Parallax-Tolerant Image Stitching with Optimal Homography

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Abstract. Artificial ghosting is a serious problem in image stitching with wide-baseline, which makes it difficult to achieve seamless stitching. A robust parallax-tolerant image stitching method combined with optimal homography matrix selection and seam-cutting processing is proposed. Optimal homography matrix is obtained by analysing feature point distribution and minimizing the registration error. And then, the aligned area is enhanced by the optimal homography matrix, which can facilitate the seam searching. To realize seamless stitching, the luminance difference and the geometrical structure are used in seam-cutting processing. At last, the experimental results show that the artificial ghosting is solved quickly and effectively in the images stitching with large parallax.

1. Introduction

Image stitching technology[1-2] has been a research hotspot in the fields of computer vision, digital image processing and virtual reality, especially the parallax-tolerant stitching[3]. For the traditional stitching method, two-dimensional transformation matrix is estimated through the input images, and then image fusion is implemented in the overlapping regions directly. However, this method does not work for complex scenes, and it is only suitable for images acquired at the same viewpoint. Therefore, lots of advanced stitching methods have been proposed to solve this problem. For example, a typical and popular panoramic stitching pipeline was proposed by Brown[4], the algorithm consists of spherical projection and beam adjustment. It is used in the current market as an efficient panoramic technology to process scene images with weak parallax efficiently, and obtain better panoramic image finally. To achieve seamless stitching of image with large parallax, Eden AM[5] proposed a method which combined with the global transformation registration and seam-cutting. Then grid optimization was first applied to the image stitching in Zaragoza J[6], the algorithm used local homography matrix of each grid to optimize the alignment image. At the same time, the efficient calculation method of moving DLT was proposed, which is applied on the image stitching of image with weak parallax. These algorithms are more reluctant when stitching images with large parallax. Because image with large parallax accurately align directly through the traditional two-dimensional transformation is difficult to achieve the perfect image fusion. In order to solve the parallax imaging problem, a method combined with optimal homography matrix selection and seam-cutting processing is proposed, in which optimal homography matrix is obtained by analysing feature point distribution and registration error. To realize seamless stitching, the luminance difference and the geometrical structure are used in seam-cutting processing. At the same time, the registration error is used to reduce the time consumption by reducing the range of seam searching.
2. Optimal homography selection

2.1. Optimal homography matrix selection

In image registration, the acquisition of the projection plane is affected by feature points in the local target area. This results in a small number of areas that can be aligned after the image is registered. As shown in Fig.1, the dotted line represents the optimal projection plane selected by the conventional method. In this paper, the optimal homography is selected by minimizing the registration error and analysing the feature points distribution. The solid line represents the optimal projection plane selected by this paper registration method in Fig.1.

Fig.1 Optimal homography matrix selection diagram

To obtain a robust feature points set, the SIFT[7] algorithm is used to extract the feature points of the input images $I_l$ and $I_r$.

The feature descriptor is used to confirm the matching pairs $p_l = (x_l, y_l)$ and $q_l = (u_l, v_l)$ in the overlapping regions. And the optimal homography is selected based on these matched points. Next, the optimal homography matrix acquisition process will be described in detail.

1. Randomly selecting 4 matched points to calculate homography, judging the remained matched points whether satisfy the homography. If matched points satisfy the homography, setting a count value for each point to mark the satisfying times. Calculating the sum of registration errors $R_l$, using the inner points set to update the homography.

2. If count value is larger than the $k$ times of average count value of all feature points, setting these feature points to invalid, and $k$ is set to 3 empirically. The total number of valid feature point named $N_l$. Updating inner points set. Otherwise, going to step(1). At the same time, if the average count value of all the matched points is larger than $n$, and $n$ is set to 2.15 empirically, dropping out the iteration. Otherwise, going to step(3).

3. Judging $N_l$ whether less than $\epsilon * N$, if that’s true, adding the homography to the set of candidate homography. Otherwise, giving up this homography. ($\epsilon$ is set to 0.15 and $N$ is number of all matched points)

After obtaining multiple candidate homography matrices, counting the distance between each feature point of every candidate homography, named $S_l$, the optimal homography matrix is selected by combining with $max(S_l/N_l)$ and $min(R_l/N_l)$.

2.2. Seam-cutting processing

After image registration, the luminance difference and the geometrical structure are used in seam-cutting processing on the overlapping area. The cost functions for calculating the best seam is:

$$E(x, y) = \alpha E_c(x, y) + (1 - \alpha)E_g(x, y), \quad (1)$$

In which $E_c$ is the luminance difference and $E_g$ is the geometrical structure, $\alpha$ is set to 0.31 empirically.

**Luminance difference** In terms of luminance intensity, it is required that the luminance difference between the pixels on the stitching seam be the smallest. If the luminance difference of local area is not zero, it means that artificial ghosting is occurred at same area due to parallax imaging. The luminance difference $E_c$ is as follows.
\[ E_c = \sum_{(x,y) \in \text{path}} I_{\text{diff}}^3 (x, y), \] 

In which \textit{path} indicated the seam coordinates, \( I_{\text{diff}} \) is the luminance difference between the overlap regions of \( I_l \) and \( I_r \) after optimized registration.

**Geometrical structure** To ensure the similarity of the adjacent points on the seam, the gradient operator as shown in formula(3) is adopted. The seam-cutting is used to search best seam on the difference image by minimizing \( E_g \). The geometrical structure calculation is as follows.

\[ S_x = \begin{bmatrix} -2 & 0 & 2 \\ -1 & 0 & 1 \\ -2 & 0 & 2 \end{bmatrix}, \quad S_y = \begin{bmatrix} -2 & -1 & -2 \\ 0 & 0 & 0 \\ 2 & 1 & 2 \end{bmatrix}, \] 

\[ E_g = \sum_{(x,y) \in \text{path}} I_{\text{diff}} (x, y) \otimes S_x(x, y), \] 

In which \( \otimes \) represents of image convolution calculation, \( S_x \) and \( S_y \) are the horizontal filter and the vertical filter respectively.

As shown in Fig.2, the star and circle represent the feature points of source image \( I_l \) and \( I_r \) respectively and yellow lines between star and circle represents registration error of a pair of matched point. A small number of feature points with small registration error were selected, to constrain the range of seam searching. So according to the registration error, it was estimated to reduce the time consumption. Similarly, a matched point with 0 registration error means that the point must be on the best seam.

![Fig.2 Seam search sketch](image-url)

3. **Experimental results**

In this paper, the proposed algorithm is compared with APAP[6] and Dominant H[5]. It is implemented by MATLAB on LINUX OS, which is running on Intel I5 pro and 8GB memory host. In order to confirm the efficiency of the proposed algorithm, multiple sets of experiments are designed. After a large number of tests for the data set[8][9], and two sets of experiments is shown in Fig.3. It is used to prove that the proposed algorithm is superior to the contrast algorithm in processing images stitching with large parallax.
In Fig. 3, the three stitching algorithms are presented to show the result. It can be viewed intuitively that the ability of three algorithms in stitched result. In the stitched results, the artificial ghosting area shown in the yellow box is enlarged and displayed on the right. The enlarged stitched result in the red box is processed by the proposed algorithm. Obviously, the stitched result of this paper has no ghosting, so it can effectively realize the seamless stitching of images with large parallax.

As can be seen from Fig. 3(a), there are significant artificial ghosting in the stitched image of the APAP algorithm. The main reason is that there exists large parallax between input images, and the APAP algorithm cannot achieve the accurate alignment of the entire overlapping region. Similarly, there are obvious cracks in the stitched images of the Dominant H algorithm in Fig. 3(b). Because the traditional homography matrix can only align the local region, the ideal seam is difficult to search on a small number of alignment areas. The stitched images of the proposed algorithm is shown in Fig. 3(c). Compared with the stitched results of the APAP algorithm and the Dominant H algorithm, the proposed algorithm can avoid these problems which are artificial ghosting or obvious cracks and achieve seamless stitching. The main reason is that the image registration is optimized by analysing feature points distribution and minimizing the registration error. Based on the optimized two-dimensional transformation, sufficient alignment areas are guaranteed to be used for seam searching.

Through a lot of experiments, it is proved that the seam-cutting has advantages in image stitching with large parallax. However, the proposed algorithm is superior to the Dominant H algorithm in stitched result and time consumption. The main reason is that the proposed algorithm put forward the registration error to reduce the times of cycles in optimal homography matrix selection and raise the feature point distribution to ensures seamless stitching. At the same time, the searching range is reduced by matched points error in seam searching, and the speed of each image stitching is accelerated. The time consumption of the Dominant H algorithm and the proposed algorithm are listed below in Tab. 1.
Due to the difference in image content and the size of the image overlap area, the same stitching algorithm takes different time even if the input image has the same size, the details are shown in Tab.1. Seam-cutting is adopted in the Dominant H algorithm to deal with the image stitching with large parallax, the significant difference compared with the proposed algorithm is that the Dominant H algorithm adopts the conventional homography matrix to registration. And the Dominant H algorithm adopts the RANSAC[10] algorithm to based on all the matched points to estimate the two-dimensional transformation matrix. In the meantime, the optimal seam is selected by the seam-cutting through traversing the entire overlapping region, which increases the time consumption. In addition, in each rough registration, the proposed algorithm avoids the repeated selection of feature points by marking the use of the feature points, thus reducing the number of cycles and the consumption of time. At the same time, the registration error is used to reduce the scope of seam searching by seam-cutting, further reducing the consumption of time. Compared with the Dominant H algorithm and the proposed algorithms, the proposed algorithm has more advantages.

4. Conclusion
Images with no disparity or weak parallax require higher acquisition, which increases the consumption cost for virtual reality, panoramic technology and so on. However, the proposed algorithm has lower requirements in the image acquisition and can achieve seamless stitching for images with large parallax. In this paper, to solve the artificial ghosting for image stitching with large parallax, homography matrix is optimized to achieve seamless stitching quickly and efficiently. However, it relies heavily on image content, because the divergence of feature points are helpful to estimate the optimal homography, which can enhance local registration area. In the future research, the compensation for registration error will be studied after registration to optimize image alignment. Meanwhile, the proposed algorithm can be applied in the field of panoramic technology.

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References
[1] Brown M, Lowe D G. Automatic Panoramic Image Stitching using Invariant Features[J]. International Journal of Computer Vision, 2007, 74(1):59-73.
[2] Gao J, Kim S J, Brown M S, et al. Constructing image panoramas using dual-homography warping[C]. Computer Vision and Pattern Recognition, 2011: 49-56.
[3] Zhang G, He Y, Chen W, et al. Multi-Viewpoint Panorama Construction With Wide-Baseline Images[J]. IEEE Transactions on Image Processing, 2016, 25(7): 3099-3111.

| Image numbers | Image size (pixel) | Dominant H[5] (s) | Ours (s) |
|---------------|--------------------|-------------------|---------|
|               |                    | Best H  | Seam   | Best H  | Seam   |
| 1             | 1000x662           | 0.777   | 1.221  | 0.631   | 1.180  |
| 2             | 1000x662           | 0.775   | 2.049  | 0.350   | 1.853  |
| 3             | 1280×720           | 1.379   | 4.209  | 1.073   | 3.636  |
| 4             | 1280×720           | 1.280   | 2.802  | 0.649   | 2.044  |
| 5             | 2000×1329          | 2.518   | 11.515 | 0.365   | 10.409 |
| 6             | 2000×1329          | 2.029   | 12.940 | 0.380   | 11.112 |
| 7             | 2160x1440          | 3.650   | 14.968 | 0.419   | 13.189 |
| 8             | 2160x1440          | 2.154   | 12.304 | 0.383   | 12.073 |
[4] Brown M, Lowe D G. Automatic Panoramic Image Stitching using Invariant Features[J]. International Journal of Computer Vision, 2007, 74(1):59-73.

[5] Eden A M, Uyttendaele M, Szeliski R, et al. Seamless Image Stitching of Scenes with Large Motions and Exposure Differences[C]. Computer Vision and Pattern Recognition, 2006: 2498-2505.

[6] Zaragoza J H, Chin T, Brown M S, et al. As-Projective-As-Possible Image Stitching with Moving DLT[C]. Computer Vision and Pattern Recognition, 2013: 2339-2346.

[7] Lowe D G. Distinctive Image Features from Scale-Invariant Keypoints[J]. International Journal of Computer Vision, 2004, 60(2): 91-110.

[8] Zhang F, Liu F. Parallax-Tolerant Image Stitching[C]. Computer Vision and Pattern Recognition, 2014: 3262-3269.

[9] Lin K, Jiang N, Cheong L F, et al. SEAGULL: Seam-Guided Local Alignment for Parallax-Tolerant Image Stitching[C]. European Conference on Computer Vision, 2016: 370-385.

[10] Fischler M A, Bolles R C. Random sample consensus: a paradigm for model fitting with applications to image analysis and automated cartography[J]. Communications of The ACM, 1981, 24(6): 381-395.