Geometrical Compensation for Multi-view Video in Multiple Camera Array

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Abstract – *In this paper, we present a geometrical compensation method for a calibrated multi-view video that is captured by the one-dimensional (1-D) parallel or arc camera array. Since the multi-view video may include geometical errors, we define a compensating transformation based on a two-dimensional (2-D) homography. After we apply the compensating transformation, we obtain all the image planes which are aligned vertically and rotated to be suitable for the camera array. Experimental results show that the proposed method correctly compensates the geometrical errors of the multi-view video. We can provide not only a clear viewpoint change in the multi-view video but also the simplicity and accuracy in matching between adjacent views.*

Keywords - *Multi-view Video, Multiple Camera Array, Geometrical Image Compensation*

1. INTRODUCTION

Multi-view video is a collection of videos that captures a three-dimensional (3-D) scene using two or more cameras. Unlike the single-view video, we can generate 3-D dynamic scenes from multiple viewpoints, which means that viewers can choose viewpoints within the available range. It is also possible to extract depth maps and implement 3-D videos from multi-view video. Recently, various multi-view video applications, such as free viewpoint TV (FTV), 3-D TV, surveillance, and immersive teleconference have been discussed [1][2].

To capture multi-view video, we construct a multiple camera array and arrange cameras on that. There are several types of multiple camera array. The multiple camera arrays in Stanford University have more than 100 cameras in the two-dimensional (2-D) parallel array and the 2-D arc array, respectively [3]. In Nagoya University, 100 cameras are employed and set up the one-dimensional (1-D) parallel array, the 1-D arc array, and the 2-D parallel array [4]. Each camera array has its own regular distance and angle between neighboring cameras. We can also make camera arrays by considering the number of cameras, scenes, purposes, and so on.

However, multi-view video has unavoidable geometrical errors which are due to an image mismatch in the vertical direction and an irregular camera rotation. These errors can occur since we construct camera arrays by human hands. Therefore, we have serious obstacles to time and accuracy in matching between views. In addition, we cannot expect a clear and smooth viewpoint change in multi-view video. Therefore, we need to compensate these errors in multi-view video.

In the case of stereo camera system, rectification can be one solution for those problems. Rectification is a classical topic in stereo vision. It makes all the epipolar lines of two images parallel and aligns the vertical mismatch [5]. After rectification, the two image planes become coplanar and the corresponding points in both images have the same vertical coordinates. There are numerous algorithms for stereo rectification. However, there are few methods to compensate the geometrical errors of multi-view video.

In this paper, we present a geometrical compensation method for calibrated multi-view video in 1-D parallel array and 1-D arc array. We introduce a pinhole camera model and features of multiple camera array. We then explain the proposed method and show our experimental results.

2. GEOMETRICAL CHARACTERISTICS OF MUILTIPLE CAMERA ARRAY

2.1. Camera model

A pinhole camera is modeled by the optical center **C** and the image plane R. A 3-D point **M** in space is projected onto R as an image point **m**. Since **C** plays a role of the center of the projection, **m** is the intersection of R and the line through **C** and **M**.

The line containing **C** and orthogonal to R is called the optical axis. The distance between **C** and R is the focal length. The intersecting point of the optical axis and R is the principal point. The image plane R has its own 2-D orthogonal coordinate system. Figure 1 shows a pinhole camera model.

In order to describe the camera operation, which means the relationship between **M** and **m**, we can define the camera projection matrix **P**.

$$\tilde{\mathbf{m}} = \mathbf{P}\tilde{\mathbf{M}} = \mathbf{A}[\mathbf{R}|\mathbf{t}]\tilde{\mathbf{M}}, \qquad (1)$$

where tilde means that the point is represented in homogeneous coordinates. As indicated in Eq. (1), the camera projection matrix consists of matrices **A** and **R**, and the vector **t**.

The 3×3 matrix **A** is composed of the intrinsic camera parameters that characterize the physical features of the camera. The 3×3 matrix **R** and the vector **t** are the extrinsic camera parameters that indicate the orientation and the position of the camera, respectively. The world coordinate system can be transformed to the camera coordinate system through **R** and **t**.

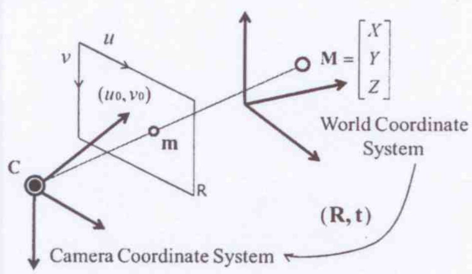


Fig. 1. Pinhole camera model

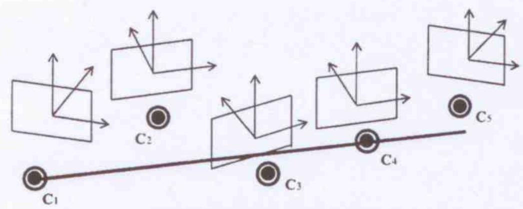
2.2. Multiple camera array

In general, there are two main types of multiple camera array, which are parallel camera array and arc camera array. Ideal parallel camera array has cameras which are located on a line called the baseline. Each camera has an equal distance to the neighboring cameras. Every optical axis is orthogonal to the baseline.

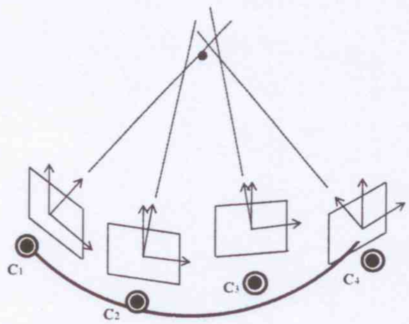
Ideal arc camera array can be constructed based on an ideal arc in space. Cameras are placed on the arc with the same distance to the adjacent cameras and the same angle between the neighboring optical axes. Then, the distance from the arc origin to each optical center becomes identical.

However, practical multiple camera array does not satisfy the ideal conditions since it is constructed by human hands without any mechanical aligning instruments. Therefore, cameras have the errors in the camera rotation and translation. In addition, each camera has different physical characteristics, which means that the intrinsic parameters of all the cameras are not equal. This problem also becomes a reason that yields the errors in multiple camera array.

Figure 2 shows that all the cameras in practical multiple camera array are not perfectly arranged. They have different distances to the adjacent cameras, different focal lengths, and unsuitable camera rotations. Therefore, we obtain the crucial mismatch between views in vertical coordinates, and camera angles. This mismatch can be significant obstructions to time and accuracy in view matching since they deteriorate the correlation between views. In addition, we cannot avoid an uneven viewpoint change when we watch a scene from multiple views.



(a) 1-D parallel camera array



(b) 1-D arc camera array

Fig. 2. Practical multiple camera array

3. GEOMETRICAL COMPENSATION IN MULTIPLE CAMERA ARRAY

In order to solve those problems, we propose the geometrical compensation method for multi-view video in multiple camera array, especially in 1-D parallel camera array and 1-D arc camera array.

We compensate all the image planes by applying the compensating transformation that is calculated by the 2-D homography between the original view and the compensated view of each camera.

In this section, we explain the algorithm to compute the compensated projection matrices, which mean the camera parameters of the cameras in ideally arranged camera array.

3.1. Compensation for 1-D parallel camera array

To compute the compensated camera parameters, we consider both camera intrinsic parameters and camera extrinsic parameters. We can find new optical centers, which are collinear and located with an equal distance to the adjacent cameras.

For the first step, we obtain the initial line by the iterative midpoint connecting algorithm. As shown in Fig. 3, the line through two cross-marked points becomes the initial line as the result of this algorithm.

Let m be an odd number. For m cameras, the midpoint of the initial line becomes the new optical center $\mathbf{C}'_{(m+1)/2}$ of $\mathbf{C}_{(m+1)/2}$. We then set a proper 3-D search range around the two adjacent original optical centers $\mathbf{C}_{(m+1)/2-1}$ and $\mathbf{C}_{(m+1)/2+1}$. We can find the new optical centers $\mathbf{C}'_{(m+1)/2-1}$ and $\mathbf{C}'_{(m+1)/2+1}$ in each search range that have the same distance to $\mathbf{C}'_{(m+1)/2}$ as the length of the initial line. Note that they have to be collinear with the initial line.