Multi-camera Panoramic Stitching with Real-time Chromatic Aberration Correction

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Abstract—Due to uneven lighting conditions and differences between camera lenses, in actual engineering applications, there is a difference in brightness of the image collected by the camera, which will cause obvious gaps in video stitching and poor stitching effect of panoramic pictures. This paper designs and implements an algorithm based on the gray statistics of overlapping areas to achieve global correction, and combined with the fade-in and fade-out image fusion algorithm to make the splicing transition natural. The experimental results show that in the Visual Studio 2015 platform environment, real-time stitching of 8-channel cameras has a fast algorithm speed and can achieve a stitching speed of 25 frames per second. The video is smooth and the picture quality is good without obvious color difference.

1. INTRODUCTION

With the development of live video technology and virtual reality technology, video image stitching technology has become a research hotspot [1]. Video image stitching technology realizes real-time panoramic viewing by stitching each frame of multi-channel video. For some stitched images, we found that there is a clear gap between the two images [2]. There are two main reasons for this situation. First, no adjustments to the chromatic aberration of the image are made. Second, the fusion at the boundary of the two images is not completed. In order to make the overall effect of the panoramic image truly restore the scene in the large field of view, we need to complete the color difference correction between the images before stitching and the image fusion operation after the stitching is completed.

The difference in brightness between images mainly comes from the following aspects—the difference in lighting when the camera is collected, the design of the lens, and the photosensitive element. Common methods for eliminating chromatic aberration include white balance compensation and gamma correction, which are mainly aimed at the chromatic aberration correction of a single image, and it is difficult to achieve simultaneous correction for multiple cameras [12]. Therefore, it is necessary to perform correction based on the images. By using one image as a reference and other images are according to the brightness distribution of the reference image, a synchronous correction effect is achieved. Since the grayscale information has the similarities of the color image, it can reflect the brightness distribution and characteristics of the image, and reduces the amount of calculation. Therefore, this paper uses gray approximation to calculate the brightness difference between adjacent images to obtain the global correction parameters of each channel. In this way, the brightness correction of the image achieve.
For the gap of the stitching boundary caused by stitching, image fusion operation is needed. At present, there are many algorithms that can be used to fuse two images. Such as average fusion, Laplacian pyramid fusion, linear fusion and other algorithms. These algorithms are mostly used for fusion of static images. For video stitching, these algorithms require higher speed. Among them, the average fusion algorithm replaces the pixel value of the overlapping area with the average value of the corresponding positions of the two images. The algorithm is simple and the calculation amount is small, but the fusion effect is not good, and there will be obvious band marks in the transition area [3]. Laplacian algorithm is an image fusion method based on multi-resolution, which can achieve better fusion effect, but its algorithm is computationally intensive and time-consuming, which cannot meet the real-time requirements of subsequent frame stitching [4]. The linear fusion algorithm can ensure a better fusion effect, and the speed is faster, which can solve the fusion problem of the boundary gap. Therefore, based on the gray statistics of overlapping areas, this paper implements an algorithm for global correction, and combined with fade-in and fade-out image fusion algorithm to make the splicing transition natural.

For multi-camera scenes, with the increase in the number of cameras, the amount of information is greatly improved. To achieve real-time processing of video, an algorithm is required to achieve millisecond speed.

2. FUNDAMENTALS

2.1 Image chromatic aberration correction
Chromatic aberration, one kind of aberration, is a serious result of lens imaging deflection. In short, it is the difference in color after imaging. Monochromatic light does not produce chromatic aberration, but the wavelength range of daily visible light varies from 400 to 700 nm. The refractive index of light of different wavelengths passes through the lens is different. When the various light molecules of visible light reach the photoreceptor of the camera, with the light intensity does not change, the imaging changes accordingly. The chromatic aberration is mostly caused by the shooting environment and care conditions. For multi-channel camera stitching, color difference will result in uneven distribution of the chromaticity and brightness of the stitched panorama picture. Therefore, the overall viewing effect of the picture is not good.

The color image information collected by the camera is determined by the three components of RGB, where R, G, and B represent red, green, and blue. Respectively, each component is between 0-255. The grayscale image is a special color image with the same RGB three components, which corresponds to a channel. In digital image processing, the color image can be converted into a grayscale image to reduce calculations.

Since the overlapping area of the image is the common part of the two images, it can reflect the brightness distribution characteristics of the two images. If the width of the image is W, the width of the overlapping area is usually less than W/2. Compared with global statistics-based calculation, the amount of calculation is greatly reduced. At the same time, the gray value is used to calculate the distribution of pixel values, which reduces the calculation of the three-time average based on three channels.

In formula 1, $\text{Mean}_{\text{gray}}$ is used to represent the average gray value of the whole image:

$$\text{Mean}_{\text{gray}} = \frac{\sum (R + G + B) / 3}{\Delta \text{area}}$$  \hspace{1cm} (1)

Linearly transform the three components of R, G, and B, where y represents the channel value after correction, x is the channel value before correction, and $\beta$ represents the image gray value difference.

$$y = ax + \beta$$ \hspace{1cm} (2)

2.2 Image fusion
There is a stitching gap in the image after registration according to the homography matrix, and the image fusion needs to be based on the coincident area, so that the stitching area transitions naturally without
obvious seams. In this paper, a linear fusion method is used, with the distance from the point of the overlapping area to the boundary as the weight, and the weighted summation is performed based on the pixel value [5].

\[ f_1(x, y), f_2(x, y) \] represents the pixel value at the point of the two images to be stitched, \( f(x, y) \) represents the pixel value of the fused image [6]. The corresponding relationship is shown in the following:

\[
f(x, y) = \begin{cases} 
  f_1(x, y) & (x, y) \in f_1 \\
  w_1 f_1(x, y) + w_2 f_2(x, y) & (x, y) \in I \\
  f_2(x, y) & (x, y) \in f_2 
\end{cases}
\]  

\[ I = f_1 \cap f_2 \]  

(3)

The scale factor \( w_1, w_2 \) is determined by the distance from the point to the boundary, which satisfies \( w_1, w_2 \in (0,1) \), \( w_1 + w_2 = 1 \).

This method can make the image transition natural, and the algorithm can meet the real-time requirements of video stitching.

3. ALGORITHM DESIGN AND RESULT ANALYSIS

The flow chart of this algorithm is shown in Fig. 1. First collect multiple channels of video, and perform an initial color difference parameter correction in an offline environment. For a short period of time, there are small changes of color in subsequent frames. Within a certain frame, the parameter does not change within the threshold range. The brightness difference between each current image is calculated and each channel value can be corrected during the image stitching processing. After reaching a certain range, the color difference correction parameters are recalculated [7-10]. At the same time, after the image stitching is completed, a fusion operation based on progressive detection is performed to achieve a natural transition of the picture.

3.1 Calculate the average gray value

In formula 5, calculate the RGB distribution of the two images in the overlapping area, and calculate the average gray value \( M_1, M_2 \). Take \( (R+G+B)/3 \) to represent the gray value of the image at any point, \( \text{diff} \) to represent the difference in gray value of the overlapping area of the two images.

\[
M_{1,2} = \frac{1}{w*h} \sum_{j=0}^{h} \sum_{i=0}^{w} \frac{R_{1,2} + G_{1,2} + B_{1,2}}{3}
\]  

\[ \text{diff} = M_1 - M_2 \]  

(5)

(6)

\( w \) is the width of the image and \( h \) is the height of the image.

3.2 The corrected pixel value of the target image

In formula 7, \( \text{Re}s(i, j) \) represents the pixel value before correction for the image to be corrected, \( \text{Dst}(i, j) \) represents corrected pixel value.

\[
\text{Dst}(i, j) = \text{Re}s(i, j) + \text{diff}
\]  

(7)

3.3 Transboundary processing

In order to avoid the pixel value exceeding the maximum value of 255 after linear correction, an out-of-bounds processing operation needs to be performed to keep it in the range of 0-255.
\[ Dst(i, j) = \begin{cases} 
0 & Dst(i, j) \leq 0 \\
Dst(i, j) & 0 < Dst(i, j) < 255 \\
255 & Dst(i, j) \geq 255 
\end{cases} \] (8)

### 3.4 Color difference adjustment

As shown in Figure 4, taking the first image as the reference image, rt2~rt8 are the color difference correction parameters of each image, corresponding to $\beta$ in the formula 2. $Rr_1$ represents the gray value of the region overlapping with two pictures, $ll_2$ represents the gray value of the overlapping region of the left border of picture 2, and $rr_2$ represents the gray value of the overlapping portion of the right side of picture 2 and picture 3. Then difference between $rr_1$ and $ll_2$ represents the difference in the brightness values of picture 1 and 2 at the same position [11].

![System flow chart](image1)

![Original Image](image2)
Fig. 2. (b) Corrected Image

Fig. 3. (a) The spliced picture without color difference processing

Fig. 3. (b) The effect after fusion

Fig. 3. (c) The effect after color correction

Fig. 4 Real-time color difference adjustment relationship

Fig. 5. (a) RGB distribution with reference to the original image
4. CONCLUSION

In this paper, on the premise of meeting the real-time requirements of video stitching, experiments on the image fusion effect and color unification are carried out, which proves the effectiveness of the algorithm in practical engineering applications.

Usually online video playback will not be lower than 20 frames per second, which means that the real-time video splicing system speed must reach at least 20 fps. For one frame, ignoring the overhead time of the initialization, the total time of video stitching, image fusion and color difference processing which we designed is about 35 milliseconds. The system can achieve a splicing speed of 25 frames per second, which exactly meet the real-time requirements.
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