STEREOSCOPIC PANORAMIC VIDEO GENERATION USING CENTRO-CIRCULAR PROJECTION TECHNIQUE

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ABSTRACT

This paper presents a method of stereoscopic panoramic video generation including techniques for panorama projection, stitching and calibration for various depth planes. The methods described can be used on video sequences captured by an arrangement of multiple pairs of cameras or multiple stereoscopic cameras mounted on a regular polygonal shaped camera rig. Algorithms can also be used in combination or separately, for generating both stereoscopic and monoscopic video and still panoramas.

1. INTRODUCTION

Panoramic images are images of a scene having a wide field of view, up to a complete 360 degrees around a chosen point in space. Generally, panoramic images are captured of *still scenes at far depth planes*.

A Stereoscopic image captured for human visualization comprises of two images recorded of a scene from two positions that are slightly horizontally displaced. One of these images is presented to the left eye of the human viewer, and the other to the right eye, providing a perception of depth. Generally, stereoscopic images are captured of *dynamic scenes at near depth planes.*

Therefore, fusion of panoramic and stereoscopic imaging poses both depth plane inconsistency and scene dynamics dilemma. It is required to capture both near and far depth plane information from two distinct points in space, along every possible direction over 360-degree field of view.

Monoscopic panorama generation using multiple images of a scene, and image mosaic techniques, can be commonly found in literature [1]. However, methods for generating stereoscopic panorama have been proposed by only a few. One such image capture system consists of a rotating camera on a vertical shaft [2]. Left and right image portions (strips) are extracted digitally from each image frame assuming a slit camera model. These strips are merged separately to generate left and right panoramas. Disadvantages of this system are:

- To avoid stitching artifacts, only a very thin strip from each image frame can be used, hence requiring 1000's of images to generate a single panorama.
- Physical constraints nullify the use of multiple cameras for this technology, since accommodation of 1000's of cameras on the rig is impossible.
- Due to the rotating camera system, dynamically changing environments cannot be captured with this technology.

Alternative systems [3][4] using special mirrors and lenses are described for generating video rate stereoscopic panoramic movies. However, such systems are economically and practically non-viable due to:

- Lenses and mirrors must be custom made with complicated spiral shapes.
- High accuracy on reflective/refractive surfaces are essential for minimizing image distortions.
- Since the panorama is optically compressed onto a single camera frame, the resolution of the image content is compromised.
- Loss of signal strength, due to multiple reflection and refraction.
- Occlusion of part of one view due to the mirror/lens arrangement of the other view [5].
- Distortion of perspective and disparity information.

Therefore, the solution addressed by this paper is to enable a limited number of multiple pairs of cameras or multiple stereoscopic cameras mounted on a regular polygonal shaped camera rig, to be able to generate stereoscopic panoramic video of dynamic scenes with high movement, such as automobile sporting events.

2. PANORAMA PROJECTION

There are two projection methods predominantly used for panorama generation. "Central projection" is used for generating monoscopic panorama, whereas "circular projection" is used for generating stereoscopic panorama.

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2.1 Central Projection

Main features are:

- Directions of captured image frames are perpendicular to the projection plane.
- Can be used with limited number of cameras
- Can be used to generate panoramic video
- Cannot be used for stereo-panorama generation.

2.2 Circular Projection

Main features are:

- Projection circles and surfaces for left and right projections overlap with each other.
- Directions of captured image frames are not perpendicular to the projection plane.
- Only a few vertical columns near the mid-frame can be used for panorama.
- Need large number of captured frames/ cameras to produce a panorama.
- Suitable for a rotating double camera system rather than a multi-camera system, hence not suitable for dynamic video capture.
- Need to use central projection when displaying left and right panoramas and disparity adjustment is required.

2.3 Proposed Centro-Circular Projection method

The Centro-Circular projection is designed to combine the favorable features of both the Central and Circular projections for the specific case of a camera set-up comprising of limited number of cameras mounted on a camera rig. The main features of the projection method are as follows:

- Projection circles for left and right projections overlap with each other.
- All the captured frame directions are unaltered, and perpendicular to the projection plane.
- Image frames are warped to the projection plane, in order to match the tangents at the overlap region.
- Stereo pairs are naturally rectified for parallel viewing.
- Can be used with a limited number of cameras.
- An ideal projection method for stereoscopic multi-camera systems.

Figure 1 shows a graphical illustration of Centro-Circular Projection method applied to a multi-camera set-up on a regular polygonal head.

The viewing circles for Centro-Circular projection are similar to the Central projection where the camera directions are tangential to the circle. These circles overlap on each other for left and right projections. Since a limited number of cameras (say N) are available for image capture, there can be only "N" correct perspectives available for each panorama projection. Compared to the rotating camera, where thousands of frames (hence correct perspectives) are available for each panorama, with limited number of multiple cameras, it is important to preserve the captured N true perspectives when projected on to the panoramic surface. Therefore, it is ensured that the N camera directions are perpendicular to the projection surface, similar to the central projection. Hence, there is no necessity to convert to central projection at the display or viewing stage, and also preserves the original disparity between the left and right captured image information.

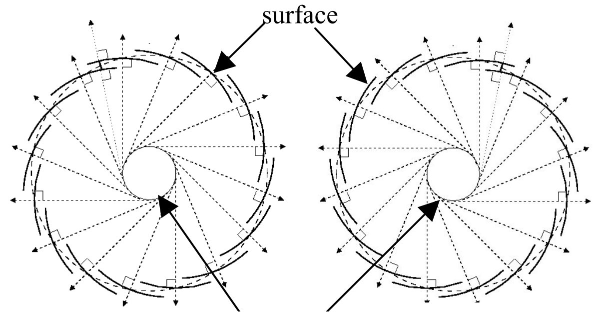

Figure 1: Illustration of Centro-Circular Projection Method.

2.3.1 Image Warping

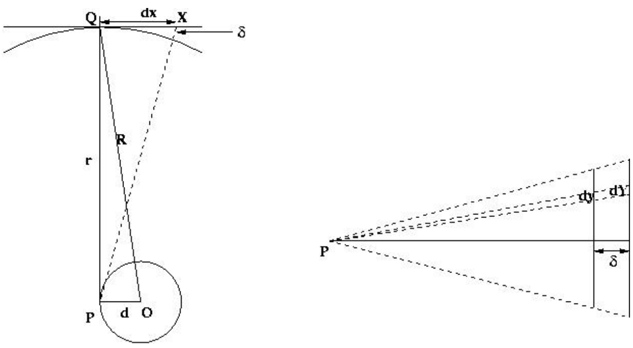

Figure 2: Illustration of image warping geometry for Centro-Circular Projection

With reference to Figure 2, image-warping equation is as follows

$$dy = \frac{r}{\sqrt{r^2 + (dx)^2}} dY \qquad (1)$$

All the captured image frames are warped according to Equation (1) to project on to the required projection surface for Centro-Circular projection. Other geometric relationships are:

$$R = \sqrt{r^2 + d^2} \quad (2)$$

$$\delta = \sqrt{r^2 + (dx)^2} - r \quad (3)$$

2.3.2 Blend Stitching Algorithm

In general, if there is M-number of facets on the regular polygonal camera head, the angle between two consecutive cameras for each panorama is given by

$$\theta = \frac{360^\circ}{M} \quad (4)$$

Consecutive image frames are warped and projected on to the projection surface so that camera directions at $\frac{\theta}{2}$ angular intervals are perpendicular to the projected surface.

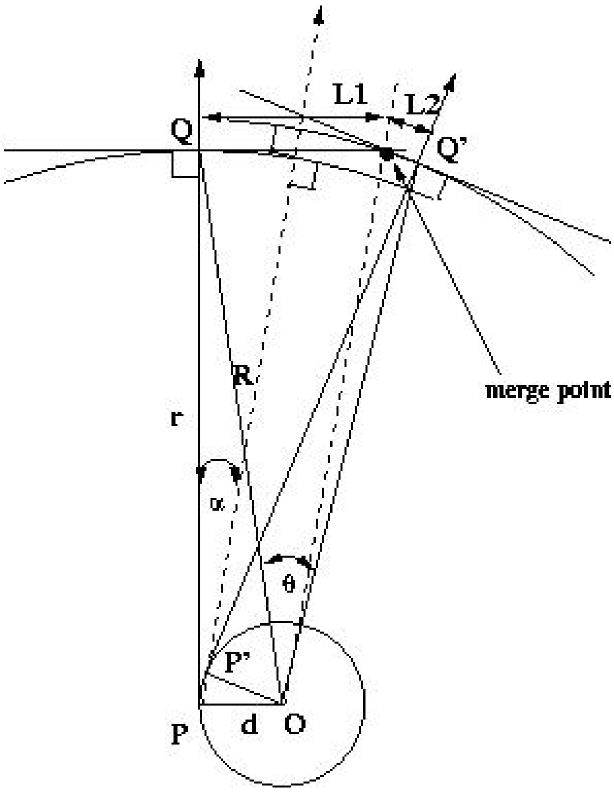

Figure 3: Illustration of blend stitching geometry for Centro-Circular Projection

In Figure 3, by considering the triangle POP', it can be easily shown that

$$\alpha = \frac{\theta}{2} \quad (5)$$

Merge points for panorama stitching is defined by the parameters L1 and L2. A simple geometric analysis of Figure 3 leads to the following

$$L1 = r\tan\alpha + d \quad (6)$$

$$L2 = r\tan\alpha - d \quad (7)$$

The above relationship applies to both the left and right panoramas. However, in the case of left panorama, the value of **d** is positive, whereas for the right panorama it is negative.

In order to convert the physical distances in to captured image frame pixel distances, the following equations involving the focal length of the cameras (**F**), image sensor pixel cell sizes **CH** (horizontal) and **CV** (vertical) are used.

Pixel width (unit length) = $r \times (CH)/F$ (8)

Pixel height (unit length) = $r \times (CV)/F$ (9)

It should be noted that r, CH, CV and F should be converted to the same unit lengths before applying the above equations.

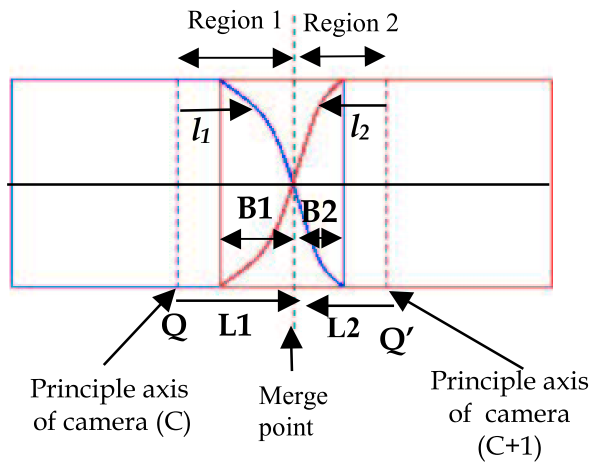

Figure 4: Illustration of image-frame merging at the merge point

The blending weights are computed according to the column distance from Q and Q' (in Figures 3 and 4) for each of the pair of columns that needs to be blended. The blending (overlapping) region is divided into two regions as shown in Figure 4. For Region 1, the blending weight parameters are given by,

$$W_C = 1 - 0.5\left(\frac{l_1}{L1}\right)^2 \quad (10)$$

$$W_{C+1} = 1 - W_C \quad (11)$$

For Region 2, the weight parameters are given by,

$$W_{C+1} = 1 - 0.5\left(\frac{l_2}{L2}\right)^2 \quad (12)$$

$$W_C = 1 - W_{C+1} \quad (13)$$

(a)

(b)

Figure 5: Stereoscopic panorama of a slowly changing scene (a) Left Panorama and; (b) Right Panorama.

The blend stitch will generally have a maximum width of $\mathbf{B}1+\mathbf{B}2$ as shown in Figure 4. This method is also capable of regularizing the illumination differences that may be present between two consecutive image frames. However, it is not compulsory to use this full blending width. Any arbitrary blend width can be specified on either side of the stitch line, provided that

$$T \leq \min\{B1, B2\} \quad (14)$$

However, small T values are less effective in illumination regularization than large T values, although they inflict less ghosting artifacts at the image stitch.

3. PANORAMA CALIBRATION

It should be noted that due to the characteristic nature of "panorama", the system could be accurately calibrated for a particular iso-plane that is at a distance of user's choice, from the camera rig. When objects are further away from this plane, the panoramic stitching will not be exact. However, there is always a particular depth of field, which can be achieved for a given number of cameras, where the artifacts due to mis-registration of objects of adjacent images are non-significant to the human vision. This depth of field is larger for video panorama than for still panoramic images.

For general usage, it is recommended that the camera system be calibrated using an iso-plane in 7m – 14m range. However, the system can also be calibrated to near objects, in which case, far objects need to be removed from the direct camera vision using opaque screens. Calibrating for a far iso-plane is both difficult to set-up and unnecessary since the stereoscopic effect will be lost due to large object distances from the camera set-up. The result would be equivalent to monoscopic panorama, which could be generated using a simpler camera set-up.

Camera calibration is also essential because the each camera within the multi camera head should be vertically and horizontally aligned with no planar rotations on the image sensors within each camera with respect to each other. Therefore, the following camera-head geometry, camera intrinsic and extrinsic parameters are generated using a one off camera calibration procedure:

Focal length (**F**), Horizontal Cell Size (**CH**), Vertical Cell Size (**CV**), Camera angular separation (θ), L and R camera separation ($2\times\mathbf{d}$), Minimum distance from the center of the camera set-up head to each facet (**r**), Radial distortion parameters of each camera, Rotation parameters of each camera, Vertical shift parameters of each camera, and Horizontal shift parameters of each camera.

4. RESULTS

The stereo panoramic images shown in Figure 5 are generated using the methods described in this paper, utilizing 32 images captured by a 16 faceted regular polygonal camera head.

5. CONCLUSION

The theory of stereoscopic panorama generation of dynamic scenes using centro-circular projection method has been presented. The method uses a limited number of cameras mounted on a regular polygonal head. A special blend-stitching algorithm is also described. An apparatus using the proposed methodology has been constructed and used successfully to produce stereoscopic panoramic video of a high-speed car-racing event.

6. REFERENCES

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