BACKGROUND OF THE INVENTION

1. Field of the Invention

One or more embodiments of the invention are related to the field of image analysis and image enhancement, (suggested class 382, subclass 254). More particularly, but not by way of limitation, one or more embodiments of the invention enable an image sequence depth enhancement system and method that allows for the rapid conversion of a sequence of two-dimensional images into three-dimensional images.

2. Description of the Related Art

~~**Prior art patents describing**~~**Known** methods for the colorizing of black and white feature films involved the identification of gray scale regions within a picture followed by the application of a pre-selected color transform or lookup tables for the gray scale within each region defined by a masking operation covering the extent of each selected region and the subsequent application of said masked regions from one frame to many subsequent frames. The primary difference between U.S. Pat. No. 4,984,072, System And Method For Color Image Enhancement, and U.S. Pat. No. 3,705,762, Method For Converting Black-And-White Films To Color Films, is the manner by which the regions of interest (ROIs) are isolated and masked, how that information is transferred to subsequent frames and how that mask information is modified to conform with changes in the underlying image data. In the U.S. Pat. No. 4,984,072 system, the region is masked by an operator via a one-bit painted overlay and operator manipulated using a digital paintbrush method frame by frame to match the movement. In the U.S. Pat. No. 3,705,762 process, each region is outlined or rotoscoped by an operator using vector polygons, which are then adjusted frame by frame by the operator, to create animated masked ROIs.

In both systems the color transform lookup tables and regions selected are applied and modified manually to each frame in succession to compensate for changes in the image data which the operator detects visually. All changes and movement of the underlying luminance gray scale is subjectively detected by the operator and the masks are sequentially corrected manually by the use of an interface device such as a mouse for moving or adjusting mask shapes to compensate for the detected movement. In all cases the underlying gray scale is a passive recipient of the mask containing pre-selected color transforms with all modifications of the mask under operator detection and modification. In these prior inventions the mask information does not contain any information specific to the underlying luminance gray scale and therefore no automatic position and shape correction of the mask to correspond with image feature displacement and distortion from one frame to another is possible.

Existing systems that are utilized to convert two-dimensional images to three-dimensional images generally require the creation of wire frame models for objects in images. The creation of wire frame models is a large undertaking in terms of labor. These systems also do not utilize the underlying luminance gray scale of objects in the images to automatically position and correct the shape of the masks of the objects to correspond with image feature displacement and distortion from one frame to another. Hence, great amounts of labor are required to manually shape

masks for applying depth or Z-dimension data to the objects. Motion objects that move from frame to frame thus require a great deal of human intervention. In addition, there are no known solutions for enhancing two-dimensional images into three-dimensional images that utilize composite backgrounds of multiple images in a frame for spreading depth information to background and masked objects. Hence there is a need for an image sequence depth enhancement system and method.

BRIEF SUMMARY OF THE INVENTION

~~**In the system and method**~~**Embodiments** of the ~~**present**~~ invention~~**,**~~ **classify** scenes to be colorized ~~**are classified**~~**and/or converted from two-dimensional to three-dimensional into movies** into two separate categories; either background elements (i.e. sets and foreground elements that are stationary) or motion elements (e.g., actors, automobiles, etc) that move throughout the scene. These background elements and motion elements are treated separately in this invention similar to the manner in which traditional animation is produced.

Motion Elements: The motion elements are displayed as a series of sequential tiled frame sets or thumbnail images complete with background elements. The motion elements are masked in a key frame using a multitude of operator interface tools common to paint systems as well as unique tools such as relative bimodal thresholding in which masks are applied selectively to contiguous light or dark areas bifurcated by a cursor brush. After the key frame is fully designed and masked, all mask information from the key frame is then applied to all frames in the display-using mask fitting techniques that include:

1. Automatic mask fitting using Fast Fourier Transform and Gradient Decent Calculations based on luminance and pattern matching which references the same masked area of the key frame followed by all prior subsequent frames in succession.

2. Bezier curve animation with edge detection as an automatic animation guide

3. Polygon animation with edge detection as an automatic animation guide

In another embodiment of this invention, these background elements and motion elements are combined separately into single frame representations of multiple frames, as tiled frame sets or as a single frame composite of all elements (i.e., including both motion and backgrounds/foregrounds) that then becomes a visual reference database for the computer controlled application of masks within a sequence composed of a multiplicity of frames. Each pixel address within the reference visual database corresponds to mask/lookup table address within the digital frame and X, Y, Z location of subsequent "raw" frames that were used to create the reference visual database. Masks are applied to subsequent frames based on various differentiating image processing methods such as edge detection combined with pattern recognition and other sub-mask analysis, aided by operator segmented regions of interest from reference objects or frames, and operator directed detection of subsequent regions corresponding to the original region of interest. In this manner, the gray scale actively determines the location and shape of each mask **(**and corresponding color lookup from frame to frame **for colorization projects or depth information for**

two-dimensional to three-dimensional conversion projects) that is applied in a keying fashion within predetermined and operator controlled regions of interest.

Camera Pan Background and Static Foreground Elements: Stationary foreground and background elements in a plurality of sequential images comprising a camera pan are combined and fitted together using a series of phase correlation, image fitting and focal length estimation techniques to create a composite single frame that represents the series of images used in its construction. During the process of this construction the motion elements are removed through operator adjusted global placement of overlapping sequential frames.

~~The~~**For colorization projects, the** single background image representing the series of camera pan images is color designed using multiple color transform look up tables limited only by the number of pixels in the display. This allows the designer to include as much detail as desired including air brushing of mask information and other mask application techniques that provide maximum creative expression. **For depth conversion projects, (i.e., two-dimensional to three-dimensional movie conversion for example), the single background image representing the series of camera pan images is utilized to set depths of the various items in the background.** Once the background color**/depth** design is completed the mask information is transferred automatically to all the frames that were used to create the single composited image. **In this manner, color or depth is performed once per scene instead of once per frame, with color/depth information automatically spread to individual frames via embodiments of the invention.**

~~Image~~**In one or more embodiments of the invention, image** offset information relative to each frame is registered in a text file during the creation of the single composite image representing the pan and used to apply the single composite mask to all the frames used to create the composite image.

Since the foreground moving elements have been masked separately prior to the application of the background mask, the background mask information is applied wherever there is no pre-existing mask information.

Static Camera Scenes With and Without Film Weave, Minor Camera Following and Camera Drift: In scenes where there is minor camera movement or film weave resulting from the sprocket transfer from 35 mm or 16 mm film to digital format, the motion objects are first fully masked using the techniques listed above. All frames in the scene are then processed automatically to create a single image that represents both the static foreground elements and background elements, eliminating all masked moving objects where they both occlude and expose the background.

Where ever the masked moving object exposes the background or foreground the instance of background and foreground previously occluded is copied into the single image with priority and proper offsets to compensate for camera movement. The offset information is included in a text file associated with each single representation of the background so that the resulting mask information can be applied to each frame in the scene with proper mask offsets.

The single background image representing the series of static camera frames is color designed using multiple color transform look up tables limited only by the number of pixels in the display. Where the motion elements occlude the background elements continuously within the series of sequential frames they are seen as black figure that are ignored and masked over. The black objects are ignored during the masking operation because the resulting background mask is later applied to all frames used to create the single representation of the background only where there is no pre-existing mask. This allows the designer to include as much detail as desired including air brushing of mask information and other mask application techniques that provide maximum creative expression. Once the background color design is completed the mask information is transferred automatically to all the frames that were used to create the single composited image. **For depth projects, the distance from the camera to each item in the composite frame is automatically transferred to all the frames that were used to create the single composited image. By shifting masked background objects horizontally more or less, there precise depth is thus set in a secondary viewpoint frame that corresponds to each frame in the scene. Areas where no image data exists for a second viewpoint may be marked in one or more embodiments of the invention using a user defined color that allows for the creation missing data to ensure that no artifacts occur during the two-dimension to three-dimension conversion process. Any technique known may be utilized in embodiments of the invention to cover areas in the background where unknown data exists, i.e., that may not be borrowed from another scene/frame for example. After assigning depths to objects in the composite background, a second viewpoint image may be created for each image in a scene in order to produce a stereoscopic view of the movie, for example a left eye view where the original frames in the scene are assigned to the right eye viewpoint.**

BRIEF DESCRIPTION OF THE DRAWINGS

The patent of application file contains at least one drawing executed in color. Copies of this patent or patent application publication with color drawing(s) will be provided by the Office upon request and payment of the necessary fee.

FIG. 1 shows a plurality of feature film or television film frames representing a scene or cut in which there is a single instance or perceptive of a background.

FIG. 2 shows an isolated background processed scene from the plurality of frames shown in FIG. 1 in which all motion elements are removed using various subtraction and differencing techniques. The single background image is then used to create a background mask overlay representing designer selected color lookup tables in which dynamic pixel colors automatically compensate or adjust for moving shadows and other changes in luminance.

FIG. 3 shows a representative sample of each motion object (M-Object) in the scene receives a mask overlay that represents designer selected color lookup tables in which dynamic pixel colors automatically compensate or adjust for moving shadows and other changes in luminance as the M-Object moves within the scene.

FIG. 4 shows all mask elements of the scene are then rendered to create a fully colored frame in which M-Object masks are applied to each appropriate frame in the scene followed by the background mask, which is applied only where there is no pre-existing mask in a Boolean manner.

FIGS. 5A and 5B show a series of sequential frames loaded into display memory in which one frame is fully masked with the background (key frame) and ready for mask propagation to the subsequent frames via automatic mask fitting methods.

FIGS. 6A and 6B show the child window displaying an enlarged and scalable single image of the series of sequential images in display memory. The Child window enables the operator to manipulate masks interactively on a single frame or in multiple frames during real time or slowed motion.

FIGS. 7A and 7B shows a single mask (flesh) is propagated automatically to all frames in the display memory.

FIG. 8 shows all masks associated with the motion object are propagated to all sequential frames in display memory.

FIG. 9A shows a picture of a face.

FIG. 9B shows a close up of the face in FIG. 9A wherein the "small dark" pixels shown in FIG. 9B are used to calculate a weighed index using bilinear interpolation.

FIGS. 10A–-D show searching for a Best Fit on the Error Surface: An error surface calculation in the Gradient Descent Search method involves calculating mean squared differences of pixels in the square fit box centered on reference image pixel (x0, y0), between the reference image frame and the corresponding (offset) location (x, y) on the search image frame.

FIGS. 11A–-C show a second search box derived from a descent down the error surface gradient (evaluated separately), for which the evaluated error function is reduced, possibly minimized, with respect to the original reference box (evident from visual comparison of the boxes with the reference box in FIGS. 10A, B, C and D,).

FIG. 12 depicts the gradient component evaluation. The error surface gradient is calculated as per definition of the gradient. Vertical and horizontal error deviations are evaluated at four positions near the search box center position, and combined to provide an estimate of the error gradient for that position, 12.

FIG. 13 shows a propagated mask in the first sequential instance where there is little discrepancy between the underlying image data and the mask data. The dress mask and hand mask can be clearly seen to be off relative to the image data.

FIG. 14 shows that by using the automatic mask fitting routine, the mask data adjusts to the image data by referencing the underlying image data in the preceding image.

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