Geometrical Compensation Algorithm of Multiview Image for Arc Multi-camera Arrays

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Abstract. In this paper, we propose a geometrical compensation algorithm for multiview image captured by an arc multi-camera array. To capture multiview image or multiview video, we require more than two cameras arranged on a multi-camera array. This multi-camera array, however, has geometrical errors since it is manually built. These errors are related to the mismatch in the vertical and horizontal directions among images and irregular camera rotations. Also, these errors become serious obstructions to implement many three-dimensional (3-D) or multiview image processing and applications such as depth map estimation and intermediate view generation. Therefore, it is required to compensate geometrical errors in multiview image. Our proposed algorithm simultaneously adjusts positions, orientations, and internal characteristics of cameras arranged on an arc multi-camera array. Experimental results show that this algorithm reduced the vertical mismatch in pixels among images. In addition, there were equal horizontal disparities and equal angles between two cameras, respectively.

Keywords: Multiview Image, Geometric Compensation, Multi-Camera Arrays.

1 Introduction

Multiview image is one of the powerful candidates to satisfy the demand for immersive multimedia contents. Multiview image is a collection of videos, which are captured by more than two adjacent cameras.

The remarkable advantage of multiview image is to provide multiple viewpoints to users. Users can choose the desired viewpoint within the available range. It can also give the immersive sense with depth information [1] [2].

In order to capture multiview image, we have to arrange a number of cameras on a multi-camera array. There are several types of multi-camera array. They can be divided into two types according to the shape of the camera arrangement and the dimension of cameras, respectively. According to the shape of the camera arrangement, there are parallel type and arc type camera arrays. Also, they can be separated into one-dimensional (1-D) and two-dimensional (2-D) camera arrays in accordance with the dimension of cameras.

On the other hand, there exist geometric errors caused by the misalignment of multiple cameras on a multi-camera array. These errors can occur because we manually build a multi-camera array without any mechanical aligning instruments. Also, these

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errors become serious obstacles to time and accuracy in the three-dimensional (3-D) or multiview image processing such as depth map estimation and intermediate-view generation. In addition, we cannot expect a clear and smooth viewpoint change between multiple images. If these errors are reduced, however, we can easily obtain a high quality in multiview image and its applications [3].

Therefore, we propose a geometrical compensation algorithm of multiview image that is captured especially by an arc multi-camera array. Our proposed algorithm calculates the baseline for compensation by considering all camera positions. Then, we can obtain the compensated multiview image by applying the compensating transformation which rotates and translates each image plane according to the characteristics of corresponding camera array.

In the following of this paper, we explain the geometrical characteristics of multi-camera arrays. We then explain our proposed method and show the experimental results.

2 Geometrical Characteristics of Multi-camera Array

2.1 Camera Model

A pinhole camera is modeled by its camera center **C**, which is the center of the projection of the camera, and its image plane *R* that has the projected image of the scene. The direction of the line through **C** and perpendicular to *R* is called the principal axis. The focal length is the distance between **C** and *R*.

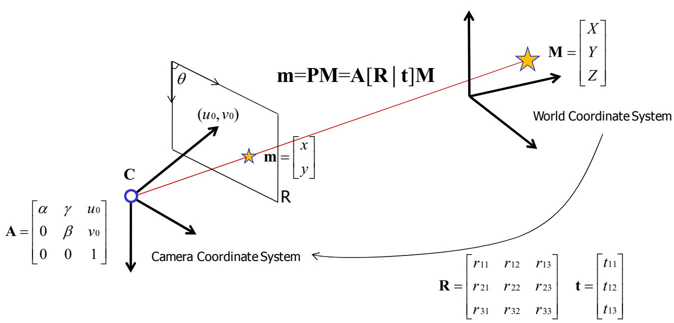

Fig. 1. Pinhole Camera Model

In the pinhole camera model shown in Fig. 1, a point **M** in 3-D space is projected to the point **m** on *R*. Then, the camera is modeled by the perspective projection, which is a linear transformation from the world coordinate to the image coordinate. The perspective transformation is given by a projection matrix **P**.

$$m \cong Pw \tag{1}$$

As indicated in Eq. 2, the perspective projection matrix consists of camera parameters. There are intrinsic parameters represented by the matrix **A** and extrinsic parameters represented by the matrix **R** and the vector **t**.

$$\mathbf{P} = \mathbf{A}[\mathbf{R}|\mathbf{t}] \tag{2}$$

Camera intrinsic parameters describe the internal characteristics of the camera such as the focal length, the non-orthogonality of the image plane, and the coordinate of the principal point.

Camera extrinsic parameters describe the orientation and position of the camera. They explain the relationship between the world coordinate system and the camera coordinate system.

2.2 Arc Multi-camera Arrays

In general, there are two main types of multi-camera arrays, which are parallel type and arc type arrays. According to the dimension, we can divide into two types of camera arrays, which are 1-D camera arrays and 2-D camera arrays. If we decide the type of the camera array, we can adjust the distances and angles between cameras to capture multiview image.

An ideal arc multi-camera array has cameras located on an ideal arc in 3-D space. In this case, cameras also have equal distances to adjacent cameras. Each principal axis of the camera has uniform angles between neighboring ones. Then, each distance from the arc origin to a camera become equal.

However, a practical arc multi-camera array does not satisfy these ideal conditions, since they are manually arranged without any mechanical aligning instruments. Therefore, there exists the misalignment in the direction and position of cameras. In addition, all cameras have different physical characteristics. Even though they are ideally arranged, we cannot obtain perfectly captured multiview image due to errors caused by different physical characteristics.

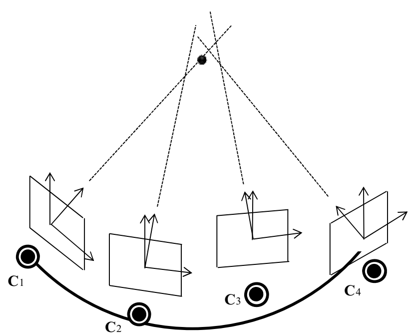

Fig. 2. A Practical Arc Multi-Camera Array

Figure 2 shows that all cameras in a practical arc multi-camera array are not perfectly arranged. They have different distances and different angles to adjacent cameras, and different focal lengths. Therefore, we may have a crucial mismatch among images in vertical coordinates of corresponding points, horizontal displacements, and camera angles. These geometrical errors can be significant obstructions to multiview and 3-D image processing and applications [4].

3 Geometrical Compensation Algorithm of Multiview Image

3.1 Homography

In Fig. 3, there are two cameras, two image planes, and a plane π in 3-D space which is not passing through both of two camera centers. The optical ray through the first camera center and the point **x** meets the plane π in a point **X**. This point **X** can be projected by the second camera in the point **x**'. This procedure is called point transfer via the plane π.

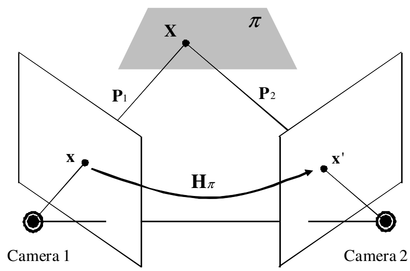

Fig. 3. Point Transfer via the Plane π

Point transfer via the plane π is defined by a 2-D homography $\mathbf{H}_\pi$. $\mathbf{H}_\pi$ maps each $\mathbf{x}_i$ in the first image plane to $\mathbf{x}_i$' in the second image plane. If two cameras are calibrated, in other words, all camera parameters of each camera are known, the homography can be easily obtained as the following equation, where $\mathbf{P}^+$ means the pseudo-inverse of **P** [5].

$$\mathbf{H}_\pi = \mathbf{P}_2\mathbf{P}_1^+ \tag{4}$$

In the proposed algorithm, we consider the image of the first camera as the original image of one of multiview cameras, and the image of the second camera as the compensated image of the corresponding camera. Then, the compensating transformation of each camera is defined by this homography between the original and compensated cameras.

3.2 Compensation for Arc Multi-camera Arrays

Geometrical compensation for an arc multi-camera array is performed in the order shown in Fig. 4. We have multiview image as an input, and we obtain camera parameters of all cameras by camera calibration [6]. We then calculate the baseline by the iterative midpoint connection [7]. According to this baseline, we estimate compensated camera parameters of each camera. With these compensated camera parameters, we compute the compensating transformation. Finally, we obtain compensated multiview image by applying the compensating transformation to the input.

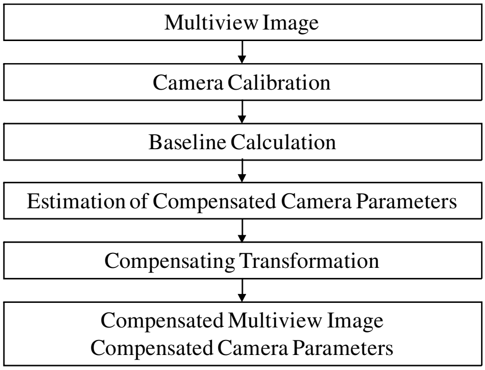

Fig. 4. Geometrical Compensation for an Arc Multi-Camera Array

Let us assume that we already know all camera parameters of all cameras. The baseline is obtained by the iterative midpoint connection indicated in Fig 5. In this case, we have five original camera centers, and we can find four midpoints between adjacent two camera centers. From the set of first midpoints, we attain three midpoints. We perform this process iteratively until the last two points are remained. Finally, the line through these two points becomes the baseline. This line can be easily calculated and simultaneously consider all camera positions.

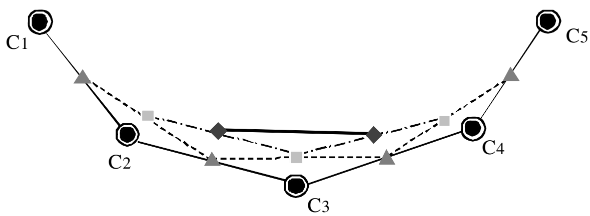

Fig. 5. Iterative Midpoint Connection

After obtaining the baseline, we measure two values. Let d be the length of the baseline and θ be the average angle between two cameras. Then, we estimate camera parameters of compensated cameras.

To find the new camera centers of compensated cameras, we set the initial point for both of cases of odd and even number of cameras. As shown in Fig. 6, $\mathbf{C}_3$ becomes the initial point, and this point is considered as the new camera center $\mathbf{C}'_3$ for odd number of cameras. We then set two 3-D search areas around $\mathbf{C}_2$ and $\mathbf{C}_4$ to find the new camera centers of these original camera centers. In each search area, we look for a point that satisfies three conditions. The line from the found point to the initial point must have the length d and the angle θ between the direction of the baseline. The line also has to be coplanar with the plane made by the baseline and the new principal axis.

After that, we can find the other new camera centers. To find $\mathbf{C'}_1$ and $\mathbf{C'}_5$, we set two search areas and obtain two points. In this case, these two points must have the length d to $\mathbf{C'}_2$ and $\mathbf{C'}_4$, and the angle θ to the line through $\mathbf{C'}_2$ and $\mathbf{C'}_3$, and $\mathbf{C'}_4$ and

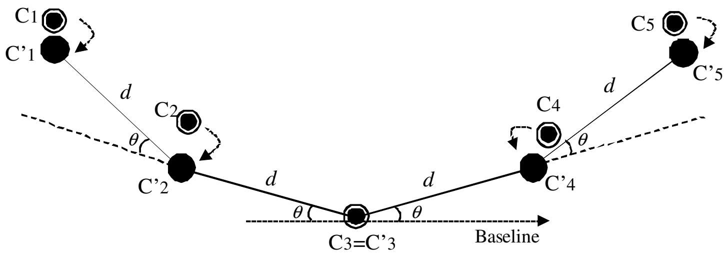

Fig. 6. Finding New Camera Centers for Odd Number of Cameras

C'$_3$, respectively. Also, these two points must be on the plane that is made by the new principal axis and the baseline.

On the other hand, in the case of even number of cameras, we decide the midpoint of $\mathbf{C}_2$ and $\mathbf{C}_3$ as the initial point shown in Fig. 7. Then, new camera centers **C'**$_2$ and **C'**$_3$ are located on spots that have distances of $2/d$ and $-2/d$ from the initial point in the direction of the baseline, respectively. After that, we can obtain all new camera centers by performing the same method of new camera center finding used in the case of odd number of cameras.

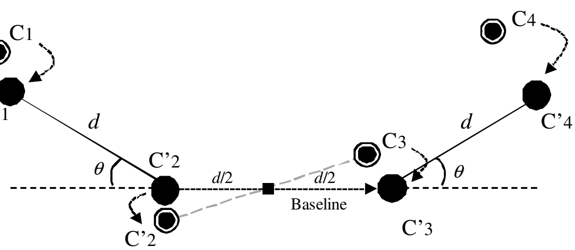

Fig. 7. Finding New Camera Centers for Even Number of Cameras

However, we need two more points that are the new camera centers of the virtual camera centers $\mathbf{C}_0$ and $\mathbf{C}_{n+1}$ after obtaining all new camera centers. We firstly extrapolate the positions of the virtual camera centers. We then set two search areas in each side and find **C'**$_0$ and **C'**$_{n+1}$ by the same process.

For the next step, we consider camera rotations and intrinsic parameters. In order to properly estimate the camera rotation of each camera according to the camera array, we make n chords by connecting two camera centers shown in Fig. 8. Then, we adjust each camera rotation matrix so that the horizontal axis of k-th image plane becomes parallel to the corresponding chord that passes **C'**$_{k-1}$ and **C'**$_{k+1}$. The principal axis of each camera has to be coplanar with the plane made by the baseline and the new principal axis.

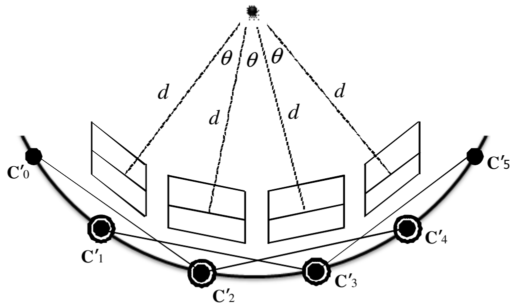

Fig. 8. Compensated Arc Multi-Camera Array

Finally, we estimate the intrinsic parameters. We replace each focal length and each vertical coordinate of the principal point by the average of their original values, respectively. Then, we can calculate the compensating transformation, and obtain images of the compensated arc multi-camera array like Fig. 8. All image planes have equal distances to the arc origin and equal angles between neighboring cameras.

4 Experimental Results

4.1 Experimental Condition

Multiview image is captured by multiple cameras on a multi-camera array. These cameras are connected to computers through a synchronization controller. We call this whole system as a multiview camera system.

Fig. 9. Multiview Camera System

Figure 9 shows our multiview camera system. For the experimentation of our proposed algorithm, we arranged six FLEA-HICOL-CS cameras on an arc multi-camera array, and we captured a test sequence. The distances and angles between adjacent cameras are 6.5 cm and 4 degrees, respectively. As shown in Fig. 10, we can easily notice that there exist geometrical errors in the test sequence.

Fig. 10. Test Sequence

4.2 Compensation Results

We firstly obtained all camera parameters of all cameras by calibration technique [6]. We then performed our proposed algorithm to captured multiview image with these camera parameters.

By experiments, we could obtain the compensated multiview image. We could reduce the vertical mismatch in pixels between images. Horizontal displacements between images were uniformly maintained. In addition, we could acquire suitable camera angles according to our camera array. We can consider that this compensated multiview image has the characteristics of the multiview image captured by an ideal arc multi-camera array.

Figure 11 shows the compensated multiview image. In this figure, however, we can notice that there are holes near by the image boundaries which are generated by applying the compensating transformation. It is because the transformation rotated and translated each image plane. Thus, these holes are unavoidable quality deterioration to compensate multiview image. On the other hand, we can remove these holes by regularly increasing the focal length of each camera.

Figure 12 and Table 1 shows the vertical mismatch between images in pixels and angles between adjacent cameras. Before the compensation, there were large amount of mismatch and irregular camera angles. However, there merely exists little amount of vertical mismatch and consistent horizontal displacements after compensation, and there are uniform angles between adjacent two cameras.

Fig. 11. Compensated Test Sequence

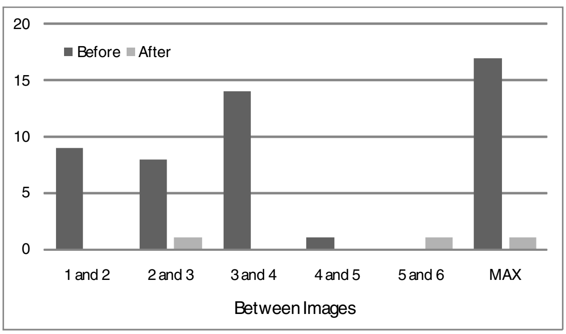

Fig. 12. Vertical Mismatch in Pixels between Images

Table 1. Angles between Adjacent Cameras

Between Cameras	1 and 2	2 and 3	3 and 4	4 and 5	5 and 6	Max. Variance of Angles
Before	4.2301	3.9750	4.1376	5.0521	4.7802	1.0771
After	4.5092	4.5111	4.5109	4.5132	4.5130	0.0040

5 Conclusions

In this paper, we have presented the geometrical compensation algorithm of multiview image captured by an arc multi-camera array. From our experiments, we could obtain the compensated multiview image. Experimental results confirm that the vertical mismatch between images was significantly reduced and horizontal displacements were uniformly adjusted. Also, angles between adjacent cameras became equal. These results can be considered as the multiview image captured by an ideal arc multi-camera array. With the compensated images, we expect that we can provide advantages of simplicity and accuracy in 3-D or multiview image processing and applications.

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