Logical Stitching: A Panoramic Image Stitching Method Based on Color Calibration Box

Weihua Ye[1,3], Kaiwen Yu[1,3], Yang Yu[3], Jia Li[1,2*]
[1]State Key Lab. of Virtual Reality Technology and Systems, School of Computer Science and Engineering, Beihang University
[2]International Research Institute for Multidisciplinary Science, Beihang University
[3]Qingdao Research Institute of Beihang University

***Abstract*—In this paper, we present a novel method to stitch two fisheye images into a panoramic image by using a color calibration box. The color calibration box is a new calibration tool with five planes for double fisheyes camera to calibrate. With the color calibration box, we obtain parameters used in our method to map the fisheye images back to the same logical sphere and stitch them according to the imaging model of the two fisheye cameras aligned back-to-back. Experimental results show that our method can not only produce 360-degree panoramic scenes but also eliminate the brightness difference from the two fisheye cameras. Moreover, our approach achieves comparable stitching performance with Gear360 camera in stitching details, and outperforms it in handling stitching colors.**

***Index Terms*—panoramic; stitching; fisheye; calibration**

I. Introduction

Image stitching is essential part in computer vision and picture processing field and has attracted a strong interest of computer researchers recently. Image stitching technology is the number of pieces of overlap images (which may be different time, different angle of view or different sensors to obtain) into a large seamless high-resolution images of technology. Recently, stitched images were used in various field, such as biology [5] [23] medical [22] and modeling [1].

The principle of image stitching can be divided into two categories: image mosaic based on camera calibration and image splicing based on feature points matching. Camera calibration is the process of solving the parameters required for the camera imaging model. While a number of methods have been developed concerning planar camera calibration [18] [19] [21], little work on panoramic camera and multi-cameras has been done. Point of feature matching is extracted by image has some local features of points (called feature points) as conjugate entity, with a characteristic point of attribute characteristic parameter is described as matching entity, by calculating the similarity measure conjugate entity registration method of image matching. Recently several works [6] [8] [9] had been done in improving traditional image stitching algorithm [7]. The problem with feature points matching is that when the feature points are too little or no feature points (such as blue sky) can not be stitched or ineffective.

In this paper, a new method is proposed to combine two fisheye images into a panoramic image with color calibration box. Color calibration box is a new type of calibration tool with five color calibration planes, which are used for double fisheye camera calibration. Using the color calibration box, we obtained the parameters used in the method. Our method is to map the fisheye image back to the same logical sphere and to splice it according to the imaging model of the fisheye lens. The experimental results show that this method can not only produce a perfect 360-degree panoramic image, but also eliminate the difference of brightness brought by two lenses in the fisheye camera. The experimental results show that our method is the same as that of Gear360 camera in splicing details, and our method is outstanding in color processing.

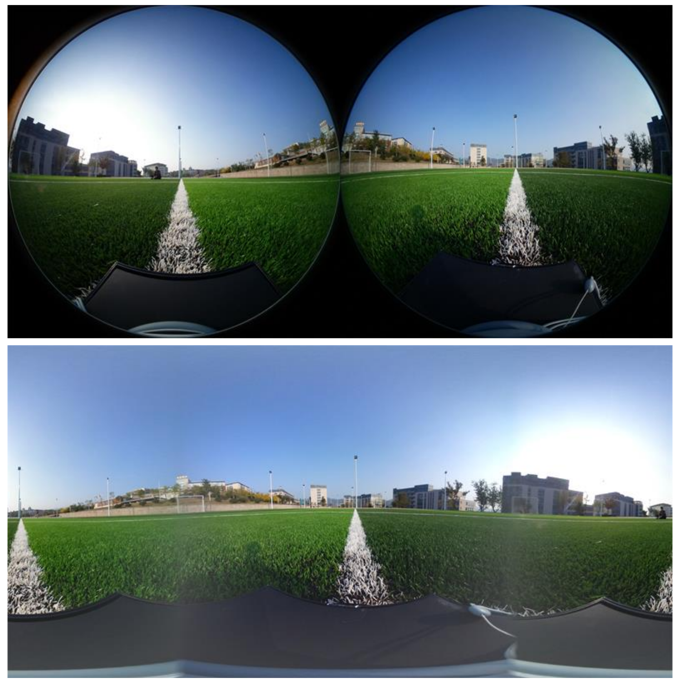

Fig. 1. A couple of fisheye images and our stitching result. Top: a couple of images sampled by two fisheye cameras aligned back-to-back. Bottom: the panorama image produced by our approach.

The main contributions of this paper include: 1) We propose a new calibration tool named color calibration box is proposed to calibrate the fisheye camera and obtain color and lightness information that other calibration equipment cannot acquire; 2) we design a new image stitching method based on color

*Corresponding author: Jia Li (jiali@buaa.edu.cn)

calibration box. By our method, two fisheye images can be used to generate a panoramic image.

II. Color Calibration Box

The color calibration box is a regular hexahedron box whose side length is 80 centimeter. At the top of the box, white light bulbs are evenly distributed, to ensure uniform illumination. The four sides of the calibration box are four color calibration plates, each of which has 64 squares, and the width and height of squares are 10 centimeter. The color distribution of the relative color calibration plate is the same. There are different colors in each grid and for each color in the grid, we value each channel of RGB in $\{32, 96, 160, 224\}$, so we can get 64 different colors.

We placed the double fisheyes camera in the center of the bottom of the color calibration box for calibration, and the uniform optical axis of the double-fisheye camera was parallel to the bottom surface. Two images from two fisheye lenses should theoretically be the same.

After obtaining the fisheye pictures, we randomly selected the same position in the smooth area from two fisheye images. Suppose that the k points obtained in the first fisheye lens are $M = \{m_1, m_2, \cdots, m_k\}$, where $m_i = \{x_{mi}, y_{mi}, R_{mi}, G_{mi}, B_{mi}\}$, $(1 \leq i \leq k)$. x_{mi}, y_{mi} is the x-coordinate and y-coordinate of the point of m_i. R_{mi}, G_{mi}, and B_{mi} are the R, G, and B values of the point of m_i. Accordingly, the k points obtained by the second fisheye lens are $N = \{n_1, n_2, \cdots, n_k\}$, where $n_j = \{x_{nj}, y_{nj}, R_{nj}, G_{nj}, B_{nj}\}$, $(1 \leq j \leq k)$. Since the point is taken at the same location in the two fisheye images, $x_{mi} = x_{ni}$, $y_{mi} = y_{ni}$, $(1 \leq i \leq k)$. In order to obtain the different brightness of the two fisheye lenses which is brought from producing, we calculate

$$\Delta R = \frac{1}{k}\sum_{i=1}^{k}(R_{ni} - R_{mi}), \tag{1}$$

$$\Delta G = \frac{1}{k}\sum_{i=1}^{k}(G_{ni} - G_{mi}), \tag{2}$$

$$\Delta B = \frac{1}{k}\sum_{i=1}^{k}(B_{ni} - B_{mi}). \tag{3}$$

$\Delta L = (\Delta R, \Delta G, \Delta B)$ is two fisheye lenses brightness difference. Before the subsequent stitching, just by adding ΔL on each pixel in the first fisheye image, the brightness difference between the two lenses can be eliminated.

For each intersection point on the calibration board, there are four different colors around. We propose a new 12-dimensional descriptor, using the surrounding color information to indicate that $ColorDot = \{R_1, G_1, B_1, R_2, G_2, B_2, R_3, G_3, B_3, R_4, G_4, B_4\}$. With this description, the computer can automatically differentiate the points and match them as long as we know the color information around each corner.

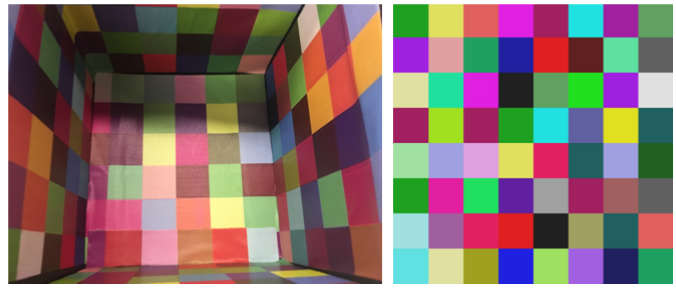

Fig. 2. The picture on the left is color calibration box and the picture on the right is example of color calibration plates. Each of the two adjacent squares in color calibration plate has a different color.

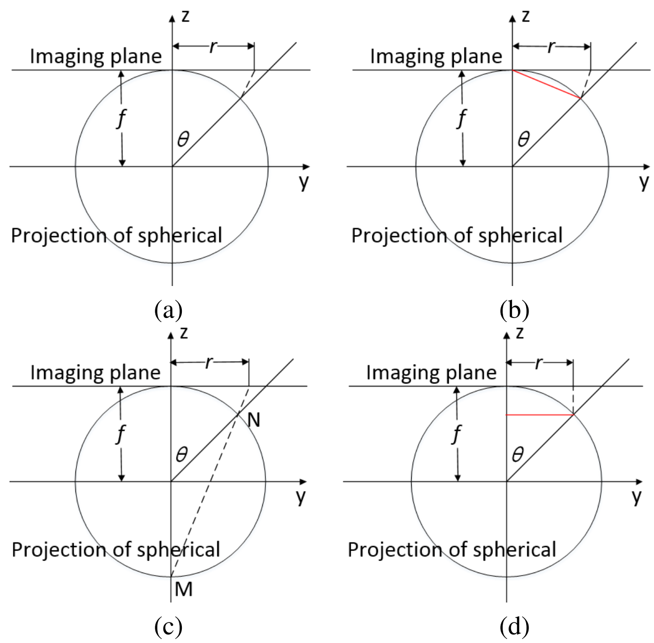

Fig. 3. Schematic diagram of each projection model. (a) is the equidistant projection model, and the arc length corresponding to Θ is equal to the length of r. (b) is the isometric projection model, and the length of red line is equal to the length of r. (c) is the stereoscopic vision projection model, and the length of r is equal to the length of the right angle in the plane of the angle of the right triangle with the dotted line as the hypotenuse. (d) is the orthogonal projection model, and the length of r is equal to the length of red line.

III. Stitching Method

A. Fisheye Camera Projection Model

The lens of fisheye camera is composed of a complex set of lenses, but we can approximate it as a ball when calculating. In general, the projection model is divided into four types: equidistant projection (EP) model, isometric projection (IP) model, stereoscopic vision projection (SVP) model and orthogonal projection (OP) model. Among them, the OP model is less than 180° from the perspective, so we are not going to use it to generate panoramas.

- EP model: the distance between each pixel and the center of the image is equal to the arc length corresponding to the incident angle.

$$r = f_e\theta. \tag{4}$$

- IP model: the distance between each pixel and the center of the image is equal to the base length of an isosceles triangle formed by the incident angle and the corresponding two radii.

$$r = 2f_i \sin(\frac{\theta}{2}). \tag{5}$$

- SVP model: suppose that the angle of incidence and the intersection of the sphere is N, and the diameter of the plane perpendicular to the imaging plane is M. The distance between each pixel and the center of the image is equal to the distance between the intersection point of the linear MN and the imaging plane and the diameter.

$$r = 2f_s \tan(\frac{\theta}{2}). \tag{6}$$

- OP model: the distance between each pixel and the center of the image is equal to the length of the angle corresponding to the Angle of the incident Angle in the right triangle with a radius of the hypotenuse.

$$r = f_o \sin\theta. \tag{7}$$

B. Calibration by color calibration box and reverse mapping

The reverse mapping refers to the location of the point before the projection based on the relationship between the point and point identified by the projection model and the point after the projection. Before this work, the value of f should be calibrated with color calibration box.

When calibrating, the double fisheyes camera is placed and photographed according to the method described above, and the required images are obtained. In the calibration image, the left and right sides of the fisheye images have the same corner points along the left and right sides of each fisheye image. The left side of the original image on the left side corresponds to the right of the fisheye image on the right, and the right side of the fisheye image on the left corresponds to the left side of the fish eye image on the right. After finding the corresponding corner points, according to the position of corresponding points on the image and the distance between corresponding points and their respective image centers, f can be calculated by the formula of the projection model. The f of each projection model here is different.

A double fisheyes camera can get a 2:1 ratio of images. Suppose (x_1, y_1) is the center of the calibration image on the left., (x_2, y_2) is the center of the right calibration image, so for any point (x, y) on the calibration image there is $r = \min(\sqrt{(x-x_1)^2 + (y-y_1)^2}, \sqrt{(x-x_2)^2 + (y-y_2)^2})$. where in the picture on the left

$$r = \sqrt{(x-x_1)^2 + (y-y_1)^2}, \tag{8}$$

in the picture on the right

$$r = \sqrt{(x-x_2)^2 + (y-y_2)^2}. \tag{9}$$

$C_1 = \{(x_{m1}, y_{m1}), (x_{m2}, y_{m2}), \cdots, (x_{mk}, y_{mk})\}$ are the supporting points in the left image, $C_2 = \{(x_{n1}, y_{n1}), (x_{n2}, y_{n2}), \cdots, (x_{nk}, y_{nk})\}$ are the supporting points in the right image. Among them (x_{mi}, y_{mi}) and (x_{ni}, y_{ni}) $(1 \leq i \leq k)$ are the same points in the real scene. We used (8) (9) to calculate $R_1 = \{r_{m1}, r_{m2}, \cdots, r_{mk}\}$, and $R_2 = \{r_{n1}, r_{n2}, \cdots, r_{nk}\}$.

When the projection model is an EP model, there is

$$f_e = \frac{2}{\pi k} \sum_{i=1}^{k} \frac{r_{mi} + r_{ni}}{2}. \tag{10}$$

When the projection model is an IP model, there is

$$f_i \geq \frac{\sqrt{2}}{2} \max_{1 \leq i \leq k} \frac{r_{mi} + r_{ni}}{2}. \tag{11}$$

Equation (11) is equal when $r_{mi} = r_{ni}$.

When the projection model is a SVP model, there is

$$f_s \leq \frac{1}{2} \min_{1 \leq i \leq k} \frac{r_{mi} + r_{ni}}{2}. \tag{12}$$

Equation (12) is equal when $r_{mi} = r_{ni}$.

Because of the small change in the overlap part, we directly take care of the latter two projection models. So

$$f_i = \frac{\sqrt{2}}{2} \max_{1 \leq i \leq k} \frac{r_{mi} + r_{ni}}{2}, \tag{13}$$

$$f_s = \frac{1}{2} \min_{1 \leq i \leq k} \frac{r_{mi} + r_{ni}}{2}. \tag{14}$$

For the left image of the fish eye image, each pixel (x, y) is available

$$\tan\varphi = \frac{y - y_1}{x - x_1}, \tag{15}$$

where $x \neq x_1$. When $x = x_1$ and $y \leq y_1$, $\varphi = \frac{\pi}{2}$. When $x = x_1$ and $y \geq y_1$, $\varphi = \frac{3\pi}{2}$.

The picture on the right

$$\tan\varphi = \frac{y - y_2}{x - x_2}, \tag{16}$$

where $x \neq x_2$. When $x = x_2$ and $y \leq y_2$, $\varphi = \frac{\pi}{2}$. When $x = x_2$ and $y \geq y_2$, $\varphi = \frac{3\pi}{2}$.

We took the IP model as an example. Combining (4)(8)(10)(15), the transformation formula of (x, y) to (f_e, θ, φ) is obtained

$$\begin{cases} f_e = \dfrac{2}{\pi k} \displaystyle\sum_{i=1}^{k} \dfrac{r_{mi} + r_{ni}}{2} \\ \theta = \dfrac{sqrt(x-x_1)^2 + (y-y_1)^2}{f_e} \\ \varphi = \arctan \dfrac{y - y_1}{x - x_1}, \end{cases} \tag{17}$$

where f_e only needs to be calculated at calibration time.

Due to shoot panorama fisheye camera viewing angle is greater than 180 degrees, so there is a certain width are repeated. For fusion processing, the linear fusion technique may be used.

C. Panorama spread

There are a lot of storage methods for panorama. In the experiment, we selected the most commonly used rectangle diagram.

The principle of expansion can be illustrated with a simple example. The earth is a sphere, and there are lines of longitude, from the North Pole to the South Pole. If we straightened these lines and placed them in order, we could get a rectangle with a height of πR and a width of $2\pi R$, where R is the radius of the earth. Each point on the top and bottom of the rectangle is the north or South Pole.

IV. Results and Discussion

The experimental results showed that the double fisheyes camera after calibration, images could be stitched well, and the result of the patchwork on the 360-degree panoramic VR devices could be perfect. In addition, when images were taken in overlapping areas with little or no feature points, they could also be well spliced. It cannot be achieved by the methods based on feature point matching.

To verify the results of the experiment, we compared the results of our algorithm with the results of Gear360 camera. The results showed that there were some mismatches and fuzzy phenomena in the results of Gear360 camera, and the brightness difference between the lens was not eliminated. Our results not only removed the dislocation phenomenon, but also eliminated the brightness difference between the lens. But if we zoom in and look at the results of our algorithm, we can see that we're not doing as well as Gear360 camera in the near distance.

In order to study the robustness of the algorithm in different environments, we chose different environments and different light intensity data. The experimental results show that our algorithm has good results under various conditions.

To investigate the sense of reality and immersion, we put results of our algorithm and Gear360 camera into Pico Goblin (a kind of all-in-one machine). We invited several computer workers to compare the difference. The investigated result showed that the results between our method and Gear360 camera are similar in VR equipments.

At present, there are still some problems to be solved: firstly, there is a certain blind area for the image splicing of the double-fisheye camera. When the object is too close, it cannot be spliced well. Secondly, this experiment requires two fisheye camera optical axis similar or consistent, when the optical axis differ too far or into the Angle is too large, will not be able to extract the overlap cannot complete panorama generation or the result is bad. Finally, the splicing time is not fast enough to achieve the real-time effect.

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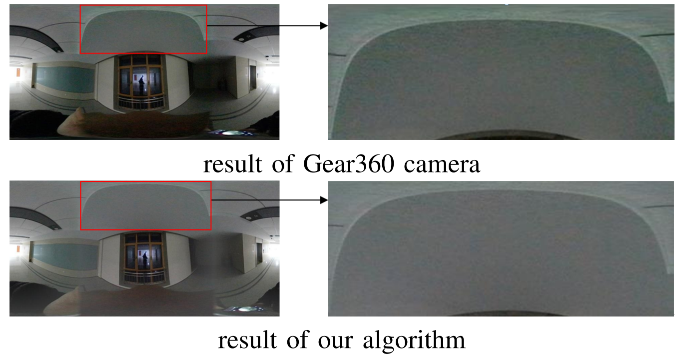

Fig. 4. The results of Gear360 camera and our algorithm. The picture on the top is the result of Gear360 camera, and the picture on the bottom is the result of our algorithm. From the right of these two pictures, we can easily find out that Gear360 camera has some shortcomings in color processing, which brings a little green light to the ceiling.

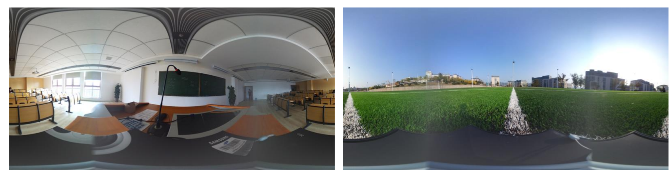

Fig. 5. Stitching results of our algorithm under different lighting conditions. Results showed that our algorithm is robust in different lighting conditions.

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fisheye Gear360 EP IP SVP

Fig. 6. The results of our algorithm and Gear360 camera.

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