

<b>PATENT ASSIGNMENT COVER SHEET</b>
--------------------------------------

Electronic Version v1.1  
 Stylesheet Version v1.2

EPAS ID: PAT5596456

<b>SUBMISSION TYPE:</b>	NEW ASSIGNMENT
<b>NATURE OF CONVEYANCE:</b>	SECURITY INTEREST
<b>CONVEYING PARTY DATA</b>	
<b>Name</b>	<b>Execution Date</b>
IMMERVISION INC.	06/26/2019
<b>RECEIVING PARTY DATA</b>	
<b>Name:</b>	BRIDGING FINANCE INC.
<b>Street Address:</b>	77 KING STREET WEST
<b>Internal Address:</b>	SUITE 2925
<b>City:</b>	TORONTO, ONTARIO
<b>State/Country:</b>	CANADA
<b>Postal Code:</b>	M5K 1K7
<b>PROPERTY NUMBERS Total: 18</b>	
<b>Property Type</b>	<b>Number</b>
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

<b>ATTORNEY DOCKET NUMBER:</b>	688266.5002
<b>NAME OF SUBMITTER:</b>	JOHN D. SIMMONS
<b>SIGNATURE:</b>	/John D. Simmons/
<b>DATE SIGNED:</b>	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 IMMERSION INC (the "Grantor"), having its registered office at 2320-2020 boul. Robert-Bourassa, Montréal, Québec 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.

CONFIRMATORY SECURITY AGREEMENT (USPTO) - SIGNATURE PAGE

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

CONFIRMATORY SECURITY AGREEMENT (USPTO) - SIGNATURE PAGE

**BRIDGING FINANCE INC.**

Per: 

Name: Natasha Sharp  
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**

	<b>Description</b>	<b>Filing Date</b>  <b>or</b> <b>371 (c) Date</b>	<b>Patent number</b>  <b>or</b> <b>Publication number</b> <b>(application number)</b>
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	2014/03-40473 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 <i>non-provisional</i> application US2017/0184813 US continuation 16/432,180
11. Image distortion transformation method and apparatus	February 16, 2017	10,204,398
<b>Families with ungranted patents applications</b>		
12. Method to Capture, Store, Distribute, Share, Stream and Display Panoramic Image or Video	July 21, 2017	US <i>non-provisional</i> application 15/656,647
13. Wide angle Stereoscopic Vision With Cameras Having Different Parameters	July 21, 2017 February 23, 2018	US <i>non-provisional</i> application 15/656,707 US <i>non-provisional</i> application 15/903,872



	<b>Description</b>	<b>Filing Date</b> <b>or</b> <b>371 (c) Date</b>	<b>Patent number</b> <b>or</b> <b>Publication number</b> <b>(application number)</b>
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

308470.00009/104794256.1

AO 120 (Rev. 08/10)

TO: <b>Mail Stop 8</b> <b>Director of the U.S. Patent and Trademark Office</b> <b>P.O. Box 1450</b> <b>Alexandria, VA 22313-1450</b>	<b>REPORT ON THE                  FILING OR DETERMINATION OF AN                  ACTION REGARDING A PATENT OR                  TRADEMARK</b>
---	--

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 IMMERSION		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	Immervision
2		
3		
4		
5		

In the above—entitled case, the following patent(s)/ trademark(s) have been included:

DATE INCLUDED	INCLUDED BY <input type="checkbox"/> Amendment <input type="checkbox"/> Answer <input type="checkbox"/> Cross Bill <input type="checkbox"/> 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: <b>Mail Stop 8</b> <b>Director of the U.S. Patent and Trademark Office</b> <b>P.O. Box 1450</b> <b>Alexandria, VA 22313-1450</b>	<b>REPORT ON THE</b> <b>FILING OR DETERMINATION OF AN</b> <b>ACTION REGARDING A PATENT OR</b> <b>TRADEMARK</b>
---	---

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 IMMERSION		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	Immervision
2		
3		
4		
5		

In the above—entitled case, the following patent(s)/ trademark(s) have been included:

DATE INCLUDED	INCLUDED BY <input type="checkbox"/> Amendment <input type="checkbox"/> Answer <input type="checkbox"/> Cross Bill <input type="checkbox"/> 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: <b>Mail Stop 8 Director of the U.S. Patent and Trademark Office P.O. Box 1450 Alexandria, VA 22313-1450</b>	<b>REPORT ON THE FILING OR DETERMINATION OF AN ACTION REGARDING A PATENT OR TRADEMARK</b>
---	---

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. <i>16-cv-2-SLR</i>	DATE FILED <i>1/4/2016</i>	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 <input type="checkbox"/> Amendment <input type="checkbox"/> Answer <input type="checkbox"/> Cross Bill <input type="checkbox"/> 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	<i>Notices of Voluntary dismissal filed.</i>		
--------------------	--	--	--

CLERK <i>John A. Cerino</i>	(BY) DEPUTY CLERK <i>Maile Holt</i>	DATE <i>8/3/2016</i>
--------------------------------	--	-------------------------

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

<b>PATENT ASSIGNMENT COVER SHEET</b>
--------------------------------------

Electronic Version v1.1  
 Stylesheet Version v1.2

EPAS ID: PAT3955186

<b>SUBMISSION TYPE:</b>	NEW ASSIGNMENT
<b>NATURE OF CONVEYANCE:</b>	SECURITY INTEREST
<b>CONVEYING PARTY DATA</b>	
<b>Name</b>	<b>Execution Date</b>
IMMERVISION INC.	07/06/2016
<b>RECEIVING PARTY DATA</b>	
<b>Name:</b>	ACG 360 L.P.
<b>Street Address:</b>	426 SAINTE-HELENE STREET, SUITE 1
<b>City:</b>	MONTREAL
<b>State/Country:</b>	CANADA
<b>Postal Code:</b>	H2Y 2K7
<b>PROPERTY NUMBERS Total: 12</b>	
<b>Property Type</b>	<b>Number</b>
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
<b>CORRESPONDENCE DATA</b>	
<b>Fax Number:</b>	(312)876-7934
<i>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.</i>	
<b>Phone:</b>	312-876-8000
<b>Email:</b>	patents.us@dentons.com, dianetatiana.filatov@dentons.com
<b>Correspondent Name:</b>	DENTONS US LLP
<b>Address Line 1:</b>	P.O. BOX 061080
<b>Address Line 2:</b>	WACKER DRIVE STATION, WILLIS TOWER

<b>Address Line 4:</b>	CHICAGO, ILLINOIS 60606
<b>ATTORNEY DOCKET NUMBER:</b>	ACG360_R.TSIBULEVSKIY
<b>NAME OF SUBMITTER:</b>	ROMAN TSIBULEVSKIY
<b>SIGNATURE:</b>	/roman tsibulevskiy/
<b>DATE SIGNED:</b>	07/11/2016
	This document serves as an Oath/Declaration (37 CFR 1.63).
<b>Total Attachments: 4</b>	
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 IMMERSION 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.

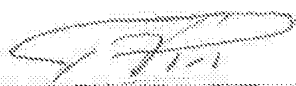
DATED: July 5, 2016.

*[signature page follows]*

Attachment 1 - Notice of Security Interest in Intellectual Property

IMMERVISION INC.

By:

  
Name: PASCAL MINT  
Title: PRESIDENTE & CEO

AFFIDAVIT OF WITNESS

I, Boisard Coles, domiciled at the following address:

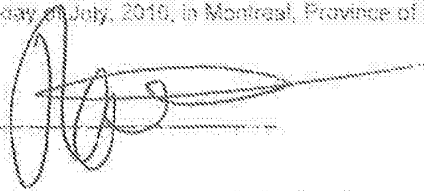
561 Ave. Victoria, Westmount, QC, Canada H3Y-2R6

solemnly declare and attest that I was present and saw the representative of 6110187 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: 

Declared before me, this 6 day of July, 2018, in Montreal, Province of Quebec, Canada.

Commissioner for Oaths:



XAVIER MAGEAU  
257 3423

Attachment 1 - 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

Attachment I - Notice of Security Interest in Intellectual Property

	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:0864023v2

Attachment I - Notice of Security Interest in Intellectual Property

AO 120 (Rev. 08/10)

TO: <b>Mail Stop 8 Director of the U.S. Patent and Trademark Office P.O. Box 1450 Alexandria, VA 22313-1450</b>	<b>REPORT ON THE FILING OR DETERMINATION OF AN ACTION REGARDING A PATENT OR TRADEMARK</b>
---	---

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 <input type="checkbox"/> Amendment <input type="checkbox"/> Answer <input type="checkbox"/> Cross Bill <input type="checkbox"/> 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

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 --  $\alpha$  --;

Column 13,

Line 17, "a" should be replaced with --  $\alpha$  --;

Column 14,

Line 65, "a" should be replaced with --  $\alpha$  --;

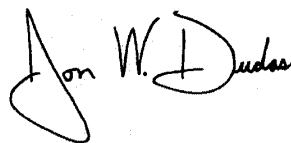
Column 16,

Line 62, the formula should read:

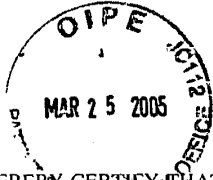
$$-- z(r) = [(C^*r^2)/(1 + \sqrt{1 - (1+k)*C^2*r^2})] + A_1r^2 + A_2r^4 + A_3r^6 + A_4r^8 + A_5r^{10} --.$$

Signed and Sealed this

Twenty-fourth Day of May, 2005



JON W. DUDAS  
Director of the United States Patent and Trademark Office



*IFU cab*

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.

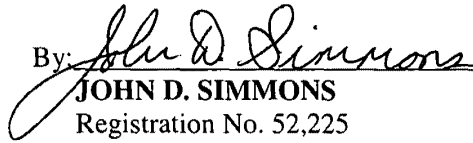
Issuance of a Certificate of Correction is believed appropriate and is respectfully solicited.

Please send the Certificate to the undersigned.

Respectfully submitted,

March 17, 2005  
(Date)

By:



**JOHN D. SIMMONS**

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](mailto:jsimmons@akingump.com)

JDS/DCM  
Enclosures

## 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 --  $\alpha$  --;**

**Column 13, line 17 and column 14, line 65, "a" should be replaced with --  $\alpha$  --;**

**Column 16, line 62, the formula should read:**

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

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



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 when appropriate. All further correspondence including 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)

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, must have its own certificate of mailing or transmission.

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 SDENB02 00000016 10706513

01 FC:1501 1370.00 OP  
 02 FC:1504 300.00 OP  
 03 FC:1501 30.00 OP



Certificate of Mailing or Transmission  
 I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Mail Stop ISSUE FEE address above, or being facsimile transmitted to the USPTO (703) 746-4000, on the date indicated below.

Deanna Marks (Depositor's name)  
 Deanna Marks (Signature)  
 12/6/04 (Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10706,513	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	\$1370 <i>1370</i>	\$300	\$1670 <i>1670</i>	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 for 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

(B) RESIDENCE: (CITY and STATE OR COUNTRY)

6115187 Canada Inc.

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  Government

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. *any discrepancy*  
 The Director is hereby authorized by charge the required fee(s), or credit any overpayment Deposit Account Number 50-1017 (enclose an extra copy of this form). *017000-0020*

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.

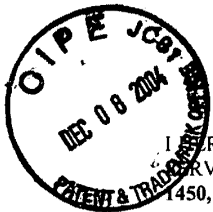
Authorized Signature John D. Simmons  
 Typed or printed name John D. Simmons

Date December 6, 2004  
 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 process) 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 complete 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.O. 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 Donna R. 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.	:	<b>Attn: Official</b>
		:	<b>Draftsperson</b>
		:	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 RESOLUTION 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,

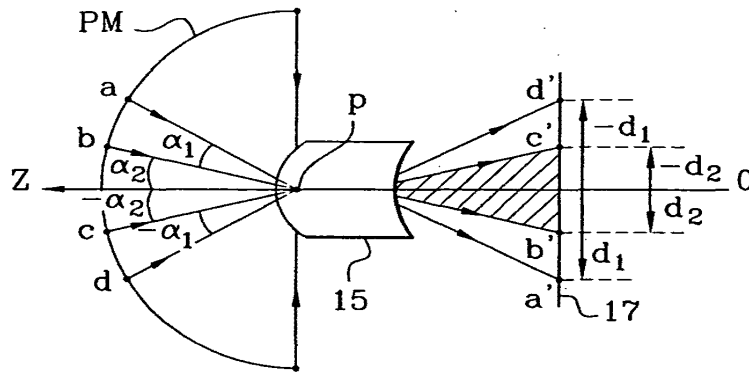
December 6, 2004  
(Date)

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

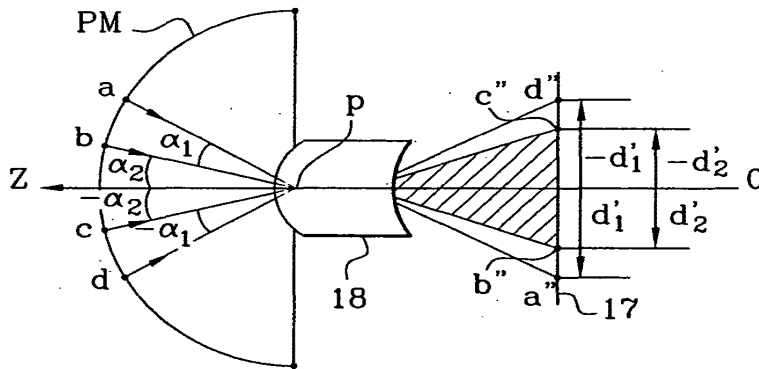


3/11

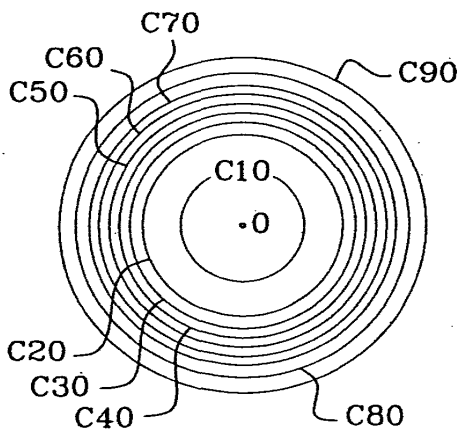


**Fig. 5**

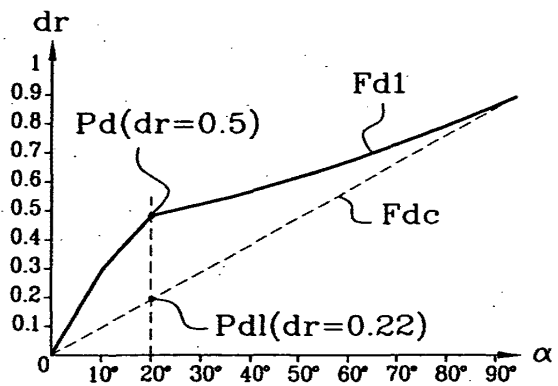
PRIOR ART



**Fig. 6**



**Fig. 7A**



**Fig. 7B**



NOTICE OF ALLOWANCE AND FEE(S) DUE

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

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT PROSECUTION ON THE MERITS IS CLOSED. THIS NOTICE OF ALLOWANCE IS NOT A GRANT OF PATENT RIGHT THIS APPLICATION IS SUBJECT TO WITHDRAWAL FROM ISSUE AT THE INITIATIVE OF THE OFFICE OR UPO PETITION BY THE APPLICANT. SEE 37 CFR 1.313 AND MPEP 1308.

THE ISSUE FEE AND PUBLICATION FEE (IF REQUIRED) MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THE STATUTORY PERIOD CANNOT BE EXTENDED. SEE 35 U.S.C. 151. THE ISSUE FEE DUE INDICATED ABOVE REFLECTS A CREDIT FOR ANY PREVIOUSLY PAID ISSUE FEE APPLIED IN THIS APPLICATION. THE PTOL-85B (OR AN EQUIVALENT) MUST BE RETURNED WITHIN THIS PERIOD EVEN IF NO FEE IS DUE OR THE APPLICATION WILL BE REGARDED AS ABANDONED.

HOW TO REPLY TO THIS NOTICE:

I. Review the SMALL ENTITY status shown above.

If the SMALL ENTITY is shown as YES, verify your current SMALL ENTITY status:

- A. If the status is the same, pay the TOTAL FEE(S) DUE shown above.
- B. If the status above is to be removed, check box 5b on Part B - Fee(s) Transmittal and pay the PUBLICATION FEE (if required) and twice the amount of the ISSUE FEE shown above, or

If the SMALL ENTITY is shown as NO:

- A. Pay TOTAL FEE(S) DUE shown above, or
- B. If applicant claimed SMALL ENTITY status before, or is now claiming SMALL ENTITY status, check box 5a on Part B - Fee Transmittal and pay the PUBLICATION FEE (if required) and 1 the ISSUE FEE shown above.

II. PART B - FEE(S) TRANSMITTAL should be completed and returned to the United States Patent and Trademark Office (USPTO) with your ISSUE FEE and PUBLICATION FEE (if required). Even if the fee(s) have already been paid, Part B - Fee(s) Transmittal should be completed and returned. If you are charging the fee(s) to your deposit account, section "4b" of Part B - Fee(s) Transmittal should be completed and an extra copy of the form should be submitted.

III. All communications regarding this application must give the application number. Please direct all communications prior to issuance Mail Stop ISSUE FEE unless advised to the contrary.

IMPORTANT REMINDER: Utility patents issuing on applications filed on or after Dec. 12, 1980 may require payment maintenance fees. It is patentee's responsibility to ensure timely payment of maintenance fees when due.

**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 where 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

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, must 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 United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Mail Stop ISSUE FEE address above, or being facsimile transmitted to the USPTO (703) 746-4000, on the date indicated below.

(Depositor's name)
(Signature)
(Date)

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

EXAMINER	ART UNIT	CLASS-SUBCLASS
SUGARMAN, SCOTT J	2873	359-725000

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.563).  
 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, 1 \_\_\_\_\_  
 (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. 2 \_\_\_\_\_  
 3 \_\_\_\_\_

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 for 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 \_\_\_\_\_ (B) RESIDENCE: (CITY and STATE OR COUNTRY) \_\_\_\_\_

Please check the appropriate assignee category or categories (will not be printed on the patent) :  Individual  Corporation or other private group entity  Government

4a. The following fee(s) are enclosed:  
 Issue Fee  
 Publication Fee (No small entity discount permitted)  
 Advance Order - # of Copies \_\_\_\_\_

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 the required fee(s), or credit any overpayment Deposit Account Number \_\_\_\_\_ (enclose an extra copy of this form).

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 party interest as shown by the records of the United States Patent and Trademark Office.

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 process) 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 complete 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.O. 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

Table with columns: APPLICATION NO., FILING DATE, FIRST NAMED INVENTOR, ATTORNEY DOCKET NO., CONFIRMATION NO., EXAMINER, ART UNIT, PAPER NUMBER. Includes application details for Jean-Claude Artonne and examiner Scott J. Sugarman.

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 Retrieval (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.



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

Table with 5 columns: APPLICATION NO., FILING DATE, FIRST NAMED INVENTOR, ATTORNEY DOCKET NO., CONFIRMATION NO.
10/706,513 11/12/2003 Jean-Claude Artonne 10000-25US 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 2873 PAPER NUMBER

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.

<b>Notice of Allowability</b>	<b>Application No.</b>	<b>Applicant(s)</b>	
	10/706,513	ARTONNE ET AL.	
	<b>Examiner</b>	<b>Art Unit</b>	
	Scott J. Sugarman	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. <input checked="" type="checkbox"/> Notice of References Cited (PTO-892)  | 5. <input type="checkbox"/> Notice of Informal Patent Application (PTO-152)            |
| 2. <input type="checkbox"/> Notice of Draftsperson's Patent Drawing Review (PTO-948)   | 6. <input type="checkbox"/> Interview Summary (PTO-413),<br>Paper No./Mail Date _____. |
| 3. <input checked="" type="checkbox"/> Information Disclosure Statements (PTO-1449 or PTO/SB/08),<br>Paper No./Mail Date <u>11-12-03</u> | 7. <input checked="" type="checkbox"/> Examiner's <del>Amendment</del> Comment         |
| 4. <input type="checkbox"/> Examiner's Comment Regarding Requirement for Deposit<br>of Biological Material                               | 8. <input checked="" type="checkbox"/> Examiner's Statement of Reasons for Allowance   |
|  | 9. <input type="checkbox"/> 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 one 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."

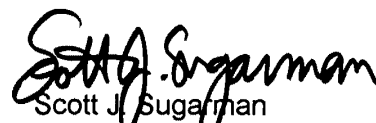
### ***Conclusion***

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				<b>Complete if Known</b>	
<b>INFORMATION DISCLOSURE STATEMENT BY APPLICANT</b>  (use as many sheets as necessary)				Applicati n Number	Not Yet Assigned
				Filing Dat	November 11, 2003
				First Named Invent r	Jean-Claude ARTONNE, et al.
				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		Name of First Inventor of Cited Document	Date of Publication of Cited Document MM-YYYY
	Number	Kind Code (if known)		
<i>SA</i>	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			Name of Applicant of Cited Document	Date of Publication of Cited Document MM-YYYY	T <sub>1</sub>
	Country Code	Number	Kind Code (if known)			
<i>SA</i>	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.	T <sub>1</sub>

Examiner Signature	<i>S. J. Sugarman</i>	Date Considered	<i>9-2004</i>
--------------------	-----------------------	-----------------	---------------

<b>Notice of References Cited</b>	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.

<b>Issue Classification</b> 	Application No.	Applicant(s)	
	10/706,513	ARTONNE ET AL.	
	Examiner	Art Unit	
	Scott J. Sugarman	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							
				/							
				/							
				/							
				Scott J. Sugarman Primary Examiner				Total Claims Allowed: 26			
(Assistant Examiner) (Date)				Scott J. Sugarman Primary Examiner				O.G. Print Claim(s)		O.G. Print Fig	
<i>Scott J. Sugarman</i> (Legal Instruments Examiner) (Date)				<i>Scott J. Sugarman</i> (Primary Examiner) (Date)				17		11	

<input checked="" type="checkbox"/> Claims renumbered in the same order as presented by applicant		<input type="checkbox"/> CPA		<input type="checkbox"/> T.D.		<input type="checkbox"/> R.1.47	
Final	Original	Final	Original	Final	Original	Final	Original
1	1		31		61		91
2	2		32		62		92
3	3		33		63		93
4	4		34		64		94
5	5		35		65		95
6	6		36		66		96
7	7		37		67		97
8	8		38		68		98
9	9		39		69		99
10	10		40		70		100
11	11		41		71		101
12	12		42		72		102
13	13		43		73		103
14	14		44		74		104
15	15		45		75		105
16	16		46		76		106
17	17		47		77		107
18	18		48		78		108
19	19		49		79		109
20	20		50		80		110
21	21		51		81		111
22	22		52		82		112
23	23		53		83		113
24	24		54		84		114
25	25		55		85		115
26	26		56		86		116
	27		57		87		117
	28		58		88		118
	29		59		89		119
	30		60		90		120
							121
							122
							123
							124
							125
							126
							127
							128
							129
							130
							131
							132
							133
							134
							135
							136
							137
							138
							139
							140
							141
							142
							143
							144
							145
							146
							147
							148
							149
							150
							151
							152
							153
							154
							155
							156
							157
							158
							159
							160
							161
							162
							163
							164
							165
							166
							167
							168
							169
							170
							171
							172
							173
							174
							175
							176
							177
							178
							179
							180
							181
							182
							183
							184
							185
							186
							187
							188
							189
							190
							191
							192
							193
							194
							195
							196
							197
							198
							199
							200
							201
							202
							203
							204
							205
							206
							207
							208
							209
							210

**Index of Claims**



Application No.

10/706,513

Examiner

Scott J. Sugarman

Applicant(s)

ARTONNE ET AL.

Art Unit

2873

√	Rejected
=	Allowed

-	(Through numeral) Cancelled
+	Restricted

N	Non-Elected
I	Interference

A	Appeal
O	Objected

Claim		Date						
Final	Original	9/3/04						
1	1	=						
2	2	=						
3	3	=						
4	4	=						
5	5	=						
6	6	=						
7	7	=						
8	8	=						
9	9	=						
10	10	=						
11	11	=						
12	12	=						
13	13	=						
14	14	=						
15	15	=						
16	16	=						
17	17	=						
18	18	=						
19	19	=						
20	20	=						
21	21	=						
22	22	=						
23	23	=						
24	24	=						
25	25	=						
26	26	=						
27								
28								
29								
30								
31								
32								
33								
34								
35								
36								
37								
38								
39								
40								
41								
42								
43								
44								
45								
46								
47								
48								
49								
50								

Claim		Date						
Final	Original							
51								
52								
53								
54								
55								
56								
57								
58								
59								
60								
61								
62								
63								
64								
65								
66								
67								
68								
69								
70								
71								
72								
73								
74								
75								
76								
77								
78								
79								
80								
81								
82								
83								
84								
85								
86								
87								
88								
89								
90								
91								
92								
93								
94								
95								
96								
97								
98								
99								
100								

Claim		Date						
Final	Original							
101								
102								
103								
104								
105								
106								
107								
108								
109								
110								
111								
112								
113								
114								
115								
116								
117								
118								
119								
120								
121								
122								
123								
124								
125								
126								
127								
128								
129								
130								
131								
132								
133								
134								
135								
136								
137								
138								
139								
140								
141								
142								
143								
144								
145								
146								
147								
148								
149								
150								



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

**\*BIBDATASHEET\***

**CONFIRMATION NO. 8287**

Bib Data Sheet

SERIAL NUMBER 10/706,513	FILING DATE 11/12/2003  RULE	CLASS 359	GROUP ART UNIT 2873	ATTORNEY DOCKET NO. 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 *SA*

\*\* FOREIGN APPLICATIONS \*\*\*\*\*

FRANCE 01 06261 05/11/2001 *SA*

IF REQUIRED, FOREIGN FILING LICENSE GRANTED

\*\* 02/13/2004

Foreign Priority claimed 35 USC 119 (a-d) conditions met	<input checked="" type="checkbox"/> yes <input type="checkbox"/> no	STATE OR	SHEETS	TOTAL	INDEPENDENT
Verified and Acknowledged	<input checked="" type="checkbox"/> yes <input type="checkbox"/> no <input type="checkbox"/> Met after Allowance	COUNTRY	DRAWING	CLAIMS	CLAIMS
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	FEES: Authority has been given in Paper No. _____ to charge/credit DEPOSIT ACCOUNT RECEIVED 1008	<input type="checkbox"/> All Fees
		<input type="checkbox"/> 1.16 Fees ( Filing )
		<input type="checkbox"/> 1.17 Fees ( Processing Ext. of time )
		<input type="checkbox"/> 1.18 Fees ( Issue )
		<input type="checkbox"/> Other _____

**Search Notes**



Application No.

10/706,513

Applicant(s)

ARTONNE ET AL.

Examiner

Scott J. Sugarman

Art Unit

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



	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

09/07/2004, EAST Version: 1.4.1

	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



Attorney Docket No.: 10000-250S  
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)**

<u>01 06261</u> (Number)	<u>FR</u> (Country)	<u>11/05/2001</u> (Day/Month/Year filed)	<b><u>Priority claimed</u></b> <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
_____	_____	_____	<b><u>Priority Claimed</u></b> <input type="checkbox"/> Yes <input type="checkbox"/> 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**

_____		<b><u>Priority Claimed</u></b> <input type="checkbox"/> Yes <input type="checkbox"/> No
(Application No.)	(Filing Date)	
_____	_____	<b><u>Priority Claimed</u></b> <input type="checkbox"/> Yes <input type="checkbox"/> 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)

---

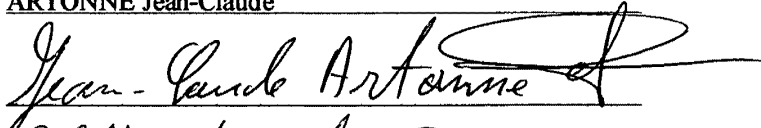
(Application Serial No.)              (Filing Date)                      (Status) (patented, pending, abandoned)

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.

Full name of sole or first inventor      ARTONNE Jean-Claude

Inventor's signature                      

Date    26<sup>th</sup> November 2003

Residence                                      MONTREAL QUEBEC, CANADA

Citizenship                                      FRANCE

Post Office Address                              2145, Rachel Est #205,  
H2H 1R1 MONTREAL QUEBEC - CANADA

Full name of second joint inventor  
(if any)

MOUSTIER Christophe

Inventor's signature

Christophe Moustier

Date

December 8<sup>th</sup> 2003

Residence

MARSEILLE, FRANCE

Citizenship

FRANCE

Post Office Address

35, avenue de KALLISTE,

13012 MARSEILLE - FRANCE

Full name of third joint inventor  
(if any)

BLANC Benjamin

Inventor's signature

Benjamin Blanc

Date

26<sup>th</sup>, November 2003

Residence

MONTREAL QUEBEC, CANADA

Citizenship

FRANCE

Post Office Address

2177 rue prud'homme,

H4A 3H3 MONTREAL QUEBEC - CANADA

This Page Is Inserted by IFW Operations  
and is not a part of the Official Record

## **BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning documents *will not* correct images,  
please do not report the images to the  
Image Problem Mailbox.**







01 06262  
①

# BREVET D'INVENTION

## CERTIFICAT D'UTILITÉ - CERTIFICAT D'ADDITION

### COPIE OFFICIELLE

Le Directeur général de l'Institut national de la propriété industrielle certifie que le document ci-annexé est la copie certifiée conforme d'une demande de titre de propriété industrielle déposée à l'Institut.

Fait à Paris, le 29 OCT. 2003

Pour le Directeur général de l'Institut  
national de la propriété industrielle  
Le Chef du Département des brevets

Martine PLANCHE

INSTITUT  
NATIONAL DE  
LA PROPRIÉTÉ  
INDUSTRIELLE

SIEGE  
26 bis, rue de Saint Petersburg  
75800 PARIS cedex 08  
Téléphone : 33 (0)1 53 04 53 04  
Télécopie : 33 (0)1 53 04 45 23  
www.inpi.fr





INSTITUT NATIONAL DE LA PROPRIÉTÉ INDUSTRIELLE  
26 bis, rue de Saint Pétersbourg  
75800 Paris Cedex 08  
Téléphone : 01 53 04 53 04 Télécopie : 01 42 94 86 54

**BREVET D'INVENTION  
CERTIFICAT D'UTILITÉ**  
Code de la propriété intellectuelle - Livre VI




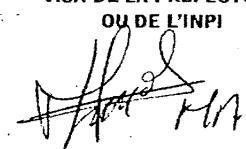
REQUÊTE EN DÉLIVRANCE 1/2

Cet imprimé est à remplir lisiblement à l'encre noire DB 540 W / 260899

REMISE DES Papiers DATE <b>11 MAI 2001</b> LIEU <b>13 INPI MARSEILLE</b> N° D'ENREGISTREMENT <b>0106261</b> NATIONAL ATTRIBUÉ PAR L'INPI DATE DE DÉPÔT ATTRIBUÉE PAR L'INPI <b>11 MAI 2001</b>		Réservé à l'INPI <b>1</b> 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 <input type="checkbox"/> N° attribué par l'INPI à la télécopie			
<b>2</b> NATURE DE LA DEMANDE		Cochez l'une des 4 cases suivantes	
Demande de brevet		<input checked="" type="checkbox"/>	
Demande de certificat d'utilité		<input type="checkbox"/>	
Demande divisionnaire		<input type="checkbox"/>	
Demande de brevet initiale		N°	Date
ou demande de certificat d'utilité initiale		N°	Date
Transformation d'une demande de brevet européen		<input type="checkbox"/>	Date
Demande de brevet initiale		N°	Date
<b>3</b> TITRE DE L'INVENTION (200 caractères ou espaces maximum)			
Procédé d'obtention et d'affichage d'une image panoramique numérique à résolution variable			
<b>4</b> DÉCLARATION DE PRIORITÉ OU REQUÊTE DU BÉNÉFICE DE LA DATE DE DÉPÔT D'UNE DEMANDE ANTÉRIEURE FRANÇAISE		Pays ou organisation _____ N° _____ Date / / _____ Pays ou organisation _____ N° _____ Date / / _____ Pays ou organisation _____ N° _____ Date / / _____ <input type="checkbox"/> S'il y a d'autres priorités, cochez la case et utilisez l'imprimé «Suite»	
<b>5</b> DEMANDEUR		<input type="checkbox"/> S'il y a d'autres demandeurs, cochez la case et utilisez l'imprimé «Suite»	
Nom ou dénomination sociale		IMMERVISION INTERNATIONAL PTE LTD	
Prénoms			
Forme juridique			
N° SIREN			
Code APE-NAF			
Adresse	Rue	French Business Centre Singapore Pte Ltd. 89 Neil Road	
	Code postal et ville	088849 SINGAPOUR	
Pays		SINGAPOUR	
Nationalité		SINGAPOUR	
N° de téléphone (facultatif)			
N° de télécopie (facultatif)			
Adresse électronique (facultatif)			


**BREVET D'INVENTION  
CERTIFICAT D'UTILITÉ**

REQUÊTE EN DÉLIVRANCE 2/2

REMISE DES FICHES DATE <b>13 MAI 2004</b> LIEU <b>13 INPI MARSEILLE</b> N° D'ENREGISTREMENT <b>0106261</b> NATIONAL ATTRIBUÉ PAR L'INPI		Réserve à l'INPI DB 540 W / 260399
<b>Vos références pour ce dossier :</b> <i>(facultatif)</i>		100137 FR
<b>6 MANDATAIRE</b>		
Nom		MARCHAND
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
N° de téléphone <i>(facultatif)</i>		04.42.99.06.60.
N° de télécopie <i>(facultatif)</i>		04.42.99.06.69.
Adresse électronique <i>(facultatif)</i>		
<b>7 INVENTEUR (S)</b>		
Les inventeurs sont les demandeurs		<input type="checkbox"/> Oui <input checked="" type="checkbox"/> Non Dans ce cas fournir une désignation d'inventeur(s) séparée
<b>8 RAPPORT DE RECHERCHE</b>		
		Uniquement pour une demande de brevet (y compris division et transformation)
Établissement immédiat ou établissement différé		<input checked="" type="checkbox"/> <input type="checkbox"/>
Paiement échelonné de la redevance		<b>Paiement en trois versements, uniquement pour les personnes physiques</b> <input type="checkbox"/> Oui <input checked="" type="checkbox"/> Non
<b>9 RÉDUCTION DU TAUX DES REDEVANCES</b>		
		<b>Uniquement pour les personnes physiques</b> <input type="checkbox"/> Requête pour la première fois pour cette invention ( <i>joindre un avis de non-imposition</i> ) <input type="checkbox"/> Requête antérieurement à ce dépôt ( <i>joindre une copie de la décision d'admission pour cette invention ou indiquer sa référence</i> ):
Si vous avez utilisé l'imprimé «Suite», indiquez le nombre de pages jointes		
<b>10 SIGNATURE DU DEMANDEUR OU DU MANDATAIRE</b> (Nom et qualité du signataire) MARCHAND André - CPI N° 95 0303 OMNIPAT		<b>VISA DE LA PRÉFECTURE OU DE L'INPI</b>  

La loi n°78-17 du 6 janvier 1978 relative à l'informatique, aux fichiers et aux libertés s'applique aux réponses faites à ce formulaire. Elle garantit un droit d'accès et de rectification pour les données vous concernant auprès de l'INPI.

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 ordinateur 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( $\varphi, \theta$ ),  $\varphi$  étant la latitude et  $\theta$  la longitude d'un point image, les angles  $\varphi$  et  $\theta$  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  $\alpha$  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 :

$$dr = Fdc(\alpha) = K \alpha$$

30 dans laquelle la constante K est égale à 0,111 degré<sup>-1</sup> (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.

10 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 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  $\pm 10\%$  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

5 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  
10 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  
15 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  
20 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  
25 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  
30 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  
35 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  $\pm 10\%$  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.

5 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.

10 Selon un mode de réalisation, l'objectif panoramique dilate le centre d'une image et comprime les bords de l'image.

15 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.

20 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.

25 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.

30 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,
- 5 - 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
- 10 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
- 15 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,
- 20 - 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
- 25 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
- 30 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
- 35 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,

5 - 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/dilatation d'une image initiale

##### 10 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  $\alpha_1$ ,  $\alpha_2$ ,  $-\alpha_2$ ,  $-\alpha_1$ . 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  $\alpha_1$  est égal à deux fois l'angle  $\alpha_2$ . 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  $d_1$ ,  $d_2$ ,  $-d_2$ ,  $-d_1$ . Comme la répartition des points image en fonction de l'angle de champ des points objet est linéaire avec un objectif panoramique classique, les 20 30 distances  $d_1$  et  $d_2$  sont liées par la relation suivante:

$$d_1/\alpha_1 = d_2/\alpha_2$$

L'angle  $\alpha_1$  étant ici égal à  $2\alpha_2$ , il vient que :

35

$$d_1 = 2d_2$$

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.

5 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  $\alpha_1$ ,  $\alpha_2$ ,  $-\alpha_2$  et  $-\alpha_1$  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  $d_1'$ ,  $d_2'$ ,  $-d_2'$ ,  $-d_1'$ .

10  
15  
20

Selon l'invention, l'objectif 18 présente une fonction de répartition des points image qui n'est pas linéaire et le rapport des distances  $d_1'$ ,  $d_2'$ ,  $-d_2'$ ,  $-d_1'$  n'est pas égale au rapport des angles d'incidence  $\alpha_1$ ,  $\alpha_2$ ,  $-\alpha_2$ ,  $-\alpha_1$ . Sur l'exemple représenté, la distance  $d_2'$  est nettement supérieure à  $d_1'/2$ , de sorte que la partie centrale de l'image panoramique projetée sur le capteur d'image 17, qui correspond à un angle solide  $2\alpha_2$  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 linéaire. 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

25  
30  
35



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 linéaires 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  $Fdc = K\alpha$  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  $180^\circ$ , soit une pente de  $0,111$  degré<sup>-1</sup>). L'angle de champ  $\alpha$  des points objet est représenté en abscisse et est compris entre  $0$  et  $90^\circ$ . 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  $\alpha$  compris entre  $0$  et  $20^\circ$ , puis une pente plus faible au-delà des  $20^\circ$  et jusqu'à  $90^\circ$ . 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  $\alpha = 20^\circ$ . On entend par "point de divergence maximale" le point image  $Pd(\alpha)$  où l'on observe le plus grand écart en distance relative  $dr$  par rapport à un point correspondant  $Pd1(\alpha)$  sur la droite de répartition linéaire  $K\alpha$ . Dans cet exemple, le point  $Pd(\alpha=20^\circ)$  présente une distance relative  $dr$  égale à  $0,5$  relativement au centre de l'image tandis que le point correspondant  $Pd1(\alpha=20^\circ)$  sur la courbe linéaire  $Fdc$  présente une distance relative  $dr$  de  $0,222$ . La divergence maximale  $DIV_{max}$  de la fonction de répartition  $Fd1$  selon l'invention peut être calculée par une formule du type :

$$DIV_{max}\% = \frac{[dr(Pd) - dr(Pd1)]}{[dr(Pd1)]} * 100$$

soit :

$$DIV_{max}\% = \frac{[dr(Pd) - K*\alpha(Pd)]}{[K*\alpha(Pd)]} * 100$$

Dans laquelle  $dr(Pd)$  est la distance relative par rapport au centre du point de divergence maximale  $Pd$ ,  $dr(Pd1)$  est la distance relative par rapport au centre du point correspondant sur la droite de répartition linéaire  $Fdc$ ,

$\alpha(Pd)$  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 Pd11, Pd12 de même abscisse appartenant à la fonction de répartition linéaire Fdc. Le taux TX peut être déterminé par une formule du type :

$$TX = [dr(Pd1)^2 - dr(Pd2)^2] / [(dr(Pd11))^2 - (dr(Pd12))^2]$$

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  $Fd_2$  selon l'invention, présentant ici un point de divergence maximale  $Pd$  à l'angle  $\alpha=70^\circ$ , ayant une distance relative par rapport au centre de l'image de 0,3. La divergence maximale de la courbe  $Fd_2$  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  $Fd_2$ , 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  $Fd_3$  selon l'invention, présentant un premier point de divergence maximale  $Pd_1$  ( $\alpha=30^\circ$ ,  $dr=0,1$ ) et un second point de divergence maximale  $Pd_2$  ( $\alpha=70^\circ$ ,  $dr=0,9$ ). 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  $Pd_1$ , une zone d'image dilatée entre le cercle  $C30$  et le cercle  $C70$  passant par le point  $Pd_2$ , 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  $TX(O, C30)$ ,  $TX(C30, C70)$ ,  $TX(C70, C90)$  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  $Fd_3$ , 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 peut 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  $F_d$  selon l'invention. La fonction de répartition  $F_d$  étant connue et déterminée au moment de la conception de l'objectif non linéaire, il est aisé d'en déduire la fonction réciproque  $F_d^{-1}$ . 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  $F_d$  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  $F_d^{-1}$ , 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,

- 5 - 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*.

10 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*,
- 15 - *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*,
- 20 - *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
- 25 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
- 30 disque image initial *ID1* (soit la résolution maximale du disque image *ID1* exprimée en différence d'angle).

Algorithme 1 :

[recherche de *DAM*]

- 35 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
5 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]
10 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]
15 13/      R = √(I2+J2)
14/      Si R < R2 alors
15/          Si J < 0 alors
16/              θ = arc cosinus(I/R)
17/          Sinon
20 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 ]
25 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
30 [attribution de la couleur noire aux points en dehors du
disque image]
25/      Img2[I,J] = Noir
26/      Fin si
27/  Fin pour
35 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  $R > R_2$ ). D'autre part, l'algorithme 1 peut être amélioré en effectuant a posteriori une interpolation bilinéaire sur l'image  $Img_2$ , 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 ordinateur, 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  $Img_2$  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  $Img_1$  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  $180^\circ$  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  $Im_1$  au moyen de la fonction de répartition non linéaire  $F_d$  selon l'invention, ce qui nécessite le calcul préalable de l'angle de champ  $\alpha$  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  $\alpha$  des points objet et l'allure de la fonction  $F_d$ . La projection des points image P sur le disque image  $ID_1$  permet d'obtenir des points image  $p(p_u, p_v)$  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  $ID_1$  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  $ID_1$ , au moyen de la fonction  $F_d$ , les points image  $p(p_u, p_v)$  correspondant aux points images  $E(i, j)$  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,
- $I_{max}$  et  $J_{max}$  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,
- 5 - 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
- 10 d'affichage formant la base d'une pyramide de vision de l'observateur dont le sommet est le point O (position de l'observateur),
- $\theta_0$  et  $\varphi_0$  sont les longitudes et latitudes correspondant à la direction du regard depuis le point O vers le centre M de
- 15 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-
- 20 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),
- 25 -  $\alpha$  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
- 30 une valeur par défaut égale à R.
- " $\sqrt{\quad}$ " est la fonction racine carrée.

**Algorithme 2 :**

- 1/ Pour  $i=-I_{max}/2$  à  $i=I_{max}/2$  faire [par incréments de 1]
- 35 2/ Pour  $j=-J_{max}/2$  à  $j=J_{max}/2$  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/  $Ey = j*\cos(\varphi_0) - Zoom*\sin(\varphi_0)$

```

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)
5 [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
10 [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 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 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  
 5  $L*U*Fd(\alpha)$  et  $L*V*Fd(\alpha)$  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  
 10 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  $\alpha$  des points  
 15 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  
 20 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  
 25 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,  
 30 - 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 :

35  
 18/  $pu = L*U*Fd(\alpha)$   
 19/  $p_v = L*V*Fd(\alpha)$   
 20/ Si  $P_z \geq 0$  alors

```
21/ Pixel_Ecran[i,j] = Pixel_Image_Devant[pu,pv]
22/ Sinon Pixel_Ecran[i,j] = Pixel_Image_Derriere[L-pu,pv]
23/ Fin si
24/ fin pour
5 25/ 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.

## 20 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.

### 30 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  $F_d$  obtenue au moyen de l'objectif 30 est la fonction  $F_{d1}$  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  
 5 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  
 10 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-  
 15 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  
 20 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  
 25 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  
 30 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  
 35 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,

5 "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  
10 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 :

$$15 \quad \varphi(r) = \alpha_1 (r/R_0)^2 + \alpha_2 (r/R_0)^4$$

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,

20  $\alpha_1$  et  $\alpha_2$  sont des constantes définissant le déphasage de la surface d'onde, :

"R0" est une constante permettant de normaliser r, et

" $\varphi$ " est le déphasage introduit par la surface diffractive au point considéré.

25 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  
30 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  
35 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  $F_d$  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  $F_d$  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  $F_d$  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  
5 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.

10 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  
15 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  
20 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  
25 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

<b>S1 - Acquisition</b>
- 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 $F_d$ non linéaire
<b>S2 - Transfert du fichier image dans un ordinateur</b>
- Transfert du fichier image (disque image) dans un micro-ordinateur - Stockage en mémoire de masse (optionnel)
<b>S3 - Linéarisation du disque image</b>
- 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 $F_d^{-1}$ ⇒ Obtention d'un disque image linéaire
<b>S4 - Numérisation</b>
- 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
<b>S5 - Affichage Interactif</b>
- 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
<p>- 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 <math>F_d</math> non linéaire</p>
S2 - Transfert du fichier image dans un ordinateur
<p>- Transfert du fichier image (disque image) dans un micro-ordinateur</p> <p>- Stockage en mémoire de masse (optionnel)</p>
S3' - Affichage interactif avec correction implicite de la non-linéarité de l'image initiale
<p>A - Détermination de la couleur des points <math>E(i, j)</math> d'un secteur d'image à afficher à partir des points <math>p(p_u, p_v)</math> du disque image :</p> <ol style="list-style-type: none"> <li>1 - détermination des coordonnées <math>E_x, E_y, E_z</math> dans le repère OXYZ de chaque point <math>E(i, j)</math> du secteur à afficher,</li> <li>2 - détermination des coordonnées <math>P_x, P_y, P_z</math> de points <math>P</math> de la demi-sphère correspondant aux points <math>E(i, j)</math>,</li> <li>3 - calcul des coordonnées, dans le repère O'UV du disque image, de points <math>p(p_u, p_v)</math> correspondants aux points <math>P</math> de la demi-sphère, au moyen de la fonction <math>F_d</math>,</li> </ol> <p>B - Présentation du secteur d'image dans une fenêtre d'affichage,</p> <p>C - Détection des actions de l'utilisateur sur un pointeur d'écran ou tout autre moyen de commande</p> <p>D - Détection des actions de l'utilisateur sur des touches de grossissement</p> <p>E - Modification du secteur d'image affiché (déplacement et/ou rétrécissement/grossissement du secteur d'image) .</p>

REVENDEICATIONS

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  
5 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  $\pm 10\%$  par rapport à une fonction de répartition linéaire  
10 (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  
15 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.

20 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.

25 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.

30 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.

35 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  
5 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  
10 objet (a-d) du panorama, la fonction de répartition présentant une divergence maximale d'au moins  $\pm 10\%$  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  
15 (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  
20 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  
25 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  
30 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  
35 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).

5

8. Procédé selon la revendication 6, dans lequel le jeu de lentilles formant apodiseur comprend au moins une lentille diffractive (L6).

10 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).

15 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  
20 linéaire.

11. Procédé selon la revendication 10, dans lequel l'étape de correction (S3) comprend une étape de  
25 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).

30 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  
35 - 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).

5

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 :

20 - 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

25 - 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

35 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).

5

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.

10

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.

15

16. Procédé selon la revendication 15, dans lequel la projection des points image de la fenêtre d'affichage sur l'image initiale comprend :

20

- une étape de projection des points image de la fenêtre d'affichage sur une sphère (HS) ou une portion de sphère,

25

- une étape de détermination de l'angle ( $\alpha$ ) 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 ( $\alpha$ ) que présente chaque point à projeter par rapport au centre de la sphère ou de la portion de sphère.

30

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")

35

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 ( $\alpha$ ) 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 ( $\alpha$ ) 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  $\pm 10\%$  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  $\pm 10\%$  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.

10 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  
15 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

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.

25 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.

30

22. Objectif panoramique selon l'une des revendications 17 à 21, comprenant un jeu de lentilles (L4-L6) formant apodiseur.

35 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).

5           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  
10 moins un miroir déformant (M2).

1/11

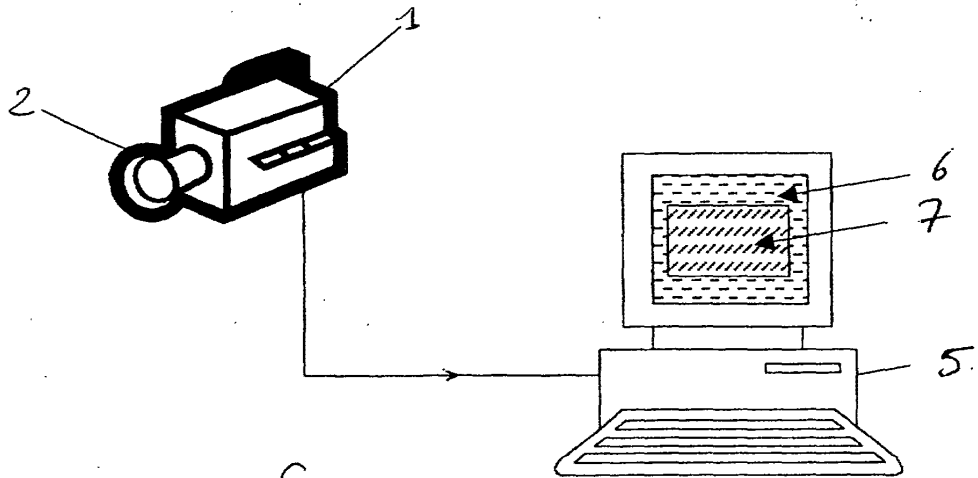


Fig. 1

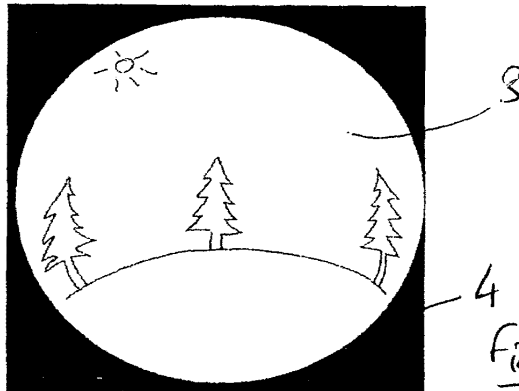


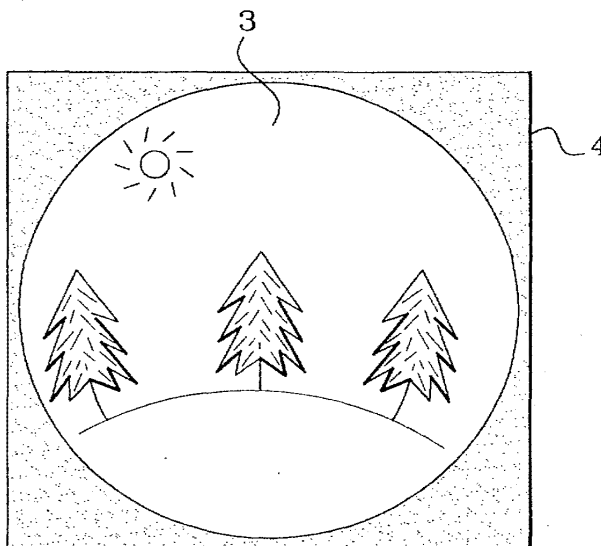
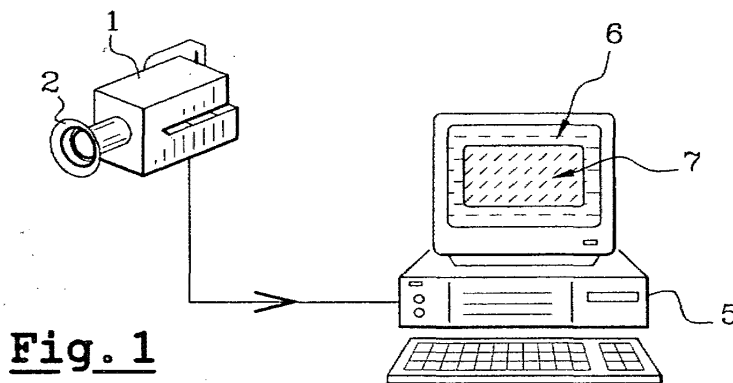
Fig. 2

DESSINS PROVISOIRES

Dessins Définitifs en cours d'élaboration



1/11





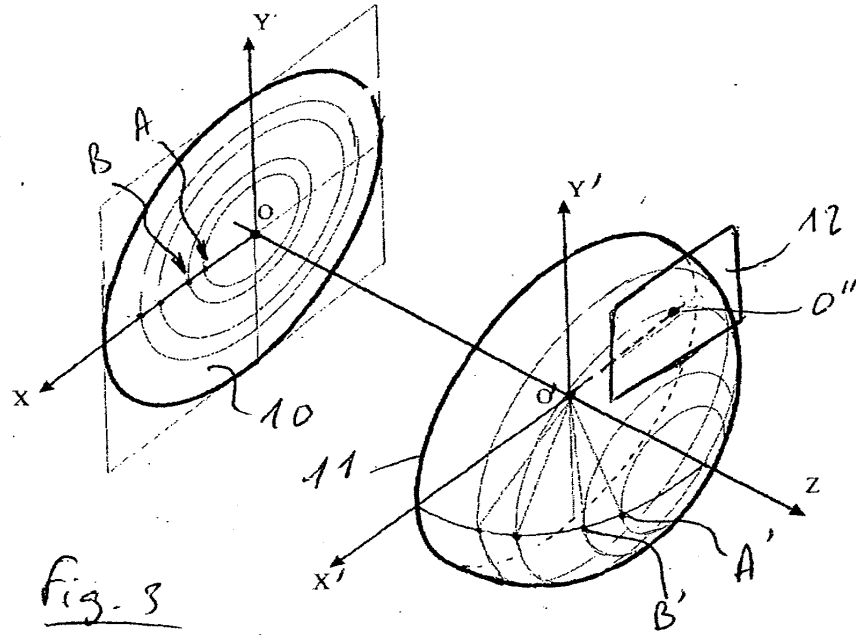


Fig. 3

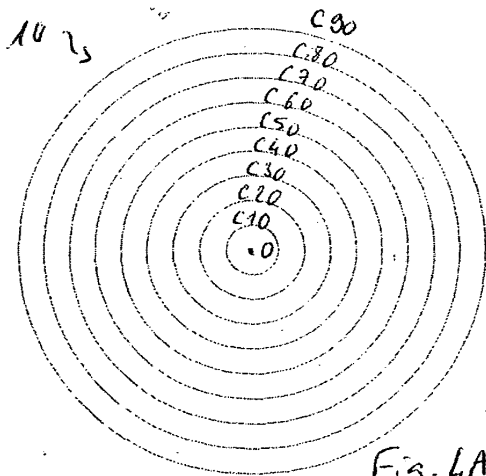


Fig. 4A

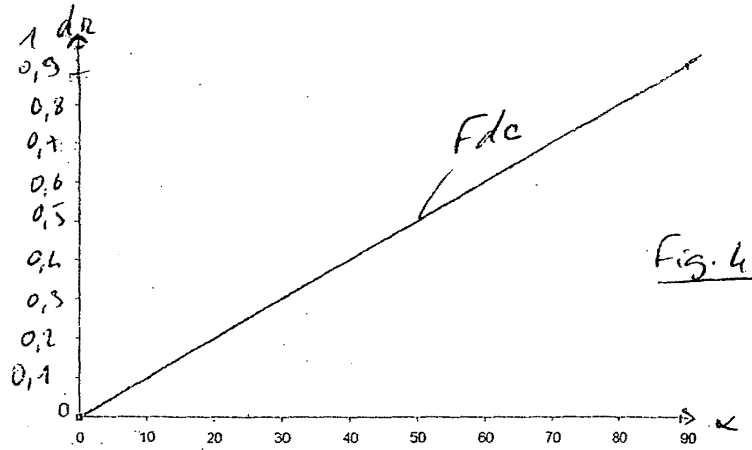
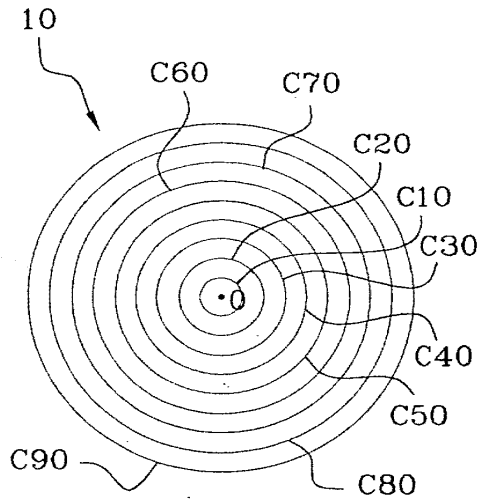
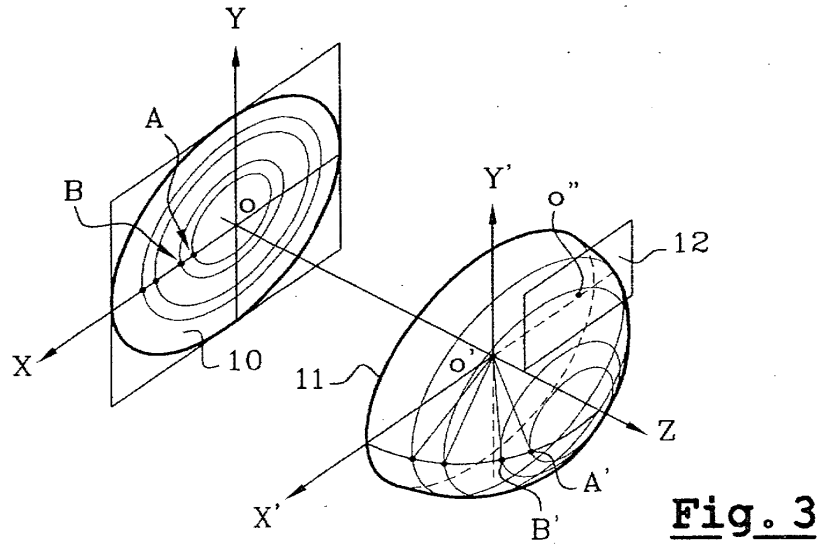
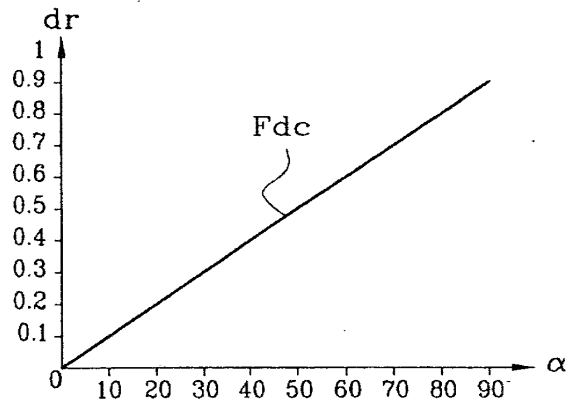


Fig. 4B

DESSINS PROVISOIRES  
 Dessins Définitifs en cours d'élaboration

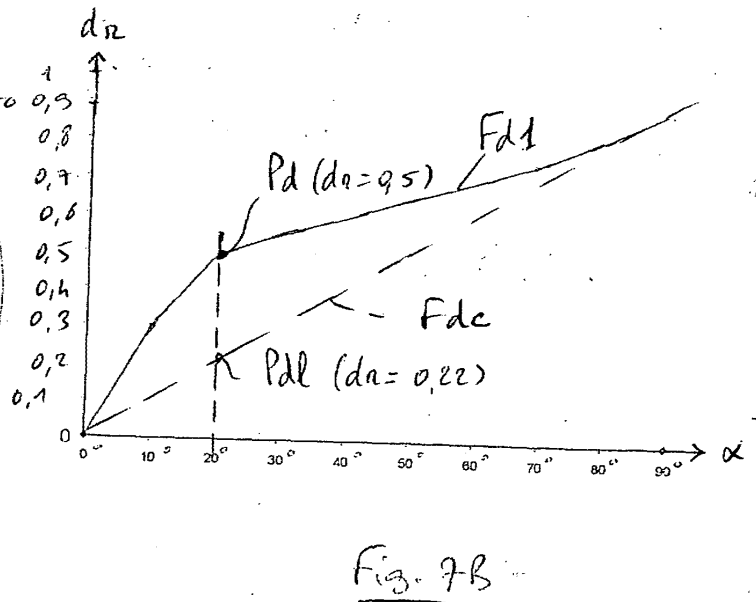
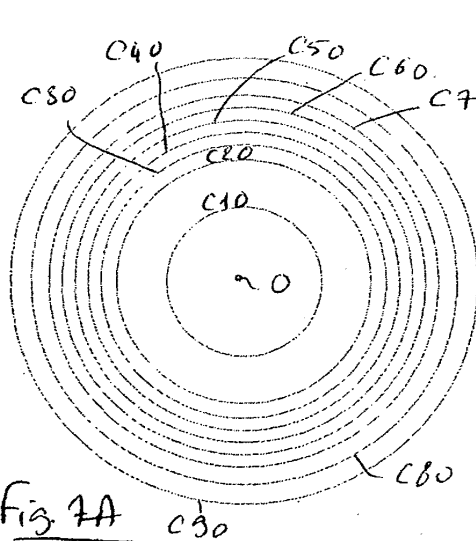
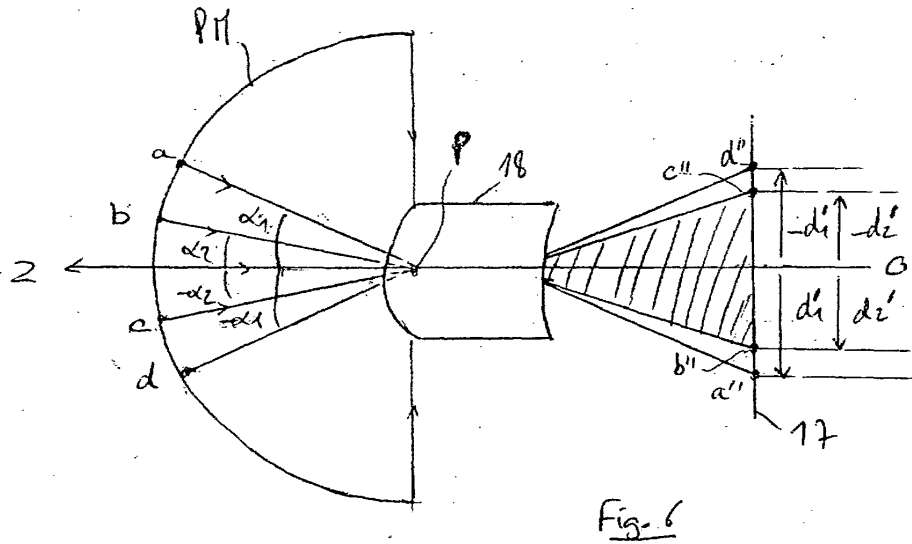
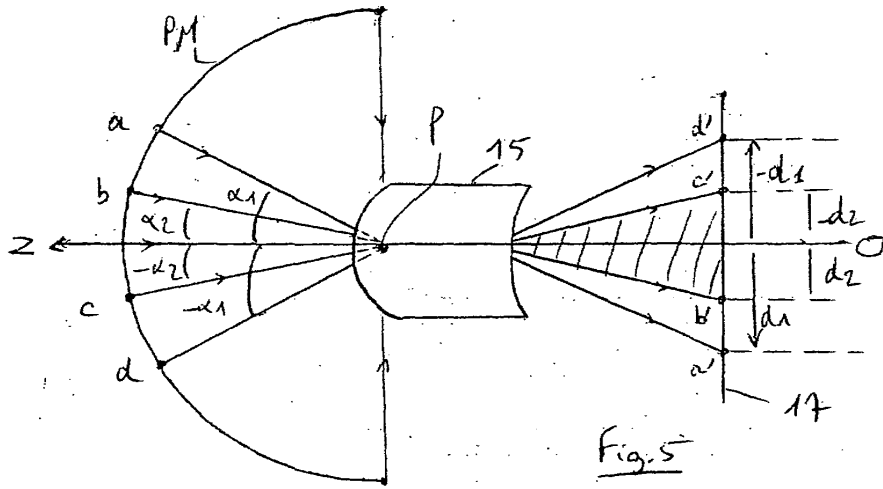


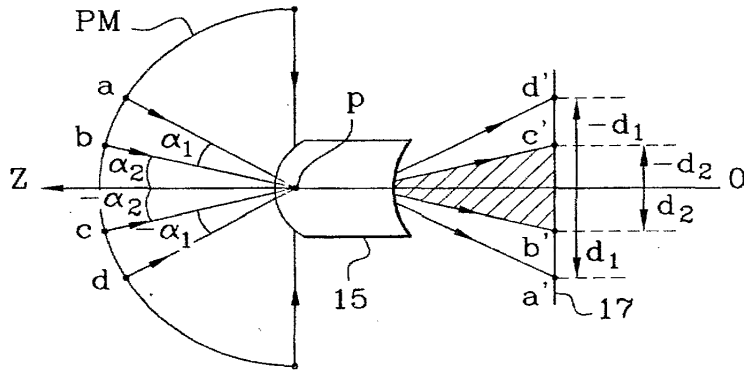
**Fig. 4A**



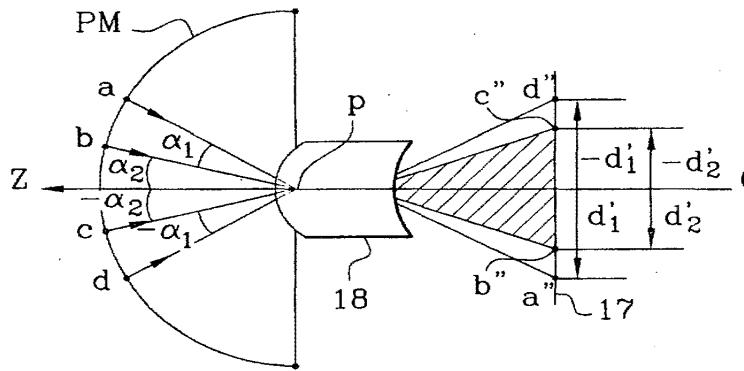
**Fig. 4B**

3/11

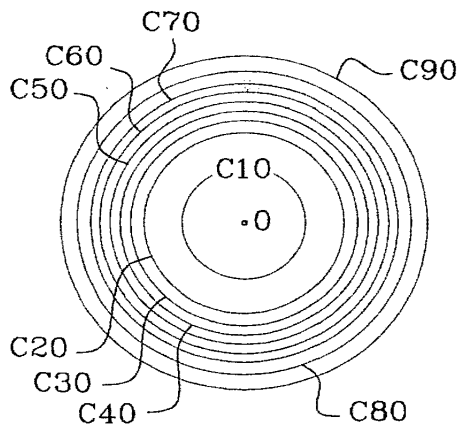




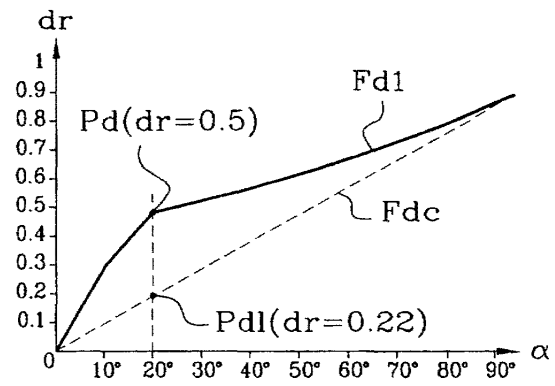
**Fig. 5**



**Fig. 6**



**Fig. 7A**



**Fig. 7B**

100 137 FR

4/11

Fig. 8

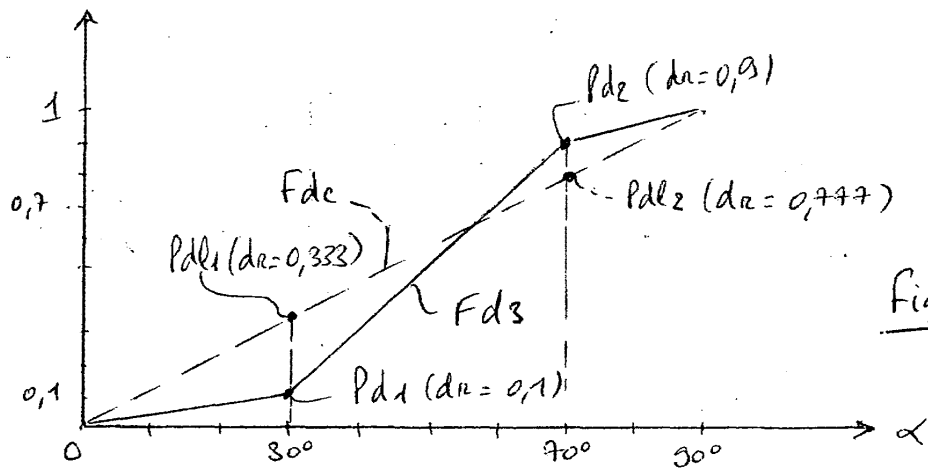
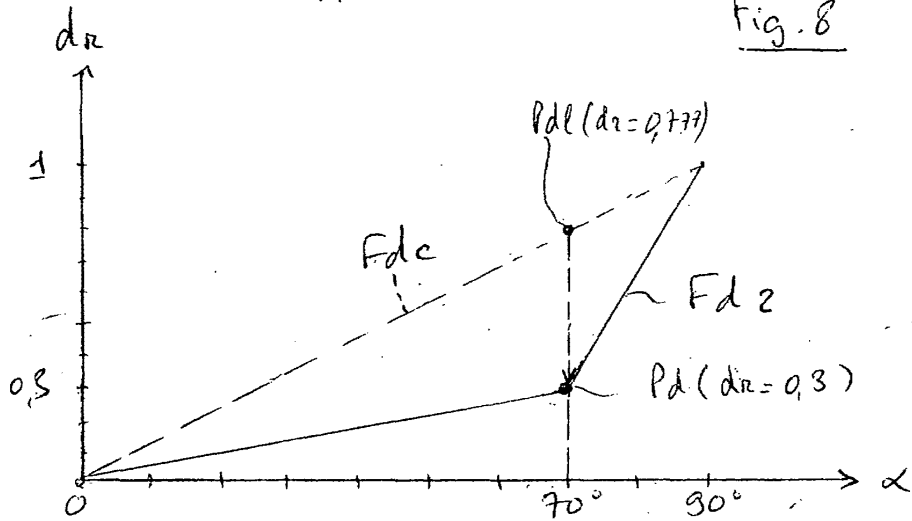
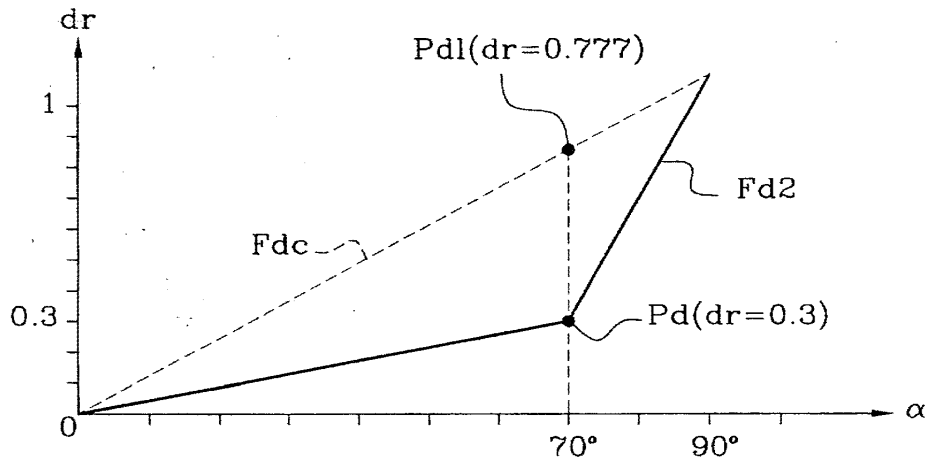
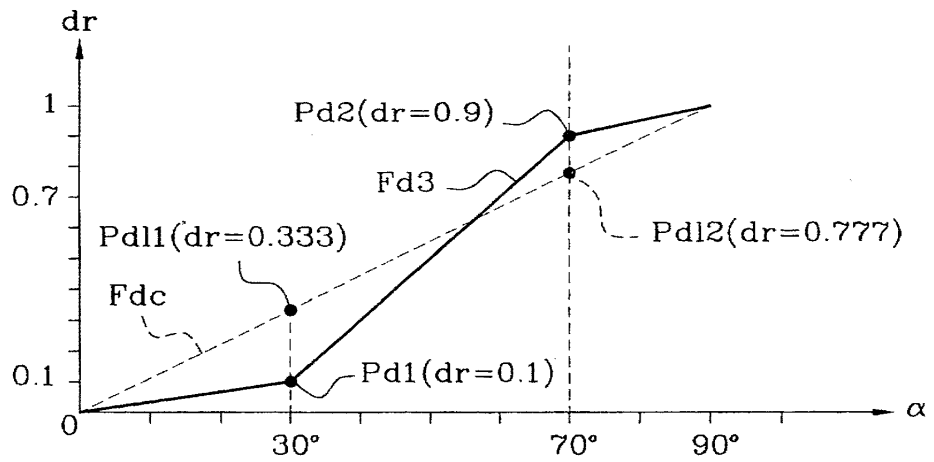


Fig. 9



**Fig. 8**



**Fig. 9**

5/11

100 137 F6

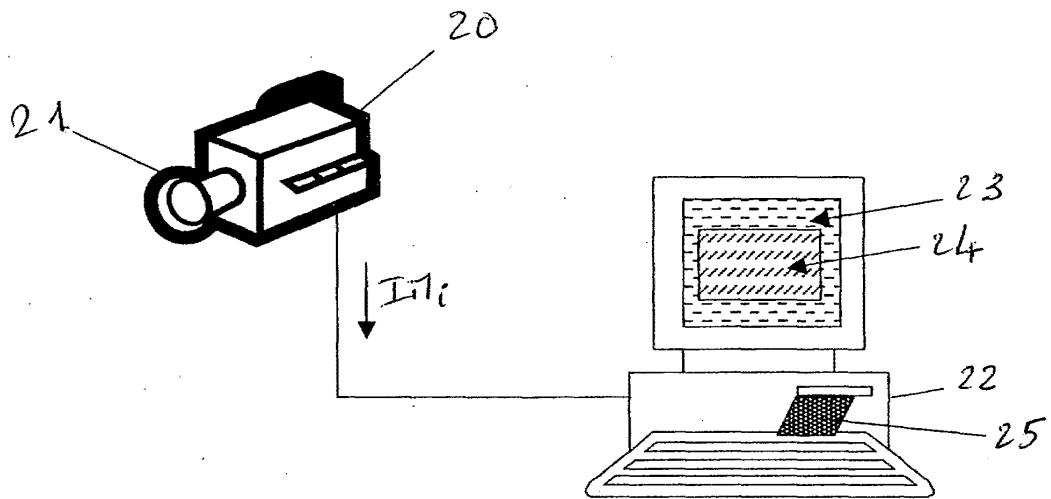


Fig. 10

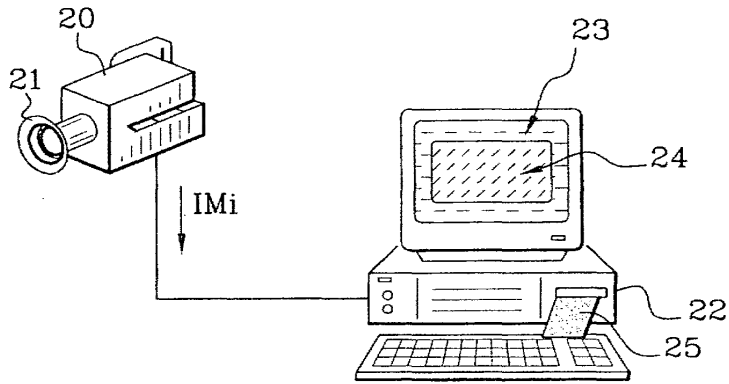


Fig. 10



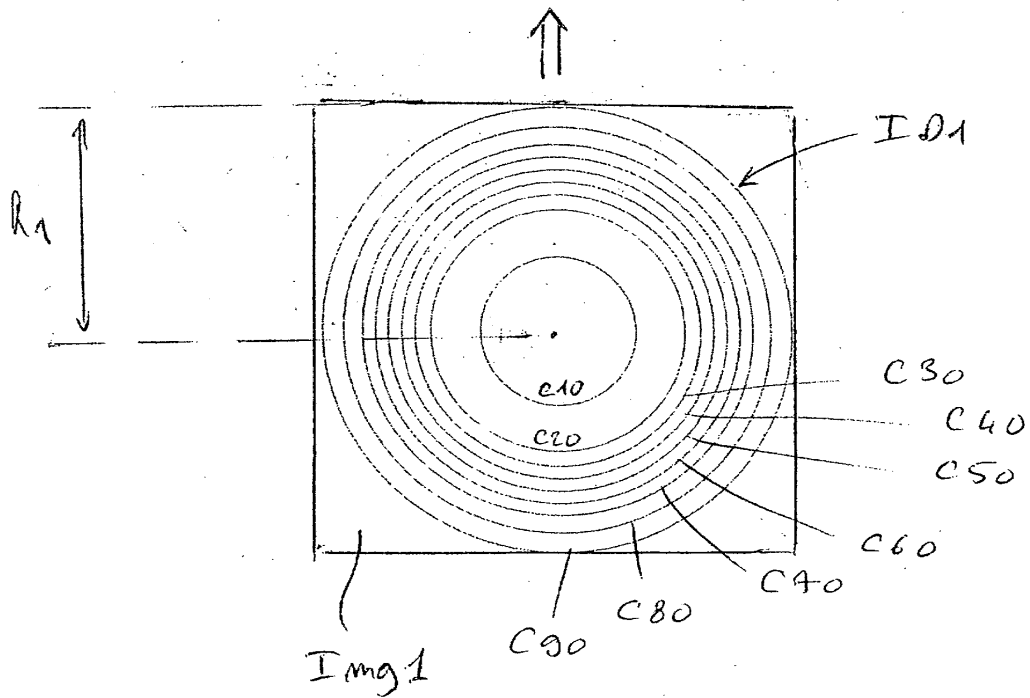
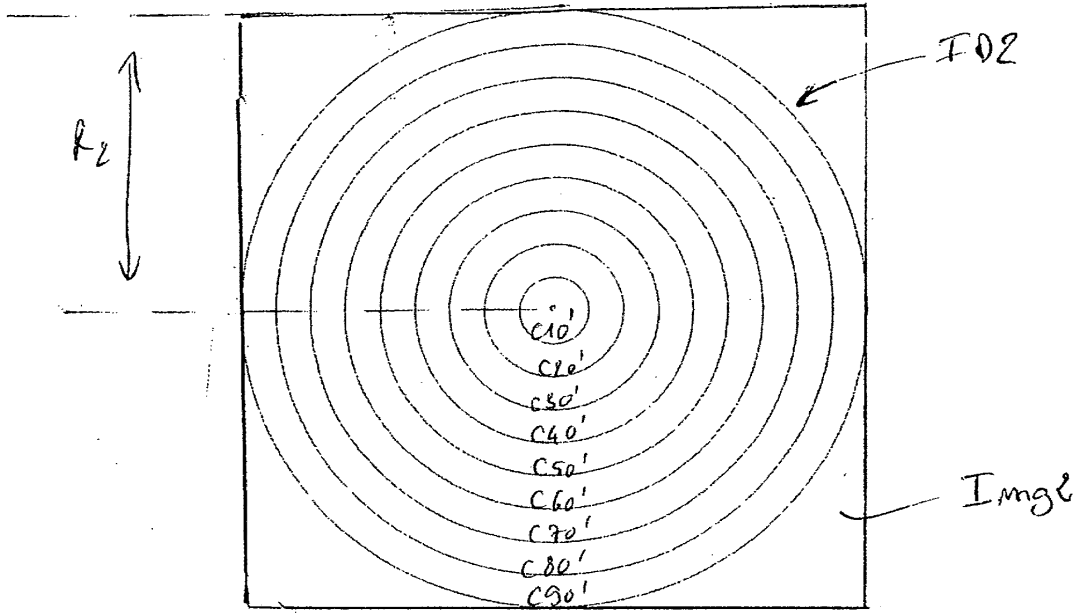
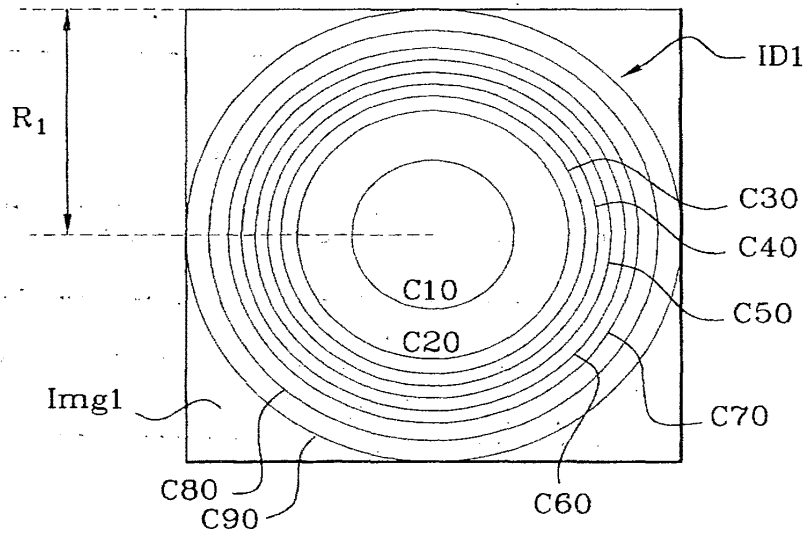
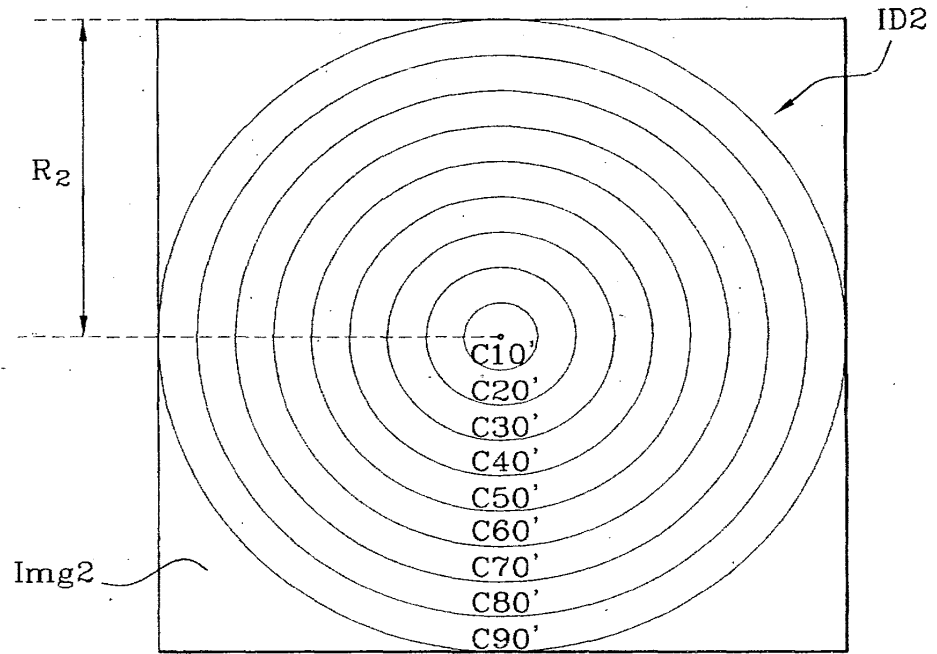
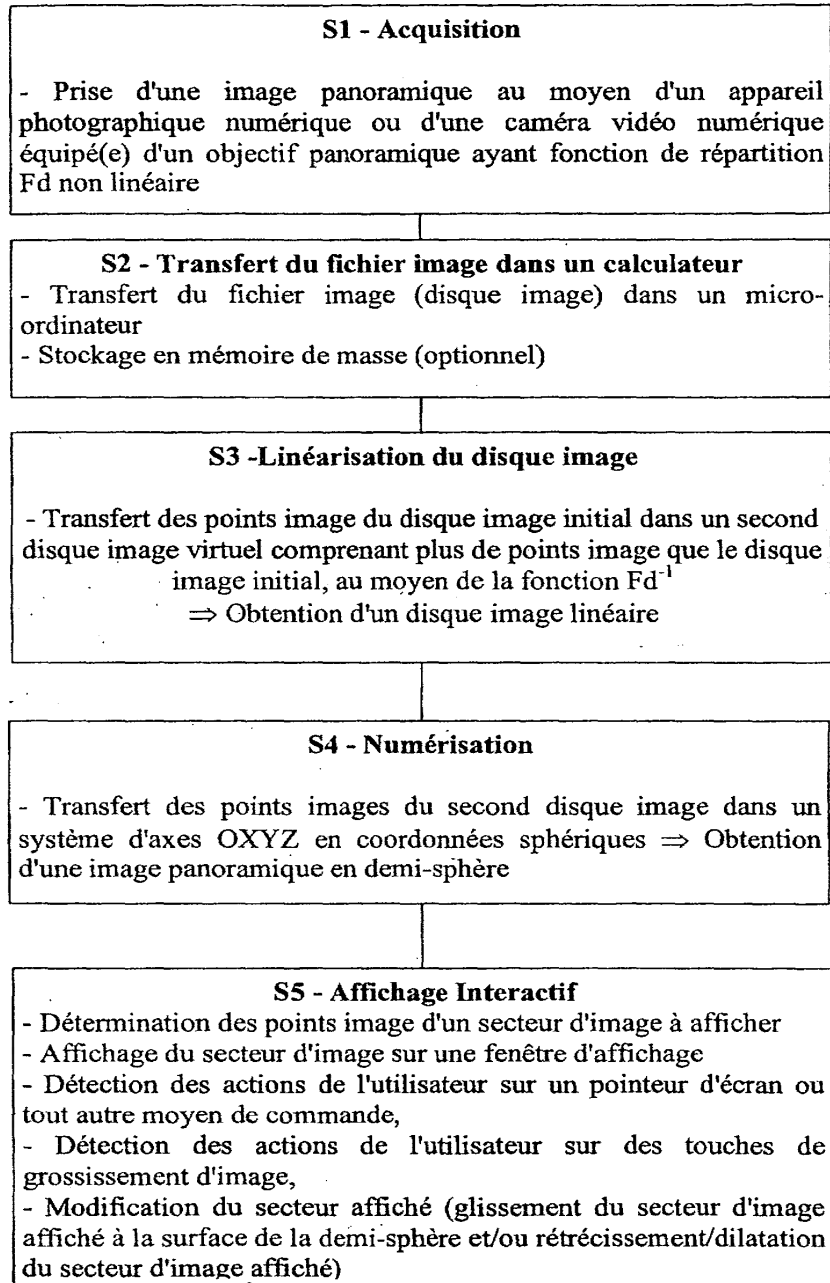


Fig. 11

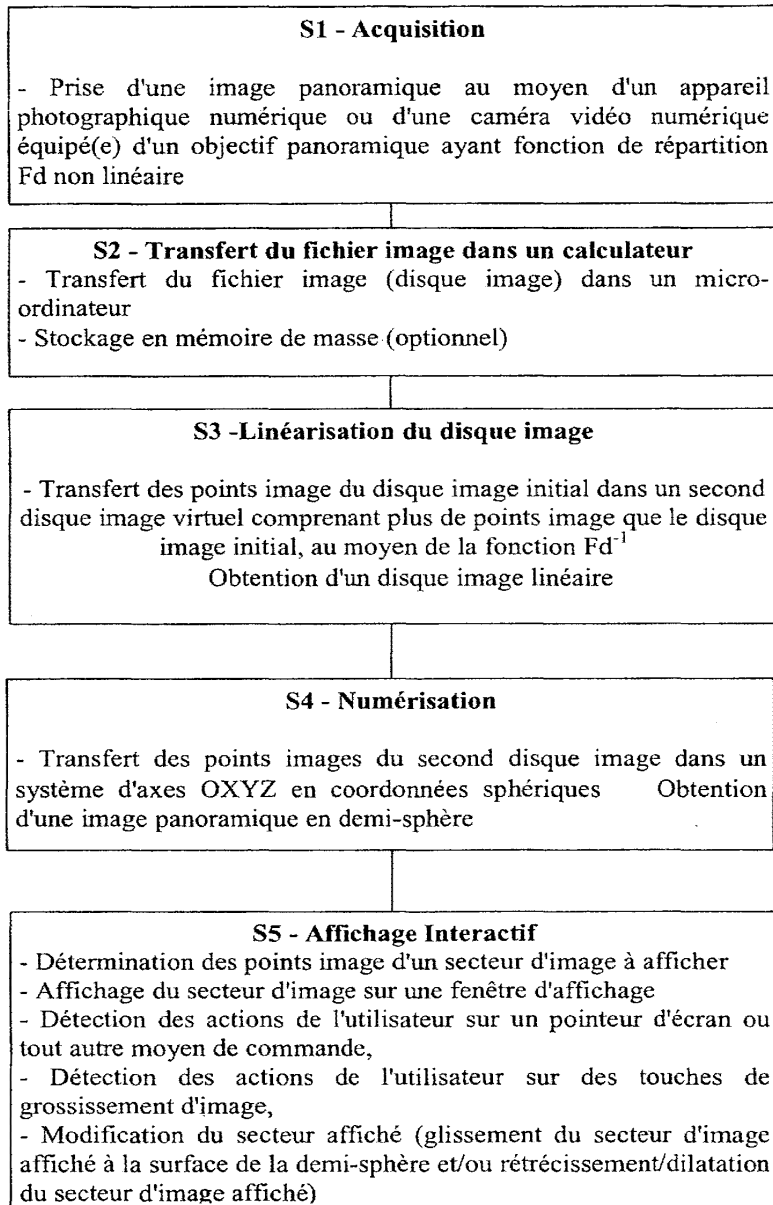
6/11

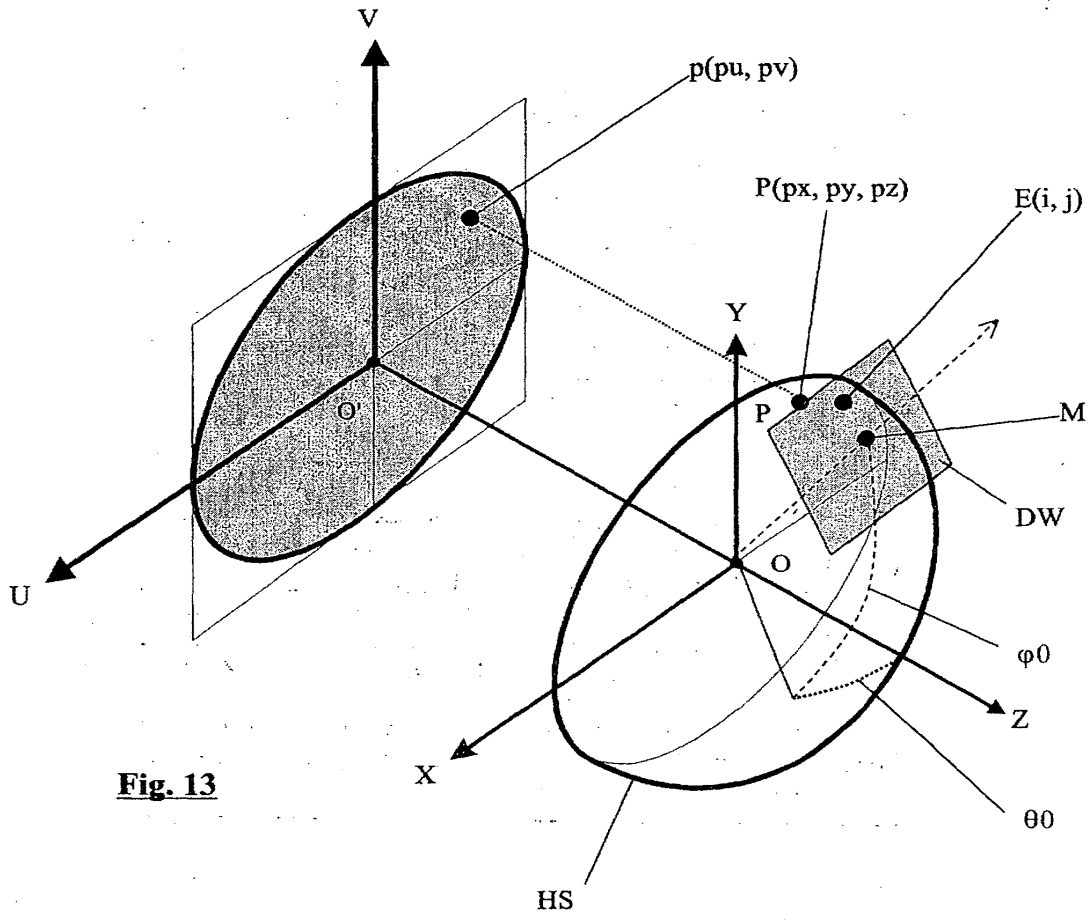


**Fig. 11**

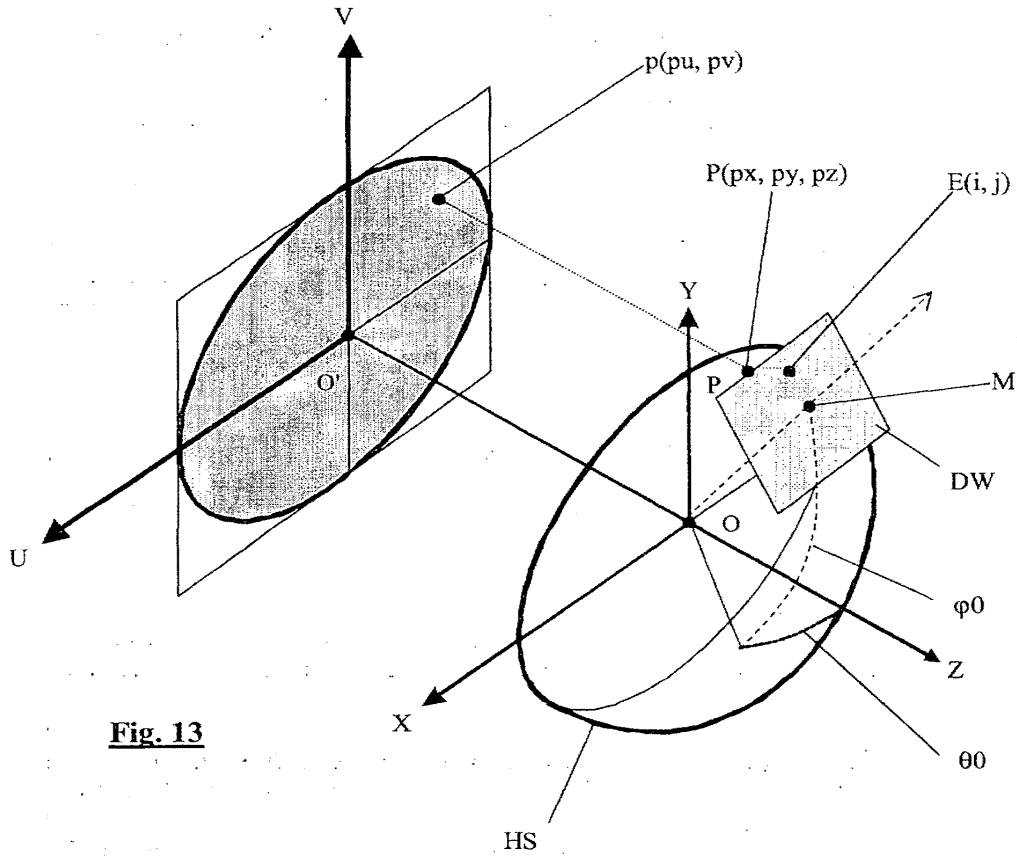
**Fig. 12**

**Fig. 12**

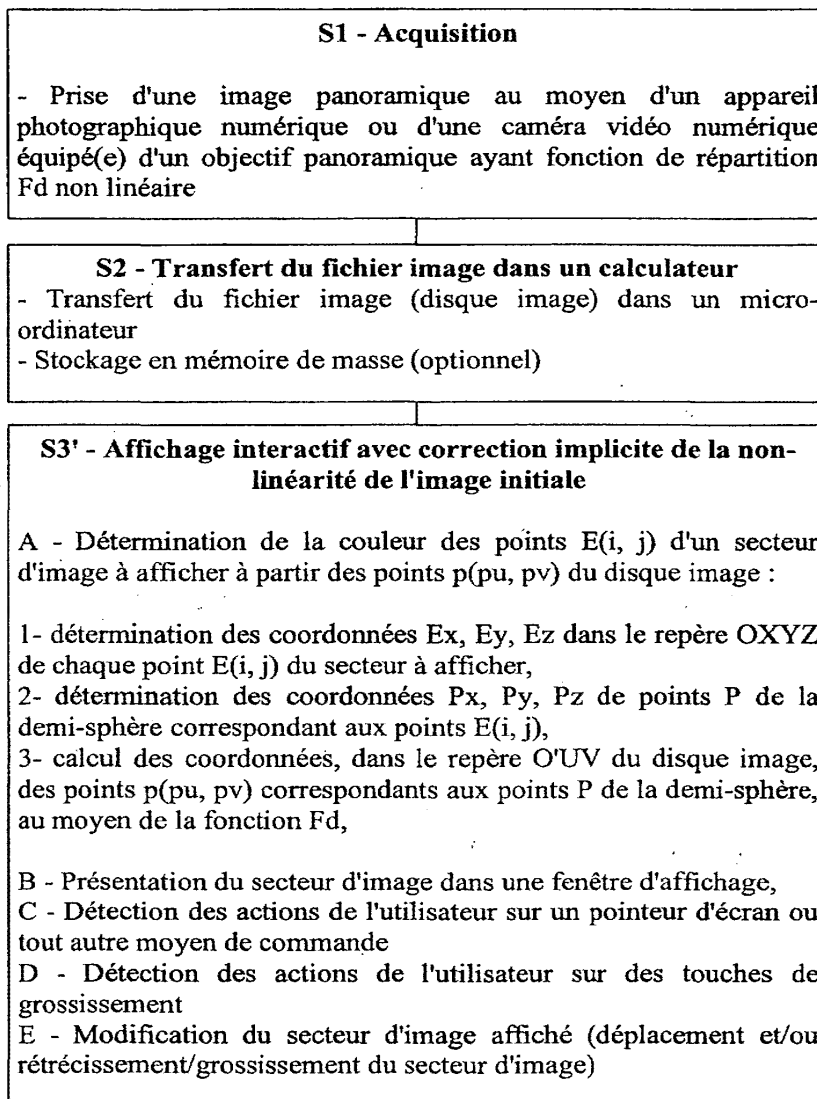




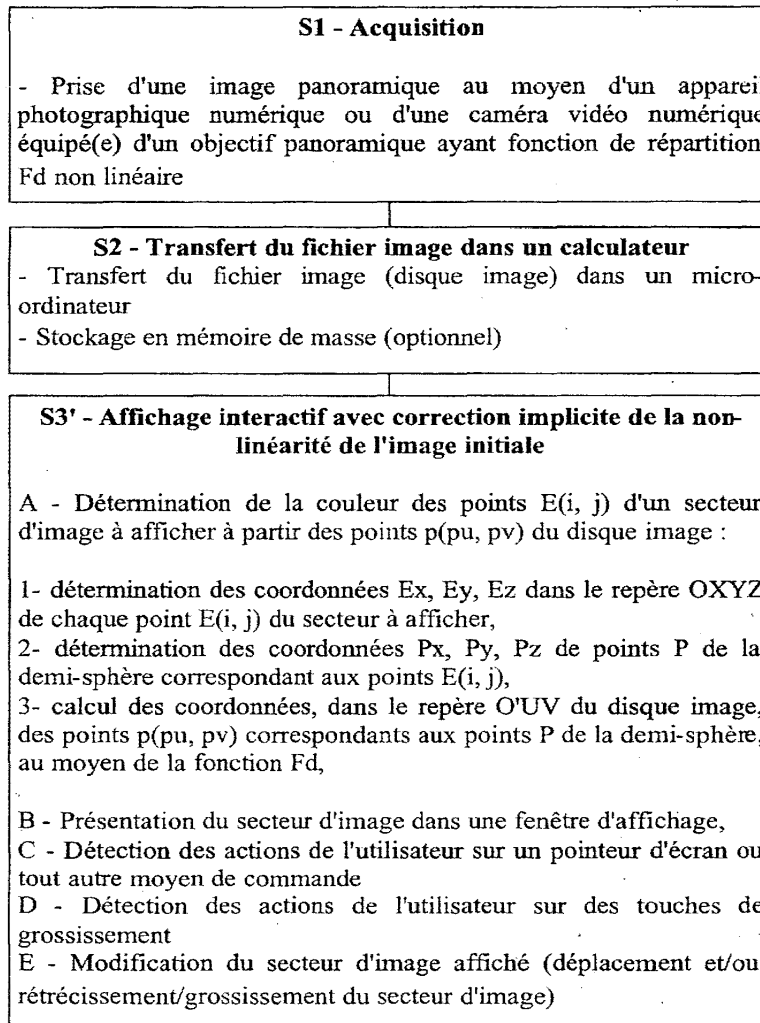
**Fig. 13**



**Fig. 13**

**Fig. 14**

**Fig. 14**





100111

100139 FR

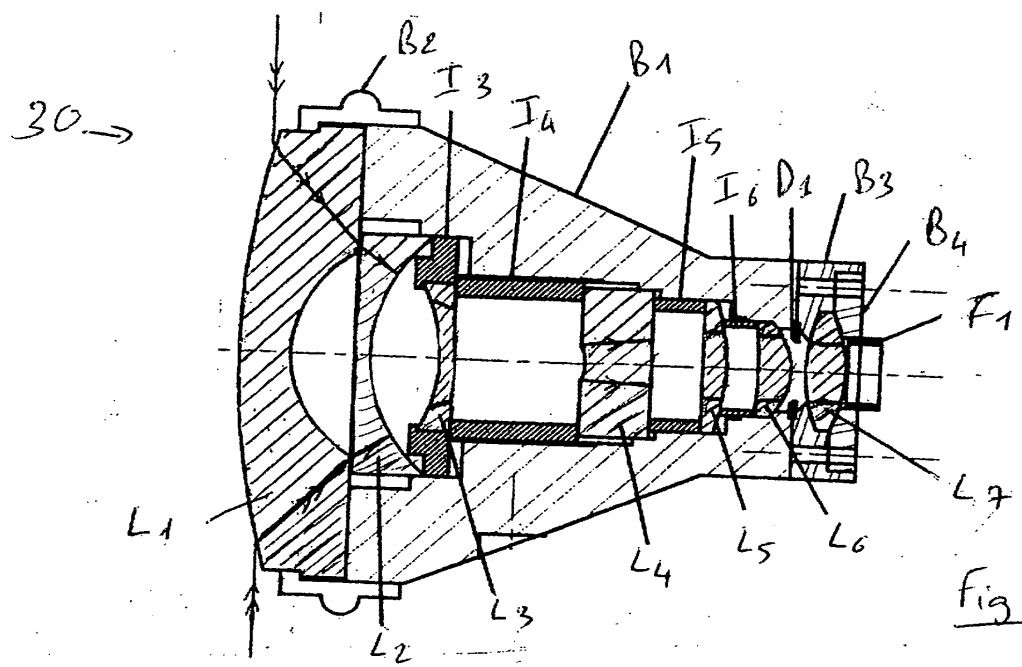


Fig. 15

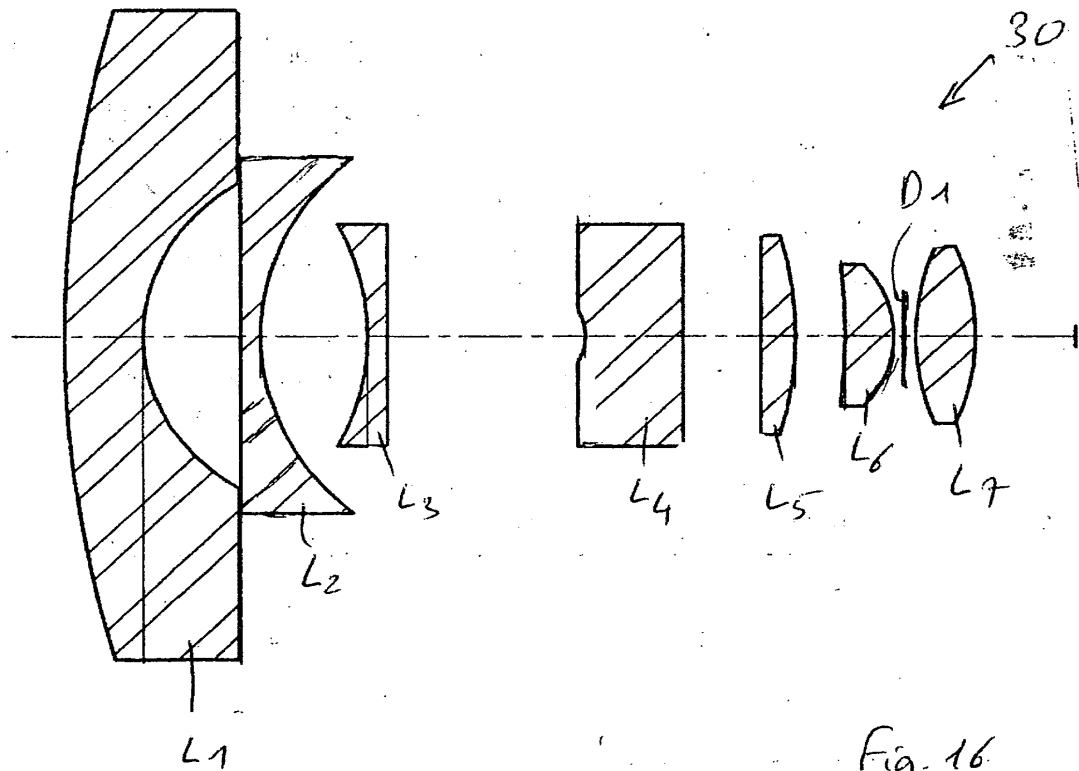


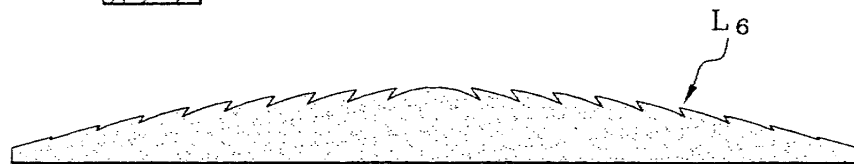
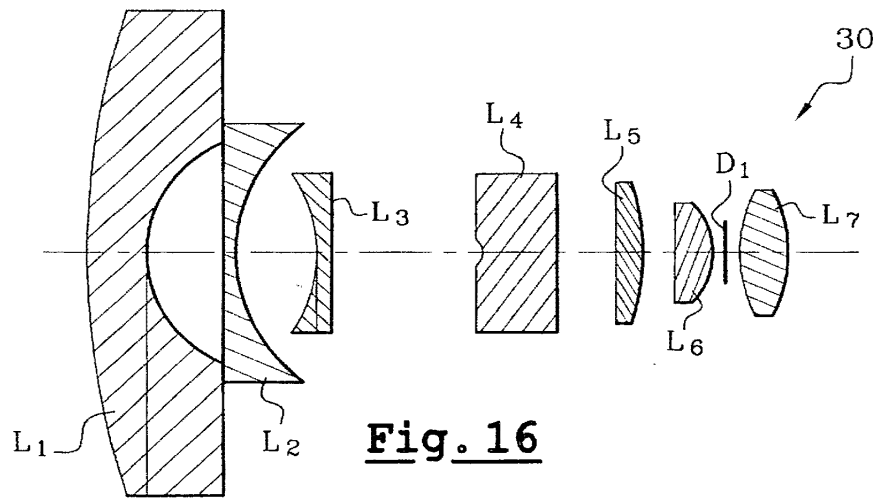
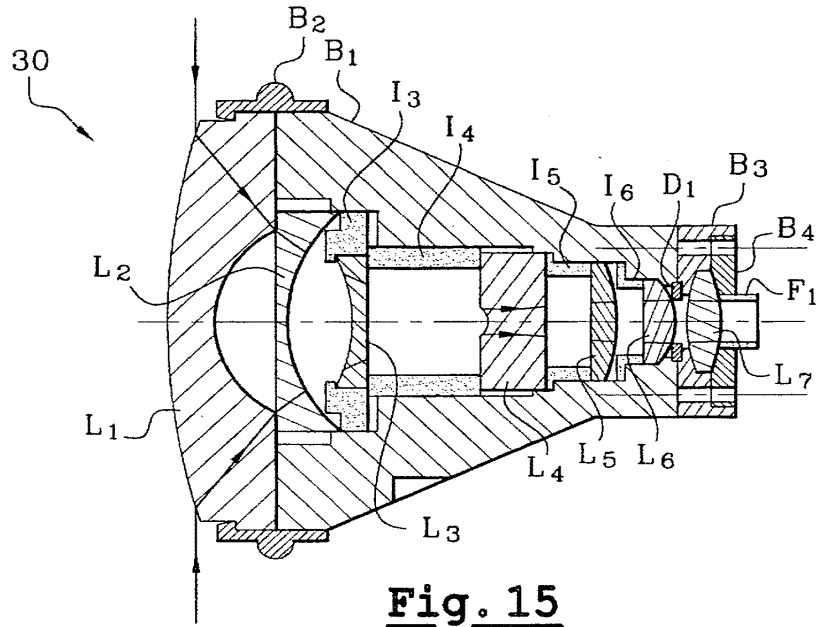
Fig. 16



Fig. 17



10/11



11117

100137 FR

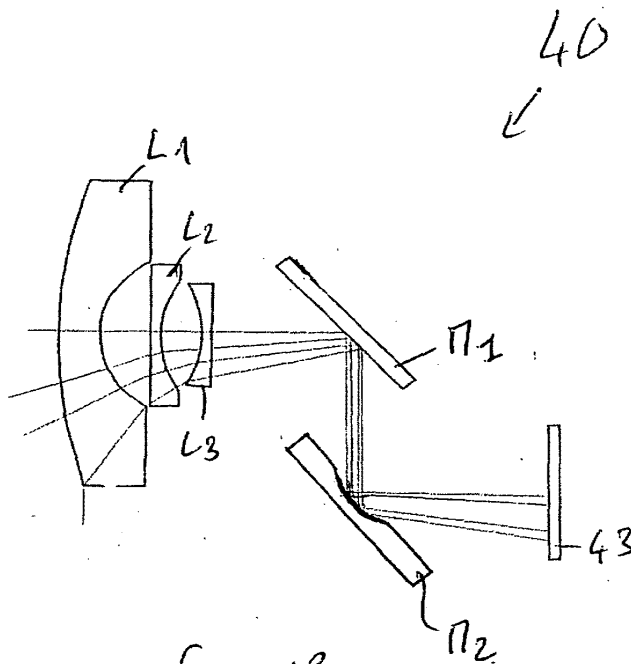
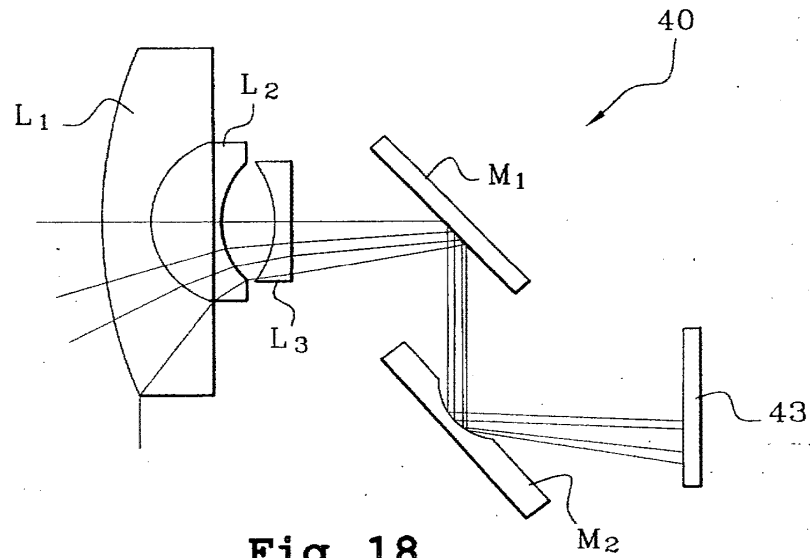


fig. 18



**Fig. 18**

reçue le 31/05/01



**BREVET D'INVENTION**  
**CERTIFICAT D'UTILITÉ**  
Code de la propriété intellectuelle - Livre VI



DÉPARTEMENT DES BREVETS

26 bis, rue de Saint Pétersbourg  
75800 Paris Cedex 08  
Téléphone : 01 53 04 53 04 Télécopie : 01 42 93 59 30

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**

Vos <del>services</del> <b>services</b> <b>MARSEILLE</b> (facultatif)		100137 FR	
N° D'ENREGISTREMENT <b>0408261</b>		<b>01 06261</b>	
<b>TITRE DE L'INVENTION (200 caractères ou espaces maximum)</b>  Procédé d'obtention et d'affichage d'une image panoramique numérique à résolution variable			
<b>LE(S) DEMANDEUR(S) :</b> MARCHAND André OMNIPAT 24, Place des Martyrs de la Résistance 13100 AIX EN PROVENCE			
<b>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).</b>			
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)			
<b>DATE ET SIGNATURE(S) DU (DES) DEMANDEUR(S) OU DU MANDATAIRE</b> (Nom et qualité du signataire) Aix en Provence, le 10 mai 2001 MARCHAND André - CPI N° 95 0303 OMNIPAT			

La loi n°78-17 du 6 janvier 1978 relative à l'informatique, aux fichiers et aux libertés s'applique aux réponses faites à ce formulaire. Elle garantit un droit d'accès et de rectification pour les données vous concernant auprès de l'INPI.

Inventor(s): Jean-Claude ARTONNE, et al.  
Title: Method for Capturing and Displaying a Variable Resolution Digital  
Panoramic Image Appln. No.: 10/706,513  
Atty. Docket No.: 10000-25US(100137/US/WO) Customer No.: 000570


**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 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**

 000570  
 AKIN GUMP STRAUSS HAUER & FELD L.L.P.  
 ONE COMMERCE SQUARE  
 2005 MARKET STREET, SUITE 2200  
 PHILADELPHIA, PA 19103-7013

**FORMALITIES LETTER**


\*OC000000011906029\*

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:**

 Total additional fee(s) required for this application is **\$130** for a Large Entity

- **\$130** Late oath or declaration Surcharge.

 Replies should be mailed to: Mail Stop Missing Parts  
 Commissioner for Patents  
 P.O. Box 1450  
 Alexandria VA 22313-1450

*A copy of this notice **MUST** be returned with the reply.*

*P. Phuong*

Customer Service Center

Initial Patent Examination Division (703) 308-1202

PART 3 - OFFICE COPY

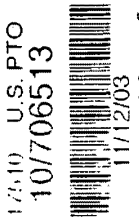


NON-PROVISIONAL  
UTILITY PATENT APPLICATION  
TRANSMITTAL - 37 CFR 1.53(b)

Duplicate  
(check, if applicable)

MAIL STOP PATENT APPLICATION  
Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

Attorney Docket No.: 10000-25US (100137/US/WO)  
First Named Inventor: Jean-Claude ARTONNE et al.  
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  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:

- Specification (including Abstract) and claims: 31 pages.
- 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
- 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.
- Information Disclosure Statement, PTO/SB/08A, and cited references.
- Request for Nonpublication of Application Under 35 U.S.C. §122(b)
- Other:

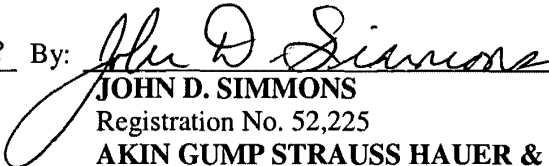
The filing fee is calculated as follows:

			SMALL ENTITY		LARGE ENTITY	
CLAIMS	NO. FILED	NO. EXTRA	BASIC FEE:		BASIC FEE:	
				\$385		\$770
Total	26-20 =	6	X9	\$	OR	X18 \$ 108.00
Independent	2- 3 =	0	X43	\$	OR	X86 \$
<input type="checkbox"/> Multiple Dependent Claims Present			\$145	\$	OR	\$290 \$
			<b>TOTAL</b>	<b>\$</b>	<b>OR</b>	<b>TOTAL \$ 878.00</b>

- The Commissioner is not authorized to charge the filing fee at this time as we elect to defer payment of the entire filing fee until receipt of a Notice to File Missing Parts
- A check in the amount of \$878.00 to cover the filing is enclosed.
- The Commissioner is hereby authorized to charge and/or credit **Deposit Account No. 50-1017 (Billing No. 210000.0025)** as noted below. A duplicate copy of this sheet is enclosed.
  - Any overpayments or deficiencies in the above-calculated fee.
  - Filing fee in the amount of \$\_\_\_\_\_ as calculated above.
  - Any additional fees required under 37 C.F.R. § 1.16 and § 1.17.
  - In the event that a Petition for Extension of Time is required during the prosecution of this application, but not submitted, please charge any extension fee under 37 C.F.R. § 1.136(a) to our Deposit Account noted above.

**CORRESPONDENCE ADDRESS**

November 11, 2003  
(Date)

By: 

**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

Telephone: 215-965-1200

**Direct Dial: 215-965-1268**

Facsimile: 215-965-1210

E-Mail: jsimmons@akingump.com

Customer Number or Bar Code Label: **000570**

JDS:sm

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,  
5 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  
10 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  
15 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  
20 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  
25 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  
30 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( $\varphi, \theta$ ),  $\varphi$  being the latitude and  $\theta$  the longitude of an image point. The angles  $\varphi$  and  $\theta$  are coded in 4 to 8 bytes (IEEE standard). These image points form a hemisphere 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 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 10°, 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  $\alpha$  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:

$$dr = Fdc(\alpha) = K \alpha$$

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

[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

7078397 v1

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  
5 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  
10 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,  
15 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  
20 (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  
25 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  
30 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  
5 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  $\pm 10\%$  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  
10 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  
15 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  
20 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  
25 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-  
30 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.

5 [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.

10 [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.

15 [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  
20 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  
25 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  
30 points of the panorama, the distribution function having a maximum divergence of at least  $\pm 10\%$  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.

5 [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  
10 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  
15 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.

20 [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  
25 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  
30 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;
- 5 [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  
10 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;
- 15 [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  
20 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;
- 25 [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  
30 [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  $d_1$ ,  $d_2$ ,  $-d_2$ ,  $-d_1$ . 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  $d_1$  and  $d_2$  are linked by the following relation:

$$d_1/\alpha_1 = d_2/\alpha_2$$

As the angle  $\alpha_1$  is here equal to  $2\alpha_2$ , it follows that:

$$d_1 = 2d_2$$

**[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  $d_1'$ ,  $d_2'$ ,  $-d_2'$ ,  $-d_1'$ .

**[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  $d_1'$ ,  $d_2'$ ,  $-d_2'$ ,  $-d_1'$  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  $d_2'$  is clearly greater than  $d_1'/2$ , such that the central part of the panoramic image projected onto the image

sensor 17, which corresponds to a solid angle  $2\alpha_2$  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  $10^\circ$ , the circle C20 is formed by image points corresponding to object points having a field angle of  $20^\circ$ , 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  $F_{dc} = K\alpha$  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  $180^\circ$ , i.e., a gradient of 0.111 per degree). The field angle  $\alpha$  of the object points is represented on the X-axis and is between  $0$  and  $90^\circ$ . 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  $1$ .

5 The curve of the function  $Fd1$  has a higher gradient than the straight line  $Fdc$  for angles  $\alpha$  of between  $0$  and  $20^\circ$ , then a lesser gradient after  $20^\circ$  and up to  $90^\circ$ . 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  $\alpha = 20^\circ$ . "Point of maximum divergence" refers to the image point  $Pd(\alpha)$  at which the  
10 greatest gap in relative distance  $dr$  in relation to a corresponding point  $Pdl(\alpha)$  on the linear distribution straight line  $K\alpha$  can be observed. In this example, the point  $Pd(\alpha=20^\circ)$  has a relative distance  $dr$  equal to  $0.5$  relative to the center of the image while the corresponding point  $Pdl(\alpha=20^\circ)$  on the linear curve  $Fdc$  has a relative distance  $dr$  of  $0.222$ . The maximum divergence  $DIV_{max}$  of the distribution function  $Fd1$  according to the present invention can be calculated by a formula of  
15 the type:

$$DIV_{max}\% = \frac{[dr(Pd) - dr(Pdl)]}{[dr(Pdl)]} * 100$$

i.e.:

$$DIV_{max}\% = \frac{[dr(Pd) - K * \alpha(Pd)]}{[K * \alpha(Pd)]} * 100$$

In which  $dr(Pd)$  is the relative distance in relation to the center of the point of maximum divergence  
20  $Pd$ ,  $dr(Pdl)$  is the relative distance in relation to the center of the corresponding point on the linear distribution straight line  $Fdc$ ,  $\alpha(Pd)$  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  
25 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.

30 [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 Pd1, Pd2 of the same abscissa belonging to the linear distribution function Fdc. The rate TX can be determined by a formula of the type:

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

i.e.:

5 
$$TX = [dr(Pd1)^2 - dr(Pd2)^2] / [K^2[(\alpha(Pd1))^2 - (\alpha(Pd2))^2]]$$

[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  $\alpha=70^\circ$ , 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 ( $\alpha=30^\circ$ ,  $dr=0,1$ ) and a second point of maximum divergence Pd2 ( $\alpha=70^\circ$ ,  $dr=0,9$ ). 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-  
5 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  
10 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  
15 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  
20 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  
25 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  
30 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  $F_d$  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

5 [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  $Img_1$  comprising a non-linear image disk  $ID_1$  of radius  $R_1$ , having for example an expansion zone in the center (circles  $C_{10}$  and  $C_{20}$ ). The initial image  $Img_1$  is transformed into a corrected image  $Img_2$  comprising a linear image disk  $ID_2$  of radius  $R_2$ . The radius  $R_2$  of the image disk  $ID_2$  is higher than the radius  $R_1$  of the initial image disk  
10  $ID_1$  and the image disk  $ID_2$  has a resolution equal or substantially equal to the resolution offered by the zone of the image disk  $Img_1$  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  $C_{20}$ .

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

15 initially, the size  $R_2$  of the linearized image disk  $ID_2$  is calculated by means of the reciprocal function  $F_d^{-1}$ , considering on the initial image disk  $ID_1$  the place in which the image is the most expanded, so that the corrected image  $Img_2$  has a resolution equal or substantially equal to the resolution offered by the zone of the image  $Img_1$  in which the greatest density of information is to be found,  
20 then each pixel of the image to be calculated  $Img_2$  is scanned, and the position of its twin point on the image  $Img_1$  is searched for, and then  
the color of the corresponding point on the initial image  $Img_1$  is allocated to the point of the new image  $Img_2$ .

[0088] This method is implemented by means of an algorithm described below (algorithm 1), in  
25 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  $ID_1$ ,

$R_1$  is the size in pixels of the radius of the initial image disk  $ID_1$  (i.e. the number of pixels between the center and the edge of the image disk),

30  $R_2$  is the size in pixels of the radius of the linearized image disk  $ID_2$ ,

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,

5 "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

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

#### Algorithm 1

[finding DAM]

1/ DAM = A/2

15 2/ Current\_angle = 0

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

4/ Previous\_angle = Current\_angle

5/ Current\_angle =  $F_{dlin}^{-1}(D/R1)$

6/ If DAM > (Current\_angle - Previous\_angle) then

20 7/ DAM = (Current\_angle - Previous\_angle)

8/ End if

9/ End for

[determining the radius R2 of the disk ID2]

10/  $R2 = (A/2)/DAM$

25 [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', $\theta$ ) of the twin point on the image Img1 using the coordinates

30 (R, $\theta$ ) of the point of the image Img2]

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

7078397 v1

```

14/          If R < R2 then
15/              If J < 0 then
16/                   $\theta = \text{arc cosine}(I/R)$ 
17/                  If not
5 18/                       $\theta = -\text{arc cosine}(I/R)$ 
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:
10 20'          /R'= R1*Fd((R/R2) * (A/2))
[return to the Cartesian coordinates]
21/          U = R'*cos( $\theta$ )
22/          V = R'*sin( $\theta$ )
[allocation of the color of the point]
15 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
20 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  $180^\circ$  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  $\alpha$  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  $\alpha$  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  $p(p_u, p_v)$  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  $p(p_u, p_v)$  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  $F_d$ .

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

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

$I_{max}$  and  $J_{max}$  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,

$E_x, E_y$  and  $E_z$  are the Cartesian coordinates of a point  $E(i, j)$  of the display window DW  
10 in the coordinate system OXYZ,

$P_x, P_y$  and  $P_z$  are the Cartesian coordinates of a point P on the hemisphere HS,

$p_u$  and  $p_v$  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,

15 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),

$\theta_0$  and  $\phi_0$  are the longitudes and latitudes corresponding to the viewing direction from  
20 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  
25 accuracy of the calculations, R is for example chosen to be equal to 10,000),

$\alpha$  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

30 " $\sqrt{\quad}$ " is the square root function.

#### Algorithm 2

1/ For  $i=-I_{max}/2$  to  $i=I_{max}/2$  do [by increments of 1]

```

2/   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]
3/       Ey = j*cos(φ0) – Zoom*sin(φ0)
5 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)
    [calculation of the coordinates of the point P corresponding to the point E]
10 8/       aux2 = R/√(Ex*Ex + Ey*Ey + Ez*Ez)
9/       Px = Ex*aux2
10/      Py = Ey*aux2
11/      Pz = Ez*aux2
    [calculation of the coordinates of the point p corresponding to the point P, in the coordinate system
15 (O'UV), by means of the function Fd]
12/      X = Px/R
13/      Y = Py/R
14/      r = √(X*X + Y*Y)
15/      α = arcsine(r)
20 16/      U = X/r
17/      V = Y/r
18/      pu = L*U*Fd(α)
19/      pv = L*V*Fd(α)
20/      Screen_Pixel[i,j] = Image_Pixel[pu,pv]
25 21/   end for
    22/   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.

5 [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.

10 [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  $\alpha$  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.

15 [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,

25 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/  $pu = L*U*Fd(\alpha)$   
19/  $p_v = L*V*Fd(\alpha)$   
20/ If  $P_z \geq 0$  then  
30 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

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  
5 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  $F_d$  to find the points corresponding to the pixels of the display window on the image disk.

10 [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  $F_d$ , 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  
15 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  
20 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  
25 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  
30 objective lens 30 according to the present invention. The distribution function  $F_d$  obtained by means of the objective lens 30 is the function  $F_{d1}$  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.

5 [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.  
10 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.

15 [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  
20 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  $F_d$ , which is obtained here  
25 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  
30 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:

5 "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

10 "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:

$$\varphi(r) = \alpha_1 (r/R0)^2 + \alpha_2 (r/R0)^4$$

15 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

20 " $\varphi$ " 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 25 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 30 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  
5 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  $F_d$  sought for the intended application (distortion in the center, on the edges...). The result obtained is equivalent to that of the optical system described  
10 above. Obtaining the distribution function  $F_d$  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,  
15 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  
20 can be driven by an integrated circuit comprising several configurations of the micro-pistons in its memory, to obtain a distribution function  $F_d$  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  
25 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  
30 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  
5 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**

<p><b>S1 - Acquisition</b></p> <ul style="list-style-type: none"> <li>- 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 <math>F_d</math></li> </ul>
<p><b>S2 – Transfer of the image file into a computer</b></p> <ul style="list-style-type: none"> <li>- Transfer of the image file (image disk) into a microcomputer</li> <li>- Storage in the auxiliary storage (optional)</li> </ul>
<p><b>S3 -Linearisation of the image disk</b></p> <ul style="list-style-type: none"> <li>- 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 <math>F_d^{-1}</math></li> <li>⇒ Obtaining a linear image disk</li> </ul>
<p><b>S4 - Digitization</b></p> <ul style="list-style-type: none"> <li>- 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</li> </ul>
<p><b>S5 – Interactive display</b></p> <ul style="list-style-type: none"> <li>- Determination of the image points of an image sector to be displayed</li> <li>- Display of the image sector on a display window</li> <li>- Detection of the user's actions on a screen pointer or any other control means,</li> <li>- Detection of the user's actions on keys for image enlargement,</li> <li>- Modification of the sector displayed (sliding the image sector displayed on the surface of the hemisphere and/or shrinking/expanding the image sector displayed)</li> </ul>

**Table 2**

<p style="text-align: center;">S1 – Acquisition</p> <p>- 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 <math>F_d</math></p>
<p style="text-align: center;">S2 – Transfer of the image file into a computer</p> <p>- Transfer of the image file (image disk) into a microcomputer - Storage in the auxiliary storage (optional)</p>
<p>S3' – Interactive display with implicit correction of the non-linearity of the initial image</p> <p>A - Determination of the color of the points <math>E(i, j)</math> of an image sector to be displayed using the points <math>p(p_u, p_v)</math> of the image disk:</p> <p>1 - determination of the coordinates <math>E_x, E_y, E_z</math> in the coordinate system <math>OXYZ</math> of each point <math>E(i, j)</math> of the sector to be displayed,</p> <p>2 - determination of the coordinates <math>P_x, P_y, P_z</math> of points <math>P</math> of the hemisphere corresponding to the points <math>E(i, j)</math>,</p> <p>3 – calculation of the coordinates, in the coordinate system <math>O'UV</math> of the image disk, of points <math>p(p_u, p_v)</math> corresponding to the points <math>P</math> of the hemisphere, by means of the function <math>F_d</math>,</p> <p>B - Presentation of the image sector in a display window,</p> <p>C - Detection of the user's actions on a screen pointer or any other control means,</p> <p>D - Detection of the user's actions on enlargement keys,</p> <p>E - Modification of the image sector displayed (moving and/or shrinking/expanding the image sector)</p>

## 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  $\pm 10\%$  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:  
5 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.  
10

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  
15 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  
20

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,  
25 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.  
30

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  $\pm 10\%$  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.

5           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.

10           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           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.

15           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.

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

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

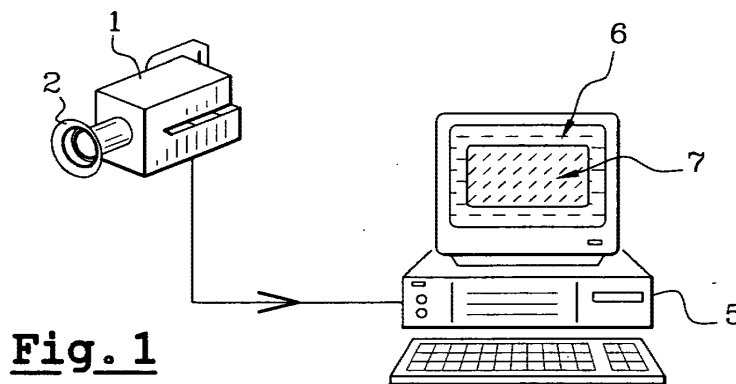
25           26. The panoramic objective lens according to claim 17, comprising a set of mirrors comprising at least one distorting mirror.

### ABSTRACT OF THE DISCLOSURE

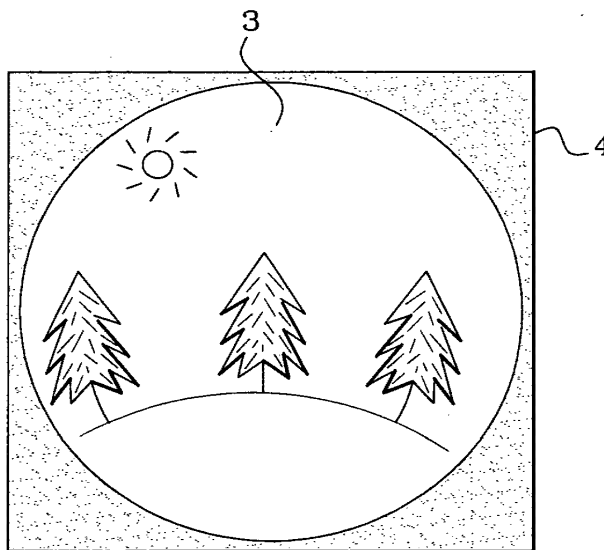
A method for capturing a digital panoramic image includes projecting a panorama onto an image sensor by means of a panoramic objective lens. The panoramic objective lens has a distribution function of the image points that is not linear relative to the field angle of the object points of the panorama, 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.

5

10

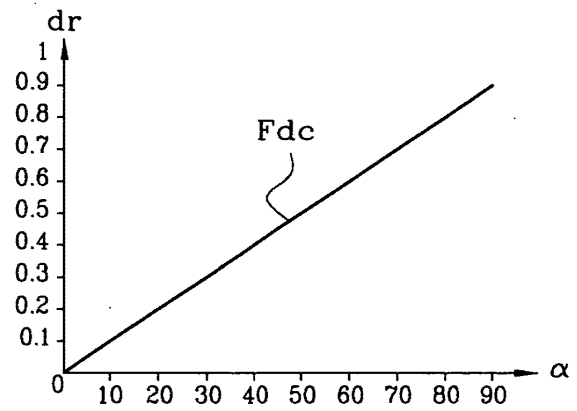
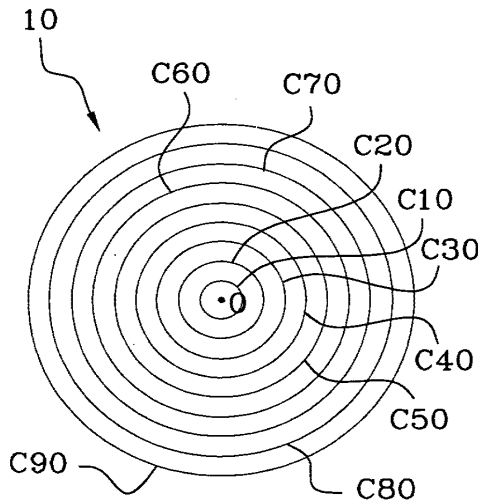
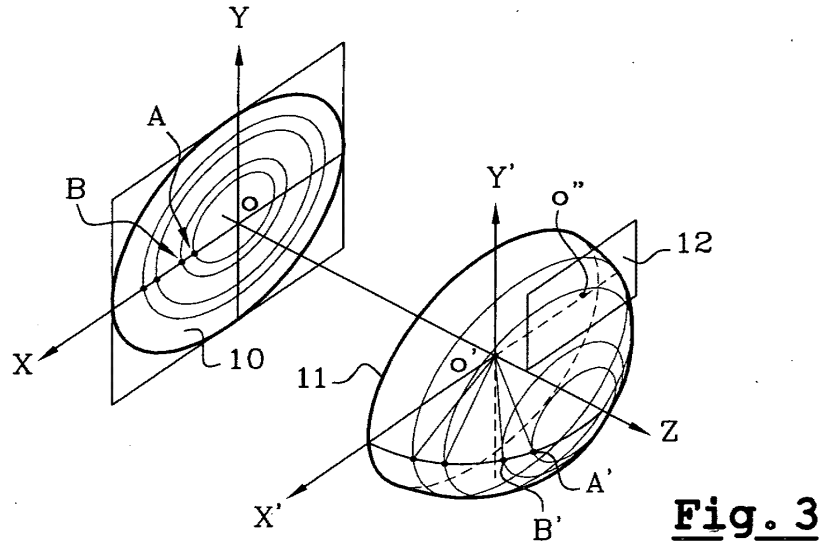


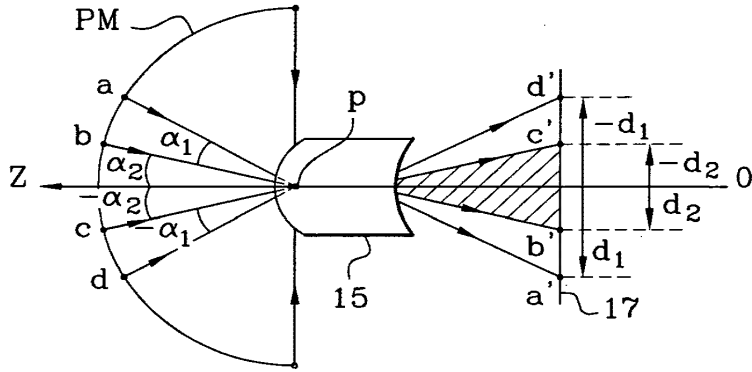
**Fig. 1**



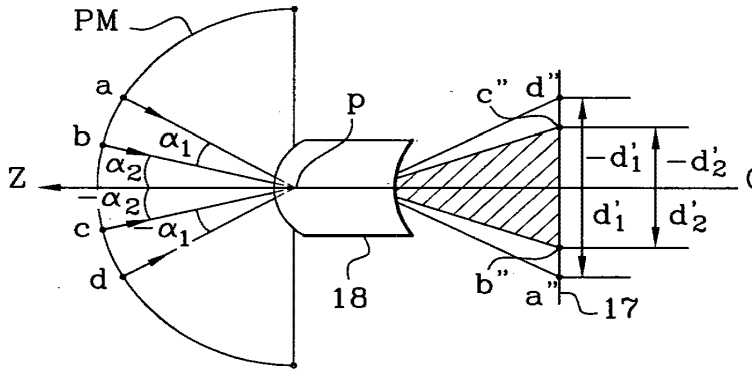
**Fig. 2**

2/11

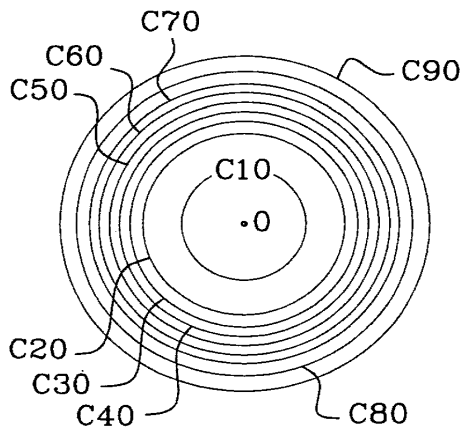




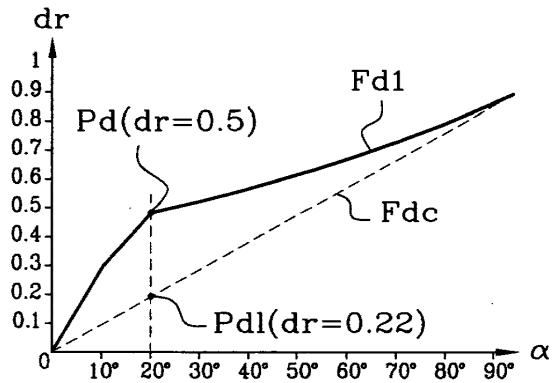
**Fig. 5**



**Fig. 6**

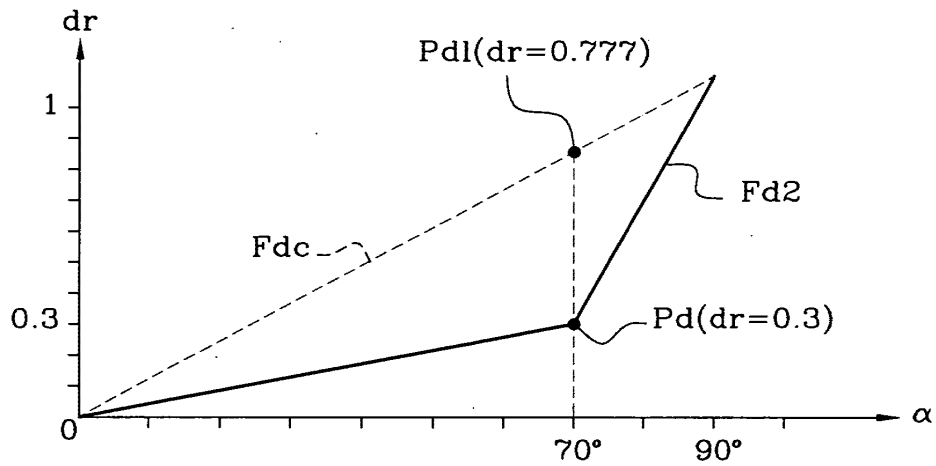


**Fig. 7A**

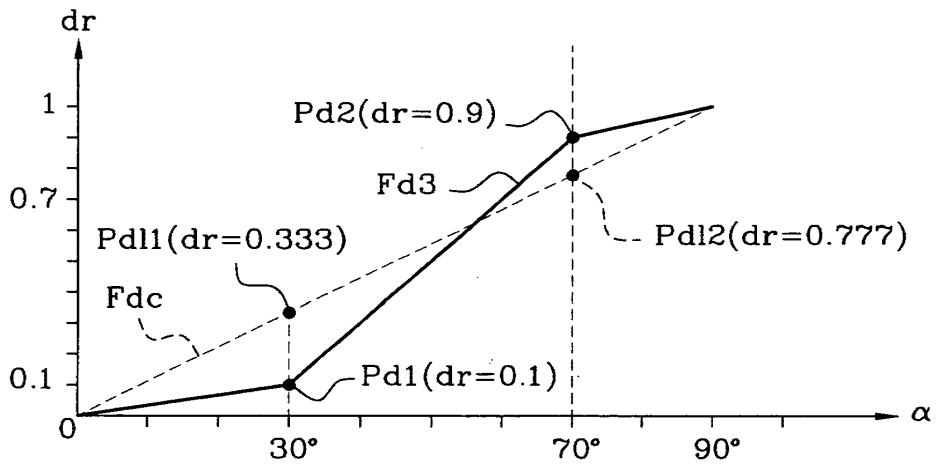


**Fig. 7B**

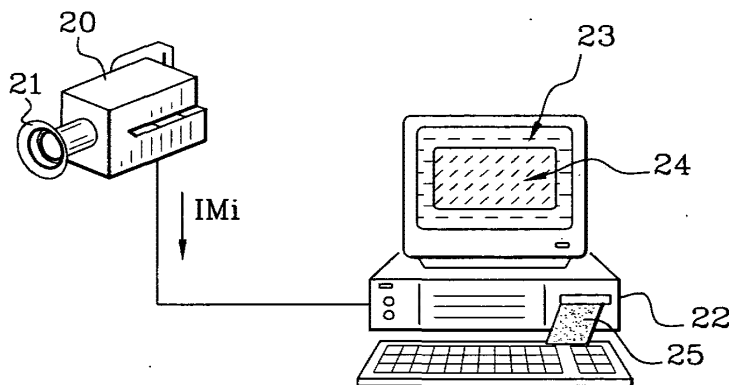
4 / 11



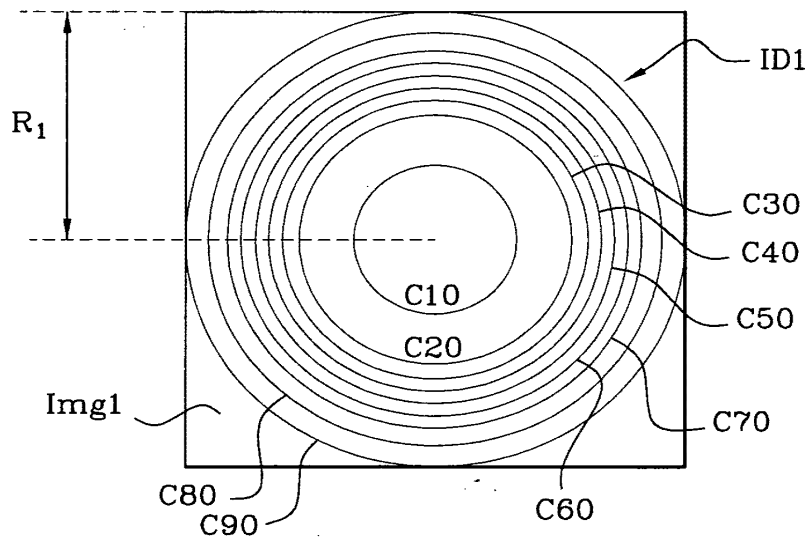
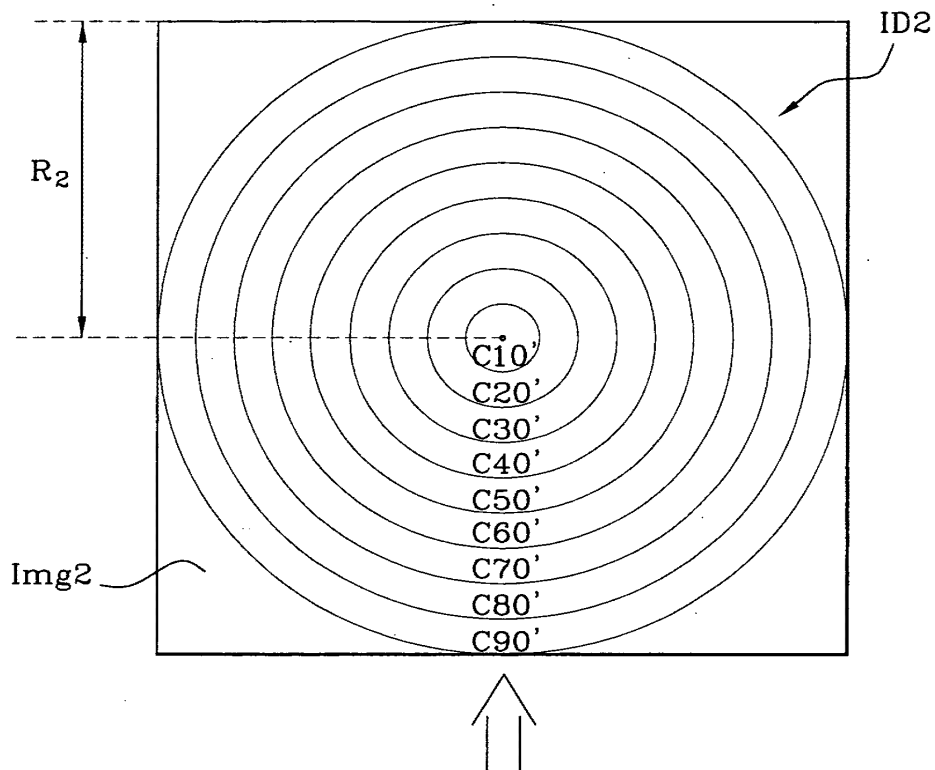
**Fig. 8**



**Fig. 9**



**Fig. 10**

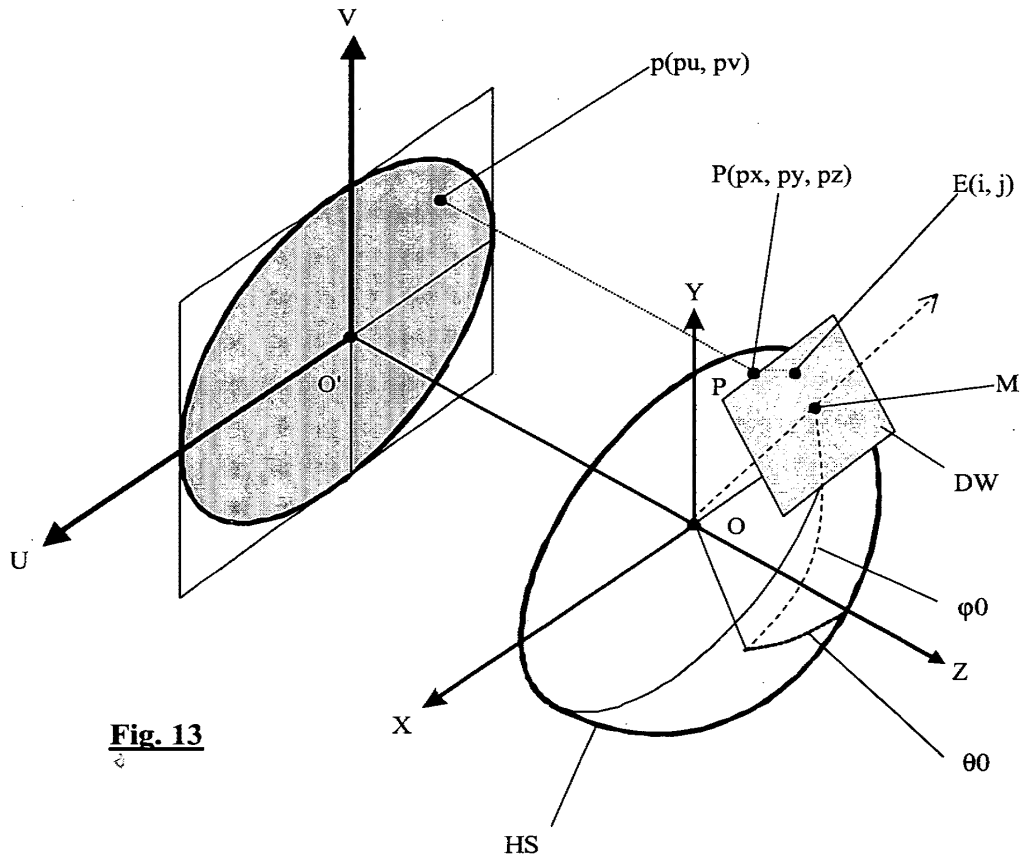


**Fig. 11**



**Fig. 12**

<p style="text-align: center;"><b>S1 – Acquisition</b></p> <p>- 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 <math>F_d</math></p>
<p style="text-align: center;"><b>S2 – Transfer of the image file into a computer</b></p> <p>- Transfer of the image file (image disk) into a microcomputer - Storage in the auxiliary storage (optional)</p>
<p style="text-align: center;"><b>S3 -Linearisation of the image disk</b></p> <p>- 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 <math>F_d</math> Obtaining a linear image disk</p>
<p style="text-align: center;"><b>S4 – Digitisation</b></p> <p>- 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</p>
<p style="text-align: center;"><b>S5 – Interactive display</b></p> <p>- 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)</p>

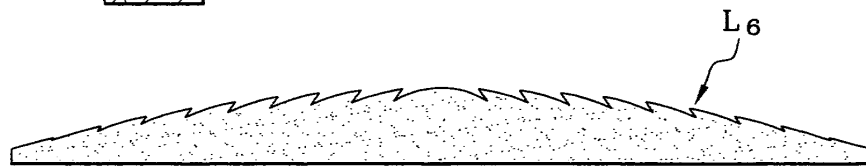
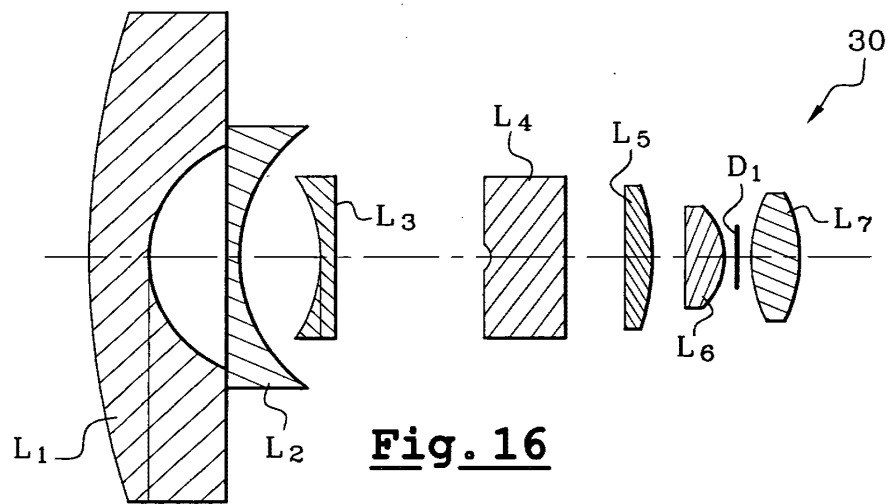
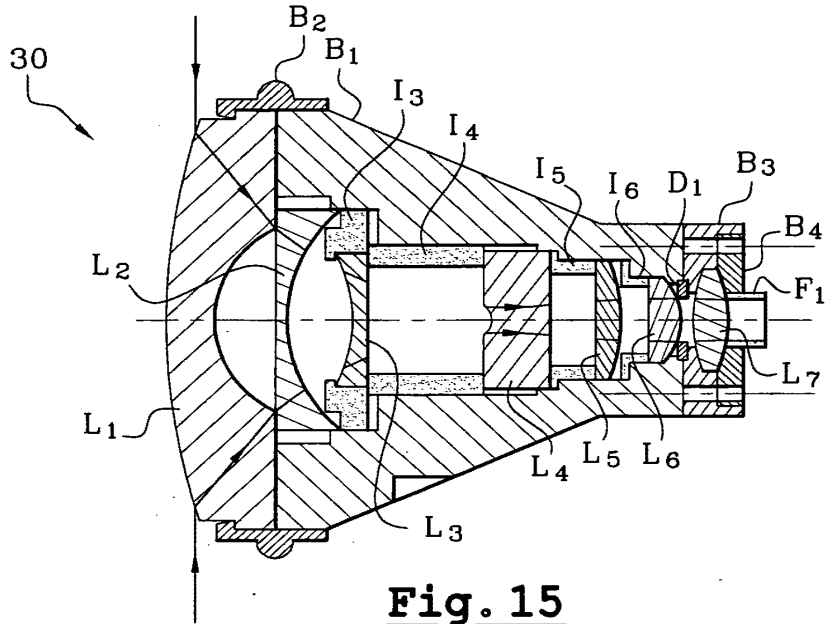


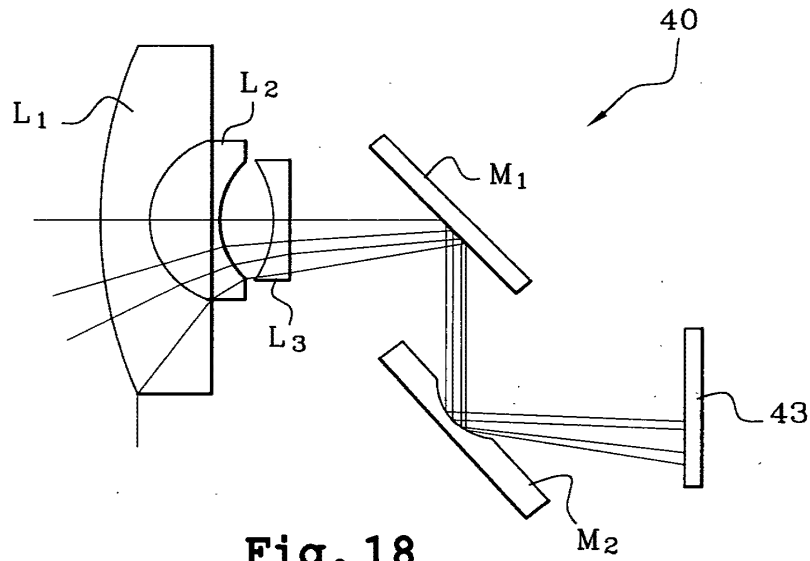
**Fig. 13**

**Fig. 14**

<p style="text-align: center;"><b>S1 – Acquisition</b></p> <p>- 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 <math>F_d</math></p>
<p style="text-align: center;"><b>S2 – Transfer of the image file into a computer</b></p> <p>- Transfer of the image file (image disk) into a microcomputer - Storage in the auxiliary storage (optional)</p>
<p style="text-align: center;"><b>S3' – Interactive display with implicit correction of the non-linearity of the initial image</b></p> <p>A - Determination of the colour of the points <math>E(i, j)</math> of an image sector to be displayed using the points <math>p(p_u, p_v)</math> of the image disk:</p> <p>1- determination of the coordinates <math>E_x, E_y, E_z</math> in the coordinate system OXYZ of each point <math>E(i, j)</math> of the sector to be displayed, 2- determination of the coordinates <math>P_x, P_y, P_z</math> of points P of the hemisphere corresponding to the points <math>E(i, j)</math>, 3- calculation of the coordinates, in the coordinate system O'UV of the image disk, of the points <math>p(p_u, p_v)</math> corresponding to the points P of the hemisphere, by means of the function <math>F_d</math>,</p> <p>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)</p>

10/11





**Fig. 18**

Express Mail Label No.: EV312205282US

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

First Named Inventor:	Jean-Claude	§	
	ARTONNE, et al.	§	
		§	
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.

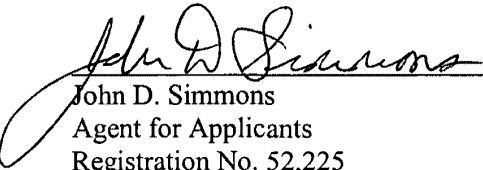
No fee is believed to be due in connection with the filing of this Information Disclosure Statement since it is being filed within three months of the filing date of the above-identified application. However, the Commissioner is hereby authorized to charge any deficiencies or credit any overpayments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

  
John D. Simmons  
Agent for Applicants  
Registration No. 52,225  
Direct Dial: 215-965-1268  
E-Mail: jsimmons@akingump.com

Akin Gump Strauss Hauer & Feld LLP  
One Commerce Square  
2005 Market Street, Suite 2200  
Philadelphia, PA 19103  
Telephone No.: 215-965-1200  
Fax No.: 215-965-1210

JDS:sm  
Enclosures

Form PTO/SB/08A		<b>Complete if Known</b>	
<b>INFORMATION DISCLOSURE STATEMENT BY APPLICANT</b>  (use as many sheets as necessary)		<b>Application Number</b>	Not Yet Assigned
		<b>Filing Date</b>	November 11, 2003
		<b>First Named Inventor</b>	Jean-Claude ARTONNE, et al.
		<b>Group Art Unit</b>	Not Yet Assigned
		<b>Examiner Name</b>	Not Yet Assigned
Sheet 1 of 1	<b>Attorney Docket Number</b>		10000-25US (100137 USWO)

U.S. PATENT DOCUMENTS				
Exr Initials	U.S. Patent Document		Name of First Inventor of Cited Document	Date of Publication of Cited Document MM-YYYY
	Number	Kind Code (if known)		
	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			Name of Applicant of Cited Document	Date of Publication of Cited Document MM-YYYY	T <sub>1</sub>
	Country Code	Number	Kind Code (if known)			
	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.	T <sub>1</sub>

Examiner Signature		Date Considered	
--------------------	--	-----------------	--



**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	<i>26</i>	
FOR	NUMBER FILED	NUMBER EXTRA
TOTAL CHARGEABLE CLAIMS	<i>26</i> minus 20 =	* <i>6</i>
INDEPENDENT CLAIMS	<i>2</i> minus 3 =	* <i>-</i>
MULTIPLE DEPENDENT CLAIM PRESENT <input type="checkbox"/>		

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

SMALL ENTITY TYPE  OR

OTHER THAN SMALL ENTITY

RATE	FEE
BASIC FEE	385.00
X\$ 9=	
X43=	
+145=	
TOTAL	

RATE	FEE
BASIC FEE	770.00
X\$18=	<i>108</i>
X86=	
+290=	
TOTAL	<i>878</i>

**CLAIMS AS AMENDED - PART II**

(Column 1) (Column 2) (Column 3)

AMENDMENT A		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA
	Total	*	Minus	**	=
	Independent	*	Minus	***	=
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM <input type="checkbox"/>				

*17*

SMALL ENTITY OR

OTHER THAN SMALL ENTITY

RATE	ADDI-TIONAL FEE
X\$ 9=	
X43=	
+145=	
TOTAL	
ADDIT. FEE	

RATE	ADDI-TIONAL FEE
X\$18=	
X86=	
+290=	
TOTAL	
ADDIT. FEE	

(Column 1) (Column 2) (Column 3)

AMENDMENT B		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA
	Total	*	Minus	**	=
	Independent	*	Minus	***	=
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM <input type="checkbox"/>				

RATE	ADDI-TIONAL FEE
X\$ 9=	
X43=	
+145=	
TOTAL	
ADDIT. FEE	

RATE	ADDI-TIONAL FEE
X\$18=	
X86=	
+290=	
TOTAL	
ADDIT. FEE	

(Column 1) (Column 2) (Column 3)

AMENDMENT C		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA
	Total	*	Minus	**	=
	Independent	*	Minus	***	=
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM <input type="checkbox"/>				

RATE	ADDI-TIONAL FEE
X\$ 9=	
X43=	
+145=	
TOTAL	
ADDIT. FEE	

RATE	ADDI-TIONAL FEE
X\$18=	
X86=	
+290=	
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."  
 The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

PATENT APPLICATION SERIAL NO. \_\_\_\_\_

U.S. DEPARTMENT OF COMMERCE  
PATENT AND TRADEMARK OFFICE  
FEE RECORD SHEET

11/17/2003 ZJUARI 00000141 10706513

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

PTO-1556  
(5/87)

\*U.S. Government Printing Office: 2002 -- 489-267/69033

This Page Is Inserted by IFW Operations  
and is not a part of the Official Record

## **BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS ✓
- GRAY SCALE DOCUMENTS

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning documents *will not* correct images,  
please do not report the images to the  
Image Problem Mailbox.**





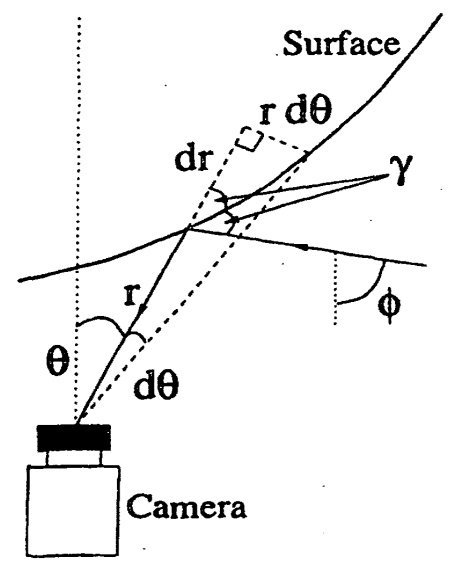
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<p>(51) International Patent Classification <sup>7</sup> : <b>G03B 37/00, G02B 5/10, 13/06, 17/06, B25J 19/04</b></p>	<p><b>A1</b></p>	<p>(11) International Publication Number: <b>WO 00/42470</b> (43) International Publication Date: 20 July 2000 (20.07.00)</p>
<p>(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  (71) Applicant (for all designated States except US): THE AUSTRALIAN NATIONAL UNIVERSITY [AU/AU]; Acton, ACT 2601 (AU).  (72) Inventors; and (75) Inventors/Applicants (for US only): MOORE, John, Barratt [AU/CN]; 8a Residence 8, Chinese University of Hong Kong, Sha Tin, New Territories, Hong Kong (CN). CONROY, Tanya, Louise [AU/AU]; 8 Fenwick Place, Belconnen, Canberra, ACT 2617 (AU).  (74) Agents: ALLEN, Leon, K. et al.; Davies Collison Cave, 1 Little Collins Street, Melbourne, VIC 3000 (AU).</p>	<p>(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).  <b>Published</b> <i>With international search report.</i></p>	

(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.



**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

## RESOLUTION INVARIANT PANORAMIC IMAGING

### FIELD OF THE INVENTION

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

### BACKGROUND ART

Panoramic imaging is becoming an important tool in the area of mobile robotics and machine  
10 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  
15 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  
20 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  
25 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  
30 general case orientation of the planes is arbitrary.

- 2 -

All the mirror shapes mentioned above share a common drawback. 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.

30



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

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

- where  $r$  is the radial distance from the reflective surface to the imaging device  
 5  $\theta$  is the angle from the optical axis of the imaging device  
 $\alpha(\theta)$  is the mirror gain given by

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

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

10

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

In one approach  $r$  can be plotted against  $\theta$  at selected intervals to describe the profile by  
 15 solving the above equation for selected values of  $\theta$ . For example determining values of  $r$  for incremental values of  $\theta$  of about  $1/5^{\circ}$  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  
 20 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.

- 10 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  
15 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  
20 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  
25 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 aperture can be provided in the first  
30 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  
5 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  
10 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  
15 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  
20 view direction in a panoramic imaging system;

- 6 -

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  
5 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;

10 Figures 7A and 7B, shows ray 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  
15 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;

20 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.

## 25 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

30

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

### 5 1.1 Constant Image Pixel Density - The Variable Gain ( $\alpha$ ) 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  
 10 between the pixel density and the angle of elevation in the scene or more precisely, the solid angle. The mirror gain  $\alpha$ , 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

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

15 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  $\alpha$  becomes a function of image angle  $\theta$  which is related to the radial coordinate in the image,  $\rho$ , as shown in Figure 2.

Figure 3 schematically shows an imaging system including an imaging device in the form of  
 20 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  $(r, \theta)$  in polar coordinates where  $r$  is the radial distance to the  
 25 camera and  $\theta$  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  $\gamma$  and the angle of an incoming light ray with respect to the vertical is  $\phi$ . Then

- 8 -

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

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

$$2\gamma + \theta + \phi = \pi \quad (3)$$

5 Differentiating (2) and (3) with respect to  $\theta$

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

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

so, substituting  $\alpha$  from (1) gives

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

10

Now, for a variable gain mirror,  $\alpha$  is a function of image angle  $\theta$  (related to the radial coordinate in the image,  $\rho$ ) so (4) becomes

$$\frac{d}{d\theta} \left[ \tan^{-1} \left( \frac{rd\theta}{dr} \right) \right] = -\frac{1}{2} (1 + \alpha(\theta)) \quad (5)$$

or, rearranging

15

- 9 -

$$\frac{dr}{d\theta} = r \cot[-\frac{1}{2} f(1 + \alpha(\theta)) d\theta] \quad (6)$$

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

5

### 1.1.1 Pixel Density Invariance Profiles

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

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

10 pixels in an area of radius  $\rho$ , where  $\kappa$  is the number of pixels per unit area, a constant. Differentiating by  $\rho$  gives

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

Now, the radius in the image,  $\rho$  is related to the radial angle of a ray reflected from the 15 mirror,  $\theta$  by the focal length of the camera,  $f$  (a constant)

$$\rho = f \tan(\theta) \quad (8)$$

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

20

- 10 -

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

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

5

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

where  $\beta$  and  $C(\phi)$  are constants. Differentiating both sides of (10) by  $\phi$  and substituting (1) and (9) gives

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

10

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  $B_\alpha$  is a constant. Integrating this expression for  $\alpha(\theta)$  by  $\theta$  gives an expression for  $\phi$  (see (1)), the elevation of an object imaged at angle  $\theta$ . That is



- 11 -

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

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

The constants  $B_{\alpha}$  and  $\phi(\theta = 0)$  can be determined from the maximum and minimum values of  $\theta$  and  $\phi$  which are known for a desired mirror configuration, using (13).

$$B_{\alpha} = \frac{2(\bar{\phi} - \phi)}{\tan^2(\bar{\theta}) - \tan^2(\underline{\theta})} \quad (14)$$

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

It appears not possible to find an analytical solution to (6) if  $\alpha$  is a function of  $\theta$ , 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  $\theta$  (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  $\theta$ , with about  $2^{\circ}$  between each ray. It is clear from Fig. 4A that in the constant gain case these rays are constantly spaced in  $\phi$ , with about  $8.5^{\circ}$  between each ray, and from Fig. 4, that the spacing between the rays in the variable gain case increases with increasing  $\phi$ . 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,  $\alpha$ . 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 ( $\phi$  and  $\bar{\phi}$ ) are to be equal for both mirrors in the double mirror system, the range of reflected angles ( $\bar{\theta} - \underline{\theta}$ ) 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 ( $\bar{\theta}_2$ ) are known. So, since (12) holds over the entire mirror,  $B_a$  is constant, and from (14)

$$\frac{2(\bar{\phi} - \phi)}{(\tan^2(\bar{\theta}_1) - \tan^2(\underline{\theta}_1))} = \frac{2(\bar{\phi} - \phi)}{\tan^2(\bar{\theta}_2) - \tan^2(\underline{\theta}_2)} \quad (15)$$

$$\tan^2(\bar{\theta}_1) - \tan^2(\underline{\theta}_1) = \tan^2(\bar{\theta}_2) - \tan^2(\underline{\theta}_2)$$

$$\tan^2(\bar{\theta}_1) + \tan^2(\underline{\theta}_2) = \tan^2(\bar{\theta}_2) + \tan^2(\underline{\theta}_1)$$

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  $\bar{\theta}_1 = \underline{\theta}_2$ , so

$$2 \tan^2(\bar{\theta}_1) = \tan^2(\bar{\theta}_2) + \tan^2(\underline{\theta}_1)$$

$$\bar{\theta}_1 = \tan^{-1} \left[ \left( \frac{\tan^2(\bar{\theta}_2) + \tan^2(\underline{\theta}_1)}{2} \right)^{1/2} \right] \quad (16)$$

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

5

The information available for range calculation are the image angles for a single object reflected in both mirrors,  $\theta_1$  and  $\theta_2$  as shown in Figure 8. The two mirrors  $\theta_1$  and  $\theta_2$  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

10 upper mirror.

In order to find the position of object  $P$ , the equations of the incident beams from  $P$  to each mirror reflection point  $(r_1, \theta_1)$  and  $(r_2, \theta_2)$  must be found. These equations can then be solved simultaneously to give the position of object  $P$ ,  $(x_P, y_P)$ .

15

$$\begin{bmatrix} y_P \\ x_P \end{bmatrix} = \begin{bmatrix} 1 & -m_{11} \\ 1 & -m_{12} \end{bmatrix}^{-1} \begin{bmatrix} C_{11} \\ C_{12} \end{bmatrix}$$

$$= \begin{bmatrix} -\frac{m_{12}}{m_{12}-m_{11}} & \frac{m_{11}}{m_{12}-m_{11}} \\ -\frac{1}{m_{12}-m_{11}} & \frac{1}{m_{12}-m_{11}} \end{bmatrix} \begin{bmatrix} C_{11} \\ C_{12} \end{bmatrix} \quad (17)$$

- 14 -

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

$$C_{II} = y_1 - m_{II} x_1 \quad (18)$$

where

5

$$\begin{aligned} x_1 &= r_1 \sin \theta_1 \\ y_1 &= r_1 \cos \theta_1 \end{aligned} \quad (19)$$

are the Cartesian coordinates of the reflection point  $(r_1, \theta_1)$ . The gradient of the incident  
10 beam is found using the law of reflection

$$m_{II} = \tan \left[ \tan^{-1} \left( \frac{dy_1}{dx_1} \right) + \tan^{-1} \left( \frac{1}{m_{RI}} \right) - \tan^{-1} \left( \frac{dx_1}{dy_1} \right) \right] \quad (20)$$

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

$$m_{RI} = \tan \theta_1 \quad (21)$$

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

20

- 15 -

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

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

$$\begin{aligned} \int d \tan^{-1} \left( r \frac{d\theta}{dr} \right) &= -\frac{1}{2} \int (1 + \alpha(\theta)) d\theta \\ \tan^{-1} \left( r \frac{d\theta}{dr} \right) &= -\frac{1}{2} \theta - \frac{B_\alpha}{2} \int (\tan(\theta) + \tan^3(\theta)) d\theta \\ &= -\frac{1}{2} \theta - \frac{B_\alpha}{4} \tan^2(\theta) + D \end{aligned} \quad (23)$$

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

5

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

Now from (23) and (2),

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

10 so, for the lower variable gain mirror profile

- 16 -

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

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  
5 point. Note that as in the constant gain case, the gradient depends only on  $\theta$ .

The equation constants for the incident beam equations from (18) require the polar coordinates  
of the reflection points from each mirror,  $(r_1, \theta_1)$  and  $(r_2, \theta_2)$ . Since the variable gain mirror  
equations are not known exactly,  $r_1$  and  $r_2$  must be found using a differential equation solver  
10 to find solutions to (26) at  $\theta_1$  and  $\theta_2$ .

## 2 Back-to-back Stereo Mirror Families

A key disadvantage of single camera stereo panoramic systems is that since there are two  
15 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.

20

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  
25 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

- 17 -

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  
5 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  
10 to Fig. 9

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

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

15

### 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  
20 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  $\underline{\phi}_3 = \underline{\phi}_1$ ,  $\underline{\phi}_4 = \underline{\phi}_2$ ,  
25  $\bar{\phi}_3 = \bar{\phi}_1$  and  $\bar{\phi}_4 = \bar{\phi}_2$ . The constraints

- 18 -

$$\begin{aligned}\overline{\Phi}_3 &= \pi - \overline{\Phi}_2 \\ \overline{\Phi}_4 &= \pi - \overline{\Phi}_1\end{aligned}$$

align the three stereo cones.

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

### 3 Forward Looking Mirror Design

An example of a forward looking mirror design is shown in Fig. 11. For many applications,  
10 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  
15 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.

20

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  
25 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.



- 19 -

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

5

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

$\bar{D}$ , defines the minimum height for the mirror system,  $H$ . 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

10

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

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

15

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  
20 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.

5

## 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  
 5 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.
- 10 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  
 15 equation:

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

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

$\theta$  is the angle from the optical axis of the imaging device

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

20

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

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

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

- 22 -

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  $\theta$ .
5. A panoramic imaging system as claimed in claim 4 wherein the selected values of  $\theta$  are separated by about  $1/5^\circ$ .
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  
10 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.
- 15 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  
20 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  
25 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.

30

- 23 -

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.

5 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  
10 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 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  
20 equation:

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

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

$\theta$  is the angle from the optical axis of the imaging device

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

25 
$$\alpha(\theta) = B_{\alpha} [\tan(\theta) + \tan^3(\theta)]$$

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

- 24 -

$\bar{\phi}$  and  $\underline{\phi}$  are the maximum and minimum elevations viewed  $\bar{\theta}$  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  
5 portion includes by a series spaced apart points defined by determining distance  $r$  for selected values of angle  $\theta$ .

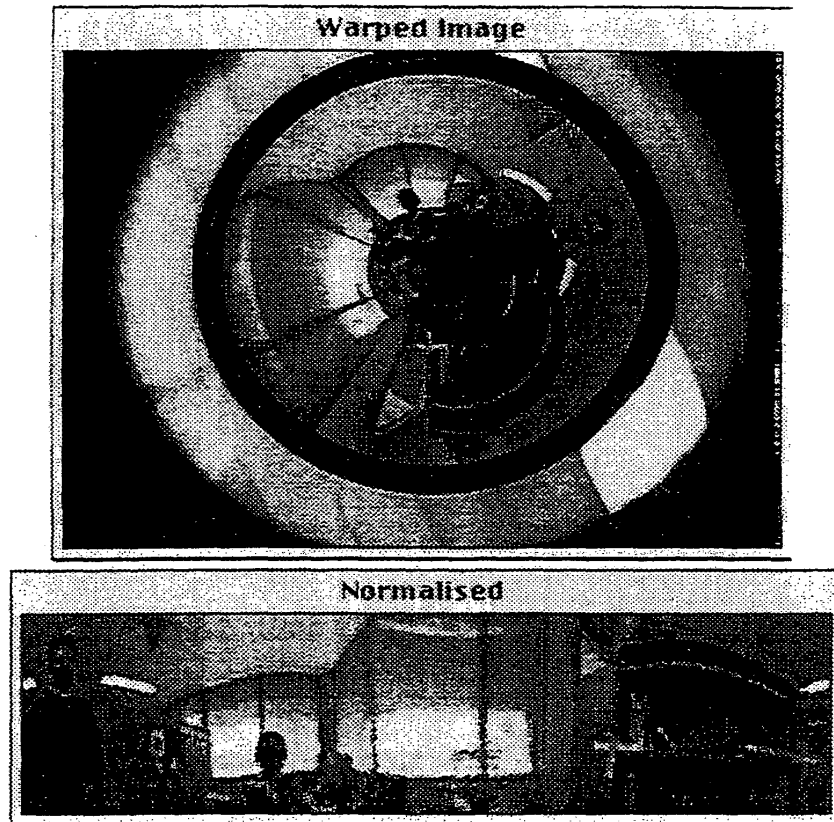
18. A reflective surface as claimed in claim 17 wherein the selected values of  $\theta$  are separated by about  $1/5^\circ$ .

10

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.

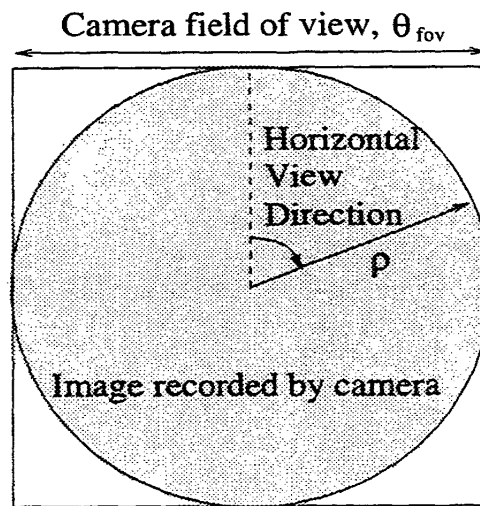
15 20. A reflective surface as claimed in claim 19 wherein said panoramic second fields of view are substantially co-incident.

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



**FIGURE 1**

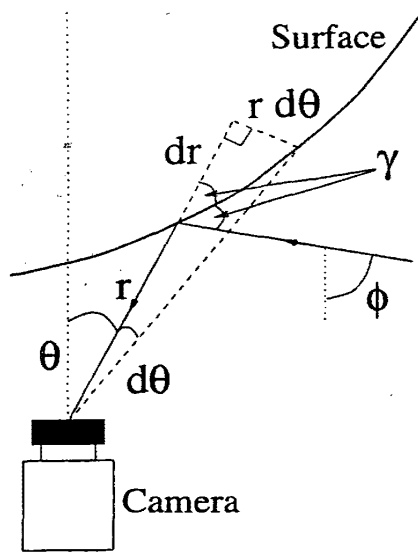
Substitute Sheet (Rule 26) RO/AU



**FIGURE 2**

Substitute Sheet (Rule 26) RO/AU





**FIGURE 3**

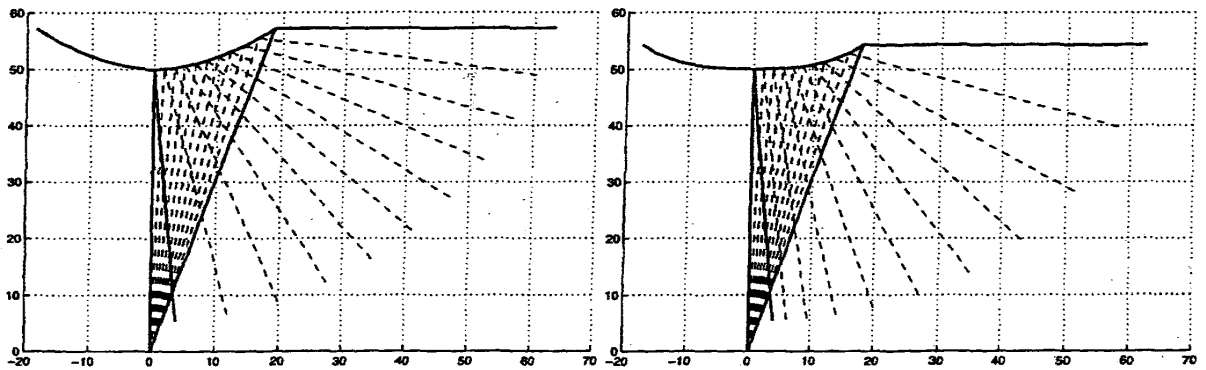
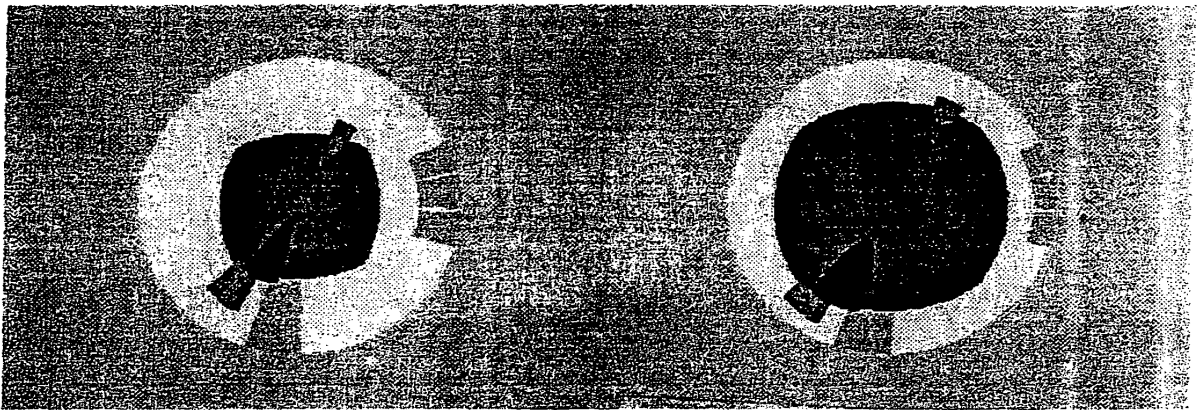


FIGURE 4A

FIGURE 4B

Substitute Sheet (Rule 26) RO/AU



**FIGURE 5A**

**FIGURE 5B**

Substitute Sheet (Rule 26) RO/AU

6/12

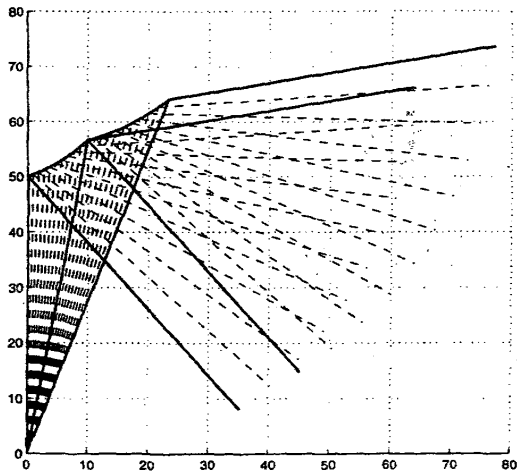


FIGURE 6A

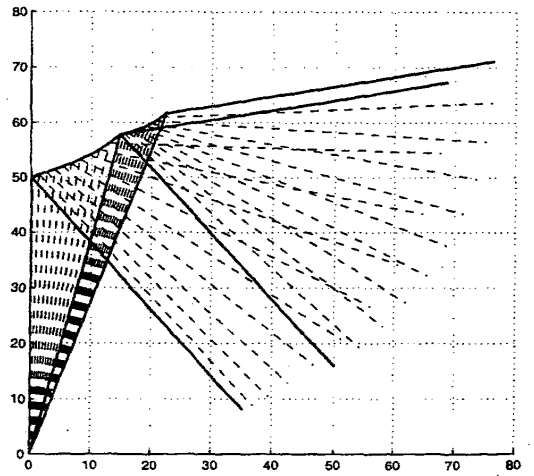
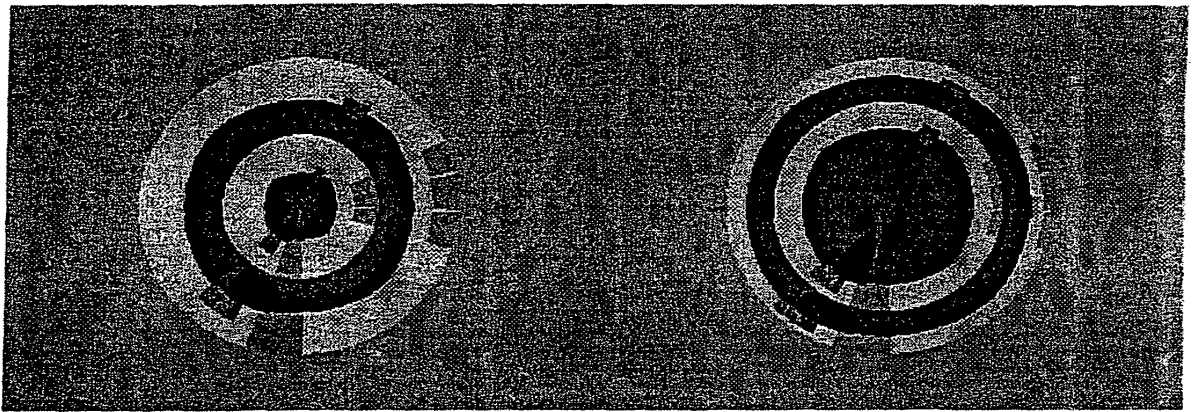


FIGURE 6B

Substitute Sheet (Rule 26) RO/AU



**FIGURE 7A**

**FIGURE 7B**

Substitute Sheet (Rule 26) RO/AU

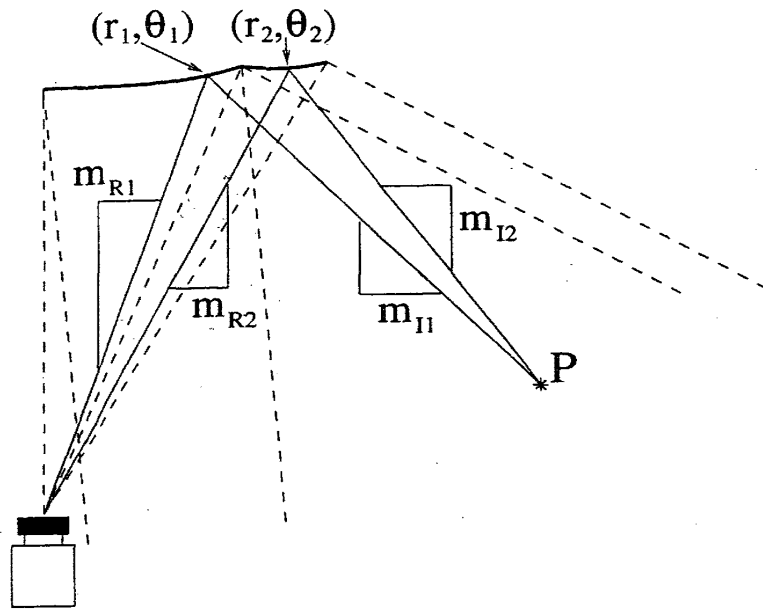


FIGURE 8

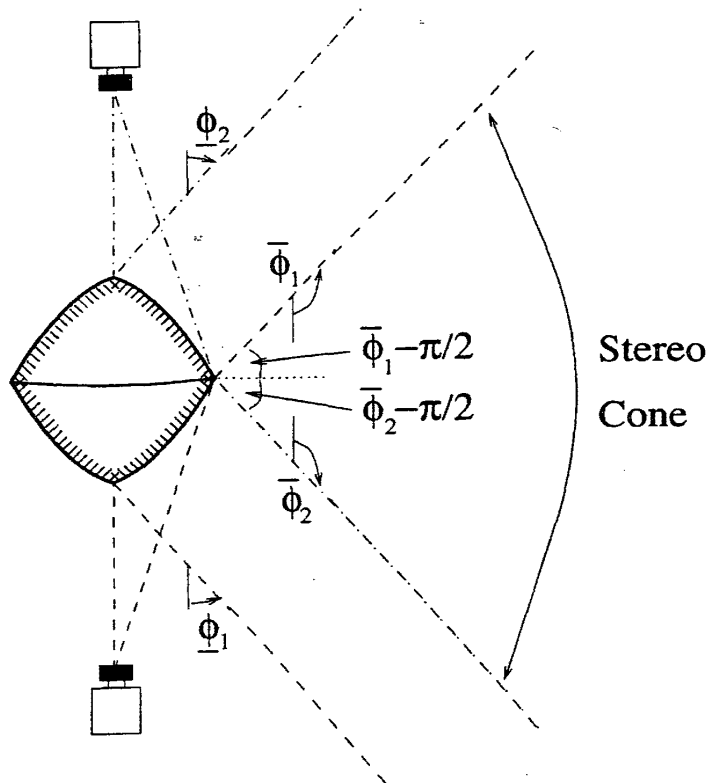


FIGURE 9

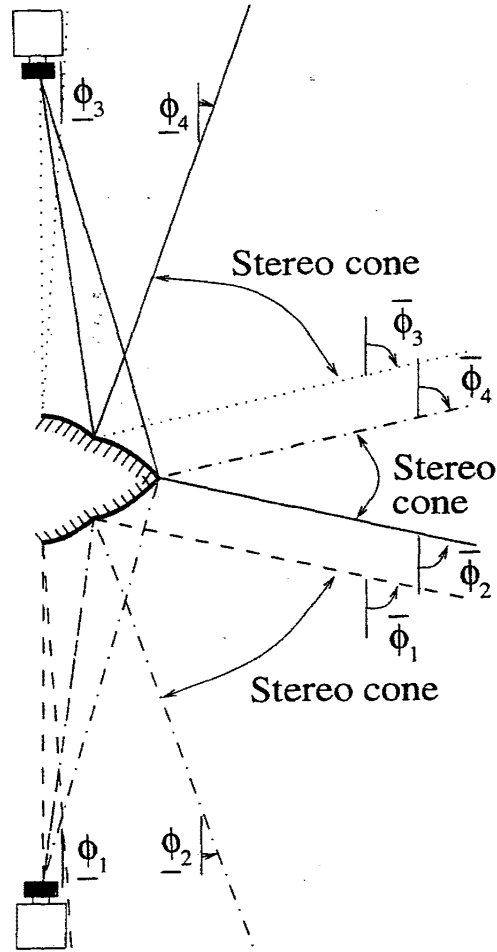


FIGURE 10

Substitute Sheet (Rule 26) RO/AU



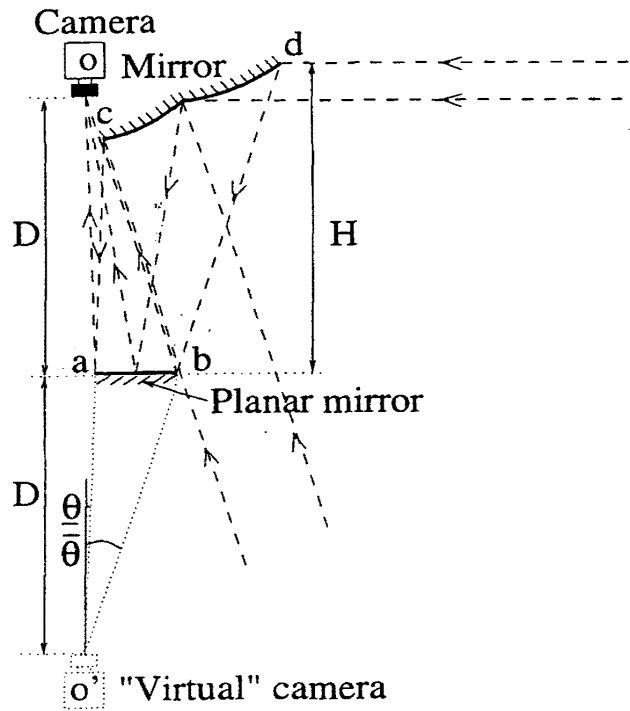


FIGURE 11

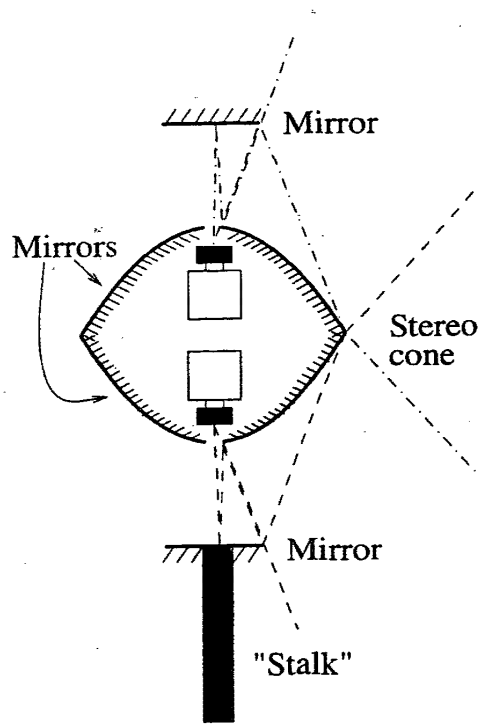


FIGURE 12

Substitute Sheet (Rule 26) RO/AU

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/AU 00/00022

<b>A. CLASSIFICATION OF SUBJECT MATTER</b>		
Int Cl <sup>7</sup> : 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>B. FIELDS SEARCHED</b>		
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		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
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	
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C <input checked="" type="checkbox"/> See patent family annex		
<p>* Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"I" 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)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"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</p> <p>"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</p> <p>"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</p> <p>"&amp;" document member of the same patent family</p>		
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@ipaustalia.gov.au Facsimile No. (02) 6285 3929		Authorized officer M.E. DIXON Telephone No.: (02) 6283 2194

Form PCT/ISA/210 (second sheet) (July 1998)

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)

BNSDOCID: <WO\_0042470A1\_I\_>

**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							

**THIS PAGE BLANK (USPTO)**



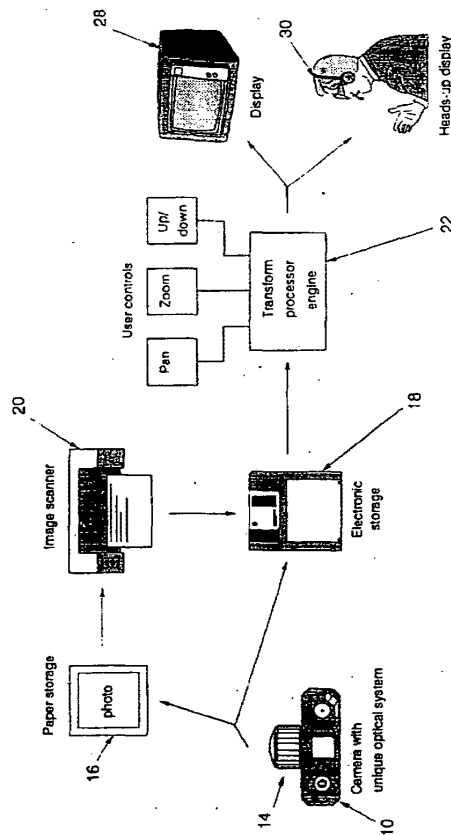
(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication: **31.01.1996 Bulletin 1996/05**  
 (51) Int Cl.<sup>6</sup>: **H04N 5/262, G02B 13/06**  
 (21) Application number: **95304930.1**  
 (22) Date of filing: **14.07.1995**

<p>(84) Designated Contracting States: <b>CH DE FR GB IT LI NL SE</b></p> <p>(30) Priority: <b>27.07.1994 US 281331</b></p> <p>(71) Applicant: <b>International Business Machines Corporation</b> <b>Armonk, N.Y. 10504 (US)</b></p> <p>(72) Inventors:  <ul style="list-style-type: none"> <li>• <b>Baker, Robert Grover</b> <b>Delray Beach, FL 33444-4341 (US)</b></li> </ul> </p>	<ul style="list-style-type: none"> <li>• <b>Flattery Freedenburg, Candace Joy</b> <b>Poughkeepsie, NY 12603 (US)</b></li> <li>• <b>Kettler, Kevin</b> <b>Pittsburg, PA 15217 (US)</b></li> <li>• <b>Suarez, Gustavo Armando</b> <b>Boca Raton, FL 33428 (US)</b></li> <li>• <b>Uplinger, Kenneth Allen</b> <b>Austin, TX 78750 (US)</b></li> </ul> <p>(74) Representative: <b>Burt, Roger James, Dr.</b> <b>Winchester, Hampshire SO21 2JN (GB)</b></p>
---	---

(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**

**D s r i p t i o n**

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-hemispheric 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. Al-



though 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 op-

tical imaging system includes a colour-aberrated multiple element wide field 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 worn 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 memory 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 memory, 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 hemispherical 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 hemispherical 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 hemispherical 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 hemispherical 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 either 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 ref-

erence 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 orienta-

tion-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 Miyamoto; 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  $\theta$  (theta), a standard wide-field lens design is scaled in "f", the focal length, to provide  $r'$  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:

$$\text{Area at imager} = (\pi)r_y'^2 - (\pi)r_x'^2 = (\pi)(r_y'^2 - r_x'^2)$$

$$\text{Imager length} = 2r', \text{ where } r' = \sqrt{r_y'^2 - r_x'^2}$$

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. Hori-moto 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 1 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 coef-



ficients. 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 keystone effect. The remapping of the pixel locations is matched to the differential 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 ap-

propriate 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. Pre-recorded 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 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.

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

- John Gravel delivere*
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.

5

10

15

20

25

30

35

40

45

50

55

13

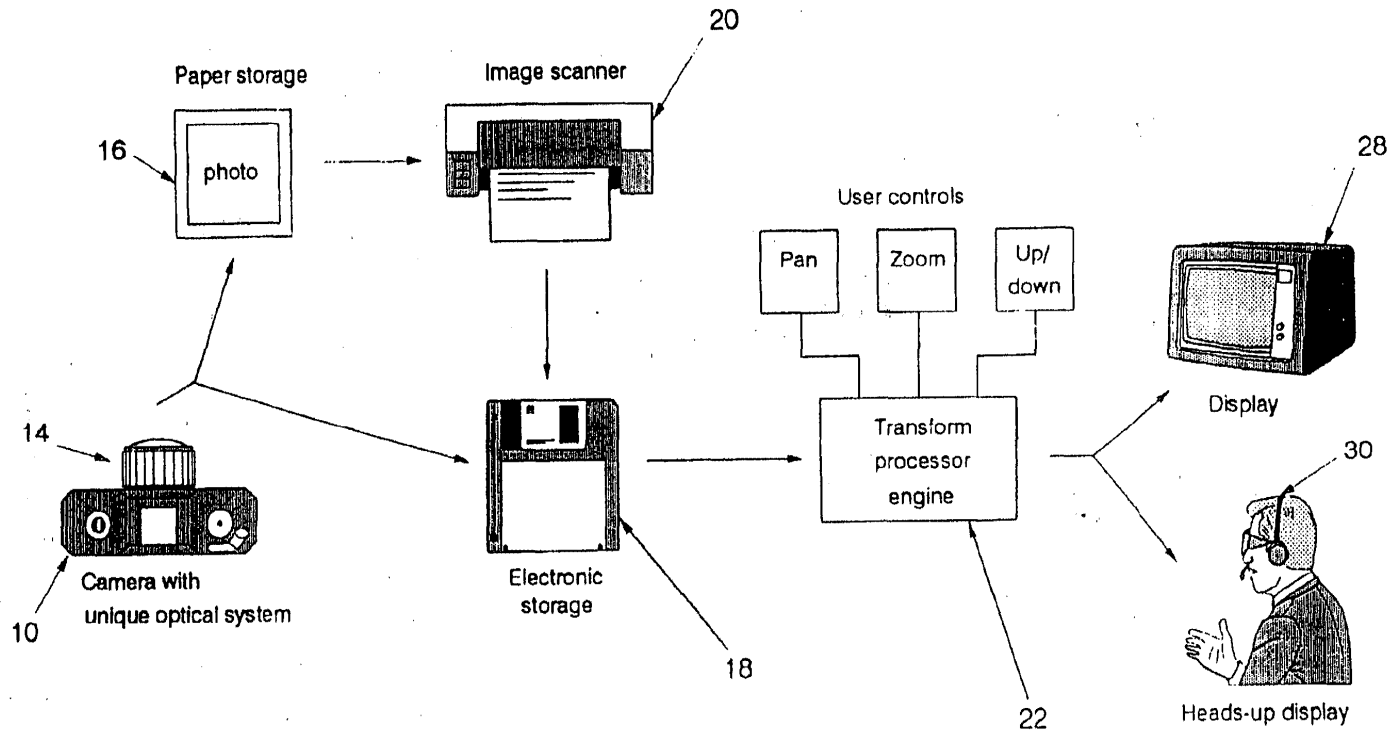
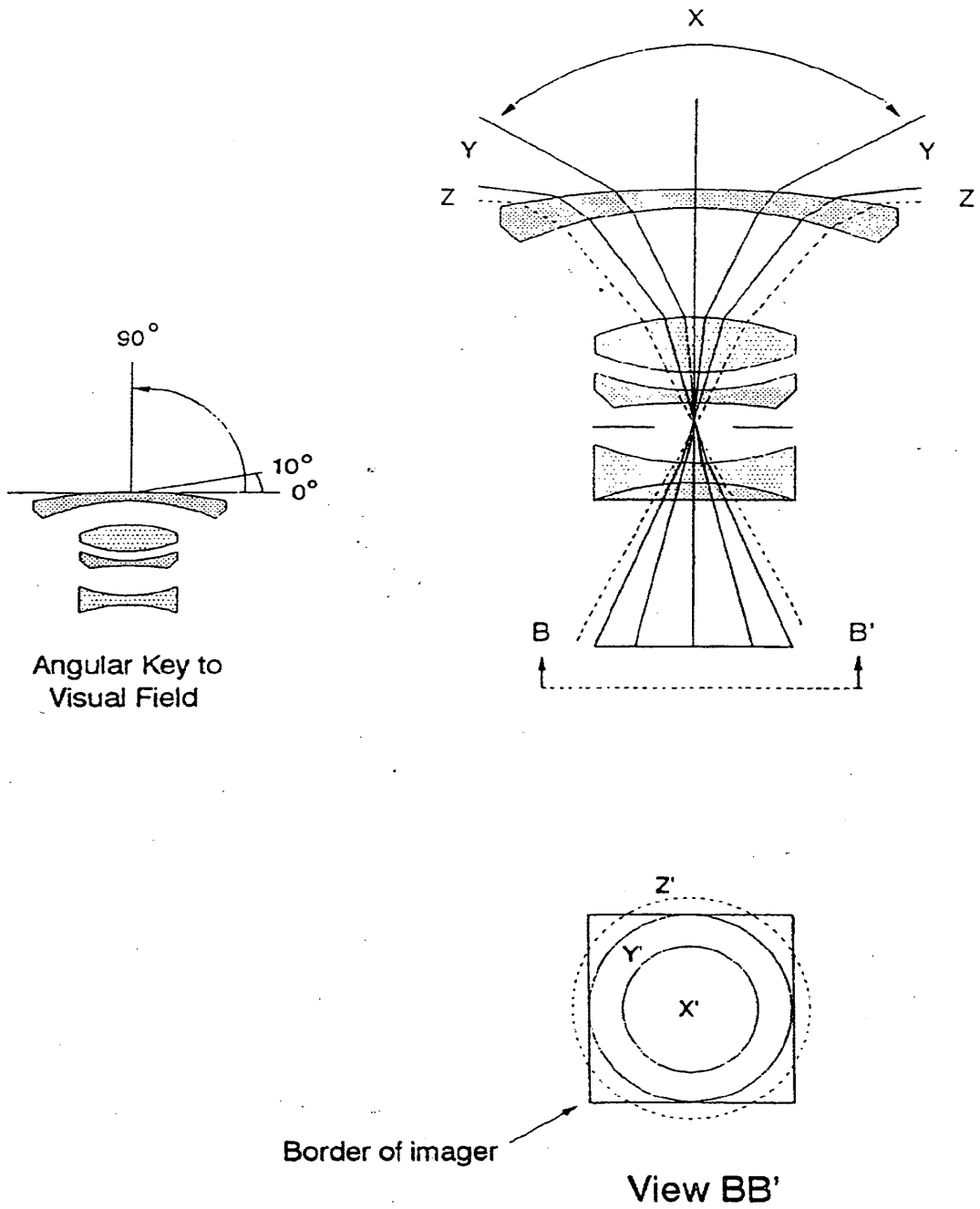
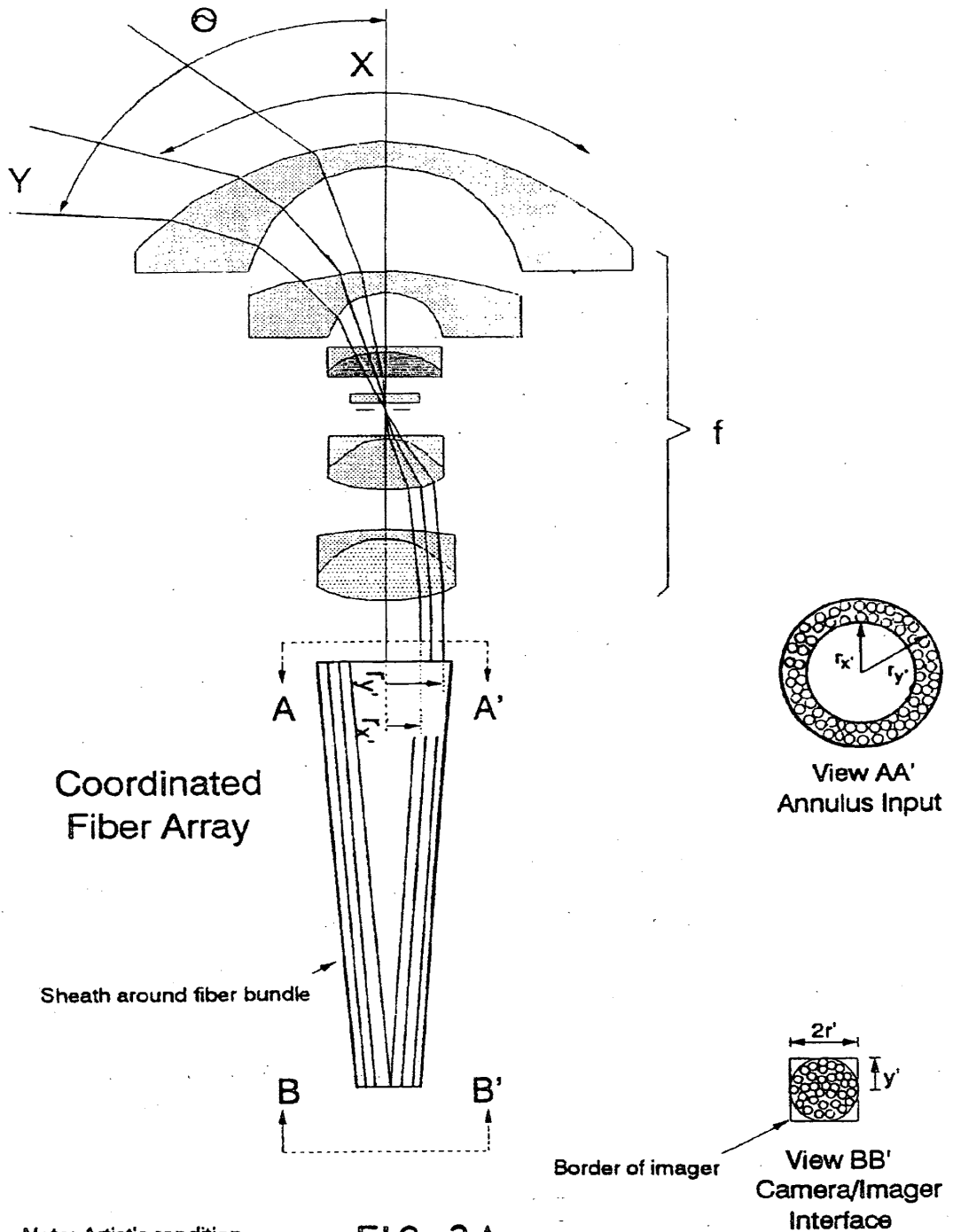


FIG. 1

EP 0 695 085 A1

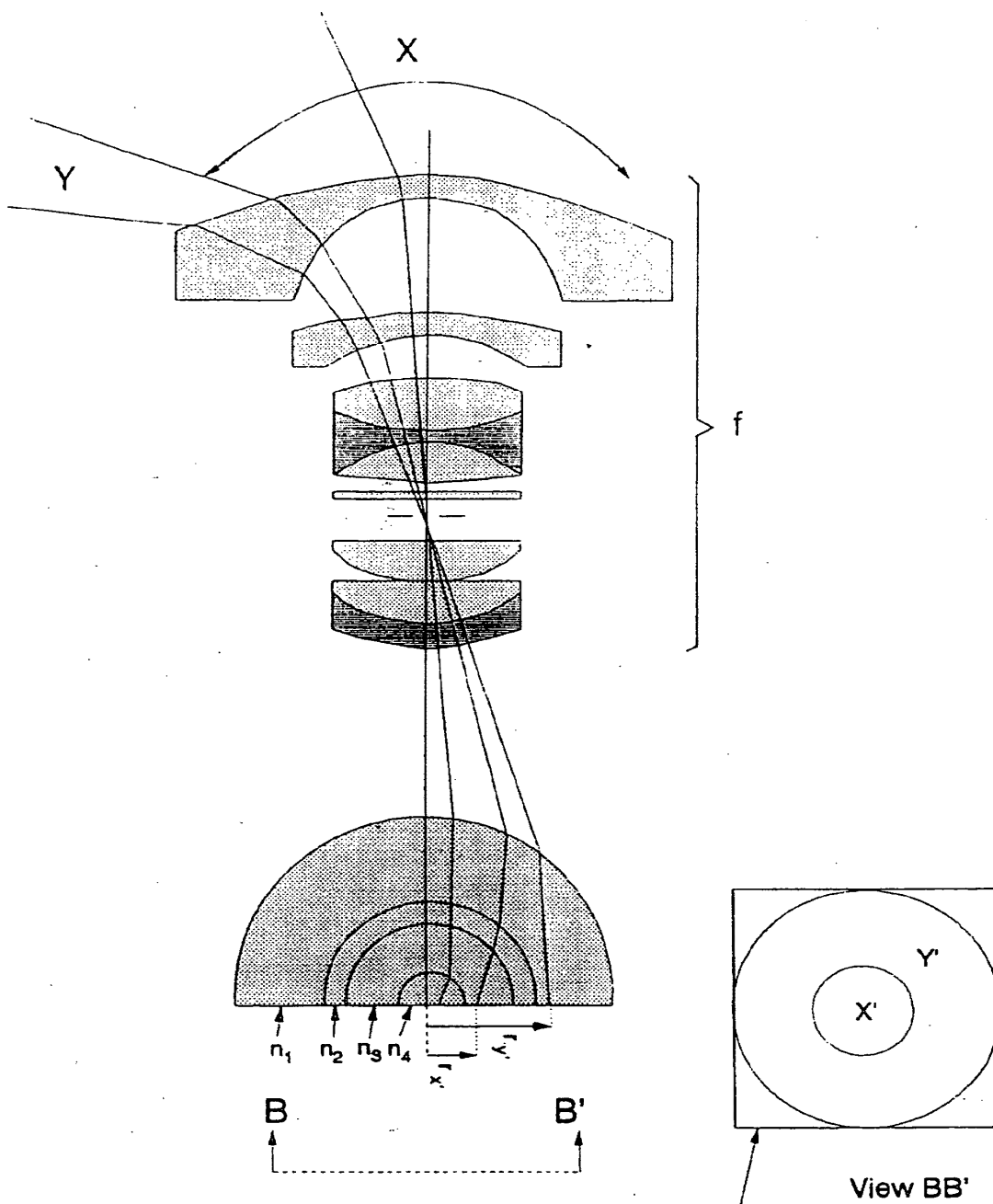


**FIG. 2**



Note: Artist's rendition  
Drawing not to scale

**FIG. 3A**



Note: Artist's rendering  
Drawing not to scale

Border of imager

**FIG. 3B**

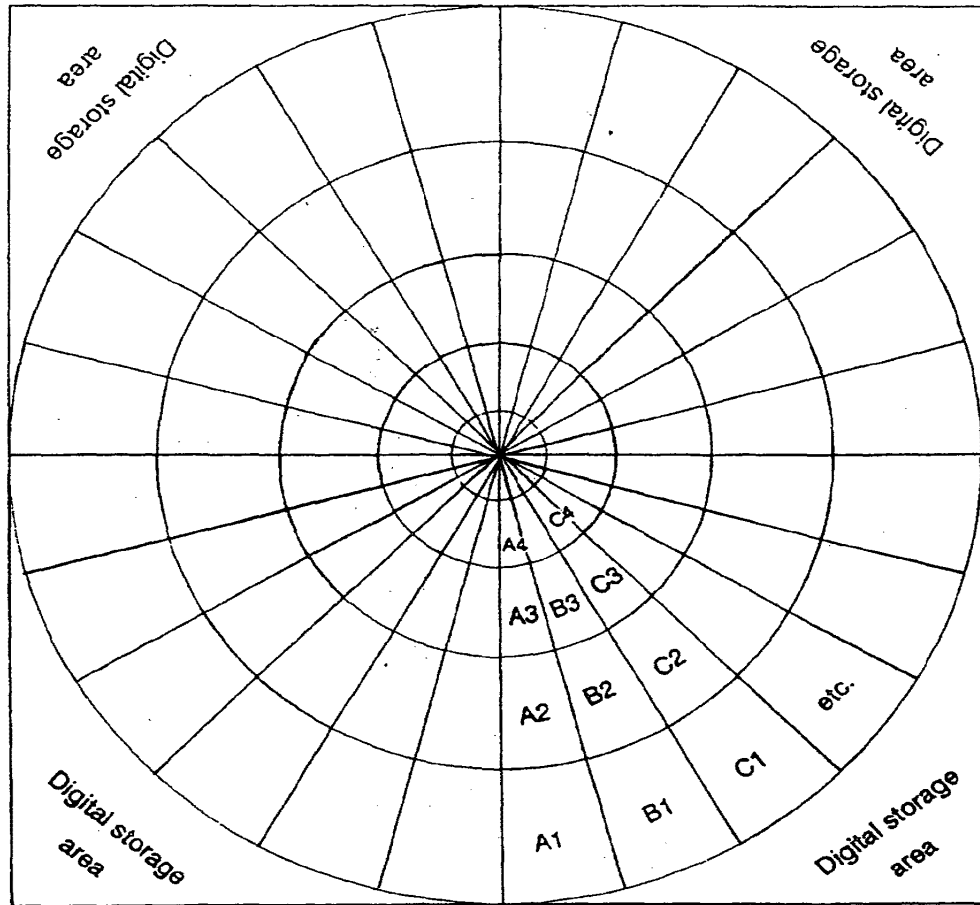
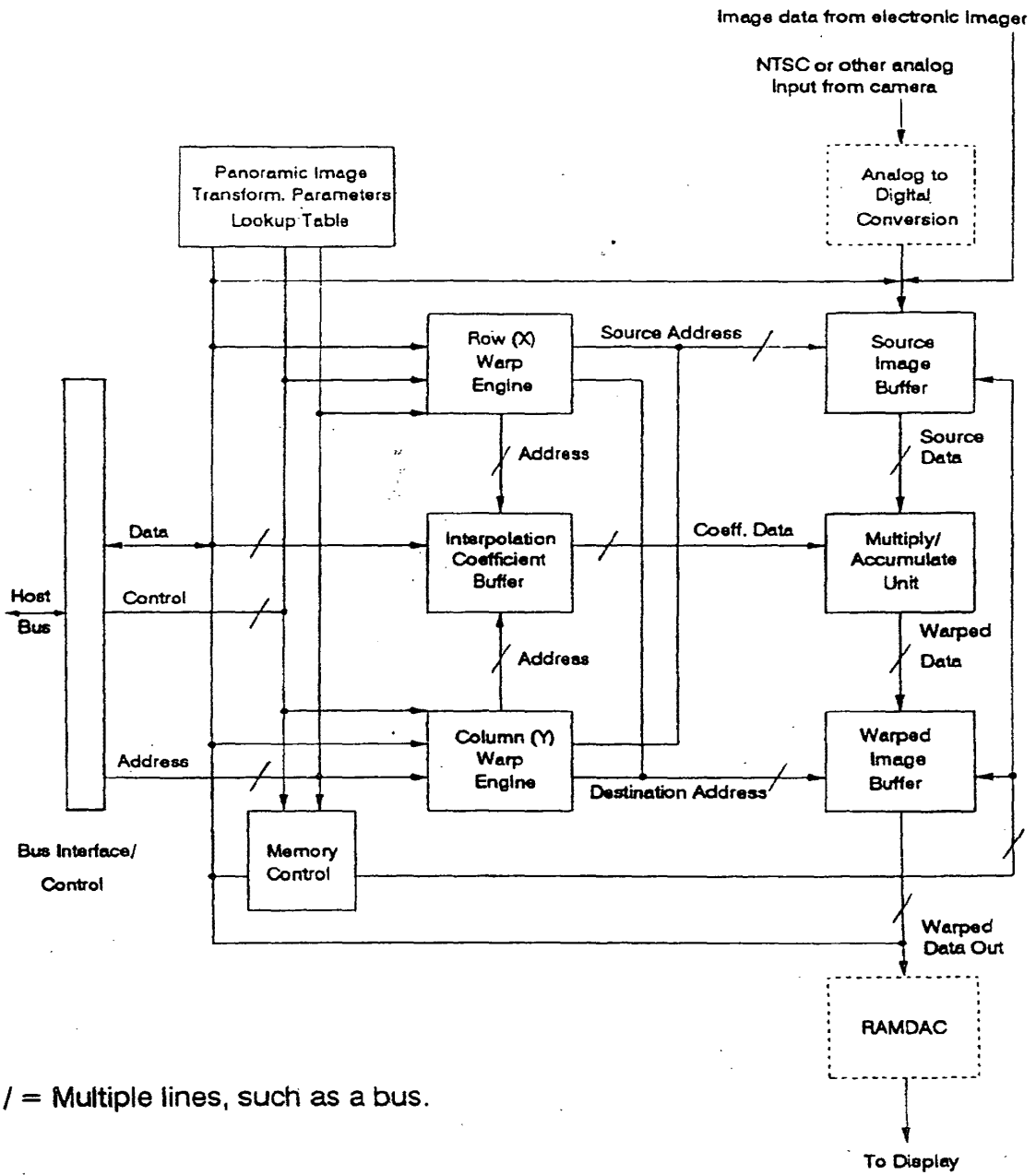


FIG. 4





/ = Multiple lines, such as a bus.

**FIG. 5**

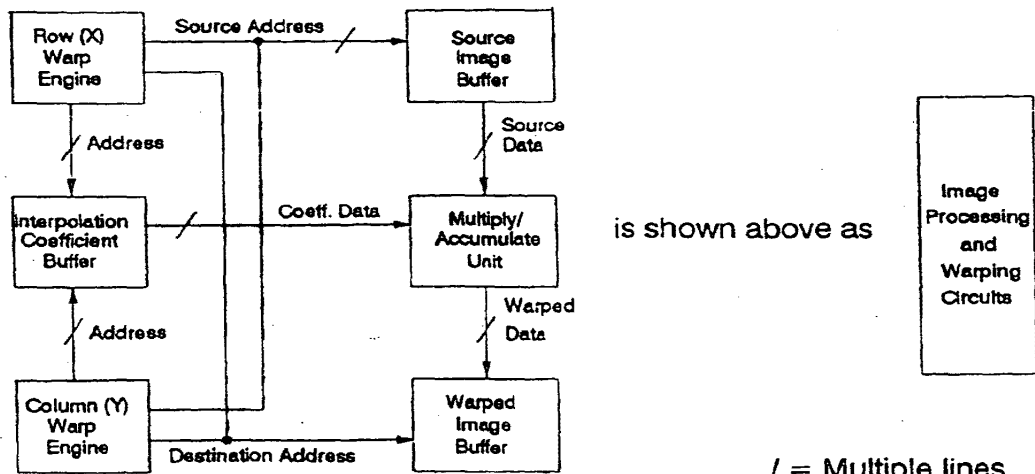
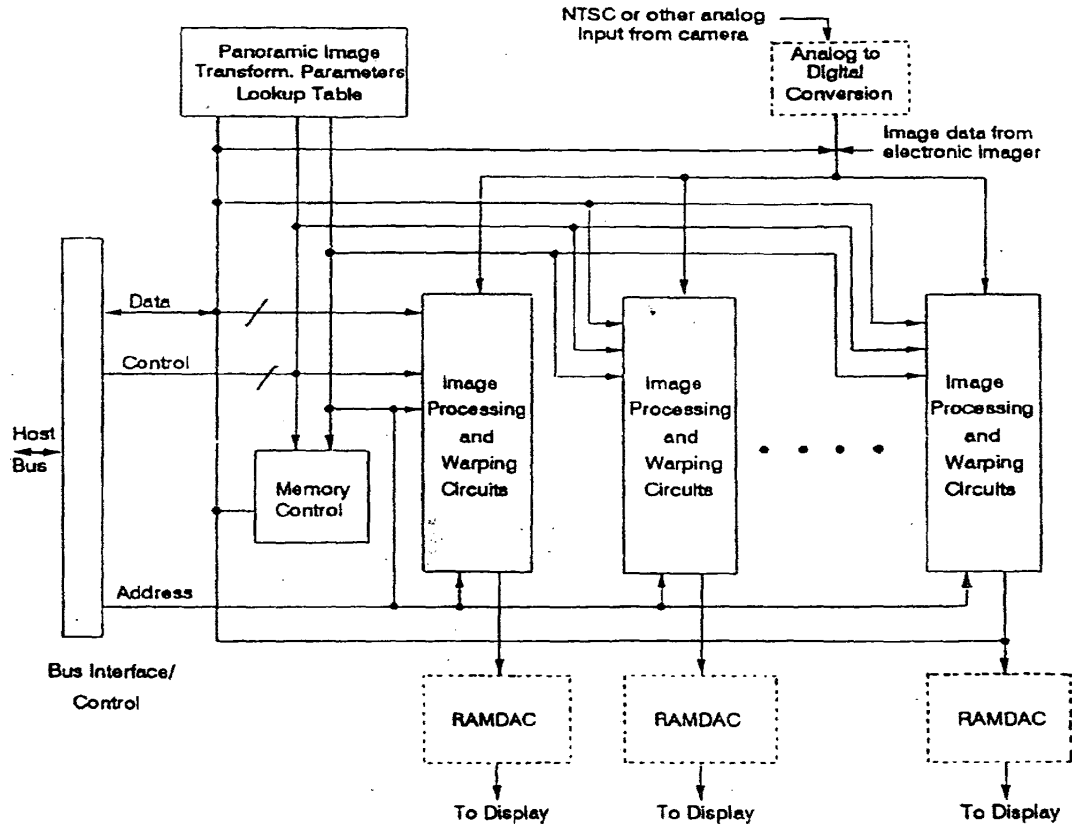


FIG. 6



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)
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		H04N G02B
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 <b>THE HAGUE</b>		Date of completion of the search <b>27 October 1995</b>	Examiner <b>De Dieuleveult, A</b>	
<b>CATEGORY OF CITED DOCUMENTS</b> X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		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 150 (04/94) (P/ACU)



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
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 THE HAGUE	Date of completion of the search 27 October 1995	Examiner De Dieuleveult, A
<p><b>CATEGORY OF CITED DOCUMENTS</b></p> <p>X : particularly relevant if taken alone                      Y : particularly relevant if combined with another document of the same category                      A : technological background                      O : non-written disclosure                      F : intermediate document</p> <p>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                      &amp; : member of the same patent family, corresponding document</p>		

EPO FORM 150 (12/1990)

[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 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. Pre-recorded 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;

**THIS PAGE BLANK (USPTO)**

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;

*marked* [ 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 out-

put 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;

**THIS PAGE BLANK (USPTO)**



# 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 

[Return to Search Screen](#)

## 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  
International Business Machines Corporation  
Old Orchard Road  
Armonk, N.Y. 10504/US [ N/P ]

[  
FOR ALL DESIGNATED STATES  
International Business Machines Corporation  
Old Orchard Road  
Armonk, N.Y. 10504/US [1996/05]  
]

## Inventor name, address

01 / Baker, Robert Grover / 2112 NW 1st Avenue / Delray Beach, FL 33444-4341 / US  
02 / Flattery Freedenburg, Candace Joy / 63 Worrall Avenue / Poughkeepsie, NY 1260  
US  
03 / Kettler, Kevin / 611 Montclair Street / Pittsburg, PA 15217 / US  
04 / Suarez, Gustavo Armando / 21482 Woodchuck Lane / Boca Raton, FL 33428 / US  
05 / Uplinger, Kenneth Allen / 10202 Lockleven Cove / Austin, TX 78750 / US [1996/05]

## Representative name, address

Burt, Roger James, Dr.  
IBM United Kingdom Limited Intellectual Property Department Hursley Park  
Winchester Hampshire SO21 2JN/GB [1996/05]

## Filing language

EN

## Procedure language

EN

## Publication language

B1 EN [2000/07]

## Classification of file and fax number for 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 communication R.51(4) 22-04-1998/M06/22-10-1998  
dispatched 04-05-1999  
- approval (yes or no) yes

**THIS PAGE BLANK (USPTO)**

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]  
]

**Documents cited in the European Search**

WO9221208 A [YD];  
WO8903076 A [Y];  
EP0574325 A [A];  
EP0547635 A [A];  
US4832472 A [A];  
JP1163079 A [A]  
[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,

**Documents cited by the Applicant**

US4125862 A;  
US4442453 A;  
US5185667 A;  
US4170400 A  
JOURNAL OF THE OPTICAL SOCIETY OF AMERICA 1964,, MIYAMOTA 'Lens Desig  
[  
SMITH W.J. 'Modern Lens Design', part CH.5.4 1992, MCGRAW-HILL, INC. article 'Sc  
a Design';  
]  
[  
'Fibre Optics, Handbook of Optics', 1978, MCGRAW-HILL INC. Sect. 13  
]

[ End of Data ]

Return to Search Screen  
22-05-2003 11:45:44

**THIS PAGE BLANK (USPTO)**

## 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 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.

Data supplied from the esp@cenet database - 12

**THIS PAGE BLANK (USPTO)**



(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**

• **Advanet, Inc.**  
**Okayama-shi, Okayama-Pref. 700-0971 (JP)**

(30) Priority: **25.11.1998 JP 35075198**

(72) Inventor:  
**Nagaoka, Tooru,**  
**c/o FIT Corporation**  
**Suwa-gun, Nagano-Pref, 393-0023 (JP)**

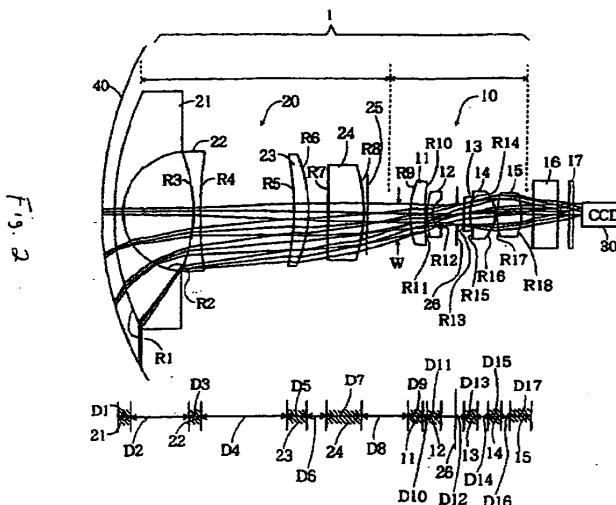
(71) Applicants:  
 • **Fit Corporation**  
**Suwa-Gun, Nagano-Pref. 393-0023 (JP)**  
 • **Rios Corporation**  
**Okayama-shi, Okayama-Pref. 700-0942 (JP)**

(74) Representative:  
**Roberts, Gwilym Vaughan et al**  
**KILBURN & STRODE,**  
**20 Red Lion Street**  
**London WC1R 4PJ (GB)**

(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,  $\theta$  is 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.



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 fish-eye 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  $\theta$  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 fish-eye 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  $\theta$  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,  $\theta$  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  $\theta$  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  $\theta$  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  $\frac{1}{2}$  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  $\theta$  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  $\theta$  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,  $\theta = 90^\circ$  shows a field angle with respect to the optical axis (the field angle of the optical axis is  $0^\circ$ ).

[0029] In Fig. 3(A), a curve C1 shows the relationship between field angle  $\theta$  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  $\theta$  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  $\theta$  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  $\theta$  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  $\theta$  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  $\theta$  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  $\theta$  of about  $90^\circ$  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  $\theta$  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  $90^\circ$  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  $90^\circ$ ) 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  $\theta$  of  $90^\circ$ ,  $\tan\theta$  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  $90^\circ$  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  $\theta$  is changed in  $10^\circ$  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  $h_p$  represents the height of an image  $M_p$  at a field angle of around  $90^\circ$ .

**[0034]** As is understood from Figs. 4(A) to 4(D), image height at a field angle of around  $90^\circ$  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  $h_p$  of an image  $M_p$  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  $90^\circ$  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  $h_p$  of the image  $M_p$  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  $90^\circ$  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  $90^\circ$  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  $90^\circ$  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  $\theta$ . 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  $\phi$ .

**[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,  $\pi$  is added to  $\phi$  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,  $\theta$  and  $\phi$  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 con-

verted 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 fish-eye 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  $\theta$  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  $\theta$  is a field angle), an image at a peripheral portion (field angle of around  $90^\circ$  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  $90^\circ$  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,  $\theta$  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 3, 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 $90^\circ$ 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,  $\theta$  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

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

10  
 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,  $\theta$  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  
 20 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. 25
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. 30
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  $h = 2f \cdot \tan(\theta/2)$ . 35
9. A recording medium having recorded thereon a program for implementing the method of any of claims 5 to 8. 40
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. 45
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  $90^\circ$  in each direction with respect to the optical axis 50  
 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,  $\theta$  being a field angle, and  $m$  having a value of  $m \leq 1.6$ . 55

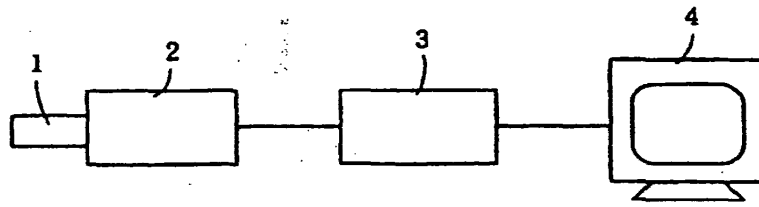
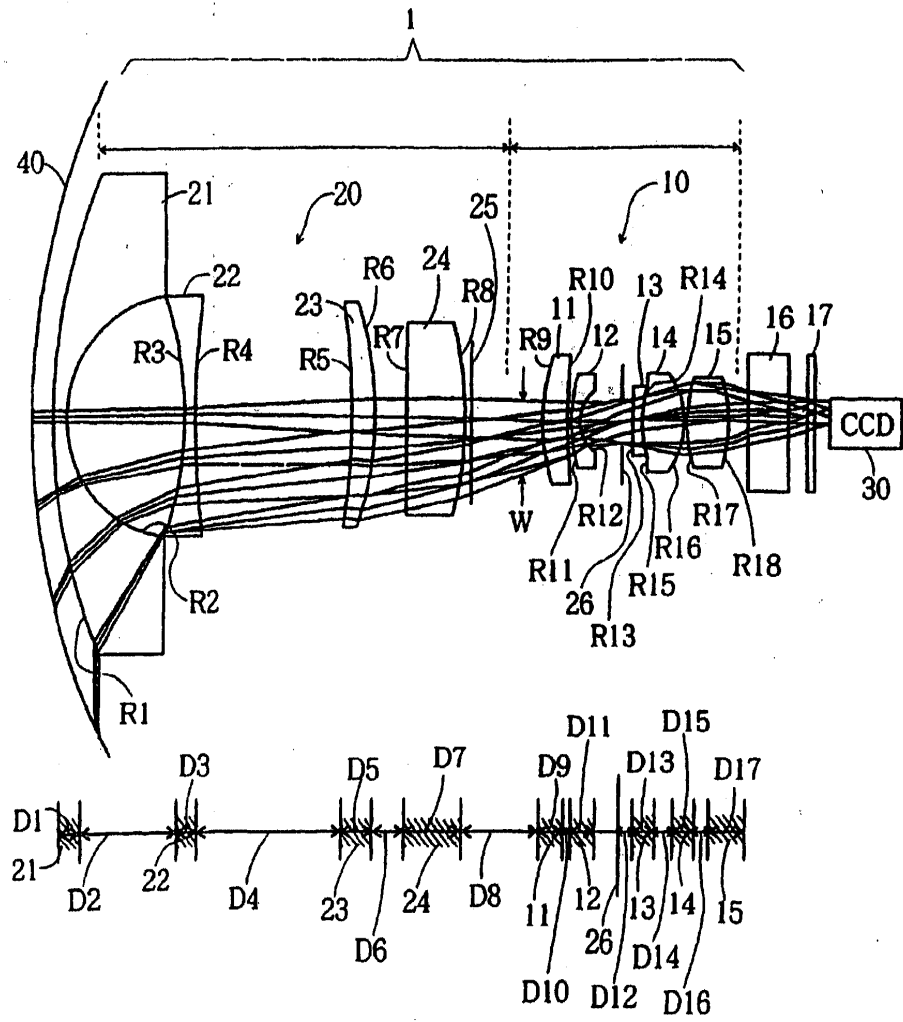


Fig. 1

Fig. 2





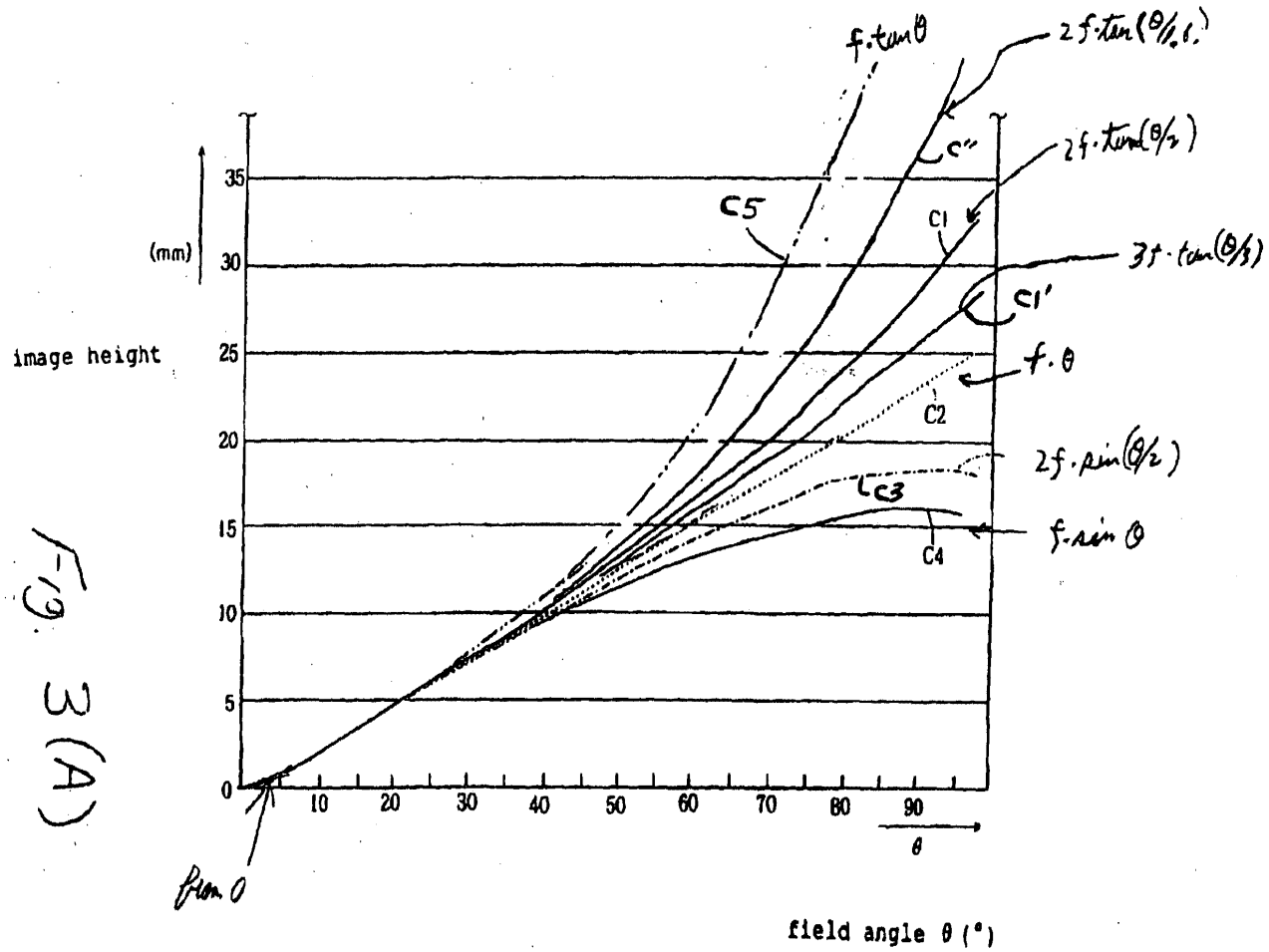


FIG. 3 (A)

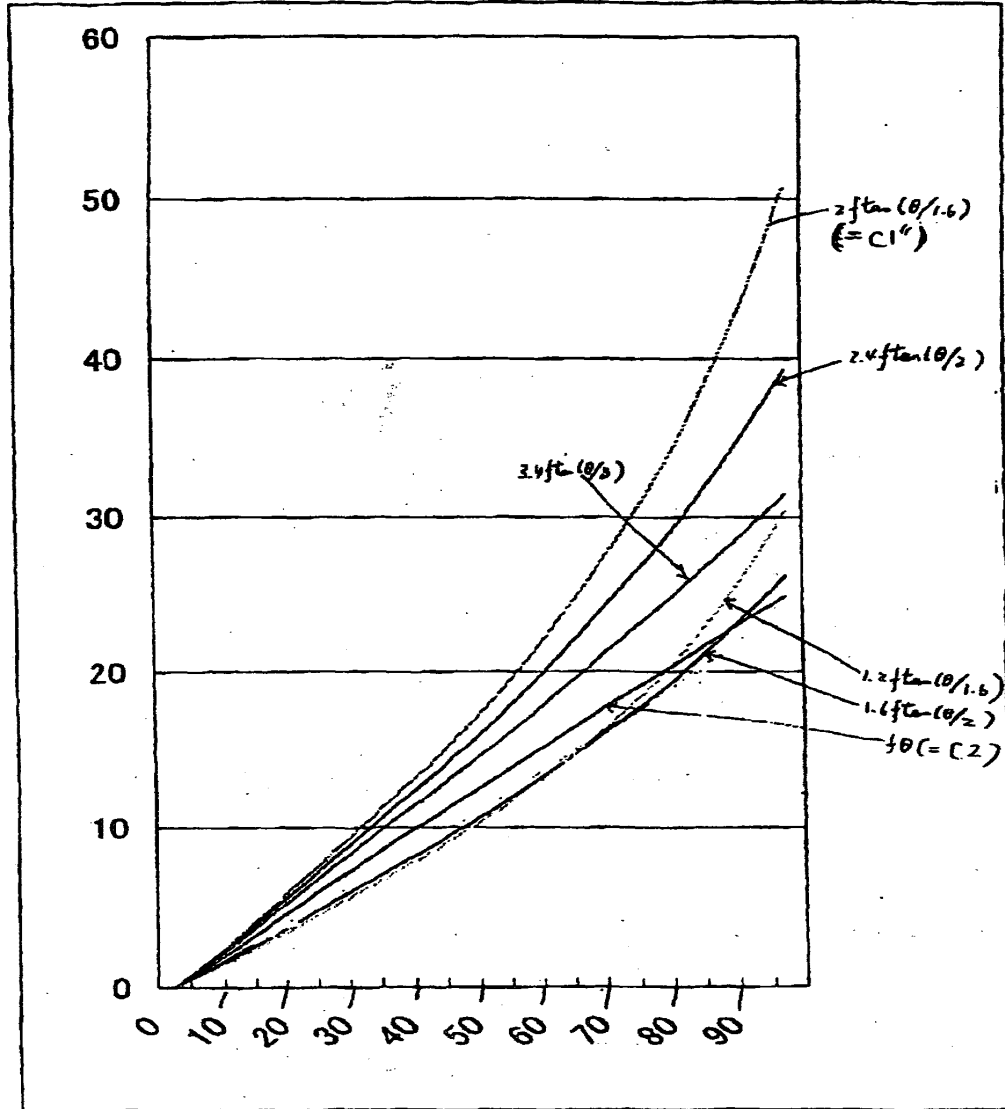
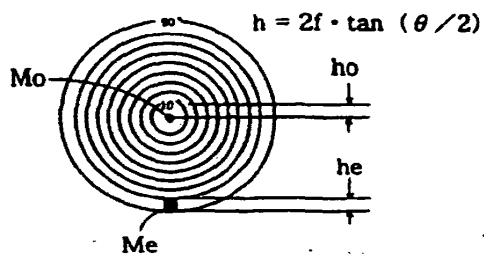


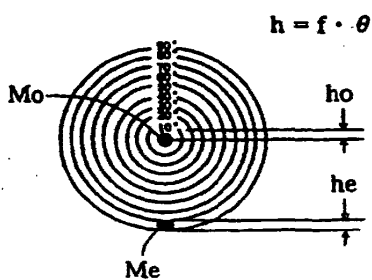
Fig. 3(B)

Fig. 4

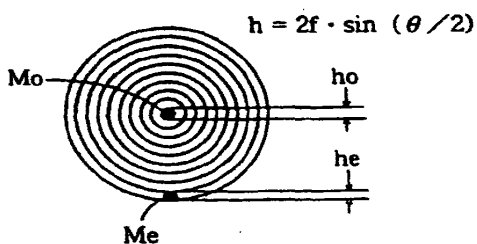
(A)



(B)



(C)



(D)

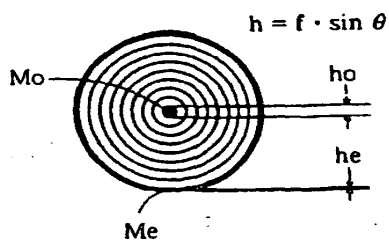


Fig. 5

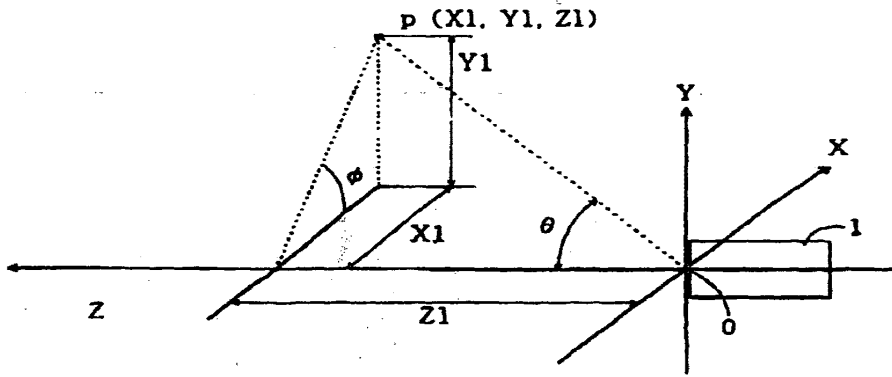


Fig. 6

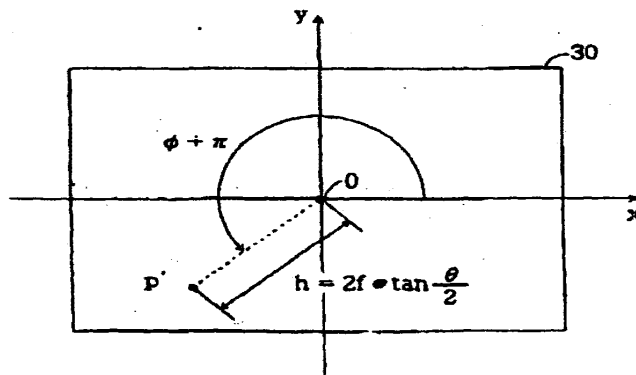


Fig. 7

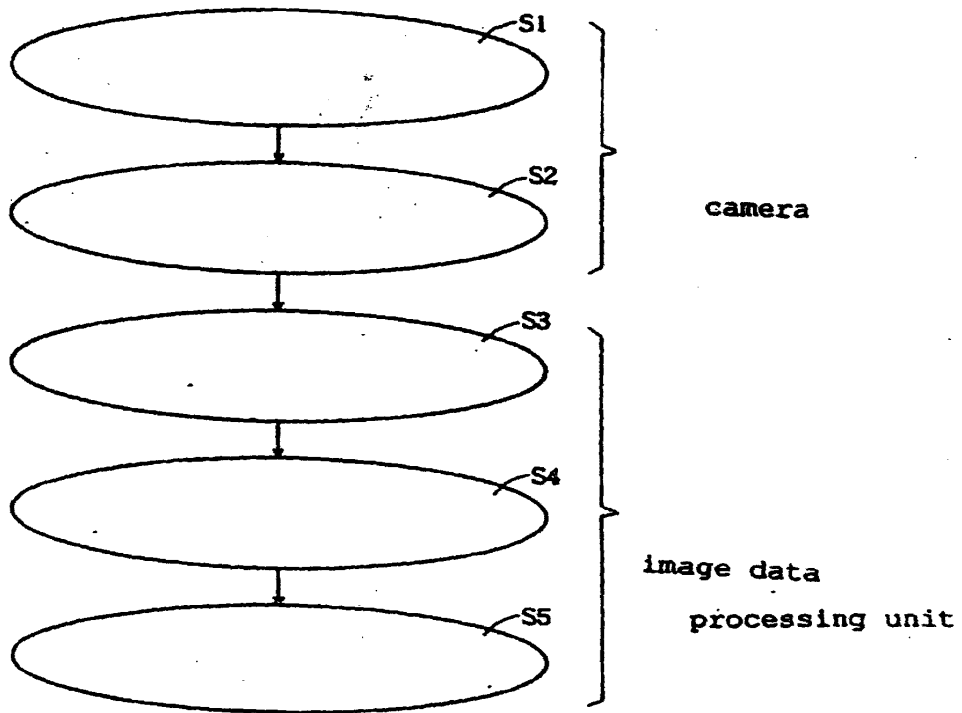
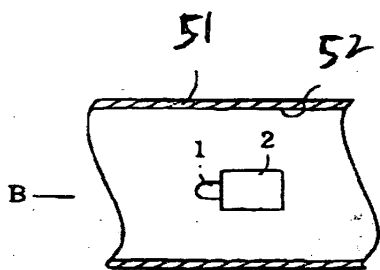


Fig. 8

(A)



(B)

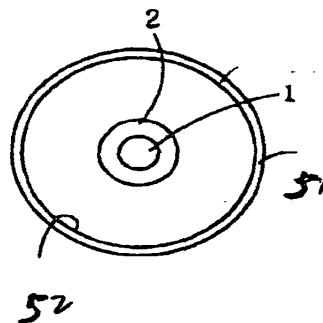
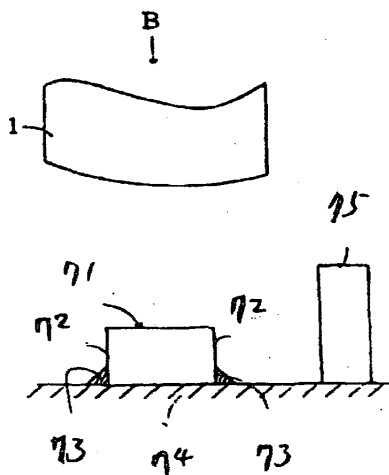


Fig. 9

(A)



(B)

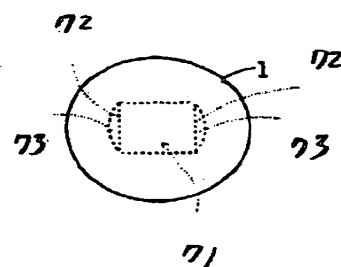
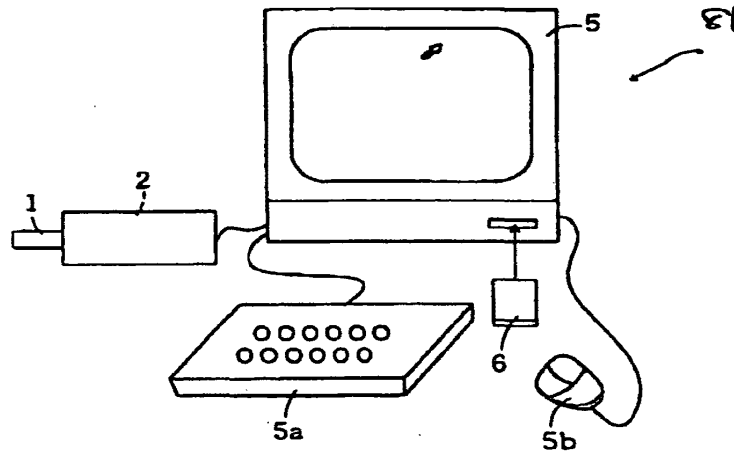


Fig. 10





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	602B13/06
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) 602B
The present search report has been drawn up for all claims			
Place of search <b>THE HAGUE</b>		Date of completion of the search <b>23 February 2000</b>	Examiner <b>THEOPISTOU, P</b>
<b>CATEGORY OF CITED DOCUMENTS</b> X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		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 1833 03/02 (P/4/01)



**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 The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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
US 5686957 A	11-11-1997	US 5508734 A	16-04-1996
		BR 9502919 A	05-03-1996
		CA 2152314 A	28-01-1996
		EP 0695085 A	31-01-1996
		JP 8055215 A	27-02-1996
US 5999660 A	07-12-1999	NONE	

EPO FORM P/468

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

**THIS PAGE BLANK (USPTO)**