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(54) GENERALIZED PANORAMIC MOSAIC

MOSAIKBILDVERARBEITUNGSSYSTEM

MOSAIQUE PANORAMIQUE GENERALISEE

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EP 0 954 828 B1

Description

FIELD OF THE INVENTION

[0001] This invention relates to video image mosaicing for obtaining panoramic mosaics of a scene.

PRIOR ART

[0002] Prior art references considered to be relevant as a background to the invention are listed below. Acknowledgement of the references herein shall not be inferred as meaning that these are in any way relevant to the patentability of the invention disclosed herein. Each reference by a number enclosed in square brackets and accordingly the prior art will be referred to throughout the specification by numbers enclosed in square brackets.

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BACKGROUND OF THE INVENTION

[0003] The need to combine pictures into panoramic mosaics existed since the beginning of photography, since the camera's field of view is always smaller than the human field of view. Also, very often large objects cannot be captured in a single picture, and only photo-mosaicing enables a more complete view. Digital photography created new applications for mosaicing [14, 15, 16, 4, 24, 23], which were first implemented for aerial and satellite images.

[0004] Three major issues are important in traditional image mosaicing:

(i) Image alignment, which determines the transformation that aligns the images to be combined into a mosaic. Paper photo-mosaicing uses rigid transformations for alignment: picture translations (shifts) and rotations. Digital processing enables more general transformations, like affine or planar-projective.

(ii) Image cut and paste is necessary since most regions in the panoramic mosaic are overlapping, and are covered by more than one picture. The cut and paste process involves either a selection of a single image for each overlapping region, or some kind of a combination of all overlapping images.

(iii) Image blending is necessary to overcome the intensity difference between images, differences that are present even when images are perfectly aligned. Such differences are created by a dynamically changing camera gain.

[0005] The simplest mosaics are created from a set of images whose mutual displacements are pure image-plane translations. This is approximately the case with some satellite images. Such translations can either be computed by manually pointing to corresponding points, or by image correlation methods. Other simple mosaics are created by rotating the camera around its optical center using a special device, and creating a panoramic image which represents the projection of the scene onto a cylinder [7, 11, 12, 13] or a sphere. Since it is not simple to ensure a pure rotation around the optical center, such mosaics can be used only in limited cases.

[0006] In more general camera motions, which may include both camera translations and camera rotations, more general transformations for image alignment are used [5, 8, 9, 10, 18]. In most cases images are aligned pairwise, using a parametric transformation like an affine transformation or planar-projective transformation (see, for example, [26]). These transformations include an intrinsic assumption regarding the structure of the scene, such as being planar. A reference frame is selected, and all images are aligned with this reference frame and combined to create the panoramic mosaic. These methods are therefore referred to as reference frame based methods.

[0007] Aligning all frames to a single reference frame is reasonable when the camera is far away and its motion is mainly a sideways translation and a rotation around the optical axis. Significant distortions are created when camera motions include other rotations. Fig. 1 shows the effects of large rotations on reference frame based methods. The objects a, b, x, y, c, d, w, z are viewed from two cameras C_1 and C_2. The image I_1 is selected to be a reference frame and image I_2 is projected onto that reference frame. Large rotations generate distortions when projecting on the reference frame, and the information derived from frames with such rotations is bluffed, and almost useless. Moreover, in long sequences in which the camera is traveling in a complex path, one frame can not be used for long as a reference frame, and projection of the entire sequence onto that frame becomes impractical.

[0008] The manifold projection method was introduced in [25], where a mosaic is constructed by scanning a scene with a one-dimensional, straight array.

[0009] However, none of the above methods can handle cases where images cannot be aligned due to parallax, or cases of zoom and forward motion.

[0010] Manifold Projection simulates the sweeping of a scene using a linear one-dimensional sensor array, see Fig. 2. Such a one-dimensional sensor can scan the scene by arbitrary combinations of rotations and translations, and in all cases the scanning will result in a sensible panoramic image if it could be figured out how to align the incoming one-dimensional image strips. Some satellite images are created by scanning the earth with a one-dimensional sensor array using a rotating mirror. Since in this case the alignment of the sensors can be done using the location of the satellite and the position of the mirror, panoramic two-dimensional images are easily obtained. Fig. 2 shows aerial photography with a linear one-dimensional scan system.

[0011] In more general cases the motion of the sweeping plane may not be known. It seems impossible to align the one-dimensional image strips coming from an arbitrary plane sweep, but the problem becomes easier when the input is a video sequence. A two-dimensional frame in a video sequence can be regarded as having a one-dimensional strip somewhere in the center of the image ("center strip"), embedded in the two-dimensional image to facilitate alignment. The motion of the sweeping plane can then be computed from the entire image, and applied on the center-strip for alignment and mosaicing.

[0012] The image transformations of the one-dimensional strips generated by the sweeping plane are only rigid transformations: image plane translations and rotations. Therefore, rigid transformations are also the transformations used in manifold projection. It should be noted that general camera motions induce, in general, non-rigid image-plane transformations. However, to simulate the plane sweep only rigid transformations are used for the center-strip.

[0013] The panoramic mosaic generated by combining the aligned one-dimensional center-strips forms the manifold projection. This is a projection of the scene into a general manifold, which is a smooth manifold passing through the centers of all image planes constructing the mosaic. In the case of pure camera translations (Fig. 3a), manifold projections turn out to be a parallel projection onto a plane. In the case of pure camera rotations (Fig. 3b), it is a projection onto a cylinder, whose principal axis is the rotation axis. But when both camera translations and rotations are involved, as in Fig. 3c, the manifold is not a simple manifold any more. In Figs. 3a, 3b and 3c the camera is located at the tip of the "field-of-view" cone, and the image plane is marked by a solid segment. The ability to handle such arbitrary combinations of camera rotations and translations is the major distinction between manifold projection and all previous mosaicing approaches.

[0014] The Proceedings of first ACM international conference on multimedia, 2-6 August 1993, Anaheim, CA, US, "Salient Video Stills: Content and Context Preserved" relates to images called salient stills..These images do not represent one discrete moment of time, as do a photograph or single video frame. By the application of an affine transformation and nonlinear temporal processing, multiple frames of an image sequence, which may include variations in focal-length of field-of-view, are combined to create a single still image. The images are warped so that the entire overlap between the images has the best possible match.

[0015] In view of the foregoing, it should be apparent that there exists a need to provide a method for the creation of panoramic image mosaics in cases not treated in the prior art. Such cases involve camera translations with image parallax; forward motion; camera motions that are combinations of translations and rotations; and camera zoom.

SUMMARY OF THE INVENTION

[0016] It is important to note that whenever the terms "video", "movie", "frame", "picture", or "image" are used, they refer to any representation of a picture or a movie (motion picture). A still picture can be recorded on film by a traditional camera, by a digital camera, by a scanner, or any other device that records still images. A video (or a motion picture) can be recorded by a film camera, an analog or a digital videotape, or any other device that records motion pictures. The area of image mosaicing in general, and this invention in particular, is applicable to all forms of images which can be manipulated by appropriate devices, whether mechanical, optical, digital, or any other technology.

[0017] Panoramic mosaics are constructed by combining strips from the image sequence. In accordance with the present invention, the shape, size and position of the strips are determined for each image in accordance with the type of camera motion. The strips are cut from the images, and pasted into the panoramic mosaic after being transformed, such that the resulting mosaic remains continuous.

[0018] In accordance with the present invention, the following constraints are preferably (but not necessarily) used in order to deal with general image plane transformations:

(a) the strips should be approximately perpendicular to the optical flow.
(b) the strips collected for pasting should be warped before pasting into the panoramic image so that after warping their original optical flow, it becomes approximately parallel to the direction in which the panoramic image is constructed.

[0019] Under these conditions, cases of zoom and forward motion can be handled as well as the other simple cases. For example, in the case of zoom or forward motion, these properties enable cutting circular strips, and proper bending of them before pasting into the panoramic image.

[0020] This invention also describes how to determine the width of the strips. For example, in order to handle image parallax properly, the size of the strips can be determined from the camera's three-dimensional motion, as can be computed from the sequence itself, or as can be measured by external devices.

[0021] To enable smooth mosaics even when frames to be combined are taken from different viewpoints, and have substantial parallax, views can be synthesized for in-between camera positions. For smoothest mosaics the number of in-between camera positions is selected such that the strip is narrow, e.g. having a width of a single pixel.

[0022] The present invention provides for a method for combining a sequence of two-dimensional images of a scene for obtaining a panoramic mosaic of said scene, said sequence of two-dimensional images being acquired by a moving camera in relative motion with respect to said scene, said relative motion giving rise to an optical flow between the images, wherein at least a part of the optical flow vectors is unparallel to each other, the method comprising: a) warping said images so that the direction of the optical flow vectors becomes substantially parallel to each other and to a direction in which said mosaic is constructed; b) pasting said warped images so that said sequence of two-dimensional images is continuous for said scene, whereby to construct said panoramic mosaic of said scene.

[0023] The invention still further provides for combining a sequence of two-dimensional images of a scene for obtaining a panoramic mosaic of the scene, said sequence of two-dimensional images being acquired by a moving camera in relative motion with respect to the scene, said camera motion giving rise to an optical flow between the images, the method comprising the steps of: a) selecting for each image of said sequence of two-dimensional images at least one family of lines perpendicular to said optical flow and defining strips having a front edge, through which said optical flow enters, and a back edge, through which said optical flow exits, in order that each strip be substantially perpendicular to said optical flow; b) warping the strips, to create non-rectangular strips, in order that said optical flow becomes substantially parallel to a direction in which said mosaic is constructed; and c) pasting said non-rectangular strips in order that said sequence of two-dimensional images be continuous for said scene,whereby said panoramic mosaic of the scene is constructed.

[0024] By one embodiment the method further comprises the step of: (a') warping the front edge of a strip defined on a two-dimensional image so that it is substantially aligned with the back edge of a strip defined on an adjacent two-dimensional image.

[0025] By another embodiment the strips are transformed by warping into strips having edges of arbitrary shape before the strips are pasted together.

[0026] By yet another embodiment the strips are transformed by warping into strips having straight edges before the strips are combined together.

[0027] According to yet another embodiment the two-dimensional images are related by an affine transformation or by a planar-projective transformation.

[0028] According to another embodiment said images are projected onto a three-dimensional cylinder whose major axis approximates the path of the camera centers of said images, the combination of the strips is achieved by translating the projected two-dimensional images substantially along the cylindrical surface of the three-dimensional cylinder.

[0029] According to yet another embodiment every two subsequent images define their own cylinder whose major axis substantially passes through the centers of the cameras of said images, and the cylinders are concatenated substantially along the image sequence.

[0030] According to still another embodiment a transformation is applied to the panoramic mosaic depending on a desired viewpoint.

[0031] According to a further embodiment the sequence of images is augmented by sets of interpolated images intermediate to the images of the sequence of images, and the strips are augmented with strips defined on the interpolated images.

[0032] According to another embodiment the system further combines a sequence of two-dimensional images of a scene to obtain a panoramic mosaic of said scene, said sequence of images being acquired by a camera in relative motion with respect to said scene, said relative motion giving rise to an optical flow between said images, wherein at least a part of the optical flow vectors is unparallel to each other, the system comprising: a warper for warping the images so that the direction of the optical flow vectors between said images becomes substantially parallel to each other and to a direction in which the mosaic is constructed; and a paster for pasting said warped images so that said sequence of two-dimensional images is continuous for said scene.

[0033] Still further, the invention provides for combining a sequence of two-dimensional images of a scene for obtaining a panoramic mosaic of said scene, said sequence of two-dimensional images being acquired by a moving camera in relative motion with respect to said scene, said camera motion giving rise to an optical flow between the images, the system comprising: a selector for selecting for each image of said sequence of two-dimensional images at least one family of lines perpendicular to said optical flow and defining at least one strip having a front edge, through which said optical flow enters, and a back edge, through which said optical flow exits, so that each strip is substantially perpendicular to said optical flow; a warper for warping said strip to create non-rectangular strips, so that said optical flow becomes substantially parallel to a direction in which said mosaic is constructed; a paster for pasting said non-rectangular strips so that said sequence of two-dimensional images is continuous for said scene.

[0034] Still yet further the invention provides a memory containing a file representing a panoramic mosaic of a scene.

[0035] The process described herein can alternatively be interpreted using three-dimensional projections of the images onto cylinders ("pipes") whose principal axis is the direction of camera motion. Such projections create warpings of the images such that the optical flow becomes parallel.

BRIEF DESCRIPTION OF THE DRAWINGS

[0036] For a better understanding the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 shows the effects of large rotations on reference frame based methods;
Fig. 2 shows aerial photography with a one-dimensional scan system;
Fig. 3a shows manifold projection for a camera performing pure translation, the projection is a parallel projection onto a plane;
Fig. 3b shows manifold projection for a camera performing pure rotation, the projection is onto a cylindrical manifold;
Fig. 3c shows manifold projection for a camera performing both translation and rotation, the projection is onto a manifold not having a simple geometrical form;
Fig. 4 shows a general flow chart of the principle steps of the panorama production process of the invention;
Fig. 5 shows the effects of parallax on the alignment and merging processes;
Fig. 6 shows a mosaic built from images taken by a camera in sideways motion using vertical linear strips perpendicular to the camera's optical axis and to the optical flow which is from right to left as the camera translates from left to right according to a known method.
Fig. 7a shows a mosaic built from images taken by a camera in forward motion with translation along the optical axis of the camera, and optionally with zoom; the optical flow is radial from the center of the image to the outside, and the strips are circular;
Fig. 7b shows the result of applying to an entire image the transformation that "bends" the strips;
Fig. 8 shows a mosaic built from images taken by a camera in translation from left to right along a line making an intermediate angle (between 0 and 90 degrees) with the optical axis; the optical flow is radial from the focus of expansion which is located to the right of the image, and the strips are circular or elliptic arcs;
Figs. 9 show the shape of strips for different cases of affine motion:

- **Fig. 9a** a straight vertical strip for horizontal motion;
- **Fig. 9b** a straight horizontal strip for vertical motion;
- **Fig. 9c** a circular strip for forward motion;
- **Fig. 9d** an elliptical strip for general motion;

Figs. 10 show an example of cutting and pasting strips for the case of affine motion:

- **Figs. 10a-c** shows strips that are perpendicular to the optical flow. Line F2 is selected in Image I2 and Line F3 is selected in Image I3. The mapping of Line F3 (in I3) into Image I2 using the same affine transformation is Line F3'. The strip S2 taken from Image I2 is bound between lines F2 and F3';
- **Fig. 10d** shows strips that are warped and pasted so that the optical flow becomes parallel, their back is fixed (e.g. F2 in strip S2) and their front (e.g. F3' in strip S2) is warped to match the back of the next strip;

Fig. 11 shows the projection of an image onto a pipe in order to achieve parallel optical flow;

Fig. 12a shows the selection of strips from different images according to the resolution obtained from each image when projecting the images onto a pipe;

Fig. 12b shows the concatenation of pipes in the case of complex camera path;

Fig. 13 shows the choice of strip width required to preserve the original resolution for the case of pure rotation; and

Fig. 14 shows the choice of strip width required to preserve the original resolution for the case of pure translation.

Fig. 15 shows the generation of a panoramic image using view interpolation by generating synthetic views from intermediate camera positions and by taking narrow strips from each intermediate view tg construct the mosaic; for either the case of translation, P_1, or for the case of rotation, P_2;

Fig. 16 shows the generation of consistent panoramic mosaics in the presence of parallax;

DETAILED DESCRIPTION OF THE INVENTION

[0037] Attention is first drawn to Fig. 4 showing a general flow chart of the principle steps of the panorama production process according to an embodiment of the invention. Motion recovery is performed at step **401**. This step can use the images as well as any external motion information. New views synthesis is performed at step **402**. This step can use the input images, and motion information. Determining the strip size is performed at step **403**. This step can also use the motion information. Determining the strip shape is performed at step **404**. The cut and paste process is performed at step **405.** This step can use the input images, the synthetic images for the intermediate views, the motion information, the strip size, and the strip shape. The result of this process is a realistic panorama. Steps **402, 403**, and **404** are optional, and incorporating any of these steps is a process covered by this invention.

[0038] A detailed example of the method of the present invention will be given and applied to the very common case, in which the motion between every two successive images can be modeled as a two-dimensional affine motion. This covers most simple scenarios, and also zoom and forward motion in cases of planar scene, parallel to the image plane. Generated mosaics have minimal distortions compared to the original images, as no global scaling is performed.

[0039] A possible geometric interpretation of the method of the invention will be given for general camera translation. This is done using a projection we call Pipe Projection. This Pipe projection can be used as an implementation of the proposed method when three-dimensional camera motion can be recovered. This interpretation of the method demonstrates the way strips can be collected and transformed, in such a way that complicated cases of oblique view can still be handled well by the proposed method.

[0040] The suggested three-dimensional interpretation of the method is that images in a video sequence are transformed by an oblique projection of the image onto a *viewing pipe* whose central axis is defined by the trajectory of the camera. After this transformation the optical flow between frames becomes parallel, and the frames can be easily mosaiced along the viewing pipe, using simple cut and paste. The *pipe mosaic* generated this way includes most of the details observed by the moving camera, where each region is taken from that image where it was captured at highest resolution. Viewing this pipe mosaic from various directions can give equivalent results to the various mosaics achieved using two-dimensional implementation.

SHAPE OF STRIPS

[0041] With no parallax and with pure image translation the construction of the panorama from the images is simple. Since over an overlap area between two images the alignment is very good, any selection of the particular image that will cover any given region is usually not critical. The shape of the strip becomes important in cases without parallax mostly with image magnification like in the case of zoom. But with image parallax, alignment over an overlap area between images will not be perfect, and the selection of which image will cover an area in the panorama becomes critical.

[0042] Fig. 5 shows the effects of parallax on the alignment and merging processes. Objects A, B, C, D, E are located on a planar surface at the top of the figure. Objects C, X, and Y induce parallax in the two input images I_1 and I_2 taken by a translating camera at C_1 and C_2. Either objects C, X, or Y can be used as aligned regions, thus giving three different ways to create panoramic images, shown as P_1, P_2 and P_3 at the bottom of the figure.

[0043] The mosaicing process can be presented as cutting "strips" from each image, and pasting those strips to a larger panorama. It will be shown that the type of camera motion determines the shape of these strips. This is in contrast to prior suggestions to use a "Voronoi Tessellation" to create the panoramic mosaic from the images, a suggestion that does not take into account at all the three-dimensional camera motion, but only the two-dimensional image displacement of the image centers.

[0044] For example, better mosaicing will result if the boundaries of the strips are taken to be approximately perpendicular to the "optical flow" (local image displacement) generated by the camera motion. Examples are camera translations: sideways motion, forward motion, and a general translation; as well as camera zoom.

[0045] The case of sideways motion was already addressed in [25]. In this case, as shown in Fig. 6, the strips are linear or rectangular at the center of the images. Given three input frames, **601**, **602**, and **603**, panoramic mosaic **604** is generated by taking strip S 1 from image **601**, strip S2 from image **602**, and strip S3 from image **603**. The images are aligned so that region S1 in image **601** matches region S1 in image **602**, region S2 in image **602** matches regions S2 in images **601** and **603**, and region S3 in image **603** matches region S3 in image **602**.

[0046] In the cases of forward motion and of zoom the strips cannot be bound by straight lines. In these cases the strips are preferably circular, centered at the focus of expansion of the image. In the example shown in Fig. 7a, the focus of expansion is located at the center of the image. Panoramic mosaic **704** will be created by "unfolding" strip S 1 from image **701**, strip S2 form image **702**, and strip S3 from image **703**, and placing them adjacent to each other.

[0047] When the strips are wide, "unfolding" them (by warping) will create a non-rectangular strip. Also, strips will not be aligned due to scale difference across seams. In this case each strip can be rescaled to a rectangular strip, thus giving the continuous panoramic mosaic **705** from panoramic mosaic **704**. Such reseating will improve alignment across seams. The place where the circle is "opened" before its unfolding is arbitrary, and possibly determined by the direction in which the panoramic mosaic is constructed. The constructed mosaic image can be considered as the surface area of a cylinder as will be described in greater detail below with reference to the three-dimensional interpretation of the method.

[0048] It should be noted that the "unfolding" of the circular strips into straight strips might cause mosaic **705** to look distorted. It is expected that only sub-parts will be used from such mosaics, for example the part that relates to the top of the image or the part that relates to the left side of the image, etc. Such a part will usually be a rectangular sub-strip of mosaic **705.** Before such a part is displayed the mosaic can be rectified by "bending" its straight sides into arcs of a circle whose radius, for example, can be the outside radius of the original circular strip (e.g. strip S3 in image **703**).

[0049] The transformation that mapped strip S1 in image **701** into strip S1 in mosaic **705** turns radial optical flow, in image **701**, into parallel optical flow, in image **705**. If the same transformation is applied to the entire image **701**, instead of just to strip S1, the transformed image will have the shape shown in Fig. 7b. As will be described in greater detail below, such transformations can be modeled by the three-dimensional interpretation using the projection onto a cylinder.

[0050] The case of camera zoom is of special interest. Whilst zooming towards a distant scene, and mosaicing as in Fig. 7a will create a mosaic image with higher resolution in locations relating to the center of the image, the case of a camera viewing objects from the side is different. Assume the camera is located at the side of a very long wall, with the optical axis parallel to the wall (Fig. 7). In this case the closest parts of the wall are seen in great detail at the edge of the image, while the distant parts of the wall are seen smaller closer to the center of the image. When zooming in, the further parts are magnified and get closer to the edge of the image, and the mosaic will therefore become a reconstruction of the wall at the highest possible resolution. Under some conditions the wall can even be reconstructed as viewed from the front, with uniform resolution all over.

[0051] In a more general case of camera translation, shown in Fig. 8, there can be any angle between the direction of camera motion and the optical axis. In this example the optical flow can be radial from the focus of expansion, which is located somewhere outside the image, and therefore the preferred shape for the strip is a circular or an elliptic arc. Given three input frames, **801**, **802**, and **803**, panoramic mosaic **804** is generated by taking strip S1 from image **801**, strip S2 from image **802**, and strip S3 from image **803**. The images are aligned so that strip S1 in image **801** matches strip S1 in image **802,** strip S2 in image **802** matches strips S2 in images **801** and **803**, and strip S3 in image **803** matches strip S3 in image **802**.

[0052] The strips in the input images, like strip S1 in image **801** and strip S2 in image **802,** are bounded by arcs of concentric circles centered at the focus of expansion. Since the radii of the two circles are different, their curvatures are different, and the strips can not be pasted together without gaps forming between the edges of the strips. In order to achieve pasting the strips without the formation of gaps the strips are warped before pasting.

[0053] Strip **810** displays an example of an original circular strip as cut from an input image. The radius r_1 of left arc **811** is larger than the radius r_2 of right arc **812**, which is closer to the focus of expansion. Strip **810** can be warped to yield strip **820**, which has the following properties: arc **821** and arc **822** are both of radius r_1; the length of arc **821** is the same as the length of arc **811**; the length of arc **822** is the length of arc **812** multiplied by r_1/r_2. This arrangement assures not only that the strips will fit without gaps, but also that features of the image will be resized properly for better alignment across the seam.

[0054] Even though the above discussion on the shape of the strip assumes a uniform camera motion along a sequence, camera motion can change, affecting the shape of the strip. Assume, for example, a forward motion between frame I_1 and frame I_2, and a sideways motion between frame I_2 and frame I_3. The strip taken from frame I_2 can have a circular arc boundary on the side of frame I_1, and a straight line boundary on the side of frame I_3.

EXAMPLE: MOSAICING FOR AFFINE MOTION

[0055] An example of strip shaping for the special case of affine motion will now be described. Affine motion is based on an affine transformation and affords a good approximation for many types of motion. Based on the detailed description given below it will be apparent to a person skilled in the art that other types of motion can be dealt with in a similar manner.

[0056] The affine transformation can be expressed as follows:

$$\begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} x_n - x_{n-1} \\ y_n - y_{n-1} \end{pmatrix} = \begin{pmatrix} a + bx_n + cy_n \\ d + ex_n + fy_n \end{pmatrix} \qquad (1)$$

where $P_{n-1} = (x_{n-1}, y_{n-1})$ and $P_n = (x_n, y_n)$ are the coordinates of corresponding points in images I_{n-1} and I_n, and the parameters of the affine transformation A are (a, b, c, d, e, f). (u, v) is the optical flow vector as a function of position (x_n, y_n). The transformation A (and the optical flow) vary continuously along the sequence of images. Numerous methods exist to recover the parameters of an affine transformation [21, 18] and they will not be described here.

[0057] In accordance with the method of the present invention, in order to define the shape of a strip, it is required to find a line $F(x,y) = 0$ which is perpendicular to the optical flow. It should be noted that this line is not necessarily a straight line, and can be a curved line. The normal to the line F = 0 is in the direction

$$\left(\frac{\partial F}{\partial x}, \frac{\partial F}{\partial y} \right),$$

and thus should be in the same direction as (u, v). This constraint can be expressed as follows:

$$\begin{pmatrix} \frac{\partial F}{\partial x} \\ \frac{\partial F}{\partial y} \end{pmatrix} = k \begin{pmatrix} u \\ v \end{pmatrix} = k \begin{pmatrix} a + bx + cy \\ d + ex + fy \end{pmatrix} \qquad (2)$$

for some value of k. By integrating, when e = c we get the line equation:

$$0 = F(x,y) = ax + dy + \frac{b}{2}x^2 + \frac{c+e}{2}xy + \frac{f}{2}y^2 + M \qquad (3)$$

[0058] Note that this line equation exists only when e = c. In most cases, the difference between the values of c and e is due to the rotation of the image around the optical axis by ω *(angle in radians),* such that it contributes $-\omega$ to c, and $+\omega$ to e. To approximately satisfy the condition $e \approx c \approx \frac{e+c}{2}$ it is therefore possible to rotate the image about its center by $\omega \approx \frac{e-c}{2}$ after the affine transformation is recovered, and then recompute the affine transformation.

[0059] As a result, Equation 3 defines a family of lines that are all perpendicular to the optical flow. M is used to select a specific line. It is suggested that M be set equal to the value for which the line contains a maximum number of pixels within the image. If many options exist, then it is suggested that a line be selected as close as possible to the center of the image so as to minimize lens distortions. This selection should ensure that pixels used in the mosaic will be from that image having the best resolution at that location.

[0060] Equation 3 can be easily understood for some simple cases:

(i) In the case of a uniform horizontal optical flow (either a small pan or a sideways translation of the camera), the affine transformation A takes the form $A = (a, 0, 0, 0, 0, 0)$, thus the selected line **901** becomes $0 = F(x,y) = ax + M$, which is a straight vertical line (See Fig. 9a).

(ii) In the case of a uniform vertical optical flow (either a small tilt or a vertical translation of the camera), the affine transformation takes the form $A = (0, 0, 0, d, 0, 0)$, thus the selected line **902** becomes $0 = F(x,y) = dy + M$, which is a straight horizontal line (See Fig. 9b).

(iii) In the case of zoom or forward motion (towards a planar surface which is parallel to the image plane), the affine transformation takes the form A = $(0, b, 0, 0, 0, f)$, where b is a scaling factor ($f = b$). As a result, the selected line

903 becomes $0 = F(x, y) = \frac{b}{2}(x^2 + y^2)+M$, which is a circle around the center of the image **904** (see Fig. 9c).

[0061] For general translations of the camera the line will be a circle around the focus of expansion. In more general cases the line may be approximated by an elliptic curve **905**: $0 = F(x,y) = ax + dy + \frac{b}{2}x^2 + \frac{s}{2}y^2 + cxy + M$ (see Fig. 9d).

[0062] The mosaic is constructed by pasting together strips taken from the original images. The shape of the strip, and its width, depend on the image motion. An example will now described of how to determine these strips in the case of an affine motion to conform to the methodology of the selection of best resolution. Strip selection for other types of image motion can be performed in a similar manner.

[0063] The following notation will be used to describe the strip collection along the sequence of images: the line $F_n (x_n, y_n) = 0$ is the line in image I_n, in its coordinate system, which is perpendicular to the optical flow described by the affine transformation $A_n = (a_n, b_n, c_n, d_n, e_n, f_n)$. This affine transformation A_n relates points p_n in image I_n to corresponding points p_{n-1} in image I_{n-1}.

[0064] In order to determine the strip to be taken from image I_n, the preceding frame I_{n-1}, and the succeeding frame I_{n+1}, should be considered. Let A_n be the affine transformation relating points $p_n = (x_n, y_n)$ in image I_n to the corresponding points $p_{n-1} = (x_{n-1}, y_{n-1})$ in image I_{n-1}, and let A_{n+1} be the affine transformation relating points $p_{n+1} = (x_{n+1}, y_{n+1})$ in image I_{n+1} to the corresponding points $p_n = (x_n, y_n)$ in image I_n.

[0065] Given the affine transformations A_n and A_{n+1}, the lines $F_n(x_n, y_n) = 0$ and $F_{n+1}(x_{n+1}, y_{n+1}) = 0$ are selected respectively (see Figs. 10a to 10c). The line $F_n(x_n,y_n) = 0$ in I_n corresponds to the line $F'_n(x_{n-1}, y_{n-1}) = 0$ in I_{n-1} using the affine transformation A_n. In the same way, the *line* $F_{n+1}(x_{n+1}, y_{n+1}) = 0$ in I_{n+1} corresponds to the line $F'_{n+1}(x_n, y_n) = 0$ in I_n using the affine transformation A_{n+1}.

[0066] The strip that is taken from the image I_n is bounded between the two lines $F_n(x_n,y_n) = 0$ and $F'_{n+1}(x_n, y_n) = 0$ in I_n (see Figs. 10a to 10c). For example, in Fig. 10b, line F2 is selected in image I2, and in Fig.10c line F_3 is selected in image 13. The mapping of line F3 (in I3) into image I2 using the affine transformation is line F3'. Hence the strip S2 taken from image 12 in Fig. 10b is bounded between lines F2 and F3'. It should be noted that the strips S1, S2, and S3 are perpendicular to the lines of optical flow 1001.

[0067] Using this selection, the first boundary of the strip will be defined by the selected line F_n, thus will be exactly orthogonal to the optical flow with regard to the previous image. The second boundary of the strip is defined by the line F'_{n+1} which is the projection of the line F_{n+1} onto the current image I_n, having the same property in the next image.

[0068] This selection of the boundaries of the strip ensures that no information is missed nor duplicated along the strip collection, as the orthogonality to the optical flow is retained.

[0069] Consider the common approach to mosaicing where one of the frames is used as a reference frame, and all other frames are aligned to the reference frame before pasting. In term of strips, the first strip is put in the panoramic image as is. The second strip is warped in order to match the boundaries of the first strip. The third strip is now warped to match the boundaries of the *already warped* second strip, etc. As a result, the mosaic image is continuous. However, major distortions may be caused by the accumulated warps and distortions. Large rotations cannot be handled, and cases such as forward motion or zoom usually cause unreasonable expansion (or shrinking) of the image.

[0070] To create continuous mosaic images while avoiding accumulated distortions, it is proposed by this invention that the warping of the strips should depend only on the adjacent original frames, independent of the history of previous distortions.

[0071] In accordance with the present invention, it is preferable that one side of each strip, e.g. the back side, is not being warped. This is the side of the strip that corresponds to the boundary between image I_{n-1} and image I_n and defined by F_n. For example, in Fig. 10b, line F2 is the back of strip S2 of image 12. The front of the strip is warped to match the back side of the next strip. This is the boundary between image I_n and image I_{n+1} which is defined by F'_{n+1}. For example, in Fig. 10b, the line F3' is the front of strip S2 of image 12.

[0072] In the example described in Fig. 10d, the first strip S1 is warped such that its left side (i.e., back side) 1002 does not change, while its right side (i.e., front side) 1003 is warped to match the left side of the original second strip S2. In the second strip S2, the left side 1004 does not change, while the right side 1005 is warped to match the left side 1006 of the third strip S3, etc.

[0073] As a result, the constructed image is continuous. Also, if the original optical flow is warped as by the same warping as that performed on the strips, the resulting flow will become approximately parallel to the direction in which the panoramic mosaic is constructed. Moreover, no accumulative distortions are encountered, as each strip is warped to match just another original strip, avoiding accumulative warps.

POSSIBLE THREE-DIMENSIONAL INTERPRETATION OF STRIP SHAPING

[0074] In general camera motion, the optical flow is induced by camera translation and by camera rotation. The rotational part can be recovered and compensated for if needed, as it does not depend on the structure of the scene (see, for example, [17]). Camera translation (and zoom) induces radial optical flow emerging from the focus of expansion, except for the singular case of sideways translation in which the optical flow is parallel.

[0075] Cases of radial optical flow are much more complicated for mosaicing since the optical flow is not parallel, and depends on the structure of the scene.

[0076] In accordance with the present invention, an example of a possible three-dimensional interpretation of the proposed mosaicing method is presented. It is also possible to use the following description to implement the mosaicing process proposed in this invention for cases in which the three-dimensional motion information is available, either from the images [21,17] or from external devices. The procedure of choosing curved strips which are approximately perpendicular to the optical flow and warping them to match each other when pasting, can be considered as transforming the video sequence of images by an oblique projection of the image onto a *viewing pipe* whose central axis is defined by the trajectory of the camera. After this transformation the optical flow between the projected images becomes approximately parallel to the central axis of the pipe, and they can be easily mosaiced using simple (traditional) strip cut and paste procedures along the pipe. The *pipe mosaic* generated this way includes most details observed by the moving camera, where each region is taken from that image where it was captured at highest resolution, thus forming a strip in that image.

[0077] In order to define the projection onto the pipe, the following notation will be used: the letter O will be used to refer to the origin of two Cartesian coordinate systems having a joint origin. One coordinate system is a global coordinate system with axes denoted by X, Y, Z. The camera is located at the origin, and the image plane is located at $Z = f_c$, where f_c is the focal length. The other coordinate system defines the pipe, and will be described below. The position of a point P in three-dimensional space is given by its coordinates in either of the coordinate systems, for example $P = (P_x, P_y, P_z)$ in the X, Y, Z coordinate system. The vector $\bar{O}P$ will also be denoted by the letter P.

[0078] Given a sequence of images taken by a translating camera, the method of the invention suggests that the images be transformed in such a way that the radial optical flow be turned into approximately parallel optical flow in the transformed representation. In order to achieve the required transformation the two-dimensional planar image is projected onto a three-dimensional cylinder, referred to herein as a *"pipe"* **1101** (see Fig.11). The axis of the pipe **1102** is chosen to pass through the optical center $O = (0, 0, 0)$ of the camera and through the focus of expansion $S = (s_x, s_y, f_c)$, where f_c is the focal length. This axis is the trajectory from the current three-dimensional camera position towards the three-dimensional camera position in the next frame. The direction of the pipe's axis is given by the unit vector $\hat{s} = \frac{S}{|S|}$. Each image point $P = (x, y, f_c)$, in image plane **1103**, is projected onto its corresponding point Q on the pipe. The point Q is collinear with O and P, and its distance from the pipe's axis **1102** is R (the radius of the pipe).

[0079] In the pipe representation of the image, the optical flow of each corresponding point Q on the pipe is now approximately parallel to the direction of the pipe's axis $\hat{s}$ **(1102).** This enables a simple mosaicing process on the pipe itself, as subsequent images, after being projected on the pipe, need only be shifted along the pipe in order to become aligned with previous images. This translation along the pipe does not reduce the resolution, as commonly happens in mosaicing methods which are based on alignment with a reference frame.

[0080] A pipe-fixed Cartesian coordinate system is defined by the three unit vectors $\hat{r}$, $\hat{d}$ and $\hat{s}$, where $\hat{s}$ is the unit vector in the direction of the pipe's axis and $\hat{r}$ and $\hat{d}$ are chosen to be perpendicular to each other and to $\hat{s}$.

[0081] Let the point L be the projection of the point Q on the axis **1102** of pipe **1101** and let k be the distance of L from O. The angle α designates the angle between the line joining L and Q and the unit vector $\hat{d}$. Hence k and α determine the position of a point Q on pipe **1101.** The three-dimensional position of a point Q on the pipe **1101** is given by the Cartesian components (Q_x, Q_y, Q_z), which can be obtained from the components of the vector $Q = k\hat{s} + R\cos(\alpha)\hat{d} + R\sin(\alpha)\hat{r}$, with respect to the pipe-fixed system. The corresponding pixel in image plane **1103** for the point Q is $P = (x, y, f_c) = (f_c Q_x / f_c Q_y / Q_z, f_c)$.

[0082] Pixels in the image plane **1103** whose original distance from the axis **1102** is less than R become magnified on the pipe, but when projected back to the image they restore their resolution. However, pixels with distance greater than R shrink on the pipe, thus loosing their original resolution. For this reason, it is recommended to choose R to be equal to

$$\sqrt{f_c^2 + \left(\frac{w}{2}\right)^2 + \left(\frac{h}{2}\right)^2}$$

, where w and h are the width and height of the image, thus ensuring that no pixel will have reduced resolution when projected onto the pipe. Alternatively, in many simple scenarios it is enough to choose R to be equal to f_c.

[0083] In the pipe representation, pipe images are aligned with each other by a simple translation (shift) along the pipe's principal axis, and the creation of the pipe mosaic involves taking the pixels with the best resolution among all projected images for every point on the pipe. It should be noted that other approaches to select the value for each point on the pipe could be used, including super resolution methods. The resolution is best preserved for pixels whose area when projected on the pipe is 1 by 1 pixels (meaning a single pixel is projected onto a single pixel on the pipe, without artificial scaling). Using this criteria, the ratio between the area consumed on the pipe and the area on the original image frame can be considered as a measure such that the resolution is preserved best when this ratio is as close as possible to 1. As a result, for each point on the pipe, its corresponding pixels in the images are considered, and the one with the ratio closest to 1 may be chosen for best resolution. As a rule of thumb, this ratio can be roughly approximated according to the ratio of the distances along the Z axis Q_z / f_c , which should be as close as possible to 1. Using this approximated measure, pixels on the image at the intersection of the pipe with the image ($Q_z = f_c$) are considered as best preserving the resolution, and the resolution preservation decreases according to $|Q_z - f_c|$. For every point on the pipe the image values (e.g. color and intensity) will be taken from the image in which the value of $|Q_z - f_c|$ is minimal, thus having best resolution preservation. This definition forms a strip in every image, which is the region in which this image best maintains the resolution when projected on the pipe, compared to the corresponding regions in other images (See Fig. 12a).

[0084] This pipe representation proposes a generalized interpretation also for the traditional mosaicing methods. Methods based on alignment to a reference frame can be simulated by viewing the pipe from the same orientation as the selected reference frame. Methods which are limited to pure sideways translation will give identical results as using a pipe mosaic, where the images are projected on the side of the pipe.

[0085] Cases like oblique view, forward motion, and zoom, can be well defined using the pipe projection, and give optimal results, while previous mosaicing methods may fail in these cases. The mosaicing process covered by this invention uses generalized strips (having their shape, size, and warping process determined according to the motion, and resolution considerations), and may be interpreted by the above description of pipe mosaicing, thus generalizing the known methods to work for the problematic cases as well.

The pipe representation can be generalized for handling complicated trajectories and rotations by concatenation of pipes along the path of the camera (See Fig. 12b).

STRIP WIDTH IN THREE-DIMENSIONAL REPRESENTATION

[0086] When the three-dimensional camera motion $T = (T_X, T_Y, T_Z)$ and $\Omega = (\Omega_X, \Omega_Y, \Omega_Z)$ (translation and rotation) is available from external devices, or by using algorithms for camera motion recovery from the images [21,17], then either of these could be used for setting the size of the strips.

[0087] Following the description of the mosaicing process using the "pipe", the projections of two images onto the pipe can be aligned with each other by simple shift along the pipe's axis. Shifting the projected image by L pixels can form a strip with a width of L pixels. A method to approximate the width, L, of a strip for two input frames will now be described.

[0088] Note that it is assumed in this section that the pipe's radius is chosen to be $R = f_c$, although other values of R are possible, and the value of L may be scaled accordingly.

[0089] It is required to compute the width of the strip, L, in such a way that the resolution of the resulting panoramic image will be no less than the resolution of the original sequence of images. For example, without parallax, the width of the strip can be equal to image displacement between the two frames.

[0090] Fig. 13 shows the choice of strip width required to preserve the original resolution for the case of pure rotation. The width of the strip L from the center of image I_1 to the center of I_2 can be set to $L = |\Omega \times (0,0,f_c)^t| = f_c \sqrt{\Omega^2_x + \Omega^2_y}$, where f_c is the focal length of the camera (or the pipe's radius), $\times$ is the cross product operator, and $()^t$ is the transpose operator. This will give similar results as in other panoramic mosaicing methods restricted to pure rotation.

[0091] Fig. 14 shows the choice of strip width required to preserve the original resolution for the case of pure translation. In the case of pure translation, it would be best if the result has the same effect as that of orthographic projection (parallax independent). It is therefor suggested that the resolution of the resulting image is considered in such a way that all objects whose distance from the camera is at least Z_{min} will maintain or improve their resolution. Z_{min} can be defined according to the application, and in general, corresponds to the closest object, having the largest image (or pipe) displacement.

[0092] For example, Fig. 14 describes a scene with objects that are not closer to the camera than some distance Z_{min}. An object of length M, will have at most $m = f_c M / Z_{min}$ pixels in the image plane, where f_c is the focal length of the camera. Consider a camera translating with $|T| = M$, such that the center of the first image looks at one end of the object, and the center of the second image looks at the other end of the object. This means that the camera has just passed that object from one end to the other, thus $L = m$ pixels are required in between in order to preserve the object's original resolution in the panoramic image. As a result, the following definition $L = f_c|T|/Z_{min}$ for the width of a strip is proposed for the case of pure translation, where f_c is the focal length (or the pipe's radius). A strip whose width is at least L pixels can be used for the creation of the panoramic image (or some narrower strips, such as L strips from L intermediate views, where each is one pixel wide, as will described later). This definition can cause all objects at a distance $Z > Z_{min}$ to have better resolution than in the original sequence of images.

[0093] In the case of general motion, the width of the stop L between I_1 and I_2 can be directly determined from f_c

(the focal length), T (the translation vector) and Ω (the rotation vector). For example, the following equation can be used:

$$L = f_c|T/Z_{\text{min}}+Q\times(0,01)'|$$

[0094] Note that T and Z can usually be recovered only up to a scale factor, but the relation between them can be recovered uniquely. The term $f_c|T|/Z_{\text{min}}$ defines the maximum magnitude of optical flow induced by camera translation, which is recoverable. This definition does not depend on any one specific region in the image, and depends only on the camera motion parameters, thus it is consistent along the sequence of images, and enables the creation of realistic panoramic mosaics.

MOSAICING USING NEW VIEW GENERATION

[0095] In order to create a manifold projection, the images are considered to be a one-dimensional (not necessarily linear) scan of the scene, which is a collection of strips that are approximately perpendicular to the direction of the camera motion.

[0096] Taking strips from different images with strip widths of more than one pixel works fine only if there is no parallax. For the general case that includes parallax, instead of taking a strip with a width of L pixels, intermediate images can be synthetically generated, and narrower strips can be used. For example, a collection of L strips, each with a width of one pixel, can be taken from interpolated views in between the original camera positions.

[0097] Fig. 15 shows the generation of a panoramic image using view interpolation by generating synthetic views from intermediate camera positions for two examples, one for the case of translation, and one for the case of rotation. In the case of translation, the objects A, B, X, Y, C, D are viewable in the two subsequent frames I_1 and I_2, taken by a camera which is translating from position C_1 to position C_2. All intermediate images required are recovered, for the in between views N_1, N_2, ..., and a single strip (one pixel wide) is taken from each intermediate image. The process of generating these intermediate views, and collecting of these strips gives as a result the panoramic mosaic P_1. This panorama is realistic, and does not suffer from parallax effects.

[0098] The same mechanism applies also for the case of rotation. Here, the objects E, F, W, Z, L, M are viewable in the two subsequent frames I_3 and I_4, taken by a camera whose location is fixed, and whose orientation changes from C_3 to C_4. All intermediate images required are recovered for the in between views N_7, N_8, ..., and a narrow strip is taken from each intermediate image. The result of this process is the panoramic mosaic P_2. This panorama is as good as the panorama created by some previous methods, as no parallax effects are encountered in pure rotation.

[0099] In order to synthesize new views various known methods can be used, such as Optical Flow interpolation [6, 19], Trilinear tensor methods [17], and others. In most cases approximate methods will give good results. The creation of the intermediate views should require only view interpolation, since in most applications view extrapolation is not required.

[0100] The use of intermediate views for strip collection gives the effect of orthographic projection, which avoids parallax discontinuities. For example, Fig. 16 shows the generation of consistent panoramic mosaics in the presence of parallax. The method described above overcomes the difficulties of parallax using view interpolation, and the result remains realistic.

[0101] Although the present invention has been described to a certain degree of particularity, it should be understood that various alterations and modifications could be made without departing from the scope of the invention as hereinafter claimed.

Claims

1. A method of combining a sequence of two-dimensional images of a scene for obtaining a panoramic mosaic of said scene, said sequence of two-dimensional images being acquired by a moving camera in relative motion with respect to said scene, said relative motion giving rise to an optical flow between the images, wherein at least a part of the optical flow vectors is unparallel to each other,
   the method comprising:

   a) warping said images so that the direction of the optical flow vectors becomes substantially parallel to each other and to a direction in which said mosaic is constructed;
   b) pasting said warped images so that said sequence of two-dimensional images is continuous for said scene,

   whereby to construct said panoramic mosaic of said scene.

2. A method of combining a sequence of two-dimensional images of a scene for obtaining a panoramic mosaic of the scene, said sequence of two-dimensional images being acquired by a moving camera in relative motion with respect to the scene, said camera motion giving rise to an optical flow between the images, the method comprising the steps of:

a) selecting for each image of said sequence of two-dimensional images at least one family of lines perpendicular to said optical flow and defining strips having a front edge, through which said optical flow enters, and a back edge, through which said optical flow exits, in order that each strip be substantially perpendicular to said optical flow;
b) warping the strips, to create non-rectangular strips, in order that said optical flow becomes substantially parallel to a direction in which said mosaic is constructed; and
(c) pasting said non-rectangular strips in order that said sequence of two-dimensional images be continuous for said scene,

whereby said panoramic mosaic of the scene is constructed.

3. The method of claim 2 wherein the step b) of warping the strips includes transforming said strips into strips having at least one of their front and back edges fitting an edge of an adjacent strip.

4. The method of claim 2 wherein the step b) of warping the strips includes transforming said strips into strips having straight edges before the strips are combined together.

5. The method of claim 2 wherein the step b) of warping the strips includes reseating said strips, defined on a two-dimensional image, to rectangular strips so that their front edge be substantially aligned with the back edge of a strip defined on an adjacent two-dimensional image.

6. The method of claim 5 wherein said strip is a circular strip, the front edge of said circular strip being an arc of length l_1 having a radius r_1, the back edge of said circular strip being an arc of length l_2 having a radius r_2, and said reseating including multiplying l_1 by r_1/r_2.

7. The method of claim 2 wherein the step a) of selecting for each image of said sequence of two-dimensional images at least one family of lines defining at least one strip includes:

- determining a shape for said strip;
- determining a size and a width for said strip;
- defining a position of said strip on a two-dimensional image; and
- cutting said strip from the two-dimensional image.

8. The method of claim 2 wherein the two-dimensional images are related by an affine transformation or by a planar-projective transformation.

9. The method of claim 8 wherein the transformation is applied to the panoramic mosaic depending on a desired viewpoint.

10. The method of claim 1 or 2 wherein said images are projected onto a three-dimensional cylinder whose major axis approximates the path of camera optical center, a combination of the strips being achieved by translating the projected two-dimensional images substantially along the cylindrical surface of the three-dimensional cylinder.

11. The method of claim 10 wherein every two subsequent images define their own cylinder whose major axis substantially passes through the optical center of the cameras, and the cylinders are concatenated substantially along the image sequence.

12. The method of claim 1 or 2 wherein the sequence of images is augmented by sets of interpolated images intermediate to the images of the sequence of images, and wherein the strips are augmented with strips defined on the interpolated images.

13. The method of anyone of claims 1 to 12, further comprising storing in a memory data representative of the panoramic mosaic of the scene.

14. A computer program comprising computer program code means for performing all the steps of any of Claims 1 to 13 when said program is run on a computer.

15. A computer program as claimed in Claim 14 embodied on a computer readable medium.

16. Use of the method of claim I or 2 for handling at least one case from the group consisting of image parallax, camera zoom, forward camera motion, and general camera motion combining translation and rotation.

17. A system for combining a sequence of two-dimensional images of a scene to obtain a panoramic mosaic of said scene, said sequence of images being acquired by a camera in relative motion with respect to said scene, said relative motion giving rise to an optical flow between said images, wherein at least a part of the optical flow vectors is unparallel to each other, the system comprising:

a warper for warping the images so that the direction of the optical flow vectors between said images becomes substantially parallel to each other and to a direction in which the mosaic is constructed; and
a paster for pasting said warped images so that said sequence of two-dimensional images is continuous for said scene.

18. A system for combining a sequence of two-dimensional images of a scene for obtaining a panoramic mosaic of said scene, said sequence of two-dimensional images being acquired by a moving camera in relative motion with respect to said scene, said camera motion giving rise to an optical flow between the images, the system comprising:

a selector for selecting for each image of said sequence of two-dimensional images at least one family of lines perpendicular to said optical flow and defining at least one strip having a front edge, through which said optical flow enters, and a back edge, through which said optical flow exits, so that each strip is substantially perpendicular to said optical flow;
a warper for warping said strip to create non-rectangular strips, so that said optical flow becomes substantially parallel to a direction in which said mosaic is constructed;
a paster for pasting said non-rectangular strips so that said sequence of two-dimensional images is continuous for said scene.

Patentansprüche

1. Verfahren zur Kombination einer Folge zweidimensionaler Bilder einer Szene, um ein Panoramamosaik der Szene zu erhalten, wobei die Folge zweidimensionaler Bilder durch eine sich bewegende Kamera erfaßt wird, die sich bezüglich der Szene in einer Relativbewegung befindet, wobei die Relativbewegung einen optischen Fluß zwischen den Bildern hervorruft, wobei die Vektoren des optischen Flusses mindestens teilweise nicht-parallel zueinander sind, wobei das Verfahren aufweist:

a) Verzerren der Bilder, so daß die Richtung der Vektoren des optischen Flusses im wesentlichen zueinander und zu einer Richtung parallel wird, in der das Mosaik konstruiert wird;
b) Einsetzen der verzerrten Bilder, so daß die Folge zweidimensionaler Bilder für die Szene zusammenhängend wird,

wodurch das Panoramamosaik der Szene konstruiert wird.

2. Verfahren zur Kombination einer Folge zweidimensionaler Bilder einer Szene, um ein Panoramamosaik der Szene zu erhalten, wobei die Folge zweidimensionaler Bilder durch eine sich bewegende Kamera erfaßt wird, die sich bezüglich der Szene in einer Relativbewegung befindet, wobei die Kamerabewegung einen optischen Fluß zwischen den Bildern hervorruft, wobei das Verfahren die Schritte aufweist:

a) Auswählen für jedes Bild der Folge zweidimensionaler Bilder mindestens einer Schar von Linien, die senkrecht zum optischen Fluß verlaufen und Streifen definieren, die eine Vorderkante, durch die der optische Fluß eintritt, und eine Hinterkante aufweisen, durch die der optische Fluß austritt, damit jeder Streifen im wesentlichen senkrecht zum optischen Fluß verläuft;
b) Verzerren der Streifen, um nicht-rechteckige Streifen zu erzeugen, damit der optische Fluß im wesentlichen parallel zu einer Richtung wird, in der das Mosaik konstruiert wird; und

(c) Einsetzen der nicht-rechteckigen Streifen, damit die Folge zweidimensionaler Bilder für die Szene zusammenhängend wird,

wodurch das Panoramamosaik der Szene konstruiert wird.

3. Verfahren nach Anspruch 2, wobei der Schritt b) des Verzerrens der Streifen das Transformieren der Streifen zu Streifen aufweist, von denen mindestens eine ihrer Vorder- und Hinterkanten zu einer Kante eines benachbarten Streifens paßt.

4. Verfahren nach Anspruch 2, wobei der Schritt b) des Verzerrens der Streifen das Transformieren der Streifen zu Streifen aufweist, die gerade Kanten aufweisen, bevor die Streifen miteinander kombiniert werden.

5. Verfahren nach Anspruch 2, wobei der Schritt b) des Verzerrens der Streifen eine Umskalierung der Streifen, die auf einem zweidimensionalen Bild definiert sind, in rechteckige Streifen aufweist, so daß ihre Vorderkante im wesentlichen mit der Hinterkante eines Streifens ausgerichtet ist, der auf einem benachbarten zweidimensionalen Bild definiert wird.

6. Verfahren nach Anspruch 5, wobei der Streifen ein kreisförmiger Streifen ist, wobei die Vorderkante des kreisförmigen Streifens ein Bogen der Länge l_1 mit einem Radius r_1 ist, die Hinterkante des kreisförmigen Streifens ein Bogen der Länge l_2 mit einem Radius r_2 ist und die Umskalierung eine Multiplikation von l_1 mit r_1/r_2 aufweist.

7. Verfahren nach Anspruch 2, wobei der Schritt a) des Auswählens für jedes Bild der Folge zweidimensionaler Bilder mindestens eine Schar von Linien, die mindestens einen Streifen definieren, aufweist:

- Bestimmen einer Form für den Streifen;
- Bestimmen einer Größe und einer Breite für den Streifen;
- Definieren einer Position des Streifens auf einem zweidimensionalen Bild; und
- Ausschneiden des Streifens aus dem zweidimensionalen Bild.

8. Verfahren nach Anspruch 2, wobei die zweidimensionalen Bilder durch eine affine Transformation oder durch eine planar-projektive Transformation in Beziehung stehen.

9. Verfahren nach Anspruch 8, wobei die Transformation abhängig von einem gewünschten Standpunkt auf das Panoramamosaik angewendet wird.

10. Verfahren nach Anspruch 1 oder 2, wobei die Bilder auf einen dreidimensionalen Zylinder projiziert werden, dessen Hauptachse den Weg des optischen Mittelpunkts der Kamera annähert, wobei eine Kombination der Streifen erzielt wird, indem die projizierten zweidimensionalen Bilder im wesentlichen längs der Zylinderoberfläche des dreidimensionalen Zylinders translatiert werden.

11. Verfahren nach Anspruch 10, wobei alle zwei aufeinanderfolgenden Bilder ihren eigenen Zylinder definieren, dessen Hauptachse im wesentlichen durch den optischen Mittelpunkt der Kamera geht, und die Zylinder im wesentlichen längs der Bildfolge verkettet sind.

12. Verfahren nach Anspruch 1 oder 2, wobei die Bilderfolge durch Sätze interpolierter Bilder erweitert wird, die zwischen den Bildern der Bilderfolge liegen, und wobei die Streifen mit Streifen erweitert werden, die an den interpolierten Bildern definiert werden.

13. Verfahren nach einem der Ansprüche 1 bis 12, das ferner das Speichern von Daten in einem Speicher aufweist, die für das Panoramamosaik der Szene repräsentativ sind.

14. Computerprogramm, das eine Computerprogrammcodeeinrichtung zur Durchführung aller Schritte der Ansprüche 1 bis 13 aufweist, wenn das Programm auf einem Computer ausgeführt wird.

15. Computerprogramm nach Anspruch 14, das auf einem computerlesbaren Medium enthalten ist.

16. Verwendung des Verfahrens nach Anspruch 1 oder 2, zur Behandlung mindestens eines Falls aus der Gruppe, die aus einer Bildparallaxe, einer Kamerabrennweitenverstellung, einer Vorwärtskamerabewegung und einer allgemeinen Kamerabewegung besteht, die eine Translation und Rotation kombiniert.

17. System zur Kombination einer Folge zweidimensionaler Bilder einer Szene, um ein Panoramamosaik der Szene zu erhalten, wobei die Bilderfolge durch eine Kamera erfaßt wird, die sich bezüglich der Szene in einer Relativbewegung befindet, wobei die Relativbewegung einen optischen Fluß zwischen den Bildern hervorruft, wobei die Vektoren des optischen Flusses mindestens teilweise nicht-parallel zueinander sind, wobei das System aufweist:

eine Verzerrungseinrichtung zur Verzerrung der Bilder, so daß die Richtung der Vektoren des optischen Flusses zwischen den Bildern im wesentlichen zueinander und zu einer Richtung parallel wird, in der das Mosaik konstruiert ist; und
eine Einsetzeinrichtung zum Einsetzen der verzerrten Bilder, so daß die Folge zweidimensionaler Bilder für die Szene zusammenhängend ist.

18. System zur Kombination einer Folge zweidimensionaler Bilder einer Szene, um ein Panoramamosaik der Szene zu erhalten, wobei die Folge zweidimensionaler Bilder durch eine sich bewegende Kamera erfaßt wird, die sich in Relativbewegung bezüglich der Szene befindet, wobei die Kamerabewegung einen optischen Fluß zwischen den Bildern hervorruft, wobei das System aufweist:

einen Selektor, um für jedes Bild der Folge zweidimensionaler Bilder mindestens eine Schar von Linien auszuwählen, die senkrecht zum optischen Fluß verlaufen und mindestens einen Streifen definieren, der eine Vorderkante, durch die der optische Fluß eintritt, und eine Hinterkante aufweist, durch die der optische Fluß austritt, so daß jeder Streifen im wesentlichen senkrecht zum optischen Fluß verläuft;
eine Verzerrungseinrichtung zur Verzerrung des Streifens, um nicht-rechteckige Streifen zu erzeugen, so daß der optische Fluß im wesentlichen parallel zu einer Richtung wird, in der das Mosaik konstruiert ist;
eine Einsetzeinrichtung zum Einsetzen der nicht-rechteckigen Streifen, so daß die Folge zweidimensionaler Bilder für die Szene zusammenhängend ist.

Revendications

1. Procédé permettant de combiner une séquence d'images bidimensionnelles d'une scène pour obtenir une mosaïque panoramique de ladite scène, ladite séquence d'images bidimensionnelles étant acquise par une caméra mobile en mouvement relatif par rapport à ladite scène, ledit mouvement relatif donnant naissance à un flux optique entre les images, dans lequel au moins une partie des vecteurs du flux optique ne sont pas parallèles les uns aux autres,
le procédé comprenant les étapes consistant à :

a) ourdir lesdites images de sorte que les directions des vecteurs du flux optique deviennent substantiellement parallèles les unes aux autres et à une direction dans laquelle la mosaïque est construite ;
b) coller lesdites images ourdies afin que ladite séquence d'images bidimensionnelles soit continue pour ladite scène,

par lequel construire ladite mosaïque panoramique de ladite scène.

2. Procédé permettant de combiner une séquence d'images bidimensionnelles d'une scène pour obtenir une mosaïque panoramique de la scène, ladite séquence d'images bidimensionnelles étant acquise par une caméra mobile en mouvement relatif par rapport à la scène, ledit mouvement de la caméra donnant naissance à un flux optique entre les images, le procédé comprenant les étapes consistant à :

a) sélectionner pour chaque image de ladite séquence d'images bidirectionnelles au moins une famille de lignes perpendiculaires audit flux optique et à définir les bandes ayant un bord antérieur, à travers lequel ledit flux optique entre et un bord postérieur, à travers lequel ledit flux optique sort, afin que chaque bande soit substantiellement perpendiculaire audit flux optique ;
b) ourdir les bandes, pour créer des bandes non rectangulaires, afin que ledit flux optique devienne substantiellement parallèle à une direction dans laquelle ladite mosaïque est construite ; et
c) coller lesdites bandes non rectangulaires afin que ladite séquence d'images bidimensionnelles soit continue pour ladite scène,

par lequel ladite mosaïque panoramique de la scène est construite.

3. Procédé selon la revendication 2 dans lequel l'étape b) consistant à ourdir les bandes inclut de transformer lesdites bandes en bandes ayant au moins l'un de leurs bords antérieur et postérieur qui s'adapte à un bord d'une bande adjacente.

4. Procédé selon la revendication 2 dans lequel l'étape b) consistant à ourdir les bandes inclut de transformer lesdites bandes en bandes ayant des bords droits avant que les bandes ne soient assemblées les unes aux autres.

5. Procédé selon la revendication 2 dans lequel l'étape b) consistant à ourdir les bandes inclut de redimensionner lesdites bandes, définies sur une image bidimensionnelle, en bandes rectangulaires de sorte que leur bord antérieur soit substantiellement aligné au bord postérieur d'une bande définie sur une image bidimensionnelle adjacente.

6. Procédé selon la revendication 5 dans lequel ladite bande est une bande circulaire, le bord antérieur de ladite bande circulaire étant un arc de longueur l_1 ayant un rayon r_1, le bord postérieur de ladite bande circulaire étant un arc de longueur l_2 ayant un rayon r_2 et ledit redimensionnement consistant à multiplier l_1 par r_1/r_2.

7. Procédé selon la revendication 2 dans lequel l'étape a) consistant à sélectionner, pour chaque image de ladite séquence d'images bidimensionnelles, au moins une famille de lignes définissant au moins une bande, inclut les étapes consistant à :

- déterminer une forme pour ladite bande ;
- déterminer une taille et une largeur pour ladite bande ;
- définir une position de ladite bande sur une image bidimensionnelle ; et
- couper ladite bande à partir de l'image bidimensionnelle.

8. Procédé selon la revendication 2 dans lequel les images bidimensionnelles sont reliées par une transformation affine ou par une transformation planaire-projective.

9. Procédé de la revendication 8 dans lequel la transformation est appliquée à la mosaïque panoramique en fonction d'un point de vue souhaité.

10. Procédé selon la revendication 1 ou 2 dans lequel les images sont projetées sur un cylindre tridimensionnel dont l'axe principal s'approche du chemin du centre optique de la caméra, une combinaison des bandes étant obtenue en traduisant les images bidimensionnelles projetées substantiellement le long de la surface cylindrique du cylindre tridimensionnel.

11. Procédé selon la revendication 10 dans lequel chaque paire d'images successives définit son propre cylindre dont l'axe principal passe substantiellement à travers le centre optique des caméras et les cylindres sont enchaînés substantiellement le long de la séquence d'images.

12. Procédé selon la revendication 1 ou 2 dans lequel la séquence d'images est augmentée par des jeux d'images interpolés intermédiaires aux images de la séquence d'images et dans lequel les bandes sont augmentées à l'aide de bandes définies sur les images interpolées.

13. Procédé selon l'une quelconque des revendications 1 à 12 comprenant également l'étape consistant à stocker dans une mémoire des données représentatives de la mosaïque panoramique de la scène.

14. Programme informatique comprenant des ressources de code de programme informatique permettant d'effectuer toutes les étapes de l'une quelconque des revendications 1 à 13 lorsque ledit programme est exécuté sur un ordinateur.

15. Programme informatique comme revendiqué dans la revendication 14 intégré à un support lisible sur ordinateur.

16. Utilisation du procédé de la revendication 1 ou 2 pour gérer au moins un cas du groupe comprenant une parallaxe d'images, un zoom de caméra, un mouvement avant de caméra et un mouvement général de caméra combinant la translation et la rotation.

17. Système permettant de combiner une séquence d'images bidirectionnelles d'une scène pour obtenir une mosaïque panoramique de ladite scène, ladite séquence d'images étant acquise par une caméra en mouvement relatif par rapport à ladite scène, ledit mouvement relatif donnant naissance à un flux optique entre lesdites images, dans lequel au moins quelques-uns des vecteurs du flux optique ne sont pas parallèles les uns aux autres, le système comprenant :

un ourdissoir pour ourdir les images de sorte que les directions des vecteurs du flux optique entre lesdites images deviennent substantiellement parallèles les unes aux autres et à une direction dans laquelle la mosaïque est construite ; et
une encolleuse pour coller lesdites images ourdies afin que ladite séquence d'images bidimensionnelles soit continue pour ladite scène.

18. Système permettant de combiner une séquence d'images bidirectionnelles d'une scène pour obtenir une mosaïque panoramique de ladite scène, ladite séquence d'images bidirectionnelles étant acquise par une caméra mobile en mouvement relatif par rapport à ladite scène, ledit mouvement de caméra donnant naissance à un flux optique entre les images, le système comprenant :

un sélecteur pour sélectionner pour chaque image de ladite séquence d'images bidirectionnelles, au moins une famille de lignes perpendiculaires audit flux optique, et définir au moins une bande ayant un bord antérieur, à travers lequel ledit flux optique entre et un bord postérieur, à travers lequel ledit flux optique sort de sorte que chaque bande est substantiellement perpendiculaire audit flux optique ;
un ourdissoir pour ourdir ladite bande pour créer des bandes non rectangulaires de sorte que ledit flux optique devienne substantiellement parallèle à une direction dans laquelle la mosaïque est construite ;

une encolleuse pour coller lesdites bandes non rectangulaires afin que ladite séquence d'images bidimensionnelles soit continue pour ladite scène.

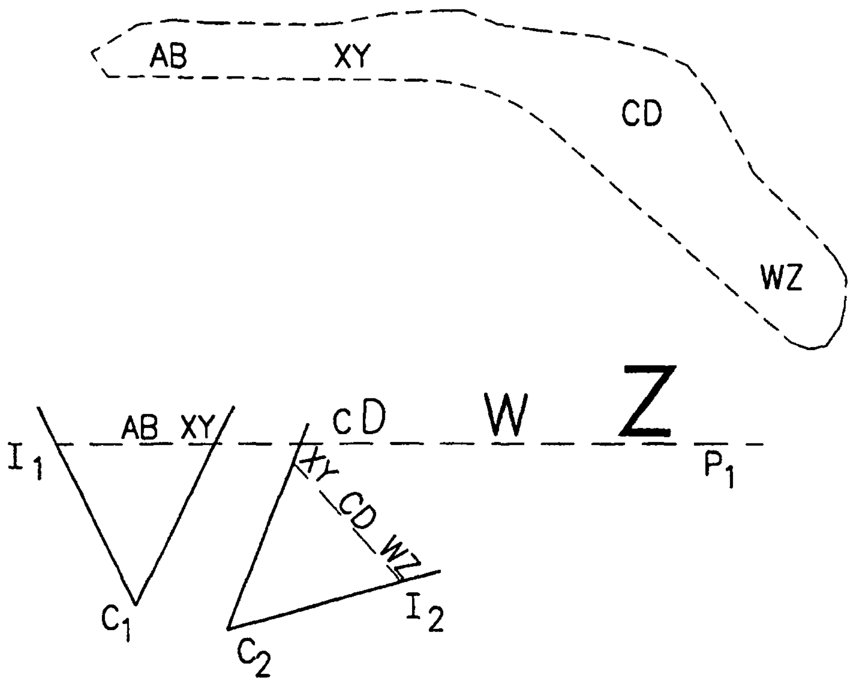


FIG.1

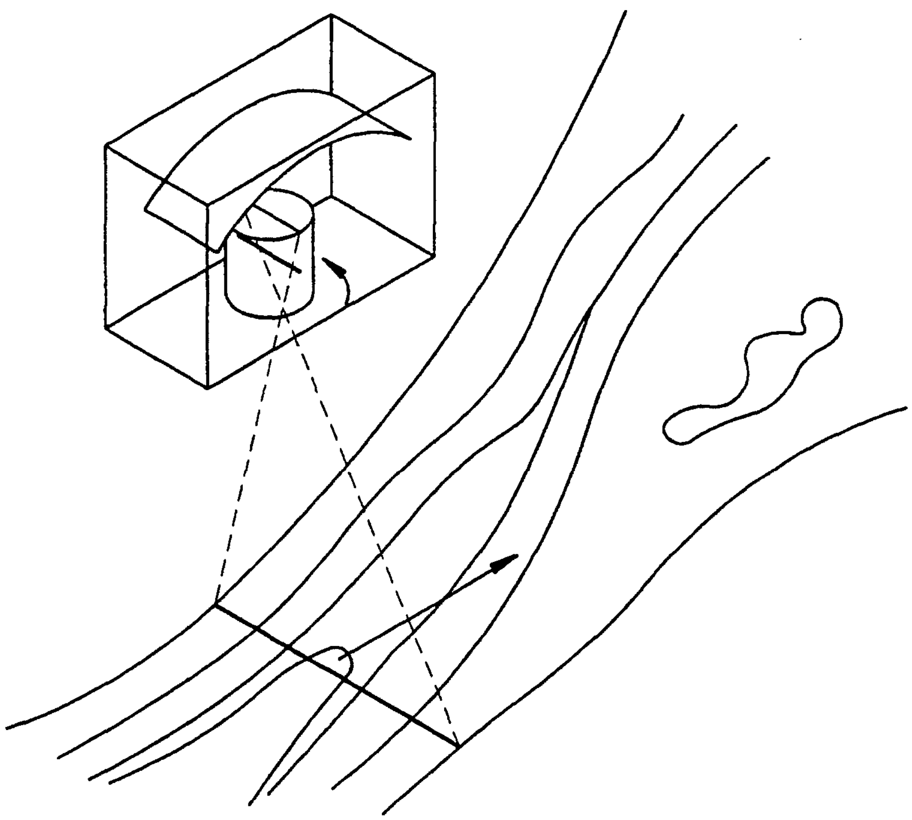


FIG.2

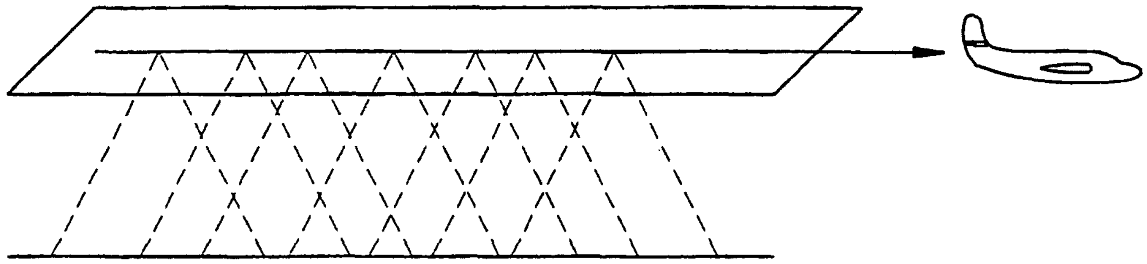


FIG.3A

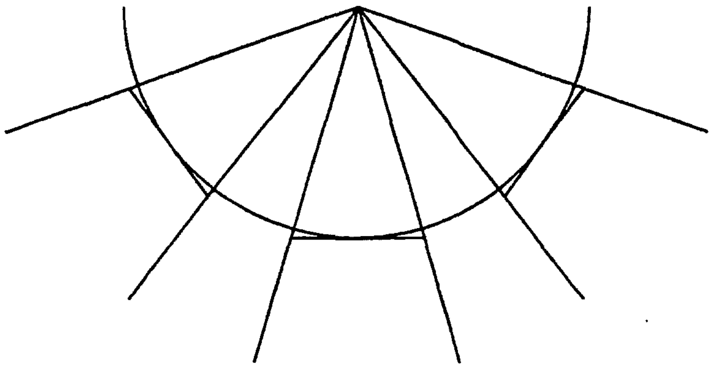


FIG.3B

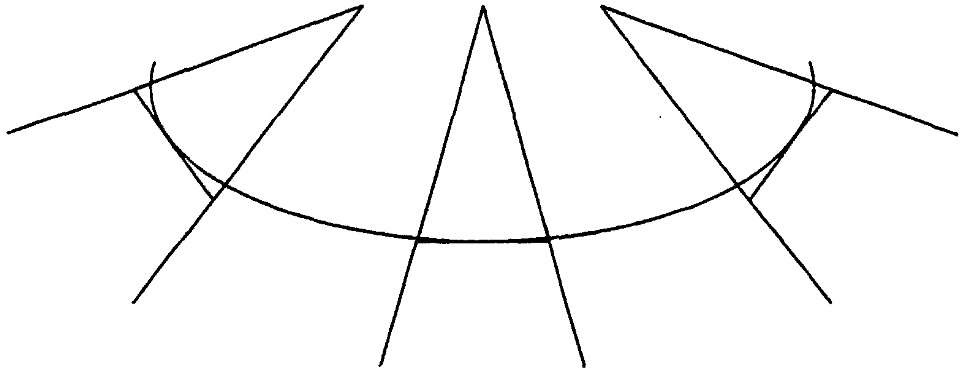


FIG.3C

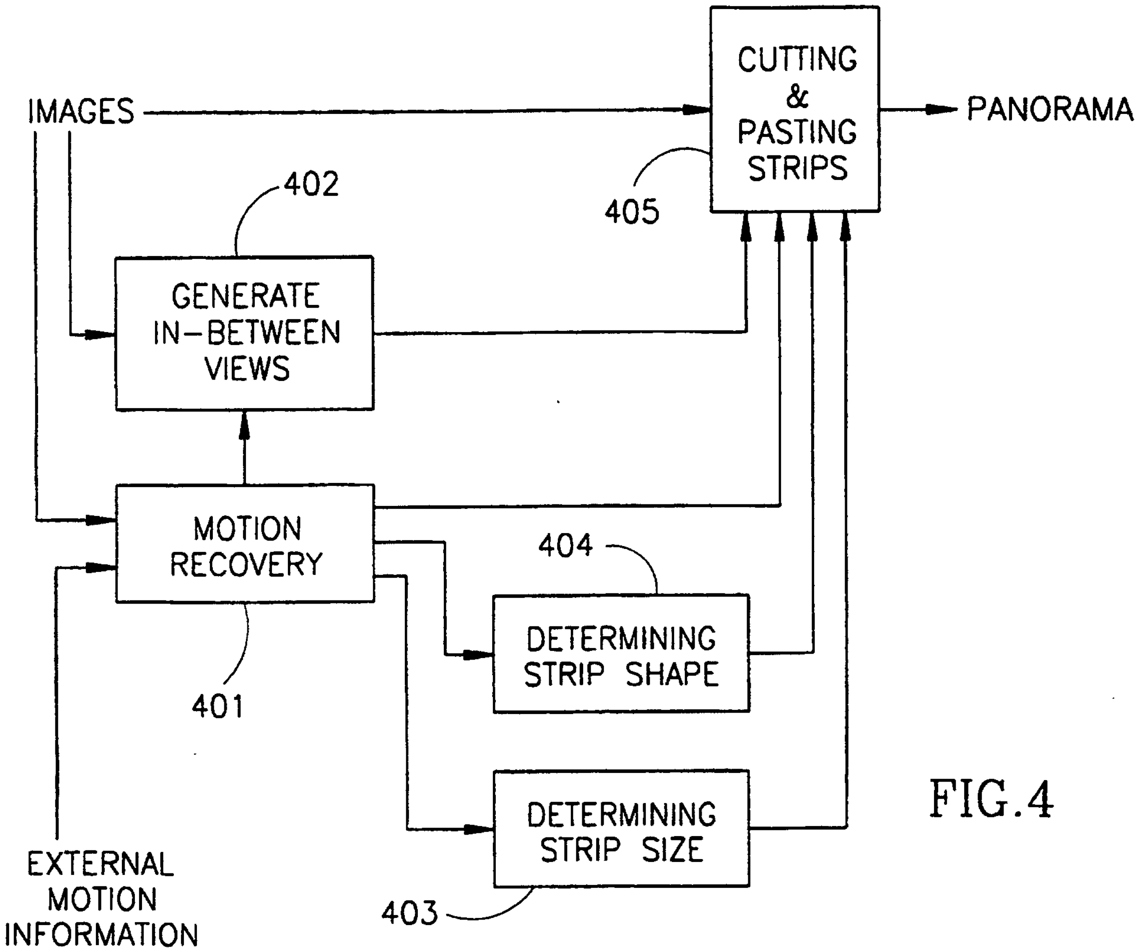

IMAGES
CUTTING & PASTING STRIPS
PANORAMA
402
405
GENERATE IN-BETWEEN VIEWS
MOTION RECOVERY
404
DETERMINING STRIP SHAPE
401
DETERMINING STRIP SIZE
EXTERNAL MOTION INFORMATION
403

FIG.4

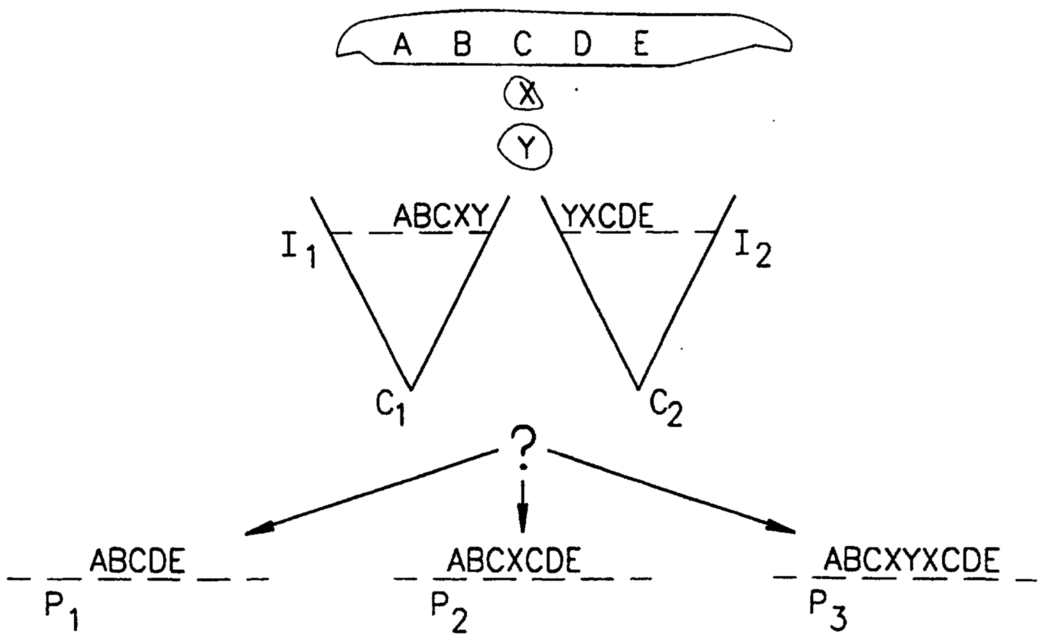

A B C D E
X
Y
ABCXY
YXCDE
I1
I2
C1
C2
?
ABCDE
ABCXCDE
ABCXYXCDE
P1
P2
P3

FIG.5

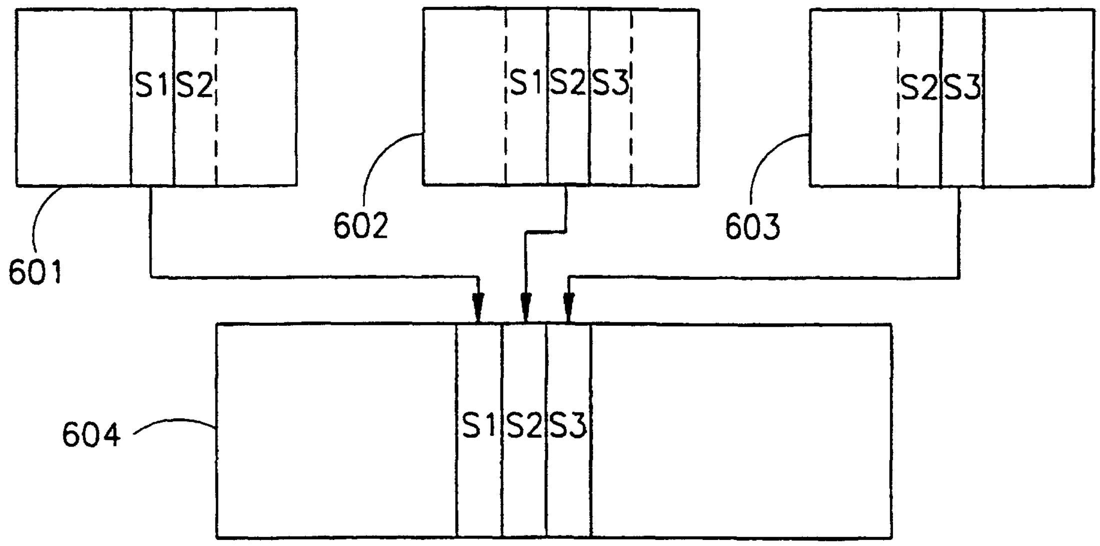

S1
S2
S1
S2
S3
S2
S3
601
602
603
604
S1
S2
S3

FIG.6

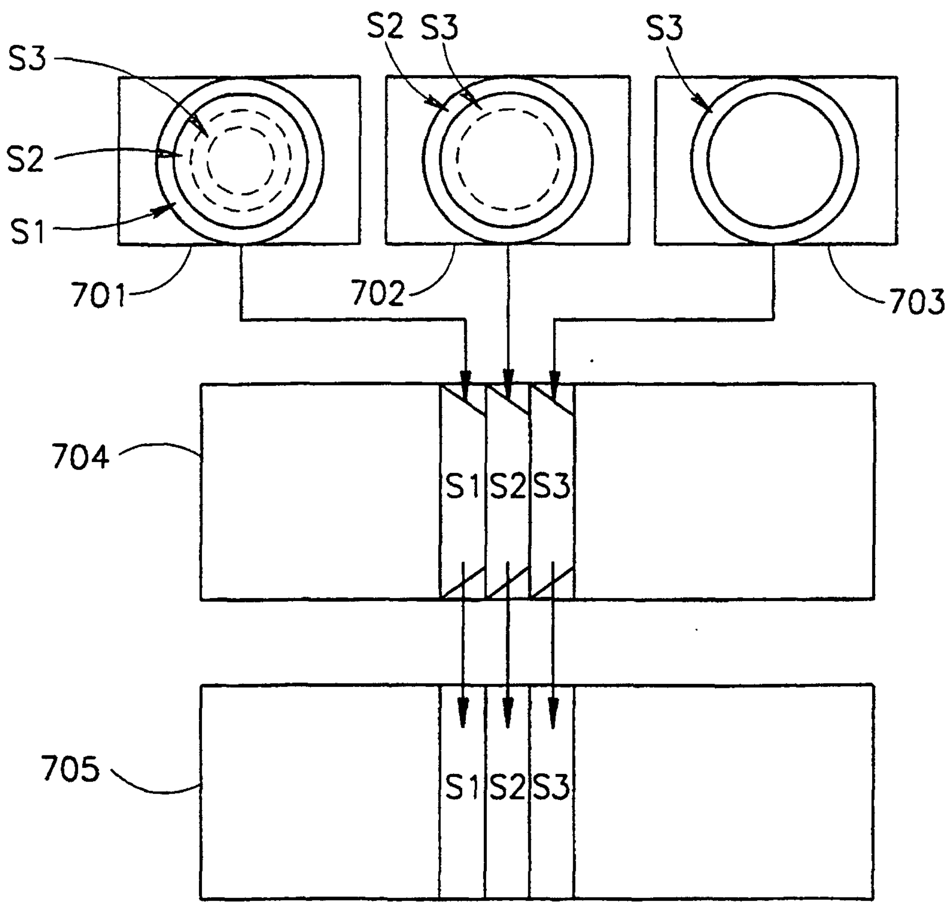

S3
S2
S1
S2
S3
S3
701
702
703
704
S1
S2
S3
705
S1
S2
S3

FIG.7A

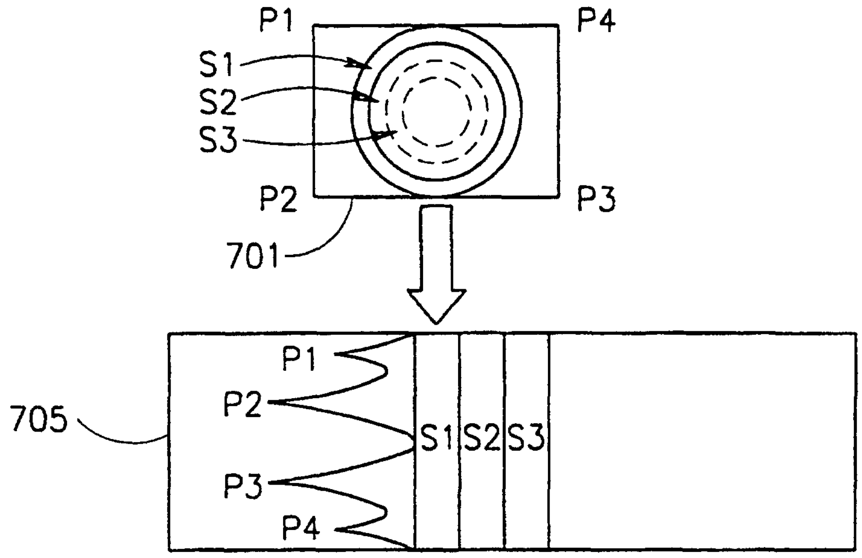
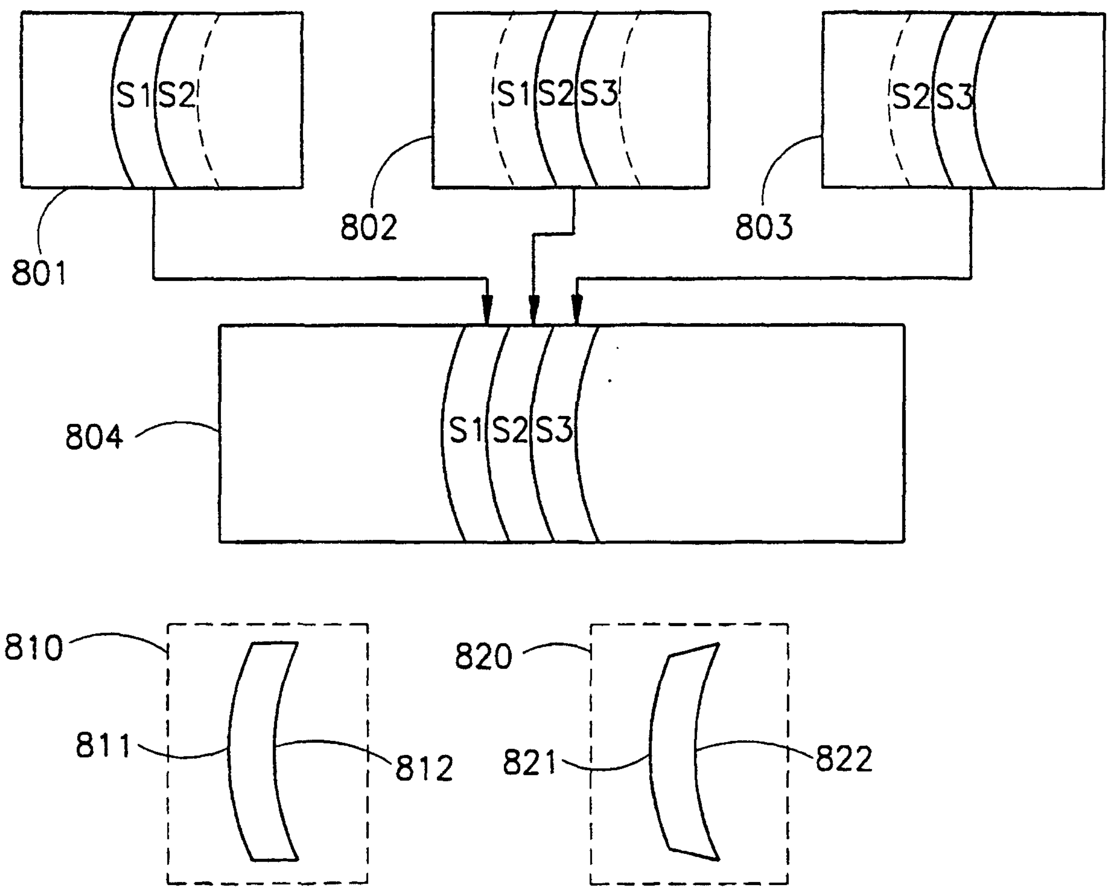

P1
P4
S1
S2
S3
P2
P3
701
705
P1
P2
P3
P4
S1
S2
S3

FIG.7B


S1
S2
S1
S2
S3
S2
S3
801
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804
S1
S2
S3
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820
821
822

FIG.8

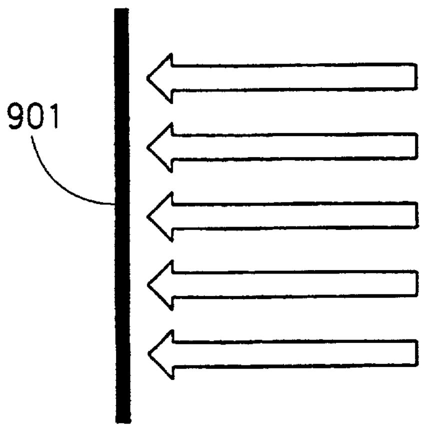

FIG.9A

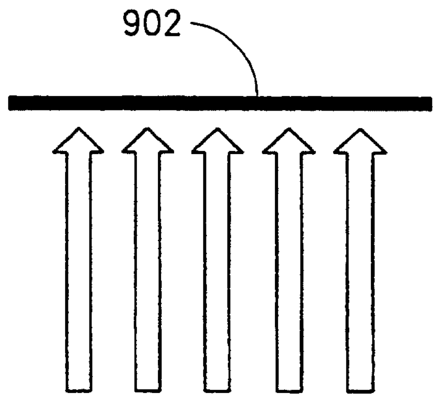

FIG.9B

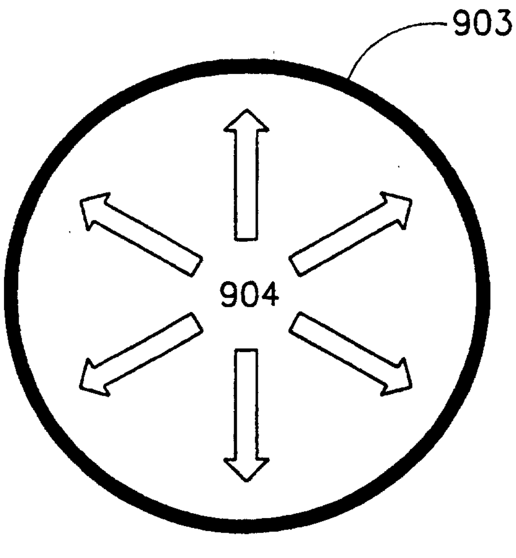

FIG.9C

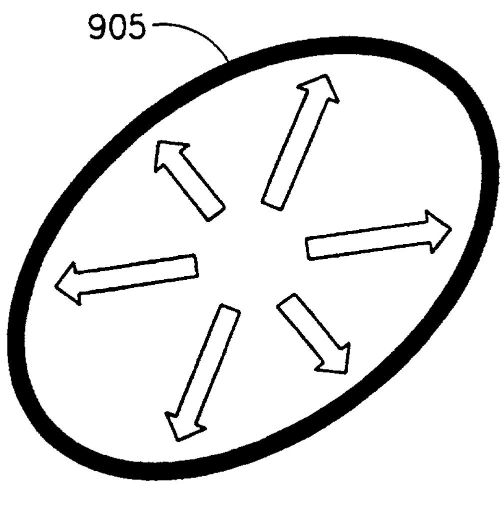

FIG.9D

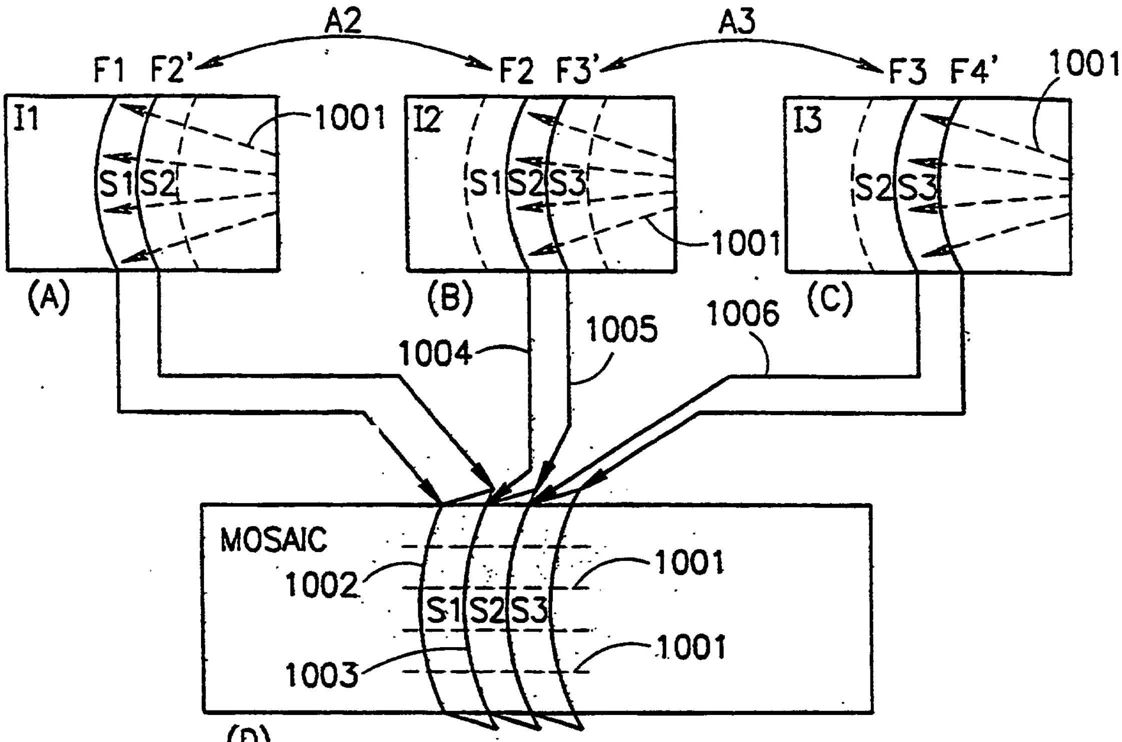
A2
A3
F1 F2'
F2 F3'
F3 F4'
1001
I1
I2
I3
S1 S2
S1 S2 S3
S2 S3
(A)
(B)
(C)
1004
1005
1006
MOSAIC
1002
1003
S1 S2 S3
(D)

FIG.10

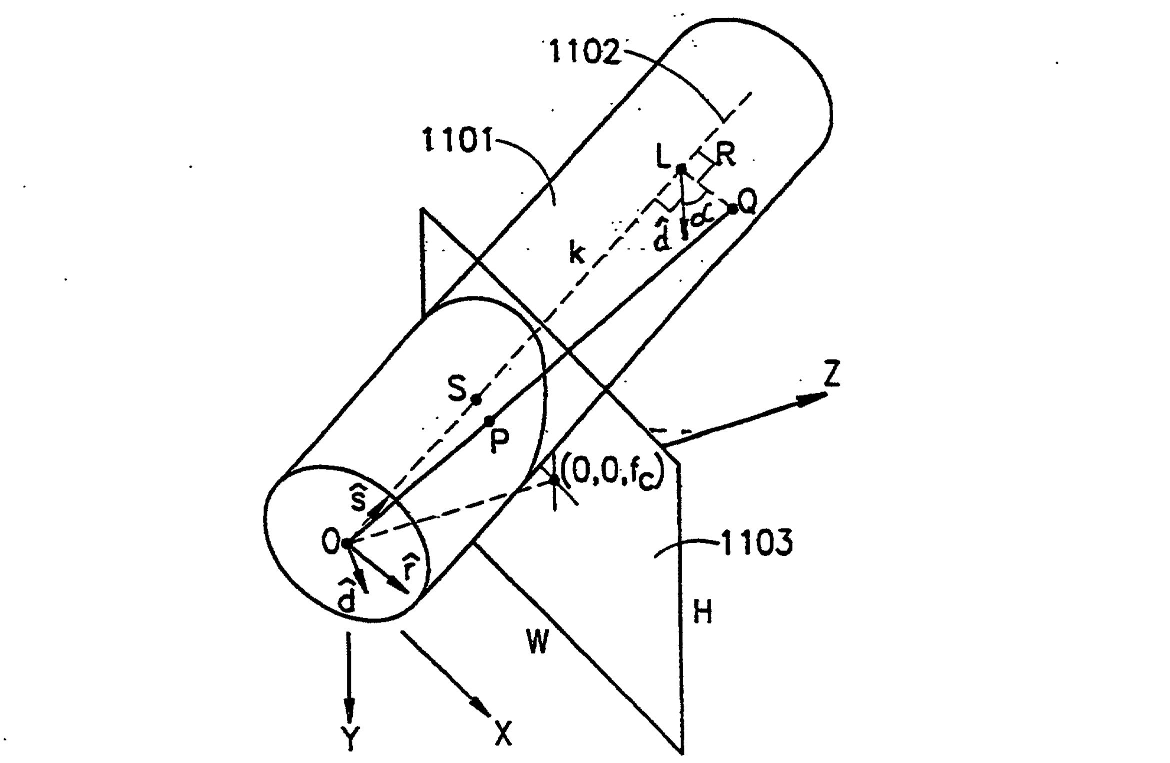
1102
1101
L
R
Q
k
S
P
(0,0,f_c)
O
1103
H
W
Y
X
Z

FIG.11

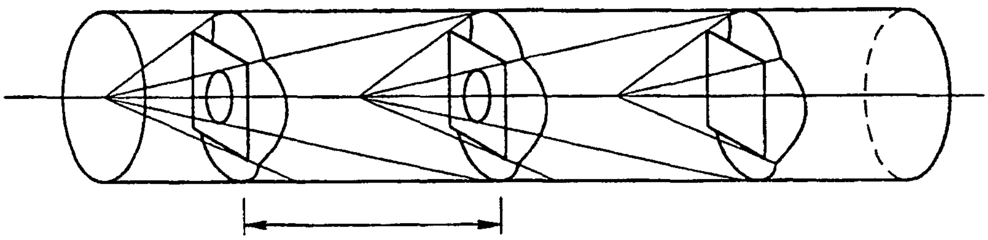

FIG.12A

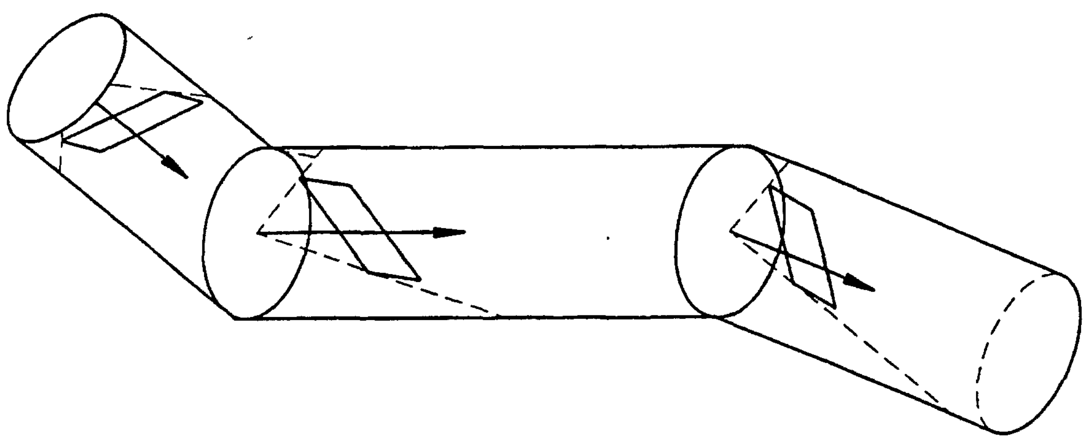

FIG.12B

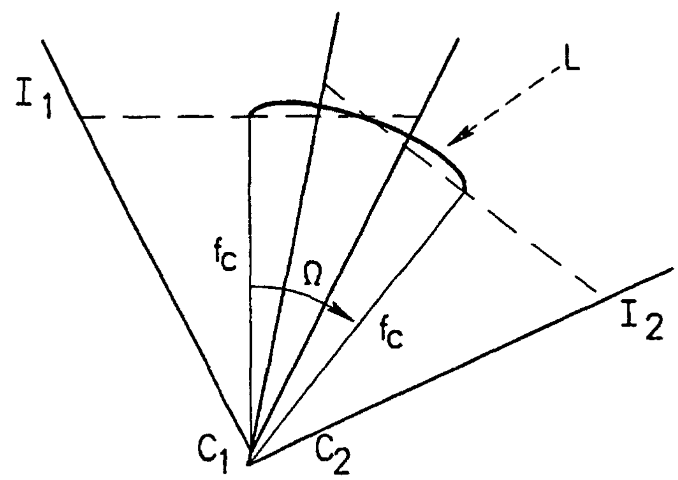

FIG.13

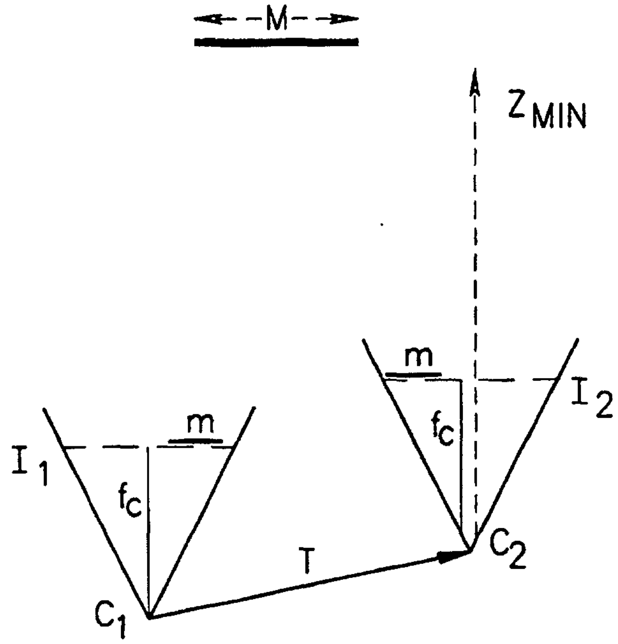

FIG.14

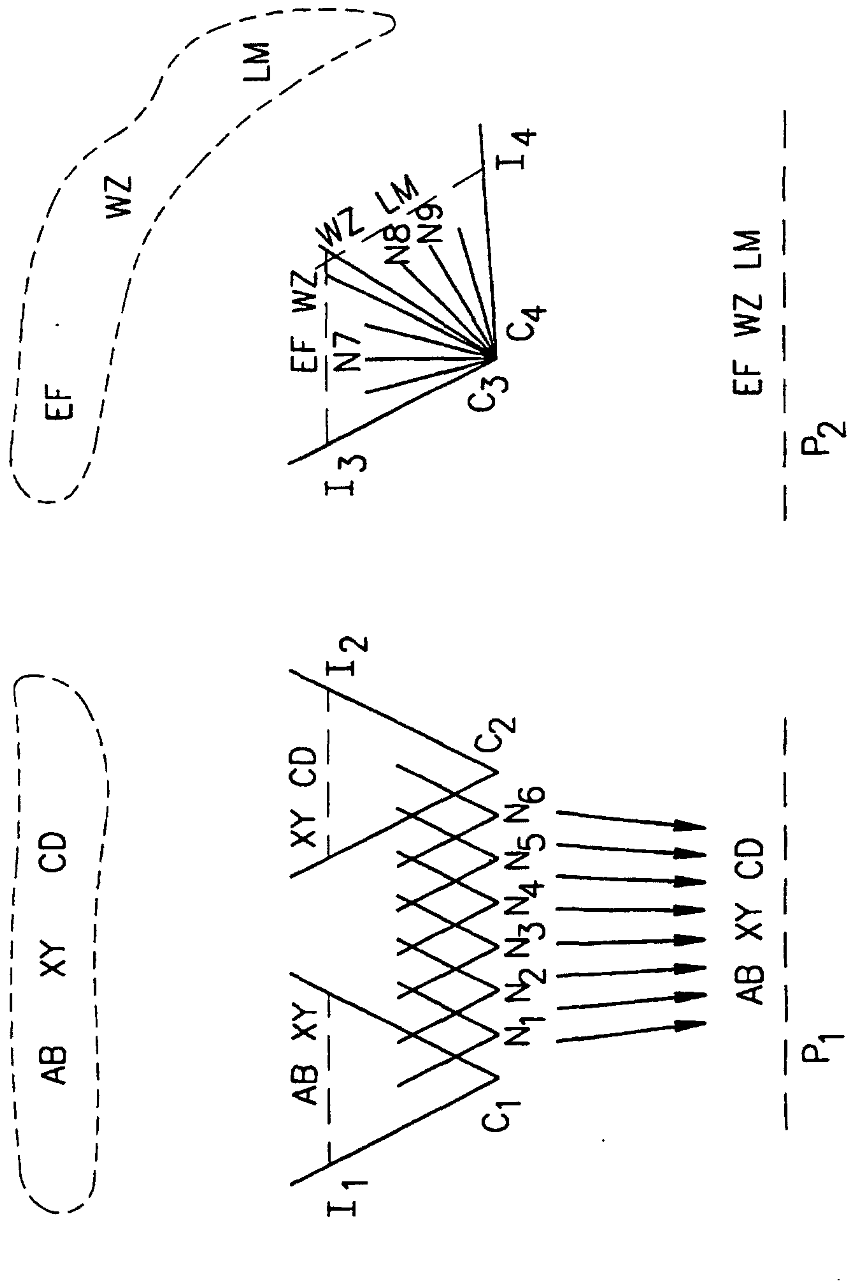
AB XY CD
EF WZ LM
AB XY
XY CD
EF WZ
WZ LM
I1
I2
I3
I4
C1
C2
C3
C4
N1 N2 N3 N4 N5 N6
N7
N8
N9
AB XY CD
EF WZ LM
P1
P2

FIG.15

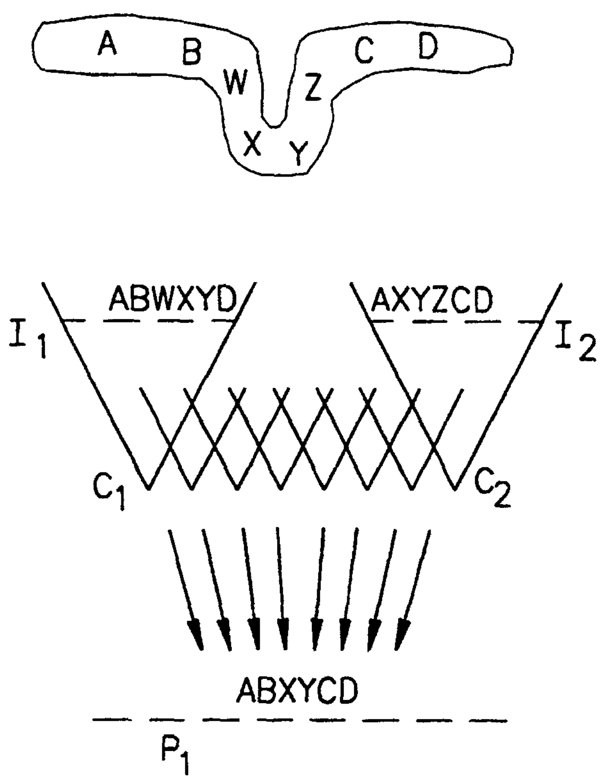

FIG.16