there is a mathematical defect in the Samsel disclosure"). As such, *Borst* does not support Petitioner's argument that one of ordinary skill in the art would have relied on the aspherical data from Tada's Table 5 when that data is an obvious error. And the same can be said of *Amgen Inc. v. Hoechst Marion Roussel, Inc.*, 314 F.3d 1313, 1357 (Fed. Cir. 2003), that Petitioner relies on as supporting that "a reference need not be enabled; it qualifies as prior art, regardless, for what is disclosed therein" (Pet. Reply 10), because regardless of what is enabled, the disclosure cannot be said to describe or suggest that which is an error obvious to one of ordinary skill in the art (*Yale*, 434 F.2d at 669).

f) Conclusion

On this record, we find that the disclosure of aspherical coefficients in Table 5 of Tada is an obvious error and that, consequently, Tada cannot be said to describe or suggest the lens system according to the prescription that includes those aspherical coefficients. Because Petitioner relies wholly on the lens system of Embodiment 3, as set forth in Tada's Table 5, to meet the limitations of the recited objective lens that compresses the center and edges and expands an intermediate zone of an image, Petitioner has not established by a preponderance of the evidence that the lens of claim 21 would have been obvious.

E. Asserted Obviousness over Tada in View of Nagaoka

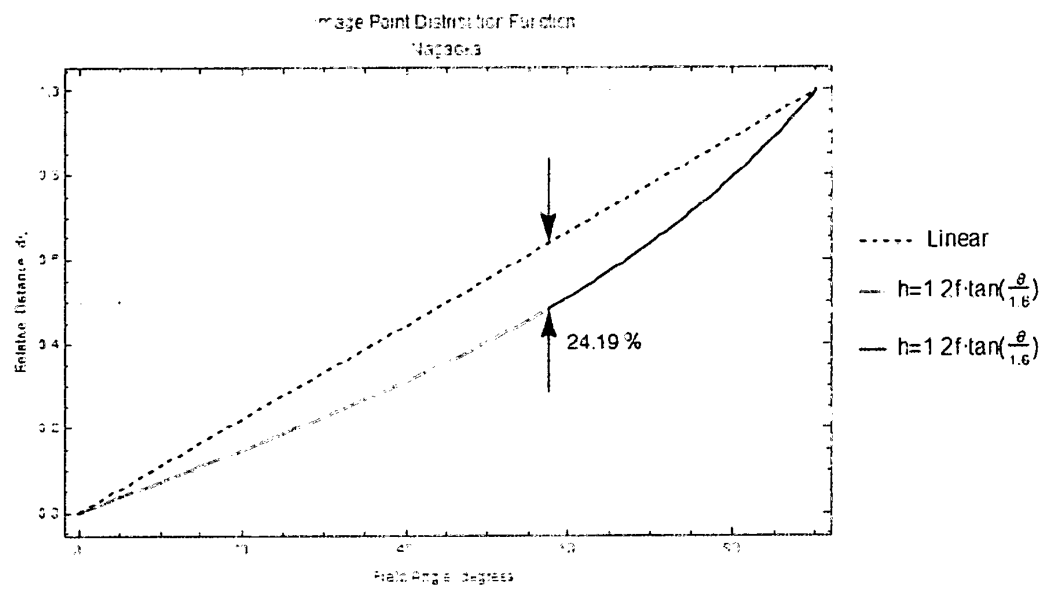
Petitioner challenges claim 21 as obvious over the combined teachings of Tada and Nagaoka. Pet. 57–68.

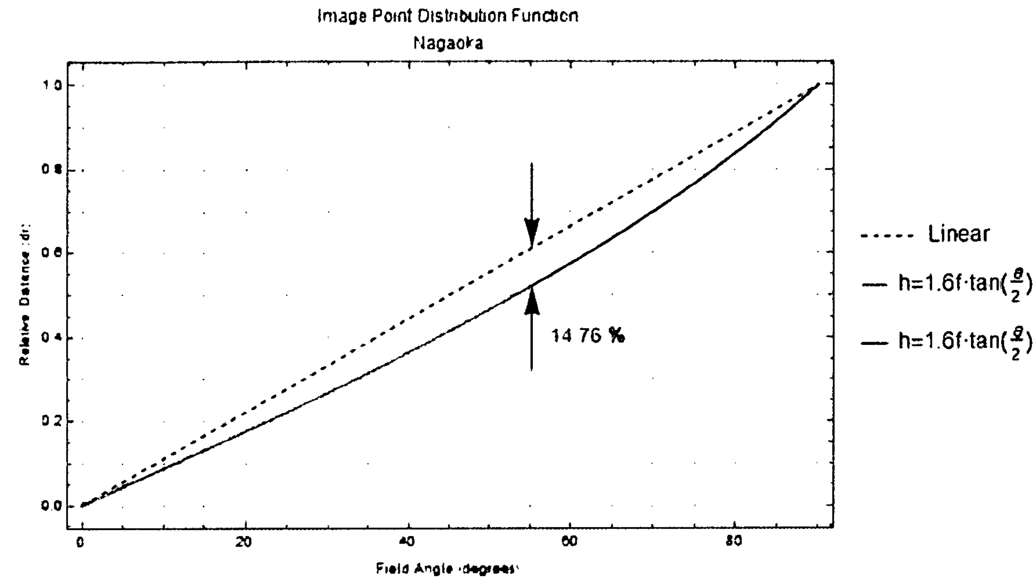
1. Overview of Nagaoka (Ex. 1004)

Nagaoka is directed to a monitoring system using a camera having a fisheye lens. Ex. 1004, 1:6–10, 1:11–14. Nagaoka discloses a number of different fisheye lenses having a nonlinear distribution function of image points relative to the field angle of the object points of the panorama. *Id.*, Figs. 3A–3B.

2. Analysis

Petitioner relies on "Tada explicitly disclos[ing] all of the elements of dependent claim 21 and independent claim 17," but adds that to the extent that Patent Owner argues that Tada falls short of disclosing "that the distribution function [has] a maximum divergence of 'at least ±10%' compared to a linear distribution function," as set forth in claim 17, that this is remedied by Nagaoka. Pet. 57–68. As set forth by Petitioner, Nagaoka discloses a fisheye lens having a nonlinear distribution function, including two examples—h=1.2f·tan(θ/1.6) and h=1.6f·tan(θ/2). *Id.* at 54–58 (citing Ex. 1004, Fig. 3B). Petitioner calculates "a plot of the relative distance of an image point in relation to the center of the image according to the field angle of the corresponding object point" for each of these two functions "with a focal length of f=1" and overlays these with a linear distribution to demonstrate that the lens having the function h=1.2f·tan(θ/1.6) has a maximum divergence -24.19% and a lens having the function h=1.6f·tan(θ/2) has a maximum divergence of at least -14.76%. *Id.* at 61–63 (citing Ex. 1008 ¶¶ 79–82). These plots are reproduced below:





The depicted plots of Nagaoka's functions include two regions, a first with a slope less than "linear" indicating "compression" (highlighted yellow) and a second with a slope greater than "linear" indicating "expansion" (highlighted blue). *Id.* at 62 (reproducing figures plotting the image point distribution function of two different, non-linear image point distribution functions). Petitioner relies on Nagaoka as teaching that it is desirable to have a lens system with a maximum divergence much larger than what Tada discloses. *Id.* at 66; Pet. Reply 23.

Petitioner relies wholly on Tada for compressing the edges of the image: "Tada teaches [a lens system having] three zones like claim 21 (compression, expansion, and compression)." Pet. Reply 24. Petitioner makes its reliance on Tada for this feature clear in stating that "[t]he fact that Nagaoka teaches two zones (compression and expansion) . . . is immaterial for a [person of ordinary skill in the art] looking for guidance on possible maximum divergence for lenses for CCTV cameras." *Id.* In other words, because Petitioner concedes that Nagaoka teaches only two zones, Petitioner is relying on Tada for disclosing the three zones. But as we explained above, Petitioner does not establish that Tada teaches or suggests three zones, so Petitioner's arguments for this ground are unpersuasive.

On this record, Petitioner has not established by a preponderance of the evidence that the panoramic objective lens of claim 21 would have been obvious over Tada in view of Nagaoka. Tada, due to its obvious error, cannot be said to describe or suggest the three zones (compression, expansion, and compression), as discussed above. Nagaoka only teaches two zones (compression and expansion). Thus, there is no basis in the ground set forth for an objective lens, as recited in claim 21, that "compresses . . . the edges of the image."

F. Asserted Obviousness over Tada in View of Baker

Petitioner challenges claim 21 as unpatentable for having been obvious over the combined teachings of Tada and Baker. Pet. 68–77. In particular, Petitioner asserts that to the extent Tada does not teach or suggest that "the distribution function [has] a maximum divergence of *at least* $\pm$*10%* compared to a linear distribution function" as required by claim 21 by virtue of its dependence on claim 17, that Baker teaches this limitation and that it would have been obvious to modify Tada in view of Baker to arrive at the subject matter of claim 21. Pet. 69, 72–77.

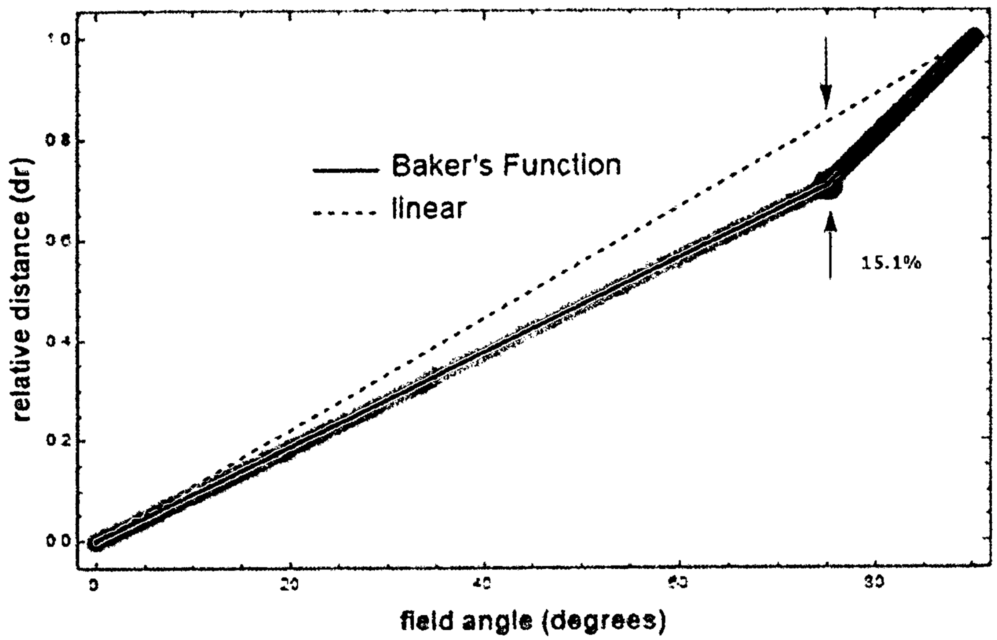
1. Overview of Baker (Ex. 1005)

Baker is directed to a videoconference system using a lens system that provides a panoramic display. Ex. 1005, Abstract. Baker discloses wide angle lenses that have "a fairly significant portion of the imaging surface dedicated to the peripheral field [of the field of view], and consequently less of the surface dedicated to the central field" than "typical with commercially available wide-angle, fish-eye, or other conventional lenses." *Id.* at 11:47–48, 12:30–32.

2. Analysis

In the Petition, Petitioner relies on Tada as set forth above in the ground based on Tada alone (*compare* Pet. 72–77, *with id.* at 33–57) and further on Baker for teaching the maximum deviation of at least ±10% (*id.* at 74–76). Petitioner contends that Baker teaches the limitations of claim 17 (*id.* at 68–72 (citing Ex. 1005, 6:48–56, 8:32–36, 12:6–11; Ex. 1008 ¶¶ 92, 94–96)), and that Patent Owner "provided a clear and unambiguous admission in the reexamination that claim 17 is taught by Baker" (*id.* at 68–69 (citing Ex. 1003, 331); *see also id.* at 71–72 (citing Ex. 1003, 240)). Petitioner does not contest that "Tada was relied on for disclosing the three zones and Baker was relied on essentially or solely for the magnitude of . . . deviation," as Petitioner's counsel responded to this characterization with "[y]ou're absolutely correct, . . . That was how the petition was laid out." Tr. 40:2–7.

Petitioner's reliance on Baker in the Petition is limited to the degree of deviation from a linear image point distribution. Pet. 68–72. Petitioner relies on Baker's disclosure of a fisheye lens having a nonlinear distribution function, a plot of such a lens showing its nonlinearity, and that "[t]o maximize data collection and resolution for analysis and/or display . . . , it is desirable to maximize the dedication of the available image detection area to this peripheral field portion." Pet. 69–71; Ex. 1005, 6:48–56, 8:32–36, 12:6–11; Ex. 1008 ¶¶ 92, 94–96. Petitioner relies particularly on a plot it contends "corresponds to the description of the lens in Baker" and "would have a maximum deviation of **15.1%**." Pet. 70–71; Ex. 1008 ¶ 95. The plot is reproduced below:



The depicted plot of Baker's function includes two regions, a first with a slope less than "linear" indicating "compression" (highlighted yellow) and a second with a slope greater than "linear" indicating "expansion" (highlighted blue). Pet. 71 (reproducing a figure plotting the image point distribution function of "Baker's [non-linear image point distribution] function" overlying a linear image point distribution function).

The ground set forth in the Petition relying on Tada in view of Baker fails. As discussed above, the necessary disclosure in Tada to support a lens system having the three zones (compression, expansion, and compression), i.e., Table 5's aspherical data (coefficients), includes an obvious error and, thus, Tada cannot be said to describe or suggest such a lens system, and there is no basis set forth in the Petition for Baker remedying this deficiency.

Patent Owner responds that Baker teaches away from the claimed lens. PO Resp. 66, 68–70.

Petitioner, in its Reply, makes a new argument that Baker discloses all three zones, and relies on portions of Baker not originally cited and relied on in the Petition to support this argument. *Compare* Pet. Reply 20–22 (citing Ex. 1005, 1:52–58, 2:10–16, 5:37–44, 13:60–65, 19:9–13 (claim 10)), *with* Pet. 68–75 (citing Ex. 1005, 2:59–61, 2:65–3:3, 6:44–56,[9] 8:32–36, 8:60–62, 10:38–41, 12:6–11, 13:11–17, 12:48–55, Fig. 3BA). This shift in Petitioner's argument and its new reliance on Baker is reflected in the cited testimony of Dr. Chipman and Mr. Aikens. Dr. Chipman's original declaration filed in support of the Petition does not address the portions of Baker only cited in Petitioner's Reply. *See* Ex. 1008 ¶¶ 90–104. Petitioner relies on new testimony in support of its Reply; cross-examination testimony of Mr. Aikens, relating to portions of Baker not relied on in the Petition (Pet. Reply 21 (citing Ex. 1018, 268:14–269:4)), and further testimony of Dr. Chipman, also relating to portions of Baker not relied on in the Petition (*id.* (citing Ex. 1019 ¶ 27)). The cited cross-examination testimony of Mr. Aikens relates to the "[l]ast paragraph of Column 13" in Baker (Ex. 1005, 13:56 *et seq.*), and most particularly to Baker, column 13, lines 60 to 65, cited in Petitioner's Reply. Ex. 1018, 262:16–269:4. Dr. Chipman's testimony in support of Petitioner's Reply (Ex. 1019), paragraph 27, cites Baker (Ex. 1005), column 13, lines 60 to 65 and column 19, lines 9 to 13.

In its Reply, Petitioner newly argues that Baker discloses a lens having three zones, including an expanded intermediate zone. Pet. Reply 20–22. At oral hearing, Petitioner's counsel conceded that the Petition does

[9] The Petition mis-cites relied-on material from column 6, lines 48 to 56, as from Exhibit 1002. Pet. 65.

not rely on Baker for disclosing three zones (Tr. 40:2–7) and that the relevant portions of Baker—column 13, lines 60 to 65 and claim 10 (column 19, lines 9 to 12)—were not cited until Petitioner's Reply (*id.* at 39:11–16). Petitioner's counsel argues, however, that there is an admission Baker discloses three different zones and that this cannot be ignored. *Id.* at 40:8–12.

Patent Owner responds that the argument that Baker discloses a lens having three zones is new, having been argued for the first time in Petitioner's Reply, and that it is contrary to what Baker actually discloses. PO Sur-Reply 19–21. At oral hearing, Patent Owner's counsel contended that we should disregard the newly-cited portions of Baker and purported admission that Baker discloses three different zones because the Petition's original grounds do not rely on Baker for disclosing or suggesting a lens having three different zones. Tr. 42:11–16.

Petitioner's counsel argued in rebuttal that Petitioner's argument raised as to Baker disclosing three zones was only that there was no teaching away, and that it is properly raised for that point. *See id.* at 67:19–22 ("Baker is talking about three zones in some of the embodiments and therefore there is no teaching away and that's really the only point we wanted to make with respect to Baker is that there is no teaching away"), 68:5–6 ("our only point is that there is no teaching away").

The argument in Petitioner's Reply that Baker does not teach away from the claimed lens was not improper; Petitioner reasonably raised it in response to Patent Owner's arguments, and Patent Owner had notice that Baker was in play as potentially relevant evidence. *See Genzyme Therapeutic Prods. Ltd. P'ship v. Biomarin Pharm. Inc.*, 825 F.3d 1360, 1366–67 (Fed. Cir. 2016) (finding that the Board may consider a prior art reference not included in an instituted ground to show the state of the art where the parties had notice of the reference).

That said, Petitioner's arguments that Baker discloses a lens with the recited three zones in the Reply raises a new theory of unpatentability, relying on newly cited portions of the reference. Such a new theory offered in the Reply cannot remedy the deficiency in the ground set forth in the Petition because "it is the petitioner's contentions" in "petitioner's petition" that "define the scope of the litigation all the way from institution through to conclusion." *Sirona*, 892 F.3d at 1356; *see also Henny Penny Corp. v. Frymaster LLC*, 938 F.3d 1324, 1330–31 (Fed. Cir. 2019) ("an IPR petitioner may not raise in reply 'an entirely new rationale' for why a claim would have been obvious"). As discussed above, the ground of unpatentability set forth in the Petition is based wholly on Tada disclosing the three zones, and not at all on Baker disclosing three zones, and the disclosures from Baker now contended by Petitioner to disclose or teach three zones are not cited in the Petition.

In sum, this proceeding is guided by the Petition, which did not assert the portions of Baker contended to disclose or teach the three zones recited in claim 21, or present any theory of obviousness grounded on Baker disclosing or teaching the three zones. Also, because the ground fails due to the obvious error in Tada, whether Baker teaches away from the claimed invention is moot. Thus, it is unnecessary for us to consider whether Baker discloses or teaches any embodiment having three zones, and we decline to do so.

On this record, for the reasons discussed above, we find that Petitioner has not established by a preponderance that the lens of claim 21 would have been obvious over Tada in view of Baker.

III. CONCLUSION

For the reasons set forth above, we determine that Petitioner has not established, by a preponderance of the evidence, that the subject matter of claim 21 of the '990 patent is unpatentable.

Claim	35 U.S.C. §	References	Claims Shown Unpatentable	Claims Not Shown Unpatentable
21	103	Tada		21
21	103	Tada, Nagaoka		21
21	103	Tada, Baker		21
Overall Outcome				21

IV. ORDER

In consideration of the foregoing, it is hereby:

ORDERED that Petitioner has *not* demonstrated by a preponderance of the evidence that claim 21 of the '990 patent is *unpatentable*; and

FURTHER ORDERED that because this is a Final Written Decision, any party to the proceeding seeking judicial review of the decision must comply with the notice and service requirements of 37 C.F.R. § 90.2.

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Paper 26
Date: May 11, 2021

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

LG ELECTRONICS INC.,
Petitioner,

v.

IMMERVISION, INC.,
Patent Owner.

IPR2020-00179
Patent 6,844,990 B2

Before KRISTINA M. KALAN, WESLEY B. DERRICK, and KIMBERLY McGRAW, *Administrative Patent Judges.*

DERRICK, *Administrative Patent Judge.*

JUDGMENT
Final Written Decision
Determining No Challenged Claims Unpatentable
35 U.S.C. § 318(a)

I. INTRODUCTION

In this *inter partes* review, LG Electronics Inc. ("Petitioner") challenges the patentability of claim 5 of U.S. Patent No. 6,844,990 B2 (Ex. 1001, "the '990 patent"), owned by ImmerVision, Inc. ("Patent Owner").

We have jurisdiction to hear this *inter partes* review under 35 U.S.C. § 6. This Final Written Decision is issued pursuant to 35 U.S.C. § 318(a) and 37 C.F.R. § 42.73. For the reasons discussed herein, Petitioner has not shown, by a preponderance of the evidence, that claim 5 of the '990 patent is unpatentable.

A. Procedural History

On November 27, 2019, Petitioner requested an *inter partes* review of claim 5 of the '990 patent. Paper 2 ("Pet."). Patent Owner filed a Preliminary Response. Paper 5 ("Prelim. Resp."). On May 13, 2020, we instituted an *inter partes* review of the challenged claim on all grounds raised in the Petition. Paper 6 ("Dec."). Following institution, Patent Owner filed a Patent Owner Response (Paper 12, "PO Resp."), Petitioner filed a Reply to the Patent Owner Response (Paper 16, "Pet. Reply"), and Patent Owner filed a Sur-Reply to Petitioner's Reply (Paper 17, "PO Sur-Reply).

Petitioner relies on the declaration testimony of Russell Chipman, Ph.D. (Exs. 1008, 1017, 1019) to support the Petition. Patent Owner took cross-examination via deposition of Dr. Chipman (Ex. 2002). Patent Owner relies on the declaration testimony of David Aikens (Ex. 2009). Petitioner took cross-examination via deposition of Mr. Aikens (Ex. 1018).

Oral hearing was requested by both parties. Papers 18, 19. We heard argument on February 8, 2021, and a transcript of the hearing has been entered into the record. Paper 25 ("Tr.").

B. Real Parties-in-Interest

Petitioner LG Electronics Inc. identifies LG Electronics U.S.A., Inc. and LG Innotek Co. Ltd. as additional real parties-in-interest. Pet. 2. Patent Owner ImmerVision, Inc., identifies itself as the real party-in-interest. Paper 4, 2. The parties do not raise any issues about real parties-in-interest.

C. Related Proceedings

The parties identify two pending district court cases involving the '990 patent: *ImmerVision, Inc. v. LG Electronics U.S.A.*, No. 1-18-cv-01630 (D. Del.) and *ImmerVision, Inc. v. LG Electronics U.S.A.*, No. 1-18-cv-01631 (D. Del.). Pet. 2; Paper 4, 2–3. The '990 patent is also the subject of an *inter partes* review in IPR2020-00195. *See* IPR2020-00195, Paper 6.

In addition, the '990 patent: (1) was the subject of *Ex Parte* Reexamination Control No. 90/013,410; (2) was challenged in an *inter partes* proceeding, *Panasonic System Networks Co., Ltd. v. 6115187 Canada Inc.*, IPR2014-01438; and (3) was the subject of three other district court cases that are no longer pending. *See* Pet. 2–3; *see also Panasonic System Networks Co., Ltd. v. 6115187 Canada Inc.*, IPR2014-01438, Paper 11 (PTAB Nov. 26, 2014) (terminating proceeding prior to institution following settlement).

D. The '990 Patent (Ex. 1001)

The '990 patent is titled "Method for Capturing and Displaying a Variable Resolution Digital Panoramic Image" and issued on January 18, 2005, from an application filed on November 12, 2003. Ex. 1001, codes (22), (45), (54). The application for the '990 patent is a continuation of application No. PCT/FR02/01588, filed on May 10, 2002, and claims priority to foreign application FR 01 06261, filed May 11, 2001. *Id.* at codes (30), (63).

The '990 patent relates to capturing a digital panoramic image that includes using a panoramic objective lens having "a distribution function of the image points that is not linear relative to the field angle [α] of the object points of the panorama," where the "distribution function Fdc . . . determines the relative distance dr of an image point in relation to the center of the image disk according to the field angle α of the corresponding object point." *Id.* at code (57), 2:30–34 (as corrected by Jan. 18, 2005, Cert. of Correction). The image obtained using such a panoramic objective lens has at least one zone that is expanded and another zone that is compressed. *Id.* at code (57). The '990 patent further explains that an image zone is "expanded" when it covers a greater number of pixels on an image sensor than it would with a linear distribution lens. *Id.* at 3:66–4:10. The '990 patent also provides that an "expanded" zone and "compressed" zone can be illustrated by comparison to a linear distribution function, with a slope greater than that of the linear distribution indicating an expanded zone and a lesser slope indicating a compressed zone. *Id.* at 9:13–35; *see also id.* at 2:30–42 (describing how "Figure 4B represents the shape of the distribution function Fdc of a classical objective lens," of ideal form, "a straight line of gradient K . . . in which the constant K is equal to 0.111 degree^{-1} (1/90°)"). Figure 9, reproduced below, depicts an image point distribution of a lens having a compressed zone between α=0° and α=30°, an expanded zone between α=30° and α=70°, and a compressed zone between α=70° and α=90°.

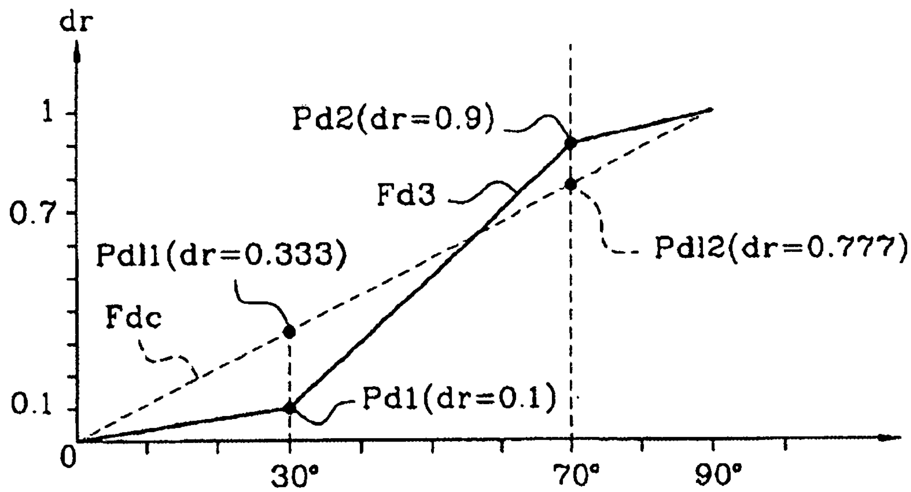

Fig. 9

Id., Fig. 9 (depicting plot of a non-linear distribution function of a panoramic objective lens). The patent further provides for correcting the non-linearity of the panoramic image initially obtained when using such lens. *Id.* at code (57).

The '990 patent was the subject of an *ex parte* reexamination. *Id.* at 25–27 (Ex Parte Reexamination Certificate (10588th)). The Reexamination Request—Control No. 90/013,410—was filed November 26, 2014. *Id.* at 25; Ex. 1003, 328–339 ("Request by Patent Owner for *Ex Parte* Reexamination of U.S. Patent No. 6,844,990"). Patent Owner cancelled claim 1 by way of preliminary amendment that accompanied its request for *ex parte* reexamination of claims 1–4, 6, 7, 10, 11, 15–20, 22, 23, and 25. *See* Pet. 17–18; Ex. 1003, 330, 341.

E. The Challenged Claim

Challenged claim 5 incorporates the limitations of cancelled claim 1, from which it depends. *See* MPEP § 2260.01 ("the content of the canceled base claim . . . [is] available to be read as part of the confirmed or allowed dependent claim"). Both claims are reproduced below.

> 1. A method for capturing a digital panoramic image, by projecting a panorama onto an image sensor by means of a panoramic objective lens, the panoramic objective lens having an image point distribution function that is not linear relative to the field angle of object points of the panorama, the distribution function having a maximum divergence of at least ±10% compared to a linear distribution function, such that the panoramic image obtained has at least one substantially compressed zone.

Ex. 1001, 19:28–37.

> 5. The method according to claim 1, wherein the objective lens compresses the center of the image and the edges of the image and expands an intermediate zone of the image located between the center and the edges of the image.

Id. at 19:49–52.

F. Instituted Grounds of Unpatentability at Issue

We instituted trial on all grounds of unpatentability proposed by Petitioner, as shown below:

Claim Challenged	35 U.S.C. §[1]	Reference(s)/Basis
5	103	Tada[2]
5	103	Tada, Nagaoka[3]
5	103	Tada, Baker[4]

[1] The Leahy-Smith America Invents Act ("AIA"), Pub. L. No. 112–29, 125 Stat. 284, 287–88 (2011), revised 35 U.S.C. § 103 effective March 16, 2013. Because the challenged patent was filed before March 16, 2013, we refer to the pre-AIA version of 35 U.S.C. § 103.
[2] US 5,861,999, issued January 19, 1999 (Ex. 1007).
[3] US 6,128,145, issued October 3, 2000 (Ex. 1004).
[4] US 5,686,957, issued November 11, 1997 (Ex. 1005).

II. ANALYSIS

A. Principles of Law

A claim is unpatentable under § 103 if "the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains." *KSR Int'l Co. v. Teleflex Inc.*, 550 U.S. 398, 406 (2007). The question of obviousness is resolved on the basis of underlying factual determinations, including: (1) the scope and content of the prior art; (2) any differences between the claimed subject matter and the prior art; (3) the level of skill in the art; and (4) when in evidence, objective evidence of nonobviousness, i.e., secondary considerations. *See Graham v. John Deere Co.*, 383 U.S. 1, 17–18 (1966).

Regarding the scope and content of the prior art, "[w]hat a reference teaches is a question of fact." *In re Beattie*, 914 F.2d 1309, 1311 (Fed. Cir. 1992). A reference is prior art for what it discloses, even if it is in error, unless the error is an "obvious error," in which case "it cannot be said to describe or suggest [what is disclosed in error] to those in the art." *In re Yale*, 434 F.2d 666, 668–69 (CCPA 1970) (holding that an error in the statement of a chemical formula would have been obvious to one of ordinary skill in the art and thus would not have put them in possession of the compound because they would have disregarded it as an error or replaced it with the correct chemical formula); *see also In re Clark*, 420 F. App'x 994, 998 (Fed. Cir. 2011) (nonprecedential) (holding that "absent an obvious error on the face of a reference, a reference is prior art for what it discloses" and that the Board did not err in relying on such a disclosure where there was "nothing in the . . . publication indicating that the [relied-on] statements . . . were in error.").

Additionally, the obviousness inquiry typically requires an analysis of "whether there was an apparent reason to combine the known elements in the fashion claimed by the patent at issue." *KSR*, 550 U.S. at 418 (citing *In re Kahn*, 441 F.3d 977, 988 (Fed. Cir. 2006) (requiring "articulated reasoning with some rational underpinning to support the legal conclusion of obviousness")); *see In re Warsaw Orthopedic, Inc.*, 832 F.3d 1327, 1333 (Fed. Cir. 2016) (citing *DyStar Textilfarben GmbH & Co. Deutschland KG v. C.H. Patrick Co.*, 464 F.3d 1356, 1360 (Fed. Cir. 2006)).

The Petition guides the proceeding. *See Koninklijke Philips N.V. v. Google LLC*, 948 F.3d 1330, 1335–36 (Fed. Cir. 2020). Our reviewing court explains that "[f]rom the outset, we see that Congress chose to structure a process in which it's the petitioner, . . . who gets to define the contours of the proceeding," and that "the statute envisions that a petitioner will seek an inter partes review of a particular kind—one guided by a petition describing each claim challenged and the grounds on which the challenge to each claim is based." *Id.* at 1335 (quoting *SAS Inst. Inc. v. Iancu*, 138 S. Ct. 1348, 1355 (2018) (internal quotations omitted)) (alterations in original). "[T]he petitioner's petition, not the Director's discretion is supposed to guide the life of the litigation," and that "the petitioner's contentions, not the Director's discretion, define the scope of the litigation all the way from institution through to conclusion." *Sirona Dental Sys. GmbH v. Institut Straumann AG*, 892 F.3d 1349, 1356 (Fed. Cir. 2018) (quoting *SAS*, 138 S. Ct. at 1356–57 (internal quotations omitted)).

To prevail, Petitioner must demonstrate by a preponderance of the evidence that the claims are unpatentable. 35 U.S.C. § 316(e); 37 C.F.R.

§ 42.1(d) (2019). "In an [*inter partes* review], the petitioner has the burden from the onset to show with particularity why the patent it challenges is unpatentable." *Harmonic Inc. v. Avid Tech., Inc.*, 815 F.3d 1356, 1363 (Fed. Cir. 2016) (citing 35 U.S.C. § 312(a)(3) (requiring *inter partes* review petitions to identify "with particularity . . . the evidence that supports the grounds for the challenge to each claim")). This burden never shifts to Patent Owner. *See Dynamic Drinkware, LLC v. National Graphics, Inc.*, 800 F.3d 1375, 1378 (Fed. Cir. 2015) (citing *Tech. Licensing Corp. v. Videotek, Inc.*, 545 F.3d 1316, 1326–27 (Fed. Cir. 2008)) (discussing the burden of proof in *inter partes* review).

B. Level of Ordinary Skill in the Art

In the Institution Decision, we adopted Petitioner's description of the level of ordinary skill in the art, not contested at that time by Patent Owner, and determined that a person of ordinary skill in the art "would have had at least a bachelor's degree in Physics, Optical Engineering, and/or Electrical Engineering and at least five years' experience in developing and designing optical products or systems and have familiarity with image processing algorithms and optical design software." Dec. 6; Pet. 20 (citing Ex. 1008 ¶ 41).

Patent Owner neither disputes Petitioner's articulation of the level of ordinary skill in the art nor presents its own articulation of the level of skill in the art, stating that "for purposes of this Response, Patent Owner does not object to Petitioner's proposed skill level." PO Resp. 20.

On this record, we have no reason to fault Petitioner's definition of the level of ordinary skill. We further note that the prior art itself demonstrates the level of skill in the art at the time of the invention, and there is no apparent inconsistency with Petitioner's definition. *See Okajima* *v. Bourdeau*, 261 F.3d 1350, 1355 (Fed. Cir. 2001) (explaining that "specific findings on the level of skill in the art . . . [are not required] 'where the prior art itself reflects an appropriate level and a need for testimony is not shown'" (quoting *Litton Indus. Prods., Inc. v. Solid State Sys. Corp.*, 755 F.2d 158, 163 (Fed. Cir. 1985))). Accordingly, we adopt the level of ordinary skill set forth by Petitioner.

C. Claim Construction

We apply the same claim construction standard that would be used to construe the claim in a civil action under 35 U.S.C. § 282(b), following the standard articulated in *Phillips v. AWH Corp.*, 415 F.3d 1303 (Fed. Cir. 2005) (en banc). 37 C.F.R. § 42.100(b). Under *Phillips*, claim terms are afforded "their ordinary and customary meaning." *Phillips*, 415 F.3d at 1312. "[T]he ordinary and customary meaning of a claim term is the meaning that the term would have to a person of ordinary skill in the art in question at the time of the invention." *Id.* at 1313. Only those terms that are in controversy need be construed, and only to the extent necessary to resolve the controversy. *See Nidec Motor Corp. v. Zhongshan Broad Ocean Motor Co.*, 868 F.3d 1013, 1017 (Fed. Cir. 2017) (citing *Vivid Techs., Inc. v. Am. Sci. & Eng'g, Inc.*, 200 F.3d 795, 803 (Fed. Cir. 1999)).

Before institution, Petitioner proposed constructions for particular claim terms, which Patent Owner, for the purposes of its Preliminary Response, did not contest. Dec. 7–8. On that record, and for the purpose of the Institution Decision, we adopted the constructions set forth by Petitioner, because the constructions appeared reasonable and were not contested. *Id.* at 9.

Following institution, Patent Owner again neither disputes Petitioner's proposed constructions nor proposes its own, stating, "[w]hile not necessarily agreeing with the proposed constructions of those terms, ***solely*** for purposes of this Response, Patent Owner does not object to the constructions set out by Petitioner." PO Resp. 20.

Considering again the proposed constructions, on this record, we adopt the definitions set forth by Petitioner: (i) "panoramic objective lens" means "a super-wide or ultra-wide objective lens"; (ii) "object points of the panorama" are "points of the object in the panorama being viewed by the lens"; (iii) "image point" means "a point of light projected by the lens onto an image plane, said light coming from the corresponding object point of a viewed object in the panorama"; (iv) "field angle of object points" are "the angles of incident light rays passing through the object points and through the center of the panorama photographed, relative to the optical axis of the objective lens"; (v) "maximum divergence" is defined by the formula "DIVmax %=[[dr(Pd)-dr(Pdl)]/[dr(Pdl)]]*100, in which dr(Pd) is the relative distance in relation to the center of the point of maximum divergence Pd, and dr(Pdl) is the relative distance in relation to the center of the corresponding point on the linear distribution line"; (vi) "expanded zone" means "the portion of the image point distribution function where the gradient is higher than the gradient of the linear distribution function"; and (vii) "compressed zone" means "the portion of the image point distribution function where the gradient is lower than the gradient of the linear distribution function." Dec. 7–8 (citing Ex. 1001, 1:18–20, 2:18–22, 7:2–5, 7:11–14, 8:38–43, 8:57–65; Ex. 1008 ¶¶ 44, 52, 57, 63). We further determine that no additional claim construction is necessary to reach our decision in this case.

D. Asserted Obviousness over Tada

Petitioner challenges claim 5 as obvious over Tada. Pet. 29–52.

1. Overview of Tada (Ex. 1007)

Tada discloses a method for capturing a digital panoramic image, including by use of "a super wide angle lens system which can be used for a monitoring camera (CCTV) etc." Ex. 1007, 1:7–9. Tada states that "[i]t is an object . . . to provide a retrofocus type super wide angle lens system . . . [having] an angle of view of approximately 120° to 140°." *Id.* at 1:48–50. Tada identifies Figures 1, 6, 11, and 16 as schematic views "showing the lens arrangement" of a first, second, third, and fourth embodiment, respectively, "of a super wide angle lens system. *Id.* at 3:18–20, 3:32–34, 3:44–46, 3:57–59, Figs. 1, 6, 11, 16. The third embodiment, depicted in Figure 11, reproduced below, "is substantially the same as the second embodiment," depicted in Figure 6, which "is substantially the same as that of the first embodiment," depicted in Figure 1. *Id.* at 6:2–3, 7:36–43, 8:58–62.

FIG. 11

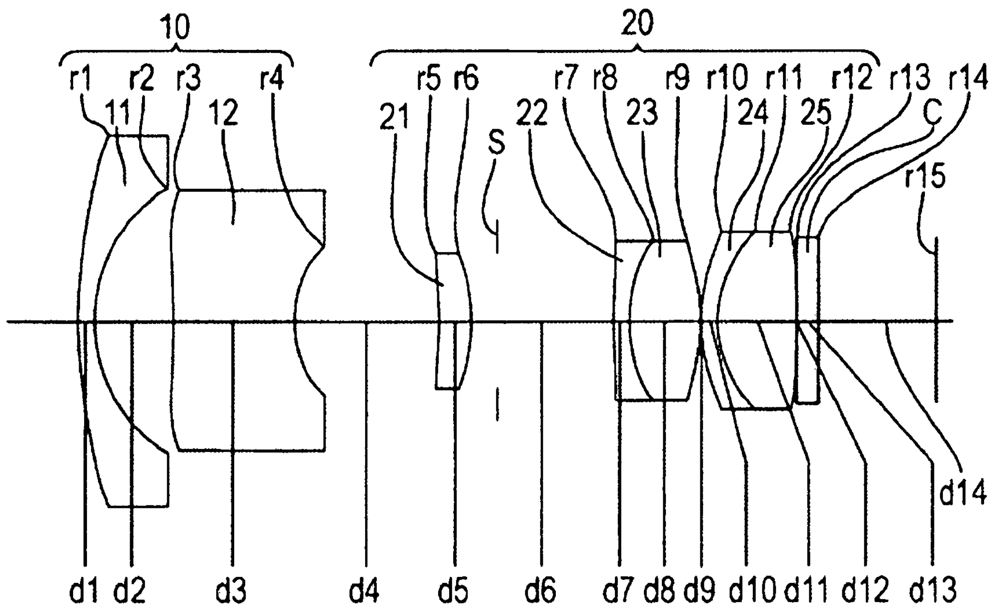

Figure 11 depicts the lens arrangement of a super wide angle lens system. *Id.* at 3:44–46, Fig. 11. The depicted super wide angle lens system consists of front lens group 10 and rear lens group 20. *See id.* at 6:4–5 (identifying elements in reference to Figure 1). Figure 11 also depicts features of a CCD[5] (charge-coupled device) used to capture an image; element C refers to "a glass cover of the CCD" and "surface No. 15 refers to the image pickup surface of the CCD." *See id.* at 6:26–32 (identifying elements in reference to Figure 1). Tada sets forth that its Figures 5 and 6 disclose numerical data regarding the third embodiment, including "[t]he surface figure, paraxial spherical amount and aspherical amount of surface No. 3." *Id.* at 8:63–9:57. Tada similarly sets forth that its Tables 1 and 2 disclose numerical data regarding the first embodiment (*id.* at 6:28–32, 6:36–7:29), Tables 3 and 4

[5] Although neither Tada nor the Petitioner define "CCD," we understand CCD to be a "charge-coupled device." *See, e.g.*, Ex. 2001 ¶ 595.

disclose numerical data regarding the second embodiment (7:42–8:53), and Tables 7 and 8 disclose numerical data regarding the fourth embodiment (9:63–10:50). Tada also sets forth "[v]alues of the ratios defined in conditions (1) through (8) for the four embodiments" in its Table 9. *Id.* at 10:53–11:12.

2. *Analysis*

Claim 5, which incorporates the limitations of cancelled claim 1 from which it depends, is directed to a method of capturing a digital panoramic image by use of a panoramic objective lens to project a panorama onto an image sensor. In general, claim 1 requires that the panoramic objective lens used to capture the image has a distribution function of the image points that is not linear to the field angle of the object points of the panorama, having a maximum divergence that is at least ±10% compared to a linear distribution function. Ex. 1001, 19:28–37. Claim 5 further requires that "the objective lens compresses the center of the image and edges of the image and expands an intermediate zone of the image located between the center and the edges of the image." *Id.* at 19:49–52.

a) Overview of Ground Based on Tada

Petitioner contends that Tada discloses the claimed method of capturing a digital panoramic image using its "third embodiment of a super wide angle lens system" (i.e., a panoramic objective lens) that compresses the center of the image and edges of the image and expands an intermediate zone of the image located between the center and edges of the image. Pet. 29–37; Pet. Reply 2–3, 10–19. Petitioner asserts that Tada's "Figure 11. . . shows a third embodiment of a super wide angle lens system" and that Table 5 provides for the "prescription of the third embodiment lens," i.e., "[n]umerical data regarding the third embodiment." Pet. 29–31, 33.

Dr. Chipman testifies that he reconstructed the lens of Figure 11 using the numerical data information in Table 5. Ex. 1008 ¶ 46; *see also id.* ¶ 49 (stating Tada's disclosure of, *inter alia*, schematic views of the lens arrangements and tables of measurements of the lens allows one of ordinary skill in the art to reconstruct the exact lens system described in Tada). In particular, Dr. Chipman testifies that he input certain information from Table 5 (i.e., the FNO and W values, the values in the R, D, Nd, and vd columns, and the "aspherical data" information) into an "optical design program called Code V" and that Code V then generated a depiction of the lens system corresponding to the lens prescription in Table 5. *Id.* ¶ 46; *see also id.* ¶ 50 (stating numerical data regarding Tada's third embodiment is shown in Table 5). Dr. Chipman also testifies that he used the Code V program to calculate the characteristics of the lens system to test and show how it would function by providing plots of the various characteristics of the lens system. Ex. 1008 ¶ 51. Dr. Chipman also testifies that he plotted the image point distribution function for the lens system at six wavelengths, and that the function is not linear in any of them (*id.* ¶¶ 52–53), that the maximum deviation from a linear distribution function is at least 8.12% to 9.88%, depending on the wavelength (*id.* at ¶¶ 57–58), and that the lens "compresses the center of the image and the edges of the image and expands an intermediate zone of the image located between the center and the edges of the image" (*id.* ¶ 68).

Petitioner relies on these calculations and plots of Tada's third embodiment lens system of Figure 11 with the prescription set forth in Table 5 to show that Tada's third embodiment meets the limitations of claim 5, and of claim 1 from which it depends. Pet. 31–52 (citing Ex. 1007, Fig. 11, Table 5); Pet. Reply 1–19. That is, Petitioner relies on the lens prescription set forth in Table 5 for the lens system depicted in Figure 11, and calculations of that lens system's properties showing it (1) "compresses the center of the image and the edges of the image and expands an intermediate zone of the image located between the center and edges of the image," as required by claim 5, and (2) for that image to have image point distribution as a function of the field angle of the object points of the panorama that is at least ±10% compared to a linear distribution function, as required by independent claim 1 from which claim 5 depends. Pet. 31–52.

b) Patent Owner's Contention of Obvious Error in Tada

Patent Owner contends that Tada's third embodiment, as set forth in Table 5, has a readily apparent error (i.e., the aspherical data). PO Resp. 1–3. Patent Owner argues that the grounds of unpatentability set forth in the Petition fail because the disclosure including an apparent error should be disregarded or corrected, and it is only in relying on the disclosure in error that Petitioner arrives at a lens that compresses the center and edges and expands an intermediate zone of an image as required by claim 5. *Id.* at 1–3, 8–14, 24–40; PO Sur-Reply 1–7. Patent Owner relies on *Yale* for its holding that "[w]here a prior art reference contains 'an error obvious to one of ordinary skill in the art, it cannot be said to describe or suggest' the erroneous feature." *Yale*, 434 F.2d at 668–669. In identifying the error, Patent Owner contends that Tada's "ratios (2)–(4) in Table 9 should respectively match Table 5's A_4, A_6, and A_8, but do not." PO Resp. 13 (citing Ex. 2002, 47:22–50:24 (cross-examination testimony of Dr. Chipman); Ex. 2009 ¶ 69 (testimony of Mr. Aikens that identified "values do not match the values in Table 5 because Table 5 is in error")). Patent Owner's declarant Mr. Aikens also testifies on cross-examination that "[b]ecause the focal length is 1 [in each of the four embodiments], Table 9 rather conveniently gives you the aspheric coefficients for each of the four embodiments, and it matches correctly for 1, 2 and 4 and is totally wrong for 3." Ex. 1018, 136:11–15. Patent Owner also sets forth calculations by Mr. Aikens for Embodiment 3 using aspherical data information from Tada's Japanese priority application JP 06-201903,[6] which Patent Owner contends is the correct lens prescription, and determines that the "compressed zone at the edge of the lens across the visible wavelength spectrum" is missing. PO Resp. 32–38 (citing Ex. 2009 ¶¶ 73, 88 90-100). Patent Owner further contends that Petitioner failed to "explain why a [person of ordinary skill in the art] would have modified [the lens system according to the correct prescription] to include a compressed edge zone." *Id.* at 40 (emphasis omitted).

c) Petitioner's Argument There is No Obvious Error

In its Reply, Petitioner does not dispute that Dr. Chipman relies on the data in Tada's Table 5 to reconstruct a lens it contends satisfies all of the limitations of claim 5, including the "three zone" limitations that require compression of the center and edges and expansion of an intermediate zone of the image (i.e., (1) a central compressed zone, (2) an intermediate expanded zone, and (3) a compressed edge zone). *See generally* Pet. Reply. Petitioner also does not dispute that if the purported error in Tada's Table 5 was corrected using the aspherical data from the Japanese priority application, that a lens reconstructed using the Japanese priority application data would not satisfy a limitation of claim 5 because the lens would not compress the edges of the produced image, and thus would not have a

[6] The JP 09-201903 application was published as JP H10115778. Ex. 2007, 1; Ex. 2008, 2. Patent Owner provides an English language translation. Ex. 2008, 1–2.

compressed edge zone. *Id.* Petitioner contends, rather, that the alleged error in the aspherical data in Tada's Table 5 is irrelevant because it was not apparent or obvious upon reading the reference. *Id.* at 3–10 (citing *Yale*, 434 F.2d at 669). Petitioner argues that Tada's Table 5, accordingly, should be considered as it reads, neither disregarding nor correcting its disclosure, and that Table 5 itself, as written, discloses and enables a lens meeting the requirements set forth for Tada's invention. *Id.*

Petitioner further argues that the error in Table 5 would not have been "readily apparent" because "there is nothing in Table 5 that would lead a [person of ordinary skill in the art] to believe that there is an error." *Id.* at 3. Petitioner contends that Table 5 "includes all of the information necessary to enable a complete lens" (*id.* at 4 (citing Ex. 1019 ¶¶ 5–8), 2), and that "[t]he lens of Table 5 as analyzed by Dr. Chipman discloses all of the elements . . . of claim 5" (*id.* at 3). Petitioner further contends that even if a person of ordinary skill in the art "were to check Table 5 with other parts of Tada, it would have taken many hours to conclude there was an error." *Id.* at 4 (citing Ex. 1018, 132:1–15, 136:5–137:12). To support its argument that the error would not have been readily apparent, Petitioner quotes testimony of Patent Owner's declarant Mr. Aikens that he "had figured out that something was wrong probably within two to three hours. Then modeling the other embodiments, that took time. And then continuing to try to understand how to recreate the surface, that took more time." *Id.* (quoting Ex. 1018, 137:8–12).

Petitioner argues that this case differs from those in which errors were determined to be "obvious on their face and detectable with little effort." *Id.* at 5. Specifically, Petitioner argues that "any purported 'error' in Table 5 of Tada" would not have been like the obvious error in *Yale*, and, thus, that this is not a case "such that a [person of ordinary skill in the art] would 'mentally disregard [the information in Table 5] as a misprint or mentally substitute [the information in Tables 6 and 9] in its place.'" *Id.* at 4–5 (citing *Yale*, 434 F.2d at 669). Petitioner relies on the court's reasoning in *Yale* "that the error was such that '[t]he public is not put in possession of the compound; thus it would not be obvious to use,'" and argues that here, in contrast, Tada puts the public in possession because "Table 5 'describes' the claimed invention" and "a [person of ordinary skill in the art] would have been able to make the Table 5 lens." *Id.* at 5–6 (citing *In re Elsner*, 381 F.3d 1125, 1128 (Fed. Cir. 2004); *Yale*, 434 F.2d at 669). Petitioner further contends that the "'error'. . . in Tada's Table 5 is more like the errors that courts have found do not rise to the level of being excluded." *Id.* at 7–8 (citing *In re Garfinkel*, 437 F.2d 1005, 1008 (CCPA 1971); *In re Borst*, 345 F.2d 851, 853 n.2 (CCPA 1965); *Clark*, 420 F. App'x at 998).

d) Analysis of Tada's Disclosure

On this record, we find that there is an obvious error on the face of Tada, in Table 5, and that this error cannot be relied on to support the grounds of unpatentability set forth by Petitioner.

As mentioned above, Tada sets forth numerical data for prescribing the lens systems of each of its first, second, third, and fourth embodiments in Tables 1, 3, 5, and 7, respectively. *See* Ex. 1007, 6:36–63 (Table 1), 7:50–8:25 (Table 3), 9:1–29 (Table 5), 10:1–29 (Table 7). These tables include values for aspherical data (coefficients) for surface No. 3 of the second lens element, with each table setting forth K (a conic constant), A4 (representing a fourth-order aspherical factor), A6 (representing a sixth-order aspherical factor), A8 (an eighth-order aspherical factor), and A10 (a tenth-order aspherical factor). *Id.* at 5:63–67, 6:59–61 (Table 1, first embodiment), 8:21–23 (Table 3, second embodiment), 9:25–27 (Table 5, third embodiment), 10:25–27 (Table 7, fourth embodiment).

Tada's Table 9 also sets forth "[v]alues of the ratios defined in conditions (1) through (8) for the four embodiments." *Id.* at 10:53–11:12. Of these, conditions (2), (3), and (4) specify the condition on the fourth-, sixth-, and eighth-order aspherical factors of the aspherical surface. *Id.* at 4:60–61, 5:3–5.

There is a readily apparent inconsistency in the aspherical coefficients A4, A6, and A8, in Tables 1, 3, 5, and 7, and of values for conditions (2), (3), and (4) for each of the four embodiments, in Table 9. The portion of each of Tables 1, 3, 5, and 7 setting forth the "Aspherical Data" for "Surface No. 3" is reproduced below, as is Table 9:

From Table 1 (Embodiment 1)

Aspherical Data:
No.3: K = 0.00, A4 = 0.41500×10^{-1}, A6 = -0.72169×10^{-2}, A8 = 0.10529×10^{-2}, A10 = 0.70513×10^{-4}

From Table 3 (Embodiment 2)

Aspherical Data:
No.3: K = 0.00, A4 = 0.30330×10^{-1}, A6 = -0.43125×10^{-2}, A8 = 0.46329×10^{-3}, A10 = -0.24092×10^{-4}

From Table 5 (Embodiment 3)

Aspherical Data:
No.3: K = 0.00, A4 = 0.30330×10^{-1}, A6 = -0.43125×10^{-2}, A8 = 0.46329×10^{-3}, A10 = -0.24092×10^{-4}

From Table 7 (Embodiment 4)

Aspherical Data:
No.3: K = 0.00, A4 = 0.88810×10^{-1}, A6 = -0.27110×10^{-1}, A8 = 0.79690×10^{-2}, A10 = -0.61180×10^{-3}

TABLE 9

	Embodiment 1	Embodiment 2
Condition (1)	−7.296	−6.981
Condition (2)	4.1500×10^{-2}	3.0330×10^{-2}
Condition (3)	-7.2169×10^{-3}	-4.3125×10^{-3}
Condition (4)	1.0529×10^{-3}	4.6329×10^{-4}
Condition (5)	2.549	2.907
Condition (6)	2.400	2.479
Condition (7)	529.729	25.228
Condition (8)	4.118	4.178

TABLE 9-continued

	Embodiment 3	Embodiment 4
Condition (1)	−8.060	−10.108
Condition (2)	2.0485×10^{-2}	8.8810×10^{-2}
Condition (3)	-2.5925×10^{-3}	-2.7110×10^{-2}
Condition (4)	2.4634×10^{-4}	7.9690×10^{-3}
Condition (5)	3.022	2.691
Condition (6)	2.425	2.512
Condition (7)	27.255	25.229
Condition (8)	4.229	4.543

The portions of Tables 1, 3, 5, and 7 set forth "aspherical data," and Table 9 sets forth values for conditions (1)–(8) for Embodiments 1–4. *Id.* at 6:59–61, 8:21–23, 9:25–27, 10:25–27, 10:57–11:12.

Comparison of aspherical coefficients A4, A6, and A8, in Tables 1, 3, 5, and 7, and of values for conditions (2), (3), and (4) for each of the four embodiments in Table 9 shows the inconsistency. The values of aspherical coefficients A4, A6, and A8 in Tables 1, 3, and 7, for Embodiments 1, 2, and 4, and the corresponding values for conditions (2), (3), and (4), for Embodiments 1, 2, and 4, are identical. *Compare id.* at 6:59–61, *with id.* at 10:57–62 (Embodiment 1); *compare id.* at 8:21–23, *with id.* at 10:57–62

(Embodiment 2); *compare id.* at 10:25–27, *with id.* at 11:2–8 (Embodiment 4). The values of aspherical coefficients A4, A6, and A8 in Table 5, however, differ from the corresponding values for conditions (2), (3), and (4) for Embodiment 3. *Compare id.* at 9:25–27, *with id.* at 11:2–8. This indicates that there is an error for Embodiment 3 in either Table 5 or in Table 9. Still looking only at the Tables, it is also apparent that the values set forth for aspherical coefficients, including A4, A6, and A8, of Embodiment 3 in Table 5, are identical to those for Embodiment 2 in Table 3. *Compare id.* at 8:21–25, *with id.* at 9:25–29. That these aspherical coefficients are identical is incongruous with the differences in the values of other data for the lens systems, including the radius of curvature (R) of lens surfaces and the distances between lens surfaces (D), prescribing these two lens systems. *Id.* at 5:48–49, 7:50–8:25 (Table 3), 9:1–29 (Table 5); *see also id.* at 6:36–63 (Table 1), 10:1–29 (Table 7).

The inconsistency between Tada's Table 5 and Table 9 makes it apparent that there is an error in Table 5's recitation of the aspherical coefficients. As discussed above, a comparison of the values for aspherical coefficients A4, A6, and A8 in Table 5 (Embodiment 3) and conditions (2), (3), and (4) for Embodiment 3 in Table 9 indicates that the data in one of Table 5 and Table 9 is in error. Mr. Aikens opines that "[b]ecause the focal length is 1 [in each of the four embodiments], Table 9 rather conveniently gives you the aspheric coefficients for each of the four embodiments, and it matches correctly for 1, 2 and 4 and is totally wrong for 3." Ex. 1018, 136:11–15; Pet. Reply 4 (citing Ex. 1018, 136:5–137:12); *see also* PO Resp. 13 ("ratios (2)–(4) in Table 9 should respectively match Table 5's A_4, A_6, and A_8, but do not." (citing Ex. 2002, 47:22–50:24 (cross-examination testimony of Dr. Chipman)); Ex. 2009 ¶ 69 (testimony of Mr. Aikens that identified "values do not match the values in Table 5 because Table 5 is in error")). We are persuaded by Dr. Aikens' testimony that a person of ordinary skill in the art would readily ascertain, from the Specification alone, that the error is in the aspherical data in Table 5. Ex. 2009 ¶ 69. As discussed above, the aspherical data from Table 5 matches that in Table 3 and, if the error is in Table 5, this can be explained as a simple transcription error, inadvertently duplicating the aspherical data from Table 3. If the error as to Embodiment 3 is in Table 9, however, then the error is more difficult to explain in the context of the lens systems of Embodiments 1–4. As set forth in Tables 3 and 5, the aspherical coefficients, including A4, A6, and A8, are identical in Embodiments 2 and 3, despite these lens systems differing throughout with respect to the lens surface's radius of curvature (R) and distances between the lens surfaces (D). The lens systems of Embodiments 1 and 4 each also differ from every other embodiment with respect to the aspherical coefficients and the values of R and D.

Tada provides that "Japanese Patent Application Nos. 08-222394 . . . and 09-201903 . . . are expressly incorporated herein by reference in their entireties." Ex. 1007, 3:9–13; *see* PO Sur-Reply 6–7 (noting Tada expressly incorporates the Japanese priority application by reference, citing Ex. 2007 (JP H115778)). The cited Japanese priority application for Tada—JP 09-201903—also includes a Table 3 with the same data as within the body of Tada itself, including the aspherical data (Ex. 2007, 5–6 ¶ 29; Ex. 2008, 13–14 ¶ 29; Ex. 1007, 7:50–8:25), and a Table 9 with the same values for conditions (2), (3), and (4) of all four embodiments[7] (Ex. 2007, 9 ¶ 37;

[7] We find no distinction in JP 09-201903 referring to Tada's "four embodiments" as "working examples."

Ex. 2008, 20 ¶ 37; Ex. 1007, 10:56–11:12). Importantly, as to Table 5, the JP 09-201903 application has different values for "aspherical surface data," including for A4, A6, and A8, than those for "[a]spherical data" in Tada itself. See Ex. 2007, 7 ¶ 32; Ex. 2008, 16 ¶ 32; Ex. 1007, 10:25–29. Also, unlike in Tada itself, the values for A4, A6, and A8 in JP 09-201903 Table 5 are identical to the values for conditions (2), (3), and (4) for Embodiment 3. Ex. 2007, 7 ¶ 32, 9 ¶ 37; Ex. 2008, 16 ¶ 32, 20 ¶ 37; Ex. 1007, 9:25–27, 11:6–8. The correspondence of the Tables 1, 3, 7, and 9 between the JP 09-201903 application and Tada itself is apparent, even prior to translation, as is the inconsistency as to the aspherical data for Table 5.

In sum, we find that one of ordinary skill in the art considering Tada would have reasonably considered the entire document, including the Japanese priority application incorporated by reference. Having done so, one of ordinary skill in the art would have readily ascertained that there was an error in the aspherical data of Table 5. The discrepancy between the data in Table 5 and Table 9 would have been apparent and obvious, because one of ordinary skill in the art would have appreciated that the values for aspherical data A4, A6, and A8 and for conditions (2), (3), and (4), respectively, should be identical, but were not identical, for Embodiment 3. Further, one of ordinary skill in the art also would have reasonably appreciated, considering the remainder of Tada's disclosure, the error to be in Table 5. The Japanese priority application incorporated by reference into Tada—JP 09-201903—confirms the error. All in all, we find it apparent that the discrepancy is grounded on a transcription error in the values for A4, A6, and A8 in Tada's Table 5, namely, inadvertent duplication of the values for the aspherical data in Table 3.

e) Analysis of Petitioner's Arguments Regarding Obvious Error

Petitioner's case-based arguments that the error was not an "obvious error" fall short. In *Yale*, the error was the listing of a particular compound, i.e., CF(3)CF(2)CHClBr, in a figure plotting characteristics of different compounds, which compound was not disclosed elsewhere in the reference, and where the value of a characteristic for the compound listed in error in that figure was identical to the value for a different compound, i.e., CF(3)CHClBr, disclosed in another figure.[8] *Yale*, 434 F.2d at 667. The court determined that "[a]ny number of these individually or cumulatively would, . . . alert one of ordinary skill in the art of the typographical error" and "that the one [the court] immediately noted was the inconsistency between Figs. 1 and 3 of [the reference]." *Id.* at 669. Petitioner argues that the error in Table 5 would not have been "readily apparent" because nothing in Table 5 itself would lead a person of ordinary skill in the art to believe there was an error, but the circumstances here appear to be essentially the same as in *Yale*, where the court relied on an inconsistency between different portions of the disclosure. *Id.*

Petitioner further argues that Table 5 "includes all of the information necessary to enable a complete lens." Pet. Reply 3 (citing Ex. 1019 ¶¶ 5–8). The court in *Yale*, however, determined that one of ordinary skill in the art, recognizing a disclosure to be an obvious error, would simply disregard it

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[8] The Appellant in *Yale* also contended an error would be apparent because, other than the compound listed in error, only known compounds were discussed in the article. *Yale*, 434 F.2d at 667. Also, the appellant in *Yale* submitted two letters, a letter sent to the author of the reference inquiring whether the compound was listed in error, and a letter in response that the listing was a typographical error. *Id.*

and not even get so far as to consider whether they knew how to make it. *Yale*, 434 F.2d at 669.

Petitioner's reliance on *Elsner* in arguing that Tada put the public in possession of the invention because "Table 5 'describes' the claimed invention" and "a [person of ordinary skill in the art] would have been able to make the Table 5 lens" (Pet. Reply 5–6 (citing *Elsner*, 381 F.3d at 1128)) fails because, as discussed above, the issue is not whether the prior art disclosure is enabled, but rather whether it would be recognized as an obvious error and simply disregarded (*see Yale*, 434 F.2d at 669). Similarly, we give little weight to Dr. Chipman's testimony that the error would not have been readily apparent because Table 5 enables a person of ordinary skill in the art to make a complete lens because it is grounded on an incorrect understanding of the law. Ex. 1019 ¶¶ 5, 7–8; *cf. Integra Lifesciences I, Ltd. v. Merck KGaA*, 496 F.3d 1334, 1342 (Fed. Cir. 2007) (holding that "when an expert witness' statement of the law is incorrect, that view of the law cannot be relied upon to support the verdict."). As discussed above, the issue is not whether Table 5 enables the lens it describes, but rather whether the disclosure would be recognized as an obvious error. Dr. Chipman's expressed opinion grounded on an incorrect understanding that this is the law fails to support Petitioner's case.

Petitioner contends that even if a person of ordinary skill in the art "were to check Table 5 with other parts of Tada, it would have taken many hours to conclude there was an error." Pet. Reply 4 (citing Ex. 1018, 132:1–15, 136:5–137:12). Petitioner supports this contention with the testimony of Dr. Chipman (*id.* at 3 (citing Ex. 1019 ¶¶ 5–8)), including that "the purported error that Mr. Aikens alleges is not obvious on its face and detectable with little effort" that relies on the reasoning that "Mr. Aikens had to spend many hours, going through a convoluted process" (Ex. 1019 ¶ 6). The relevant question is whether the error was an obvious error to one of ordinary skill in the art, not whether Mr. Aikens happened to take a circuitous route to determine that the aspherical data in Table 5 was, in fact, in error. *Yale*, 434 F.2d at 669. As laid out above, we find that one of ordinary skill in the art considering Tada would have ascertained a discrepancy between the values of aspherical data A4, A6, and A8 in Table 5 and the corresponding values for conditions (2), (3), and (4) for embodiment 3 in Table 7, and discerned an error in Table 5 through no more than considering the disclosure of Tada as a whole.

The particular manner in which Mr. Aikens determined that there was an error in Table 5, as laid out in Patent Owner's Response, does not diminish that there is an obvious error in Tada within the meaning of *Yale*. Tada's disclosure indicates on its face that there is obvious, likely typographical, error apparent upon considering the values of aspherical data A4, A6, and A8 in Table 5, and the corresponding values for conditions (2), (3), and (4) for Embodiment 3 in Table 9, and that this is confirmed by the Japanese priority application incorporated by reference into Tada.
Dr. Chipman's testimony does not address how this discrepancy between the data in Table 5 and Table 9, and the disclosure incorporated by reference, would not be sufficient indication of an obvious error. Ex. 1019 ¶ 5–8. Accordingly, we give little weight to his testimony that the "purported 'error' in Table 5 of Tada would not have been an error obvious to one of ordinary skill in the art." *Id.* ¶ 6; *Velander v. Garner*, 348 F.3d 1359, 1371 (Fed. Cir. 2003) ("It is within the discretion of the trier of fact to give each item of evidence such weight as it feels appropriate."); *Ashland Oil, Inc. v. Delta Resins & Refractories, Inc.*, 776 F.2d 281, 294 (Fed. Cir. 1985) ("Lack

of factual support for expert opinion going to factual determinations, however, may render the testimony of little probative value in a validity determination."). Indeed, Mr. Aikens' cross-examination testimony cited by Petitioner includes testimony that confirms that the presence of an error would have been immediately apparent because Mr. Aikens recognized that the values for conditions (2), (3), and (4) set forth in Table 9 do not match the aspheric coefficients for Embodiment 3 as defined in Table 5. *See* Ex. 1018, 136:11–15 ("Because the focal length is 1, Table 9 rather conveniently gives you the aspheric coefficients for each of the four embodiments, and it matches correctly for 1, 2 and 4 and is totally wrong for 3.").

Petitioner also argues that the alleged error in Tada's Table 5 is like the errors that the courts did not exclude in *Clark*, *Garfinkel*, or *Borst*. Pet. Reply 7–9. In *Clark*, the court found that reference incorrectly stated that a particular system used an FM transmitter and signal, but that nothing in the publication indicated that the statements were in error. *Clark*, 420 F. App'x at 998. Thus, while it is correct that "absent an obvious error on the face of the reference, a reference is prior art for what it discloses," here there is an "obvious error on the face of the reference," as discussed above. *Id.* In *Garfinkel*, the court did not disregard the teaching of a reference, despite the fact that an applicant had submitted an affidavit that a reference's teaching was in error, because "the error, if it exist[ed], was not apparent or obvious from reading the publication." *Garfinkel*, 437 F.2d at 1008; Pet. Reply 7–8. But here, again, the error is apparent and obvious from reading Tada. In *Borst*, the court found a prior art document to be enabling despite a possible error; Petitioner argues that, because Tada's disclosure of a lens in its Table 5 is enabling, the disclosed lens should be considered. Pet. Reply 8–9. As discussed above, however, the issue is not whether the disclosure is enabling, but rather whether there is an obvious error, such that the disclosure is simply disregarded. Even to the extent that *Borst* appears to indicate that there was an error in the disclosure of the relied-on reference in that case, there is no indication that it was an obvious error such that it informs the outcome where, as here, the error is an obvious error. *Borst*, 345 F.2d at 853 n.2 (noting that "Appellant does argue that there is a mathematical defect in the Samsel disclosure"). As such, *Borst* does not support Petitioner's argument that one of ordinary skill in the art would have relied on the aspherical data from Tada's Table 5 when that data is an obvious error. And the same can be said of *Amgen Inc. v. Hoechst Marion Roussel, Inc.*, 314 F.3d 1313, 1357 (Fed. Cir. 2003), that Petitioner relies on as supporting that "a reference need not be enabled; it qualifies as prior art, regardless, for what is disclosed therein" (Pet. Reply 10), because regardless of what is enabled, the disclosure cannot be said to describe or suggest that which is an error obvious to one of ordinary skill in the art (*Yale*, 434 F.2d at 669).

f) Conclusion

On this record, we find that the disclosure of aspherical coefficients in Table 5 of Tada is an obvious error and that, consequently, Tada cannot be said to describe or suggest the lens system according to the prescription that includes those aspherical coefficients. Because Petitioner relies wholly on the lens system of Embodiment 3, as set forth in Tada's Table 5, to meet the limitations of the recited objective lens that compresses the center and edges and expands an intermediate zone of an image, Petitioner has not established by a preponderance of the evidence that the method of claim 5 using such an objective lens would have been obvious.

E. Asserted Obviousness over Tada in View of Nagaoka

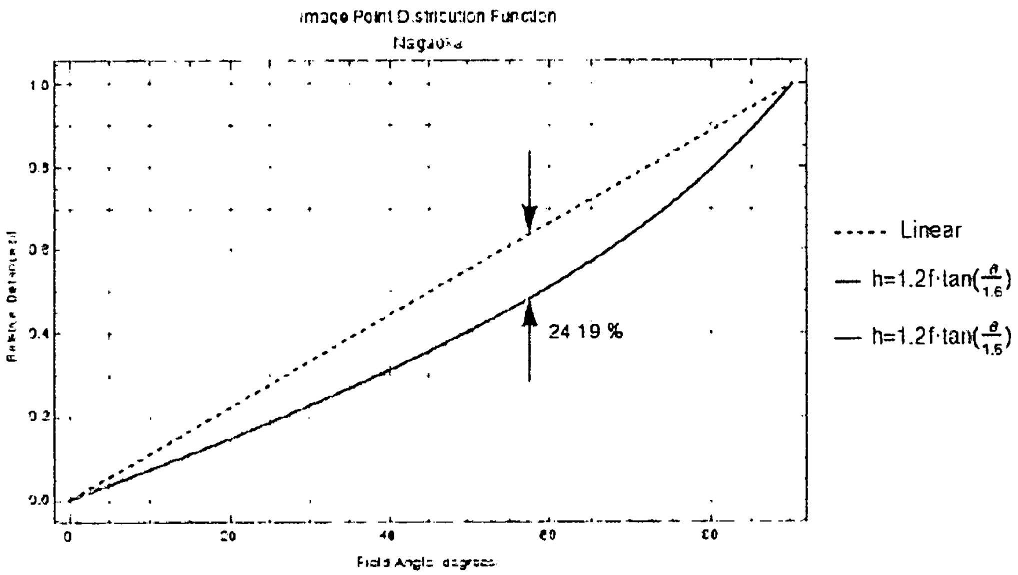
Petitioner challenges claim 5 as obvious over the combined teachings of Tada and Nagaoka. Pet. 52–63.

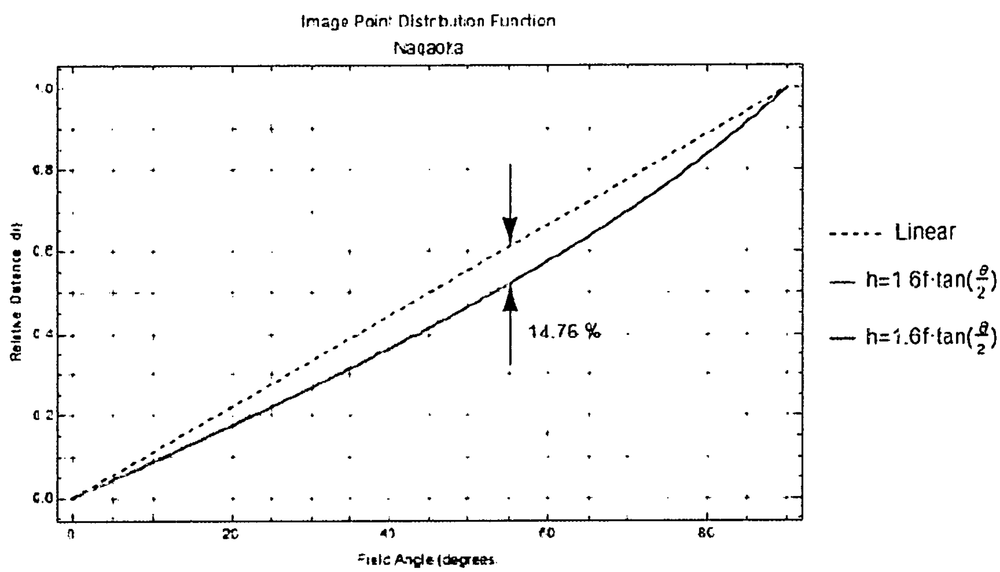
1. Overview of Nagaoka (Ex. 1004)

Nagaoka is directed to a monitoring system using a camera having a fisheye lens. Ex. 1004, 1:6–10, 1:11–14. Nagaoka discloses a number of different fisheye lenses having a nonlinear distribution function of image points relative to the field angle of the object points of the panorama. *Id.*, Figs. 3A–3B.

2. Analysis

Petitioner relies on "Tada explicitly disclos[ing] all of the elements of dependent claim 5 and independent claim 1," but adds that to the extent that Patent Owner argues that Tada falls short of disclosing "a maximum divergence of 'at least ±10%' compared to a linear distribution function," as set forth in claim 1, that this is remedied by Nagaoka. Pet. 52–63. As set forth by Petitioner, Nagaoka discloses a fisheye lens having a nonlinear distribution function, including two examples—$h=1.2f \cdot \tan(\theta/1.6)$ and $h=1.6f \cdot \tan(\theta/2)$. *Id.* at 54–58 (citing Ex. 1004, Fig. 3B). Petitioner calculates "a plot of the relative distance of an image point in relation to the center of the image according to the field angle of the corresponding object point" for each of these two functions "with a focal length of f=1" and overlays these with a linear distribution to demonstrate that the lens having the function $h=1.2f \cdot \tan(\theta/1.6)$ has a maximum divergence -24.19% and a lens having the function $h=1.6f \cdot \tan(\theta/2)$ has a maximum divergence of at least -14.76%. *Id.* at 56–58 (citing Ex. 1008 ¶¶ 79–82). These plots are reproduced below:





The depicted plots of Nagaoka's functions include two regions, a first with a slope less than "linear" indicating "compression" (highlighted yellow) and a second with a slope greater than "linear" indicating "expansion" (highlighted blue). *Id.* at 57 (reproducing figures plotting the image point distribution function of two different, non-linear image point distribution functions).

Petitioner relies on Nagaoka as teaching that it is desirable to have a lens system with a maximum divergence much larger than what Tada discloses. *Id.* at 61; Pet. Reply 23.

Petitioner relies wholly on Tada for compressing the edges of the image: "Tada teaches [a lens system having] three zones like claim 5 (compression, expansion, and compression)." Pet. Reply 24. Petitioner makes its reliance on Tada for this feature clear in stating that "[t]he fact that Nagaoka teaches two zones (compression and expansion) . . . is immaterial for a [person of ordinary skill in the art] looking for guidance on possible maximum divergence for lenses for CCTV cameras." *Id.* In other words, because Petitioner concedes that Nagaoka teaches only two zones, Petitioner is relying on Tada for disclosing the three zones. But as we explained above, Petitioner does not establish that Tada teaches or suggests three zones, so Petitioner's arguments for this ground are unpersuasive.

On this record, Petitioner has not established by a preponderance of the evidence that the method of claim 5 would have been obvious over Tada in view of Nagaoka. Tada, due to its obvious error, cannot be said to describe or suggest the three zones (compression, expansion, and compression), as discussed above. Nagaoka only teaches two zones (compression and expansion). Thus, there is no basis in the ground set forth for an objective lens, as recited in claim 5, that "compresses . . . the edges of the image."

F. Asserted Obviousness over Tada in View of Baker

Petitioner challenges claim 5 as unpatentable for having been obvious over the combined teachings of Tada and Baker. Pet. 63–72. In particular, Petitioner asserts that to the extent Tada does not teach or suggest that "the distribution function [has] a maximum divergence of *at least* ±*10%*

compared to a linear distribution function" as required by claim 5 by virtue of its dependence on claim 1, that Baker teaches this limitation and that it would have been obvious to modify Tada in view of Baker to arrive at the subject matter of claim 5. *Id.* at 67–72.

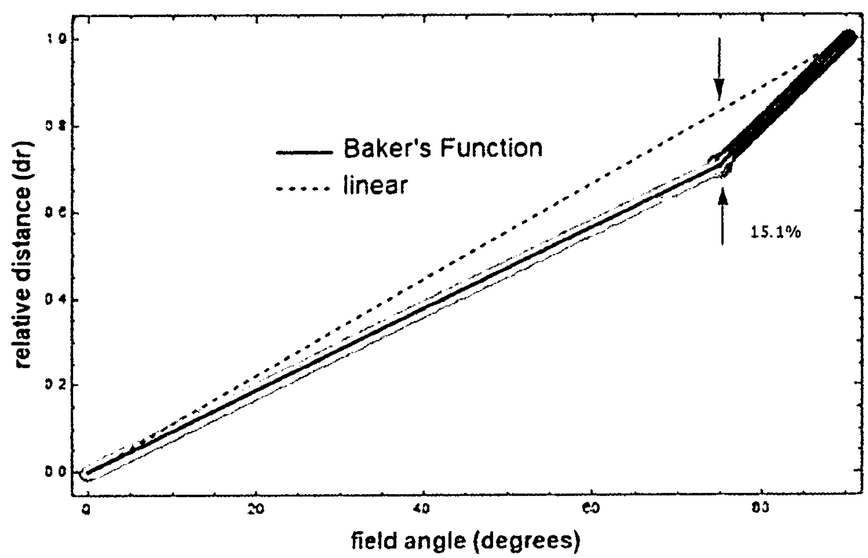
1. Overview of Baker (Ex. 1005)

Baker is directed to a videoconference system using a lens system that provides a panoramic display. Ex. 1005, Abstract. Baker discloses wide angle lenses that have "a fairly significant portion of the imaging surface dedicated to the peripheral field [of the field of view], and consequently less of the surface dedicated to the central field" than "typical with commercially available wide-angle, fish-eye, or other conventional lenses." *Id.* at 11:47–48, 12:30–32.

2. Analysis

In the Petition, Petitioner relies on Tada as set forth above in the ground based on Tada alone (*compare* Pet. 67–69, *with id.* at 29–52) and further on Baker for teaching the maximum deviation of at least ±10% (*id.* at 69–71). Petitioner contends that Baker teaches the limitations of claim 1 (*id.* at 63–67 (citing Ex. 1005, 6:48–56, 8:32–36, 12:6–11; Ex. 1008 ¶¶ 92, 94–96)), and that Patent Owner "provided a clear and unambiguous admission in the reexamination that claim 1 is taught by Baker" (*id.* at 63–64 (citing Ex. 1003, 331); *see also id.* at 66–67 (citing Ex. 1003, 237)). Petitioner does not contest that "Tada was relied on for disclosing the three zones and Baker was relied on essentially or solely for the magnitude of . . . deviation," as Petitioner's counsel responded to this characterization with "[y]ou're absolutely correct, . . . That was how the petition was laid out." Tr. 40:2–7.

Petitioner's reliance on Baker in the Petition is limited to the degree of deviation from a linear image point distribution. Pet. 63–67. Petitioner relies on Baker's disclosure of a fisheye lens having a nonlinear distribution function, a plot of such a lens showing its nonlinearity, and that "[t]o maximize data collection and resolution for analysis and/or display . . . , it is desirable to maximize the dedication of the available image detection area to this peripheral field portion." *Id.* at 64–66; Ex. 1005, 6:48–56, 8:32–36, 12:6–11; Ex. 1008 ¶¶ 92, 94–96. Petitioner relies particularly on a plot it contends "corresponds to the description of the lens in Baker" and "would have a maximum deviation of **15.1%**." Pet. 65–66; Ex. 1008 ¶ 95. The plot is reproduced below:



The depicted plot of Baker's function includes two regions, a first with a slope less than "linear" indicating "compression" (highlighted yellow) and a second with a slope greater than "linear" indicating "expansion" (highlighted blue). Pet. 66 (reproducing a figure plotting the image point distribution function of "Baker's [non-linear image point distribution] function" overlying a linear image point distribution function).

The ground set forth in the Petition relying on Tada in view of Baker fails. As discussed above, the necessary disclosure in Tada to support a lens system having the three zones (compression, expansion, and compression), i.e., Table 5's aspherical data (coefficients), includes an obvious error and, thus, Tada cannot be said to describe or suggest such a lens system, and there is no basis set forth in the Petition for Baker remedying this deficiency.

Patent Owner responds that Baker teaches away from the claimed method. PO Resp. 66, 68–70.

Petitioner, in its Reply, makes a new argument that Baker discloses all three zones, and relies on portions of Baker not originally cited and relied on in the Petition to support this argument. *Compare* Pet. Reply 19–22 (citing Ex. 1005, 1:52–58, 2:10–16, 5:37–44, 13:60–65, 19:9–13 (claim 10)), *with* Pet. 63–70 (citing Ex. 1005, 2:59–61, 2:65–3:3, 6:44–56,[9] 8:32–36, 8:60–62, 10:38–41, 12:6–11, 13:11–17, 12:48–55, Fig. 3BA). This shift in Petitioner's argument and its new reliance on Baker is reflected in the cited testimony of Dr. Chipman and Mr. Aikens. Dr. Chipman's original declaration filed in support of the Petition does not address the portions of Baker only cited in Petitioner's Reply. *See* Ex. 1008 ¶¶ 90–104. Petitioner relies on new testimony in support of its Reply; cross-examination testimony of Mr. Aikens, relating to portions of Baker not relied on in the Petition (Pet. Reply 21 (citing Ex. 1018, 268:14–269:4)), and further testimony of Dr. Chipman, also relating to portions of Baker not relied on in the Petition (*id.* (citing Ex. 1019 ¶ 27)). The cited cross-examination testimony of Mr. Aikens relates to the "[l]ast paragraph of Column 13" in Baker

[9] The Petition mis-cites relied-on material from column 6, lines 48 to 56, as from Exhibit 1002. Pet. 65.

(Ex. 1005, 13:56 *et seq.*), and most particularly to Baker, column 13, lines 60 to 65, cited in Petitioner's Reply. Ex. 1018, 262:16–269:4. Dr. Chipman's testimony in support of Petitioner's Reply (Ex. 1019), paragraph 27, cites Baker (Ex. 1005), column 13, lines 60 to 65 and column 19, lines 9 to 13.

In its Reply, Petitioner newly argues that Baker discloses a lens having three zones, including an expanded intermediate zone. Pet. Reply 20–22. At oral hearing, Petitioner's counsel conceded that the Petition does not rely on Baker for disclosing three zones (Tr. 40:2–7) and that the relevant portions of Baker—column 13, lines 60 to 65 and claim 10 (column 19, lines 9 to 12)—were not cited until Petitioner's Reply (*id.* at 39:11–16). Petitioner's counsel argues, however, that there is an admission Baker discloses three different zones and that this cannot be ignored. *Id.* at 40:8–12.

Patent Owner responds that the argument that Baker discloses a lens having three zones is new, having been argued for the first time in Petitioner's Reply, and that it is contrary to what Baker actually discloses. PO Sur-Reply 19–21. At oral hearing, Patent Owner's counsel contended that we should disregard the newly-cited portions of Baker and purported admission that Baker discloses three different zones because the Petition's original grounds do not rely on Baker for disclosing or suggesting a lens having three different zones. Tr. 42:11–16.

Petitioner's counsel argued in rebuttal that Petitioner's argument raised as to Baker disclosing three zones was only that there was no teaching away, and that it is properly raised for that point. *See id.* at 67:19–22 ("Baker is talking about three zones in some of the embodiments and therefore there is no teaching away and that's really the only point we wanted to make with respect to Baker is that there is no teaching away"), 68:5–6 ("our only point is that there is no teaching away").

The argument in Petitioner's Reply that Baker does not teach away from the claimed method was not improper; Petitioner reasonably raised it in response to Patent Owner's arguments, and Patent Owner had notice that Baker was in play as potentially relevant evidence. *See Genzyme Therapeutic Prods. Ltd. P'ship v. Biomarin Pharm. Inc.*, 825 F.3d 1360, 1366–67 (Fed. Cir. 2016) (finding that the Board may consider a prior art reference not included in an instituted ground to show the state of the art where the parties had notice of the reference).

That said, Petitioner's arguments that Baker discloses a lens with the recited three zones in the Reply raises a new theory of unpatentability, relying on newly cited portions of the reference. Such a new theory offered in the Reply cannot remedy the deficiency in the ground set forth in the Petition because "it is the petitioner's contentions" in "petitioner's petition" that "define the scope of the litigation all the way from institution through to conclusion." *Sirona*, 892 F.3d at 1356; *see also Henny Penny Corp. v. Frymaster LLC*, 938 F.3d 1324, 1330–31 (Fed. Cir. 2019) ("an IPR petitioner may not raise in reply 'an entirely new rationale' for why a claim would have been obvious"). As discussed above, the ground of unpatentability set forth in the Petition is based wholly on Tada disclosing the three zones, and not at all on Baker disclosing three zones, and the disclosures from Baker now contended by Petitioner to disclose or teach three zones are not cited in the Petition.

In sum, this proceeding is guided by the Petition, which did not assert the portions of Baker contended to disclose or teach the three zones recited in claim 5, or present any theory of obviousness grounded on Baker disclosing or teaching the three zones. Also, because the ground fails due to the obvious error in Tada, whether Baker teaches away from the claimed invention is moot. Thus, it is unnecessary for us to consider whether Baker discloses or teaches any embodiment having three zones, and we decline to do so.

On this record, for the reasons discussed above, we find that Petitioner has not established by a preponderance that the method of claim 5 would have been obvious over Tada in view of Baker.

III. CONCLUSION

For the reasons set forth above, we determine that Petitioner has not established, by a preponderance of the evidence, that the subject matter of claim 5 of the '990 patent is unpatentable.

Claim	**35 U.S.C. §**	**Reference(s)**	**Claims Shown Unpatentable**	**Claims Not Shown Unpatentable**
5	103	Tada		5
5	103	Tada, Nagaoka		5
5	103	Tada, Baker		5
Overall Outcome				5

IV. ORDER

In consideration of the foregoing, it is hereby:

ORDERED that Petitioner has *not* demonstrated by a preponderance of the evidence that claim 5 of the '990 patent is *unpatentable*; and

FURTHER ORDERED that because this is a Final Written Decision, any party to the proceeding seeking judicial review of the decision must comply with the notice and service requirements of 37 C.F.R. § 90.2.

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AO 120 (Rev. 08/10)

TO: **Mail Stop 8 Director of the U.S. Patent and Trademark Office P.O. Box 1450 Alexandria, VA 22313-1450**	**REPORT ON THE FILING OR DETERMINATION OF AN ACTION REGARDING A PATENT OR TRADEMARK**

In Compliance with 35 U.S.C. § 290 and/or 15 U.S.C. § 1116 you are hereby advised that a court action has been filed in the U.S. District Court District of Delaware on the following

☐ Trademarks or ☑ Patents. (☐ the patent action involves 35 U.S.C. § 292.):

DOCKET NO.	DATE FILED 10/22/2021	U.S. DISTRICT COURT District of Delaware
PLAINTIFF ImmerVision, Inc.		DEFENDANT Apple, Inc.

PATENT OR TRADEMARK NO.	DATE OF PATENT OR TRADEMARK	HOLDER OF PATENT OR TRADEMARK
1 US 6,844,990 B2	1/18/2005	ImmerVision, Inc.
2		
3		
4		
5		

In the above—entitled case, the following patent(s)/ trademark(s) have been included:

DATE INCLUDED	INCLUDED BY ☐ Amendment ☐ Answer ☐ Cross Bill ☐ Other Pleading	
PATENT OR TRADEMARK NO.	DATE OF PATENT OR TRADEMARK	HOLDER OF PATENT OR TRADEMARK
1		
2		
3		
4		
5		

In the above—entitled case, the following decision has been rendered or judgement issued:

DECISION/JUDGEMENT

CLERK	(BY) DEPUTY CLERK	DATE

Copy 1—Upon initiation of action, mail this copy to Director Copy 3—Upon termination of action, mail this copy to Director
Copy 2—Upon filing document adding patent(s), mail this copy to Director Copy 4—Case file copy

AO 120 (Rev. 08/10)

TO: Mail Stop 8 Director of the U.S. Patent and Trademark Office P.O. Box 1450 Alexandria, VA 22313-1450	REPORT ON THE FILING OR DETERMINATION OF AN ACTION REGARDING A PATENT OR TRADEMARK

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☐ Trademarks or ☑ Patents. (☐ the patent action involves 35 U.S.C. § 292.):

DOCKET NO.	DATE FILED 12/8/2021	U.S. DISTRICT COURT District of Delaware
PLAINTIFF ImmerVision, Inc.		DEFENDANT Apple, Inc.

PATENT OR TRADEMARK NO.	DATE OF PATENT OR TRADEMARK	HOLDER OF PATENT OR TRADEMARK
1 US 6,844,990 B2	1/18/2005	ImmerVision, Inc.
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DATE INCLUDED	INCLUDED BY ☐ Amendment ☐ Answer ☐ Cross Bill ☐ Other Pleading	
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1		
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In the above—entitled case, the following decision has been rendered or judgement issued:

DECISION/JUDGEMENT

CLERK	(BY) DEPUTY CLERK	DATE

Copy 1—Upon initiation of action, mail this copy to Director Copy 3—Upon termination of action, mail this copy to Director
Copy 2—Upon filing document adding patent(s), mail this copy to Director Copy 4—Case file copy

United States Court of Appeals for the Federal Circuit

LG ELECTRONICS INC.,
Appellant

v.

IMMERVISION, INC.,
Appellee

2021-2037, 2021-2038

Appeals from the United States Patent and Trademark Office, Patent Trial and Appeal Board in Nos. IPR2020-00179, IPR2020-00195.

Decided: July 11, 2022

JULIE S. GOLDEMBERG, Morgan, Lewis & Bockius LLP, Philadelphia, PA, argued for appellant. Also represented by DION MICHAEL BREGMAN, ALEXANDER STEIN, Palo Alto, CA; ANDREW V. DEVKAR, Los Angeles, CA; WILLIAM R. PETERSON, Houston, TX.

JOHN DAVID SIMMONS, Panitch Schwarze Belisario & Nadel, LLP, Wilmington, DE, argued for appellee. Also represented by DENNIS JAMES BUTLER; KEITH AARON JONES, STEPHEN EMERSON MURRAY, Philadelphia, PA.

Before NEWMAN, STOLL, and CUNNINGHAM, *Circuit Judges*.

Opinion for the court filed by *Circuit Judge* STOLL.

Opinion dissenting in part filed by *Circuit Judge* NEWMAN.

STOLL, *Circuit Judge*.

This appeal requires us to consider how to treat a prior art reference in which the alleged teaching of a claim element would be understood by a skilled artisan not to be an actual teaching, but rather to be an obvious error of a typographical or similar nature. LG Electronics Inc. appeals from the United States Patent Trial and Appeal Board's final written decisions in a pair of inter partes review proceedings challenging claims 5 and 21 of U.S. Patent No. 6,844,990. In both proceedings, the Board found that LG had not shown the challenged claims were unpatentable. Because substantial evidence supports the Board's finding that prior art disclosure critical to both of LG's petitions for inter partes review was an apparent error that would have been disregarded or corrected by a person of ordinary skill in the art, we affirm.

BACKGROUND

I

The '990 patent relates to capturing and displaying digital panoramic images. Panoramic (e.g., super-wide angle) objective lenses typically have linear image point distribution functions. This means there is a linear relationship between the distance of an image point from the image's center and the corresponding relative angle of the object point to the image's center. While this linearity allows digital panoramic images to be easily rotated, shifted, and enlarged or shrunk, it also limits image quality to "the resolution of the image sensor used when taking the initial image." '990 patent col. 3 ll. 1–9. This limitation on image quality is most noticeable when enlarging sectors of the image. The '990 patent purports to improve the resolution of particular sectors of a digital panoramic image "without the need to increase the number of pixels per unit of area of an image sensor or to provide an overlooking optical enlargement system." *Id.* at col. 3 ll. 35–42.

Specifically, the '990 patent specification describes capturing an initial digital panoramic image using an objective lens having a non-linear image point distribution function that "expands certain zones of the image and compresses other zones of the image." *Id.* at col. 3 l. 62–col. 4 l. 38. The "non-linearity of the initial image" can then be corrected to produce a final panoramic image for display. *Id.* at col. 4 ll. 47–53. "[T]he expanded zones of the image cover" a higher "number of pixels of the image sensor" than they would with a lens having linear image point distribution. *Id.* at col. 3 l. 62–col. 4 l. 10.

The challenged claims specify that the lens "compresses the center of the image and the edges of the image and expands an intermediate zone of the image located between the center and the edges of the image." *Id.* at col. 19 ll. 48–51. Dependent claim 5, which depends from cancelled claim 1, is representative:

> 1. (Cancelled) A method for capturing a digital panoramic image, by projecting a panorama onto an image sensor by means of a panoramic objective lens, the panoramic objective lens having an image point distribution function that is not linear relative to the field angle of object points of the panorama, the distribution function having a maximum divergence of at least ±10% compared to a linear distribution function, such that the panoramic image obtained has at least one substantially expanded zone and at least one substantially compressed zone.
>
> . . .

> 5. The method according to claim 1, wherein the objective lens *compresses the center of the image and the edges of the image and expands an intermediate zone of the image located between the center and the edges of the image.*

Id. at col. 19 ll. 26–51 (claim 5) (emphasis added); *see also id.* at col. 20 l. 51–col. 21 l. 11 (claim 21).[1]

II

On November 27, 2019, LG filed two petitions for inter partes review, each challenging a dependent claim of the '990 patent. J.A. 322–66 (IPR2020-00179 challenging claim 5); J.A. 3338–87 (IPR2020-00195 challenging claim 21). Fundamental to LG's obviousness arguments is U.S. Patent No. 5,861,999 ("Tada"), directed to a "Super Wide Angle Lens System Using an Aspherical Lens."[2] Tada describes four embodiments that share a general system structure and differ in aspects such as lens element thickness, separation distance, and lens shape. Each embodiment satisfies a set of eight conditions relating to the aspheric characteristics of various lens elements. Tada col. 2 ll. 7–67. The embodiment relevant to this appeal, Embodiment 3, is depicted in Figure 11 and described by a prescription—or set of optical parameters—set forth in Table 5. *Id.* Fig. 11, Tbl. 5.

Tada claims priority from Japanese Patent Application No. 09-201903, which was published as JP H10-115778 ("Japanese Priority Application"). Tada "expressly

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[1] Independent claims 1 and 17 were cancelled in ex parte reexamination. The claims at issue here were not subject to reexamination.

[2] Tada was published with the title "Super Wide Angel Lens System Using an Aspherical Lens"; a Certificate of Correction dated December 28, 1999, updated the title to its present form.

incorporated" these priority applications "by reference in their entireties." *Id.* at col. 3 ll. 9–13.

LG argued that Tada discloses, as recited in the challenged claims, a panoramic objective lens having a non-linear image point distribution that compresses the center and edges of an image and expands an intermediate zone of the image between the center and the edges of the image. Tada, however, does not explicitly discuss the image point distribution functions of its lenses. Instead, LG relied on its expert Dr. Russell Chipman's declaration for the proposition that Tada's third embodiment has a distribution function producing "a compressed center and edges of the image and an expanded intermediate zone of the image between the center and the edges of the image" as recited in challenged claims 5 and 21.

Dr. Chipman "reconstruct[ed] the lens of Figure 11 [of Tada] using the information in Table 5 of Tada" by inputting certain "information from Table 5 [as published] . . . into an optical design program." J.A. 1486–87 (Chipman Decl. ¶ 46). Dr. Chipman then plotted the image point distribution function for the lens system at six wavelengths and testified that the "function is not linear" in any of them. J.A. 1490–93 (Chipman Decl. ¶¶ 52–53). More specifically, Dr. Chipman explained that this embodiment of Tada's lens system "compresses the center of the image and the edges of the image and expands an intermediate zone of the image located between the center and the edges of the image." J.A. 1503 (Chipman Decl. ¶ 68). LG relied exclusively on Dr. Chipman's calculations and plots using the prescription in Table 5 to show that Tada's third embodiment meets the compression and expansion zone limitation of the challenged claims. LG did not rely on any other prior art reference or any other portion of Tada's disclosure for this limitation.

The Board instituted inter partes review in both proceedings. The parties engaged in expert discovery, with

ImmerVision deposing Dr. Chipman and LG deposing ImmerVision's expert, Mr. David Aikens. In its patent owner response, ImmerVision, relying on Mr. Aikens' declaration, argued that Tada's Table 5 includes a readily apparent error that cannot form the basis of any obviousness ground.

Mr. Aikens, who was specifically tasked with verifying Dr. Chipman's work, began by following Dr. Chipman's process, creating a lens model from the prescription, including the aspheric coefficients—values defining the surface shape of an aspherical lens—in Tada's Table 5 using an optical design program. J.A. 3031–32 (Aikens Decl. ¶ 58). From the outset, Mr. Aikens noticed that something was wrong: the physical surface of his lens model based on Tada's Table 5 and the example lens depicted in Tada's Figure 11 did not match. J.A. 3031–32 (Aikens Decl. ¶¶ 57–59). Because of this discrepancy, Mr. Aikens compared the sag table—a table of heights of a lens surface with respect to the optical axis—generated for his lens model with the sag table provided in Tada's Table 6 corresponding to Embodiment 3. J.A. 3032–33 (Aikens Decl. ¶ 60) ("[T]he sag table can be used as a check to make sure the equation and its coefficients are correctly understood . . . this is so commonly required that a sag table is a standard output of optical design codes."). They also did not match. J.A. 3034–35 (Aikens Decl. ¶¶ 61–62). Next, Mr. Aikens reviewed the image plane for his lens model to evaluate the magnitude of the error and discovered that the output image was distorted with "precisely the kind of uncorrected field curvature that Tada was explicitly trying to prevent." J.A. 3035–36 (Aikens Decl. ¶¶ 63–64); *see also* J.A. 2423 (Aikens Dep. 132:1–10) (explaining that the model "couldn't make a usable image . . . it was so clearly wrong, there was no point in spending more time on it").

Having established that the image was severely distorted, Mr. Aikens began comparing other aspects of his lens model with the "diagrams of the aberrations, astigmatism, and distortion" provided in Tada for its third embodiment using "standard output features" of optical design code. J.A. 3036–38 (Aikens Decl. ¶¶ 65–66). For example, Mr. Aikens compared the comatic aberration plot generated for his lens model to Tada's Figures 15A–D (comatic aberration plots for the model lens system using Table 5 data). J.A. 3036–38 (Aikens Decl. ¶¶ 65–67). These, too, did not match. Mr. Aikens explained that "at this point, [a person of ordinary skill in the art] would be convinced that there was an error in [the] model and that the error was significant." J.A. 3039 (Aikens Decl. ¶ 68); *see also* J.A. 2423 (Aikens Dep. 132:18–21) ("I recognized that there had to be something wrong with the aspheric coefficients. This is almost always where problems occur.").

Mr. Aikens then noticed that, as depicted in the reproduced tables below, the aspheric coefficients from Table 3, which corresponds to Tada's Embodiment 2, "were exactly the same as in Table 5," which corresponds to Embodiment 3. J.A. 2425 (Aikens Dep. 134:16–21).

TABLE 3-continued

FNO = 1:1.3
f = 1.00
W = 58.4
fB = 2.75 (=0.432/1.51633 + 2.467)

Surface No.	R	D	Nd	vd
11	2.479	1.691	1.77250	49.6
12	−10.343	0.000	—	—
13	∞	0.432	1.51633	64.1
14	∞	2.467	—	—
15	∞	—	—	—

*designates an aspherical surface with rotation symmetry around the optical axis.

Aspherical Data:

No.3: K = 0.00, A4 = 0.30330 × 10^{-1}, A6 = −0.43125 × 10^{-2}, A8 = 0.46329 × 10^{-3}, A10 = −0.24092 × 10^{-4}

No.4: K = 0.00, A4 = 0.50708 × 10^{-1}, A6 = −0.52255 × 10^{-2}, A8 = 0.34087 × 10^{-2}, A10 = −0.73846 × 10^{-3}

Tada Tbl. 3 (annotated).

TABLE 5

FNO = 1:1.3
f = 1.00
W = 58.5
fB = 2.79 (=0.437/1.51633 + 2.501)

Surface No.	R	D	Nd	νd
1	11.660	0.364	1.77250	49.6
2	3.274	1.637	—	—
3*	−8.060	2.485	1.49176	57.4
4*	3.032	3.046	—	—
5	−11.339	0.655	1.84666	23.8
6	−3.881	0.546	—	—
diaphragm	∞	2.417	—	—
7	28.148	0.327	1.84666	23.8
8	3.022	1.455	1.51633	64.1
9	−4.790	0.036	—	—
10	4.000	0.327	1.84666	23.8
11	2.425	1.637	1.77250	49.6
12	−11.318	0.000	—	—
13	∞	0.437	1.51633	64.1
14	∞	2.501	—	—
15	∞	—	—	—

*designates an aspherical surface with rotation symmetry around the optical axis.

Aspherical Data:

No.3: K = 0.00, A4 = 0.30330 × 10^{-1}, A6 = −0.43125 × 10^{-2}, A8 = 0.46329 × 10^{-3}, A10 = −0.24092 × 10^{-4}
No.4: K = 0.00, A4 = 0.50708 × 10^{-1}, A6 = −0.52255 × 10^{-2}, A8 = 0.34087 × 10^{-2}, A10 = −0.73846 × 10^{-3}

Id. Tbl. 5 (annotated).

Mr. Aikens turned next to Tada's Table 9, which provides ratios of the radius of curvature and aspherical factors of Tada's aspherical lens element to the focal length of the entire lens system. J.A. 3039–40 (Aikens Decl. ¶ 69); Tada Tbl. 9. Because the focal length of the entire lens system was defined as 1 for each embodiment, the values for conditions (2), (3), and (4) in Table 9 should have matched the aspheric coefficients A4, A6, and A8 in Table 5. But, as depicted below, they did not match:

14	∞	2.501	—	—
15	∞	—	—	—

*designates an aspherical surface with rotation symmetry around the optical axis.

Aspherical Data:

No.3: K = 0.00, A4 = 0.30330 × 10^{-1}, A6 = −0.43125 × 10^{-2}, A8 = 0.46329 × 10^{-3}, A10 = −0.24092 × 10^{-4}
No.4: K = 0.00, A4 = 0.50708 × 10^{-1}, A6 = −0.52255 × 10^{-2}, A8 = 0.34087 × 10^{-2}, A10 = −0.73846 × 10^{-3}

Tada Tbl. 5 (annotated).

TABLE 9-continued

	Embodiment 3	Embodiment 4
Condition (1)	−8.060	−10.108
Condition (2)	2.0485 × 10^{-2}	8.8810 × 10^{-2}
Condition (3)	−2.5925 × 10^{-3}	−2.7110 × 10^{-2}
Condition (4)	2.4634 × 10^{-4}	7.9690 × 10^{-3}
Condition (5)	3.022	2.691
Condition (6)	2.425	2.512
Condition (7)	27.255	25.229
Condition (8)	4.229	4.543

Id. Tbl. 9 (annotated).

Finally, Mr. Aikens reviewed Tada's Japanese Priority Application and saw that the aspheric coefficients in its Table 5—which corresponded to the same lens embodiment as Tada's Table 5—differed from those in Tada's Table 5. J.A. 3041–42 (Aikens Decl. ¶¶ 72–75). The relevant portions of these tables are reproduced below.

14	∞	2.501	—	—
15	∞	—	—	—

*designates an aspherical surface with rotation symmetry around the optical axis.

Aspherical Data:

No.3: K = 0.00, A4 = 0.30330×10^{-1}, A6 = -0.43125×10^{-2}, A8 = 0.46329×10^{-3}, A10 = -0.24092×10^{-4}

No.4: K = 0.00, A4 = 0.50708×10^{-1}, A6 = -0.52255×10^{-2}, A8 = 0.34087×10^{-2}, A10 = -0.73846×10^{-3}

Tada Tbl. 5 (annotated).

14	∞	2.501	-	-
15	∞	-	-	-

＊は回転対称非球面

非球面データ：

No.3; K=0.00 A4= 0.20485×10^{-1} A6=-0.25925×10^{-2}
A8=0.24634×10^{-3} A10=-0.11117×10^{-4}

No.4; K=0.00 A4= 0.44252×10^{-1} A6=-0.58852×10^{-2}
A8= 0.39420×10^{-2} A10=-0.79700×10^{-3}

Japanese Priority Application ¶ [0032] (Tbl. 5) (annotated).

It became clear to Mr. Aikens that, after "chang[ing] the aspheric coefficients [of his model] to match" those of the Japanese Priority Application, the aspheric coefficients in the Japanese Priority Application were the correct ones and that they yielded a lens surface that was "a perfect match to the surface described in Table 6." J.A. 3042 (Aikens Decl. ¶¶ 74–75). In other words, there was a transcription, or copy-and-paste, error in Tada. The disclosures in Tada's Table 5, which were intended to correspond to its Embodiment 3, were actually identical to those in Table 3, which corresponded to Embodiment 2.

In its final written decisions, the Board found that the "disclosure of aspheric[] coefficients in Table 5 of Tada is an obvious error" that a person of ordinary skill in the art would have recognized and corrected. *LG Elecs. Inc. v. ImmerVision, Inc.*, No. IPR2020-00179, 2021 WL 1904645, at *11 (P.T.A.B. 2021) (*Final Written Decision*).[3] Continuing, the Board found that because the correct aspheric coefficients in Table 5 of the Japanese Priority Application do not satisfy the language of the challenged claims, LG had not met its burden to prove the challenged claims unpatentable as obvious. *Id.* Although LG was free to rely on the rest of the reference, it had not done so. The Board concluded that LG did not meet its burden to prove the challenged claims would have been obvious by a preponderance of evidence. *Id.*

LG appeals. We have jurisdiction under 28 U.S.C. § 1295(a)(4)(A).

DISCUSSION

Obviousness is a legal question based on underlying findings of fact. *Univ. of Strathclyde v. Clear-Vu Lighting LLC*, 17 F.4th 155, 160 (Fed. Cir. 2021). We review the Board's ultimate obviousness determination de novo and underlying factual findings, including whether a prior art reference includes an obvious typographical or similar error that would be apparent to persons of ordinary skill, for substantial evidence. "The substantial evidence standard asks 'whether a reasonable fact finder could have arrived at the agency's decision.'" *OSI Pharms., LLC v. Apotex*

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[3] The Board issued a nearly identical decision in the proceeding concerning claim 21. *LG Elecs. v. ImmerVision, Inc.*, No. IPR2020-00195, 2021 WL 2486694, (P.T.A.B. 2021). For brevity, we cite only the decision in IPR2020-00179, the proceeding concerning claim 5.

Inc., 939 F.3d 1375, 1381–82 (Fed. Cir. 2019) (quoting *In re Gartside*, 203 F.3d 1305, 1312 (Fed. Cir. 2000)).

It is undisputed that the aspheric coefficients in Tada's Table 5 were erroneous. Appellant's Br. 15; *see also* J.A. 2903–04 (Chipman Dep. 49:2–50:24); J.A. 3039–40 (Aiken Decl. ¶¶ 68–69). And "[t]here is no dispute that if a lens were constructed using the (correct) aspherical data from Tada's Japanese priority application, the lens would not satisfy the [compression and expansion zone] limitation of claims 5 and 21." Appellant's Br. 15. Therefore, the primary question before us is whether substantial evidence supports the Board's fact finding that the error would have been apparent to a person of ordinary skill in the art such that the person would have disregarded the disclosure or corrected the error.

I

We begin with the legal standard. Over fifty years ago, our predecessor court reversed the decision of the Board of Patent Appeals and Interferences[4] affirming the rejection of certain claims directed to a specific compound of inhalation anesthetic—$CF_3CF_2CHClBr$—as obvious. *In re Yale*, 434 F.2d 666 (C.C.P.A. 1970). The obviousness rejection relied on the errant disclosure of this compound in an article published a few years prior. *Id.* at 667. That article included $CF_3CF_2CHClBr$ as one of nine compounds plotted on a graph with other inhalant anesthetic compounds. *Id.* This was the only instance of $CF_3CF_2CHClBr$ within the reference; the compound $CF_3CHClBr$ appeared throughout the rest of the article. *Id.* At the time, $CF_3CF_2CHClBr$ was not a known compound. *Id.* Our predecessor court set forth the standard for evaluating these types of apparent or "obvious typographical error[s]." *Id.* at 669.

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[4] The Board of Patent Appeals and Interferences is the predecessor of the Patent Trial and Appeal Board.

The *Yale* court explained that "any number" of several pieces of evidence "individually or cumulatively would . . . alert one of ordinary skill in the art to the existence" of the error. *Yale*, 434 F.2d at 669. First, the court noted the inconsistency between the reference's figures: "$CF_3CF_2CHClBr$ in Fig. 3 is the only compound listed in any figure which is not also listed in Fig. 1." *Id.* at 667. Second, "[a]ll eight [compounds listed in Clements] have the identical [chemical property value] in Fig. 3 that was listed for them in Fig. 1," with the exception of the $CF_3CF_2CHClBr$ compound, which "has the [chemical property value] which was assigned in Fig. 1 to $CF_3CHClBr$." *Id.* at 669. Because $CF_3CF_2CHClBr$ and $CF_3CHClBr$ are two different compounds, the court explained that it would not be "likely to have the same [chemical property value]." *Id.* at 667. Finally, in response to a letter from a reader, one of the authors of the article stated that the reference to $CF_3CF_2CHClBr$ was "of course, an error as [the reader] suppose[d,] and $CF_3CF_2CHClBr$ should read $CF_3CHClBr$." *Id.* Although the court gave less probative weight to this last piece of evidence because it "had not been sworn to," the court found it supported the conclusion that the disclosure of $CF_3CF_2CHClBr$ was in error. *Id.* at 669.

The court in *Yale* held that where a prior art reference includes an obvious error of a typographical or similar nature that would be apparent to one of ordinary skill in the art who would mentally disregard the errant information as a misprint or mentally substitute it for the correct information, the errant information cannot be said to disclose subject matter. *Id.* at 669. The remainder of the reference would remain pertinent prior art disclosure. This standard for reviewing errors in disclosures has been undisturbed for half a century and we are bound to apply it. *Deckers Corp. v. United States*, 752 F.3d 949, 955–56 (Fed. Cir. 2014) (discussing *stare decisis*). Moreover, we view *Yale*'s standard as sound law, ensuring that an obviously errant disclosure of a typographical or similar nature would not prevent a true inventor of the claimed subject matter from later obtaining patent protection.

II

We now address the Board's fact finding in this case. Based on the record before it, the Board found that the aspheric coefficients in Tada's Table 5 were an obvious error of a typographical or similar nature that would have been apparent to a skilled artisan. *Final Written Decision*, 2021 WL 1904645, at *11. As explained below, we conclude that the Board's finding is supported by substantial evidence.

The Board correctly identified several aspects of the disclosure in Table 5 that would alert the ordinarily skilled artisan that the disclosure was an obvious error of a typographical or similar nature. First, Table 5 in Tada's Japanese Priority Application has different values for the aspheric coefficients than Table 5 in Tada. J.A. 3041–42 (Aikens Decl. ¶¶ 72–75). Citing Mr. Aiken's declaration, the Board found that the discrepancy between the coefficients in Tada's Table 5 and the Japanese Priority Application's Table 5 was "grounded [in] a transcription error in the values for A4, A6, and A8 in Tada's Table 5, namely, inadvertent duplication of the values for the aspherical data in Table 3." *Final Written Decision*, 2021 WL 1904645, at *9. Indeed, Mr. Aikens identified the "obvious typographical error in Table 5" as an error in which the "aspheric coefficients listed in Table 5 were inadvertently copied over from Table 3, which describes Embodiment 2 of Tada." J.A. 3030 (Aikens Decl. ¶ 56). The Board explained that the "correspondence of the Tables 1, 3, 7, and 9 between the [Japanese Priority Application] and Tada itself is apparent, even prior to translation, as is the inconsistency as to the aspherical data for Table 5." *Final Written Decision*, 2021 WL 1904645, at *9.

Second, the Board found that an inconsistency between Tada's Tables 5 and 9 "ma[de] it apparent that there is an error in Table 5's recitation of the aspheric[] coefficients." *Id.* at *8. It was undisputed that Tada's Tables 5 and 9 are inconsistent: the aspheric coefficients A4, A6, and A8 in Tada's Table 5 should match the values for conditions (2)–(4) in Table 9 but do not. *Id.* at *7–8; *see Yale*, 434 F.2d at 667 (describing the internal inconsistency within a reference as a signal that a person of ordinary skill "would readily recognize" as portending error). As Mr. Aikens explained, and Dr. Chipman agreed, because the focal length for the entire lens system is set to 1 in each of the embodiments, "Table 9 rather conveniently gives you the aspheric coefficients for each of the four embodiments, and it matches correctly for [Embodiments] 1, 2[,] and 4 and is totally wrong for [Embodiment] 3." J.A. 2427 (Aikens Dep. 136:11–15); J.A. 3039–40 (Aikens Decl. ¶ 69) (The "values [in Table 9] do not match the values in Table 5 because Table 5 is in error."); *see also* J.A. 2902–04 (Chipman Dep. 48:9–50:24) (conceding that the aspheric coefficients in Table 5 match the values in Table 9 for each of the embodiments except for Embodiment 3).

Third, the Board found that having identical aspheric coefficients in Tada's Tables 3 and 5 "is incongruous with the differences in the values of other data for the lens systems." *Final Written Decision*, 2021 WL 1904645, at *8. In other words, given the other significant differences between the embodiments, it was unusual for Tables 3 and 5 to list the same aspheric coefficients. *Id.*; J.A. 2425 (Aikens Dep. 134:4–21) ("I noticed that when I was typing in Embodiment 2 from Table 3, the aspheric coefficients were exactly the same as in Table 5, and that's never true. That could not be right."); *see also Yale*, 434 F.2d at 667 (noting the improbability of two different compounds having the same chemical property value).

Considering all the evidence before it, the Board reasonably found that Tada's Table 5 includes an obvious error of a typographical or similar nature that would have been apparent to one of ordinary skill in the art, who would have substituted it with the correct information and, thus, that Table 5 cannot be said to disclose a lens that compresses the center of the image and the edges of the image and expands an intermediate zone of the image located between the center and the edges of the image. *Final Written Decision*, 2021 WL 1904645, at *11.

III

LG presents two additional arguments. First, LG contends that *Yale* sets forth an "Immediately Disregard or Correct" standard that imposes a temporal urgency on the discovery of the error before the error can be considered "obvious" to a skilled artisan. *See, e.g.*, Appellant's Br. 4–5, 15, 23, 25, 28. Applying this reading of *Yale*, LG argues that Mr. Aikens' "convoluted process" that took "ten to twelve hours" to complete clearly weighed against the obviousness of the error. *Id.* at 27–28. LG reasons that because Tada has remained uncorrected in the public domain for over 20 years, LG should have been able to rely on the aspheric coefficients in Tada's Table 5 as published.

LG's suggestion that *Yale* requires a person of ordinary skill in the art to *immediately* recognize the apparent error is incorrect. As the Board correctly explained, the length of time and the "particular manner" in which the error was actually discovered "does not diminish that there is an obvious error in Tada within the meaning of *Yale*." *Final Written Decision*, 2021 WL 1904645, at *10. Contrary to LG's assertions, *Yale* does not impose a temporal requirement. Nor does LG cite any other authority requiring that the error be discovered within a specified amount of time. Certainly, the amount of time it takes a skilled artisan to detect an error may be relevant to whether an error is, in fact, an apparent error under *Yale*. But this is just one factor for the fact finder to consider as part of the overall analysis. Here, the Board considered the totality of circumstances and found that Tada's disclosure of aspheric coefficients in Table 5 is an obvious error of a typographical or similar nature, notwithstanding the amount of time that preceded detection of the obvious error. For the reasons explained above, this finding is supported by substantial evidence.

Second, LG suggests that *Yale* is limited to instances in which the error is a typographical error. Appellant's Br. 22–23. For example, LG argues that *Yale* should be narrowly limited to errors such as the spelling mistake in Tada's title upon original publication ("Super Wide *Angel* Lens"), which was corrected soon after ("Super Wide *Angle* Lens"), or in Tada's cancelled claim 1 ("arranged in this order *form* an object side"), which was also corrected ("arranged in this order *from* an object side"). Appellant's Br. 30. According to LG, any other interpretation of the *Yale* standard would "grant[] a monopoly over a resource that was previously freely available to all, destabilizing the patent system." *Id.* at 24. We disagree.

While our predecessor court described the error in *Yale* as typographical, the error at issue here is not so far afield as to warrant a different outcome. As the Board found and Mr. Aikens, testified, the error in Tada's Table 5 was "a transcription error . . . namely, inadvertent duplication of the values for the aspherical data in Table 3." *Final Written Decision*, 2021 WL 1904645, at *9; *see also* J.A. 3030 (Aikens Decl. ¶ 56). The distinction between the typographical error in *Yale* and the copy-and-paste error here is a distinction without a difference.

CONCLUSION

We have considered the parties' remaining arguments and find them unpersuasive. For the foregoing reasons, we affirm the Board's final written decisions.

AFFIRMED

United States Court of Appeals for the Federal Circuit

LG ELECTRONICS INC.,
Appellant

v.

IMMERVISION, INC.,
Appellee

2021-2037, 2021-2038

Appeals from the United States Patent and Trademark Office, Patent Trial and Appeal Board in Nos. IPR2020-00179, IPR2020-00195.

NEWMAN, *Circuit Judge*, dissenting in part.

The court today finds an "error of a typographical or similar nature" in the specification of the Tada reference and rules that because the error is "obvious" the erroneous portion of the Tada reference[1] is eliminated as prior art. Maj. Op. at 16–17. I cannot agree that this error is typographical or similar in nature, for its existence was not discovered until an expert witness conducted a dozen hours of experimentation and calculation. Appx2428 (*LG Elecs. Inc.*

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1 U.S. Patent No. 5,861,999 ("Tada" or "the '999 Patent").

v. ImmerVision, Inc., No. IPR2020-00179, (P.T.A.B. Oct. 1, 2020), Aikens Dep. 137:3–138:3, Ex. 1018).

The appearance of a few of the same numbers in two different tables in the Tada reference provides no information as to which numbers and tables are correct and which may be in error. In contrast, a typographical or similar error is apparent to the reader and may conveniently be ignored without impeaching the content of the information. The error in the Tada reference cannot properly be deemed typographical or similar.

The events that preceded the expert's discovery of the error in the Tada reference cannot be ignored. The possibly erroneous numbers in the Tada tables were not noticed by any of the patent attorneys throughout the prosecution of Tada's U. S. application. The now "obvious" error was not noticed by the patent examiner during a complex prosecution in which claims were amended and prior art distinguished.

The purportedly "typographical or similar" error was not included in the Certificate of Correction that was obtained for typographical errors in the issued Tada patent. This error was not noticed by two distinct Patent Trial and Appeal Boards in instituting these two inter partes review ("IPR") petitions, despite the technological expertise of the Board.

The error in Tada Table 5 was not corrected anywhere, even after 20 years of publication. Not until an expert witness conducted experiments and compared the U. S. application with the Japanese Priority document[2] did anyone discover the possibly erroneous numbers in Table 5. Appx2422–2430; Appx3030–3042.

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2 JP H10-115778 (July 28, 1998).

The specifics of what led the expert, Mr. Aikens, to discover the erroneous values in Table 5 also cast doubt on whether the error may be deemed "obvious and apparent." Mr. Aikens testified that he had fully modeled Tada's Embodiment 3—relying on data from Table 5—without noticing the error. Appx2421–22 (Aikens Dep. 130:8–22). It was only after his model was completed that he noticed the lens created a distorted image, leading him to presume there was perhaps some error in Tada. Appx2422 (Aikens Dep. 131:3–7). At this point in his experimentation, he did not know what the error was, and certainly did not know how to correct the error; he only suspected that an error existed somewhere. Appx2423 (Aikens Dep. 132:2–10).

Upon realizing there was likely an error, Mr. Aikens undertook to discover it. *Id.* at 132:7–10 ("I wanted to understand how this lens could be so wrong and be in the patent. It just didn't make sense to me."). Mr. Aikens testified that he required several additional hours to figure out if there actually was an error in the reference and what that error was. *Id.* at 132:11–13.

First, Mr. Aikens observed that the physical surface shape of his Embodiment 3 lens model did not match the example lens depicted in Tada's Figure 11. Appx2424 (Aikens Dep. 133:11–14); Appx3042 (*LG Elecs. Inc. v. ImmerVision, Inc.*, No. IPR2020-00179, (P.T.A.B. Aug. 4, 2020), Aikens Decl. ¶ 74, Ex. 2009). This suggested that an error existed, but not where the error was or how to correct it. Mr. Aikens then performed various tasks such as comparing the diagrams of the aberrations, astigmatism, and distortion for Embodiment 3 to his model, and fully modeling two other embodiments—Embodiment 1 and Embodiment 2. Appx2425 (Aikens Dep. 134:12–15). None of these steps showed where the purported "obvious error" was located. Only after modeling the other lens embodiments did Mr. Aikens finally observe that the aspherical values from Table 3, which correspond to Tada's

Embodiment 2, "were exactly the same as in Table 5." *Id.* at 134:18–19.

Mr. Aikens testified that at this point of his experimentation he suspected there was an error in the aspherical values in Table 5, but he had yet to determine what was in error. *Id.* at 134:19–21. To investigate further, Mr. Aikens compared the sag table generated from his lens model with sag Table 6 from the Tada reference. He found they did not match, indicating that an error existed; however, he still did not know what the error was, nor how to correct it. Appx2425–26 (Aikens Dep. 134:22–135:4); Appx3032–35, Appx3042 (Aikens Decl. ¶¶ 60–62, 74). Mr. Aikens then compared the values in Table 9 to Table 5 and noticed that upon performing the required calculations, the aspherical values did not match between these two tables. Appx2426–27 (Aikens Dep. 135:9–136:15). It was here, for the first time, that Mr. Aikens testified that he could confirm there actually was an error in the Tada reference. *Id.* at 136:9–10. At this juncture Mr. Aikens felt confident that Table 5 contained erroneous information, but he *still* did not have the information to correct it. Appx2426–27 (Aikens Dep. 135:21–136:1) ("Unfortunately, Tada didn't include a constraint on his A10 term so that I had to optimize to find.").

Mr. Aikens testified that he was finally able to correct and confirm the error when he obtained the Japanese Priority Application. Appx2420 (Aikens Dep. 129:7–11); Appx3042 (Aikens Decl. ¶ 74). The Japanese application had the correct aspherical values in Table 5, as confirmed by a skilled expert in this technology, after many hours of corrective effort that included fully modeling three separate embodiments of the lens. In sum, the error was not of "typographical or similar nature."

The facts of this case readily distinguish it from *In re Yale*, 434 F.2d 666 (CCPA 1970), where our predecessor Court of Customs and Patent Appeals found that the inclusion of the molecule $CF_3CF_2CHClBr$ in a list of anesthetics was an obvious error. In *Yale* the CCPA explained that $CF_3CF_2CHClBr$ was not a known compound and that the obviously intended compound was $CF_3CHClBr$, a well-known anesthetic. This error was acknowledged by the authors of the article. As the panel majority recounts, "any number" of the pieces of evidence mentioned by the CCPA in *Yale* would "'individually or cumulatively . . . alert one of ordinary skill in the art to the existence' of the error." Maj. Op. at 14 (quoting *Yale*, 434 F.2d at 669). However, the evidence in *Yale* did not require calculations or experimentation. *Yale*, 434 F.2d at 667. The same cannot be said about the error in Tada, for without the Japanese Priority Application, there is no source of the correct information. In Tada, the error in Table 5 is not discoverable unless measurements are conducted, the embodiments are recreated, equations are recalculated, and computations are performed. Without performing these operations, the identity of a few values in both the tables does not establish error. Moreover, the tables do not suggest which table might be incorrect. As Mr. Aikens demonstrated, without modeling Embodiment 3, Table 5 cannot be compared to sag Table 6 or Figs. 11–15.

In contrast, in *Yale* it was obviously an error to replace the known chemical anesthetic compound $CF_3CHClBr$ in Fig. 1 with the unknown chemical compound $CF_3CF_2CHClBr$ in Fig. 3 and list both compounds as having the same property. The CCPA reasoned that a chemist of ordinary skill would deem it extremely unlikely that these two chemicals would have the same $LogP_f$ (partial pressure) value. *Yale*, 434 F.2d at 667.

Although the panel majority finds analogy in the view that it is highly unlikely that the Tada embodiments would have the same aspherical values, Maj. Op. at 16, such that the listing of the same values is an obvious error, there is no intrinsic reason why two different lenses could not have the same aspherical values. As Mr. Aikens remarked, "[a]nd so I thought, okay, well, maybe there's a typo on the – on the aspherics, or maybe Tada is not very good."). Appx2425 (Aikens Dep. 134:10–12). Even the Tada patent states that "[t]he basic structure of a lens system of the third embodiment is substantially the same as that of the second embodiment. Numerical data regarding the third embodiment is shown in table 5 below." '999 Patent col. 8 ll. 59–64. That Table 3 and Table 5 have some of the same aspherical values does not readily alert a person of ordinary skill that Table 5 contains an obvious error of "typographical or similar nature."

The facts in *Yale* are not readily analogous. An important consideration in *Yale* was that the molecule $CF_3CF_2CHClBr$ was not a known chemical compound at the time. The CCPA explained that the inclusion on a table of known anesthetics of a compound that did not exist would be recognized as an error, as was shown in correspondence. *Yale*, 434 F.2d at 668–69.

I agree with the panel majority that *Yale* establishes the correct standard to determine if an error would be obvious to a person of ordinary skill in the field. However, I do not agree with the majority's application of this standard to the facts herein. An "obvious error" should be apparent on its face and should not require the conduct of experiments or a search for possibly conflicting information to determine whether error exists. When a reference contains an erroneous teaching, its value as prior art must be determined.

The error in the Tada reference is plainly not a "typographical or similar error," for the error is not apparent on its face, and the correct information is not readily evident. It should not be necessary to search for a foreign document in a foreign language to determine whether there is an inconsistency in a United States patent. The foundation of the "typographical or similar" standard is that the error is readily recognized as an error. I am concerned that we are unsettling long-standing law, and thus I respectfully dissent in part.

United States Court of Appeals for the Federal Circuit

LG ELECTRONICS INC.,
Appellant

v.

IMMERVISION, INC.,
Appellee

2021-2037, 2021-2038

Appeals from the United States Patent and Trademark Office, Patent Trial and Appeal Board in Nos. IPR2020-00179, IPR2020-00195.

JUDGMENT

THIS CAUSE having been considered, it is

ORDERED AND ADJUDGED:

AFFIRMED

FOR THE COURT

July 11, 2022
Date

/s/ Peter R. Marksteiner
Peter R. Marksteiner
Clerk of Court

United States Court of Appeals for the Federal Circuit

LG ELECTRONICS INC.,
Appellant

v.

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2021-2037, 2021-2038

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MANDATE

In accordance with the judgment of this Court, entered July 11, 2022, and pursuant to Rule 41 of the Federal Rules of Appellate Procedure, the formal mandate is hereby issued.

FOR THE COURT

August 17, 2022
Date

/s/ Peter R. Marksteiner
Peter R. Marksteiner
Clerk of Court

(12) **INTER PARTES REVIEW CERTIFICATE** (2945th)
United States Patent (10) **Number: US 6,844,990 K1**
Artonne et al. (45) **Certificate Issued: Dec. 22, 2022**

(54) **METHOD FOR CAPTURING AND DISPLAYING A VARIABLE RESOLUTION DIGITAL PANORAMIC IMAGE**

(75) Inventors: **Jean-Claude Artonne**; **Christophe Moustier**; **Benjamin Blanc**

(73) Assignee: **IMMERVISION, INC.**

Trial Numbers:

IPR2020-00179 filed Nov. 27, 2019
IPR2020-00195 filed Nov. 27, 2019

Inter Partes Review Certificate for:

Patent No.: **6,844,990**
Issued: **Jan. 18, 2005**
Appl. No.: **10/706,513**
Filed: **Nov. 12, 2003**

The results of IPR2020-00179; IPR2020-00195 are reflected in this inter partes review certificate under 35 U.S.C. 318(b).

INTER PARTES REVIEW CERTIFICATE
U.S. Patent 6,844,990 K1
Trial No. IPR2020-00179
Certificate Issued Dec. 22, 2022

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AS A RESULT OF THE INTER PARTES REVIEW PROCEEDING, IT HAS BEEN DETERMINED THAT:

Claims **5** and **21** are found patentable.

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