EFFECTIVE NOVEL VIDEO STITCHING METHOD BASED ON FAST STRUCTURE DEFORMATION

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Abstract: In computer vision, video stitching is a very interesting problem. In this paper, we proposed an efficient and effective novel video stitching method based on fast structure deformation that is capable of simultaneously achieving quality stitching and computational efficiency. In our method, firstly, a two-stage seam searching algorithm is designed to search two distinct but structurally corresponding seams in the two original images. The seam location of the previous frame is further considered to preserve the inter-frame consistency. Real-time seam update is performed to reduce the deformation effect caused by moving objects. Secondly, along the double seams, 1-D feature detection and matching is performed to capture the structural relationship between the two adjacent views. Thirdly, after feature matching, we propose an efficient algorithm to linearly propagate the deformation vectors to eliminate structure misalignment. At last, image intensity misalignment is corrected by rapid gradient fusion based on the successive over slackening iteration (SOSI) solver. A principled solution to the initialization of the SOSI significantly reduced the number of iterations required. Compared to image stitching, video stitching faces several new challenges including temporal coherence, dominate foreground objects moving across views and camera jittering. Experimental results show that our method to perform the existing ones compared in terms of overall stitching quality and computational efficiency. A novel searching algorithm based on enhanced dynamic programing is presented, which can obtain satisfactory result and achieve better real-time performance.

Keywords: SOSI, LUT, MAC, CBS and SWIFT

I. INTRODUCTION

Video stitching provides high resolution panoramic video of large field-of-view and has been widely used in multi-camera surveillance systems to monitor public places in wide areas. However, most video stitching methods entail difficulty in meeting the increasing demand for real-time performance and visual quality. Video stitching is performed in three steps: registration, ridge searching and blending. In existing multi-camera surveillance systems, the locations of cameras remain stable and fixed. Thus, matching and registration of images from different cameras can be implemented only at the beginning and then keep changeless for the following frames. The real-time update is necessary for stitching ridges according to the change in video content.

To obtain a satisfied result in video stitching with a natural transition from one frame to another, it is needed to decide which pixels to use and how to blend them in the overlapping area. Compared with simple techniques such as feathering and center-weighting, finding optimal ridges in the overlapping area achieves better results. Although a variety of ridge searching algorithms have been applied in image stitching and obtain satisfactory visual quality. In this paper we make improvements on an existing ridge searching algorithm to accelerate the computing speed while maintaining the accuracy in the meantime.

When moving objects pass through the different ridges, the sections on both sides of the seam are combined in the fusion strategy. The shape of the merged moving object may be deformed owing to the inevitable registration and calibration errors. As perceivable stitching quality is more sensitive to moving objects than to static objects, the deformation of moving objects results in the artefacts and impairs the subsequent object detection, recognition and tracking. With this problem, a real-time local update strategy is associated with ridge searching process in our method and prevents the ridges from passing through moving objects. As the images to be stitched are taken with different cameras, lighting condition and intensity differences may influence the consistency of the entire scene. Thus, color correction and smooth transition should be implemented in video stitching, but traditional methods are complex and make satisfactory results difficult to achieve. Applying global color correction model, we introduce a local model to make color correction within local regions obtained by image segmentation. The local color correction model makes better use of the information of the stitching seam and achieves smooth transition in the overlapping area. Feature-based methods are used by instituting equivalences between points, lines, edges, corners or other shapes. The main uniqueness of robust detectors incorporates invariance to noisy image, scale invariance, translation invariance, and rotation transformations.

II.VIDEO STITCHING METHOD FOR MULTI CAMERA TAILING SYSTEMS

A. Implementation of Registration

Considering that the relative locations of cameras remain stable for most of the multi-camera surveillance systems, the alignment, registration and matching relations of different

images are fixed. To improve the real-time performance of coordinate transformation, the one-to-one correspondence between coordinates can be stored in a pre-calculated look-up table (LUT). For the pixel in the stitched image, the coordinates of corresponding source pixels are stored in the LUT. It is needed to look up the corresponding coordinates in the LUT. Registration and alignment of images can be implemented through simple look-up operations instead of complex conventional algorithms.

Every pixel (X_c,Y_c) in the stitched image corresponds to a source pixel (X_0^i,Y_0^i) in the source image S_i can be expressed as:

$$X_0^i = I(X_0^i) + F(X_0^i),\ Y_0^i = I(Y_0^i) + F(Y_0^i)$$

Here, I and F are the integral and the fractional part respectively. The pixel value at (X_c,Y_c) can be obtained:

$$P(X_c,Y_c) = S_i(X_0^i, Y_0^i) = S_1 . (1 - F(X_0^i)) + S_2 . F(Y_0^i)$$

Where,

$$S_1 = S(I(X_0^i), I(Y_0^i)) . (1 - F(X_0^i)) + S(I(X_0^i)+1, I(Y_0^i)) . F(X_0^i)_{1d}$$

$$S_2 = S(I(X_0^i), I(Y_0^i)+1) . (1 - F(X_0^i)) + S(I(X_0^i)+1, I(Y_0^i)+1) . F(X_0^i)$$

Static overlapped images are taken by the cameras and alignment, registration and matching of these images can be achieved using SIFT (Scale Invariant Feature Transform) algorithm. The images are projected and transformed to form the stitched image. Thus the look-up table can be constructed and then applied to video stitching. Given the fixed and immovable layout of the cameras, the same LUT is used for different scenes when this platform is moved to another location.The implementation of the LUT is shown in Fig. 1.

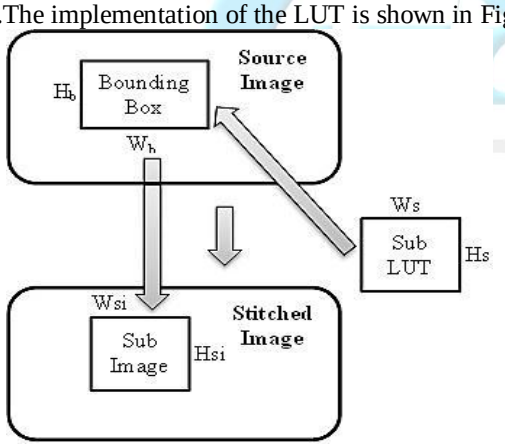


Figure 1: Look-up Table implementation

The entire LUT can be divided into a series of sub-tables (sub-LUT) that can be handled in parallel to improve the processing efficiency. The size of each sub-table is $W_s \times H_s$. A bounding box covering the corresponding part of the image can be obtained and loaded into memory.

B. Two Stage Ridge Searching Method Based on Improved Dynamic Programming

Although the traditional enhanced dynamic programming algorithm can obtain the global optimal seam, its computational complexity degrades the real-time performance. In this section, we introduce a two-stage ridge searching method based on enhanced dynamic programming algorithm. This algorithm not only takes advantage of the traditional enhanced dynamic programming, but also improves the real-time performance. The proposed algorithm is described as follows:

Stage 1: Down-sample the original image with the sampling interval of r. Perform enhanced dynamic programming algorithm on the down-sampled image and obtain the optimal seam, which is then interpolated to the original resolution, as shown in Fig. 2(a). The interpolated seam, which is the approximation of the final optimized ridge, can be used as the initial value of stage 2.

Stage 2: Perform enhanced dynamic programming algorithm in the adjacent area along the initial ridge with the width of K , and obtain the final optimized ridge, as shown in Fig. 2(b).

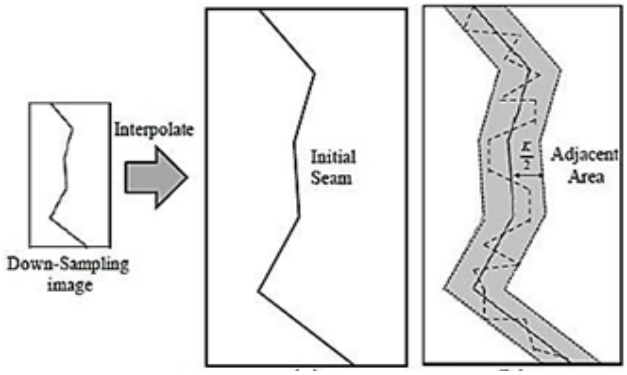


Figure 2: Two Stage Ridge Searching Method

The ridge searching process in the two stages can be implemented for each row of the overlapped area calculate the minimal accumulated cost(MAC) f (i, j) for every pixel (i, j) as f (i, j) = min($f_L(i_L,j)$, $f_R(i_R,j)$). Where $f_L(i_L,j)$ is the minimal accumulated cost calculated from the left border to the right border and $f_R(i_R,j)$ is that calculated from the opposite direction, which can be obtained as follows:

$$\begin{cases} f_L(i_L, j) = \min(d(P_{iL}) + f(P_{iL})),\ i_L = 1,2,3,4 \\ f_R(i_R, j) = \min(d(P_{iR}) + f(P_{iR})),\ i_R = 2,3,4,5 \end{cases}$$

The initial seam with the width of PK denotes the following points:

$$P1:(i,j-1), P2:(i+1,j-1), P3:(i+1,j), P4:(i+1,j+1), P5:(I,j+1)$$

The ridge searching process discussed above is illustrated in Fig. 3.

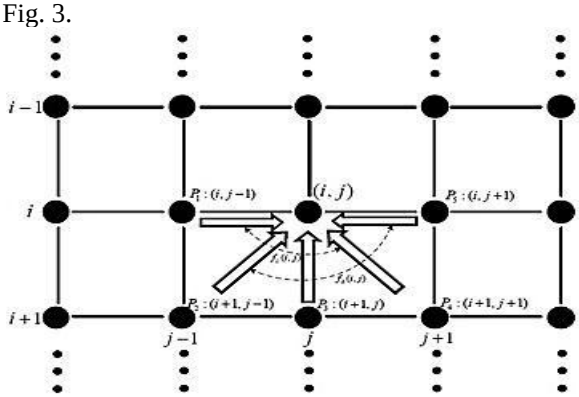


Figure 3: Ridge Searching Process

Select the point (i, j) that satisfies f(1, j) = min(f(1,j)) with limits j as the starting point of the seam, and obtain the optimal seam according to the values of minimal accumulated cost. In the ridge searching process, the definition of the cost function is similar to the definition of cost value. $\mathbf{E = \alpha\ G_s + \beta\ C_v}$, where G_s and C_v measure the gradient softness and the color

vector similarity of corresponding pixels in the overlapped region, respectively, and α,β are the weights used to balance the relative influence of the two factors. Thus the cost value in the overlapped area can be constructed as an image with pixel values indicating the gradient smoothness and the color vector similarity for each point.

However, the determination of the weights α,β as well as G_s and C_v remains a problem. The values of the weights are important to the process of ridge searching and improper selection of weights may cause imbalance of the two factors and degrade the ridge searching result and image stitching quality. To solve this problem, we use the following technique to determine the weights G_s^* and C_v^* can be defined as:

$$G_s^* = \frac{\| \nabla (I_1 + I_2) \|}{\mathrm{Max}\,(\| \nabla (I_1 + I_2) \|)} \quad \text{and} \quad C_v^* = \frac{\| (I_1 - I_2) \|}{\mathrm{Max}\,(\| (I_1 - I_2) \|)}$$

Where I_1, I_2 are the overlapped images and ▽ represents the norm of the gradient for each pixel. The Max $(\|\nabla(I_1 + I_2)\|)$ and Max$(\|I_1 + I_2\|)$ denotes the maximum value of $\nabla(I_1 + I_2)$ and $(\|I_1 + I_2\|)$ respectively.

If the two factors are considered to be of the same importance when calculating the value of cost function, then α = β = 0.5.Thus the relative influence of the two factors can be balanced. The cost value of the three testing overlapped areas in our experiments is shown in Fig. 6. The corresponding source images I_1, I_2 and I_3 are shown in Fig. 7.

C. Local Update of Stitching Ridge Process

Moving objects contained in the overlap area cause partial change in only part of the scene instead of the entire scene. For most parts, the video contents remain static and changing the segments of the ridge passing through static area is unnecessary.

We divide the existing image into sections with the ridge height and each section contains a segment of the ridge as shown in Fig. 10. Each segment can be handled independently. When the moving objects appear in the overlapped region but are far from the ridge, dealing with them immediately is not necessary. The adjacent area $A_a$is defined as the pixels located along the ridge with a horizontal distance less than Δd :

$$A_a = \{ P \; (\| X(P) - X(S_P) \|) \leq \Delta d \}$$

Where S_P is the ridge point which is of the ridge row as pixel P. Moving objects approaching the ridge result in difference in the adjacent area. Thus we only need to perform object detection in the adjacent region instead of the entire overlapped region, and make local modification to the seam if some moving objects pass through it. The code book scheme (CBS) is applied in detecting moving objects in the adjacent region. For the stitching ridge the strategy of local update can be listed as follows:

1. If the moving object is detected near the ridge segment and no moving objects are found for the adjacent segment update the ridge segment using the two-stage ridge searching method.
2. If moving objects are detected near a series of ridge segments update the ridge part using the two-stage ridge searching method.

The local update strategy 1 and 2 are illustrated in Fig. 4(a) and (b) respectively. The seam segments in red are the parts to be updated. The result for local update of stitching seam is shown in Fig. 11.

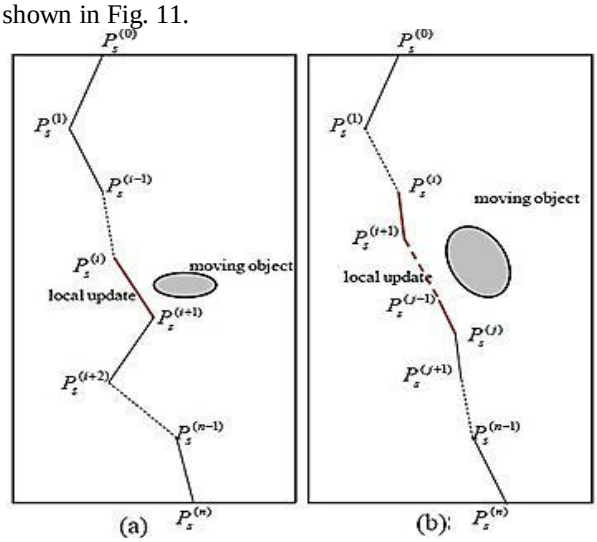


Figure 4:Local Update Strategy for Stitching Ridge

D. Ridge Based Local Color Transfer Model

Although the color difference between neighbour images is effectively decreased, stitching seam still exist in the overlapped area. Considering that perceiving visual quality turns to be more sensitive to the ridges in the transition areas, a smooth scheme is required to eliminate the visible ridges.

Instead of taking a global color correction model that often fails to consider the local feature of color difference, we introduce a local model to perform color correction within local regions. Segmentation for the overlapped areas is implemented by mean shift algorithm. We construct a ridge-based local color transfer model and apply this method to the regions passed through by the seam. Instead of blending the pixels in two images, we use a linear model for color transfer on the pixels within each local region, which is able to adjust the coefficients according to the horizontal distance to the seam.

For each local region passed through by the seam in the overlapped area, we consider the pixels on the seam for the two neighbor images. For overlapped images 1 and 2, the overlapped area in the stitched image is divided into two parts by the stitching ridge that belongs to source image 1 and 2 respectively. The overlapped area is segmented into local regions by mean shift algorithm. Within each local region, the color of pixels remains coherent and continuous, so color correction is conducted within each local region instead of the entire overlapped area.

E. Procedure

Image blending executes the adjustments that were detected in the calibration stage, combined with remapping of the images to an output projection. The procedure of the proposed algorithm is illustrated in Fig. 5.

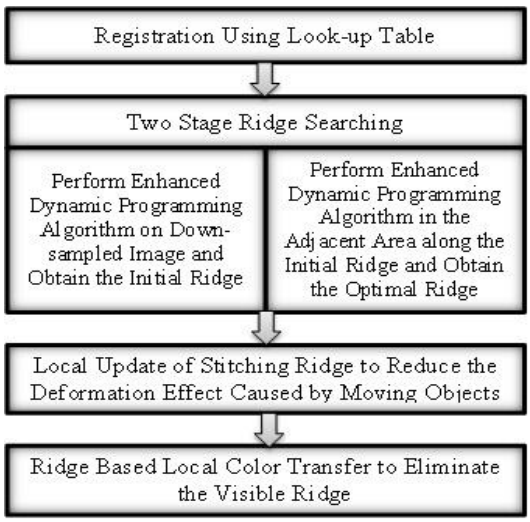


Figure 5:Flowchart of the proposed algorithm

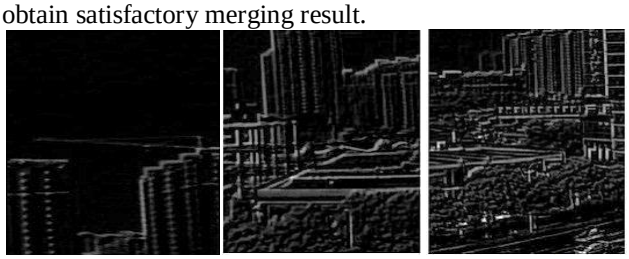
III.EXPERIMENTAL RESULTS AND ANALYSIS

The experiments are conducted on a multi-camera sampling platform using Canon ME200S-SH Multi-Purpose with 829p cameras. The proposed video stitching algorithms are implemented on a 2.00 GHz PC with 2GB memory. In Fig. 7, the results of different seam-searching algorithms for three overlapped areas: image I_1, I_2, I_3 are compared, with (a)-(c), (d)-(f) and (g)-(i) illustrating the seams obtained through dynamic programming, enhanced dynamic programming and the proposed algorithm respectively. In these algorithms, the stitching ridges are illustrated with red labels.

Compared with the dynamic programming and enhanced dynamic programming algorithm, the ridge searching result of the proposed algorithm is also satisfactory. For now, the proposed ridgesearching algorithm can effectively reduce the computational complexity, as illustrated in Table 1.

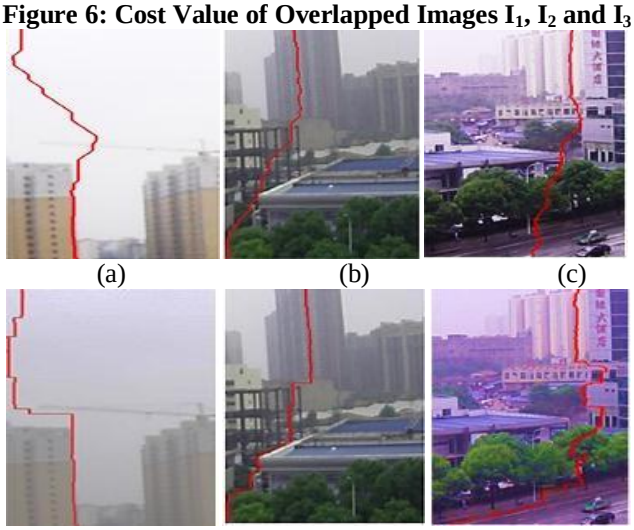
Video stitching based on the proposed ridge searching algorithm obtains almost the same satisfactory result as enhanced dynamic programming, while the dynamic programming algorithm suffers worse stitching results. As shown in Fig. 1, when the ridge obtained by dynamic programming passes through unsmooth region, deformation and incoherence occur in the red pane. Ridge searching using the proposed algorithm is more flexible in the searching direction because the seam can extend on the horizontal direction. Thus the unsmooth region can be detoured by the ridge. The overlapped areas have a dimension of 640 x 480, based on the surveillance videos.

The comparison of merging results for the proposed method and the traditional dynamic programming algorithm are shown in Fig. 8. Structure deformations occur in the red boxes for dynamic programming, while the proposed algorithm can obtain satisfactory merging result.



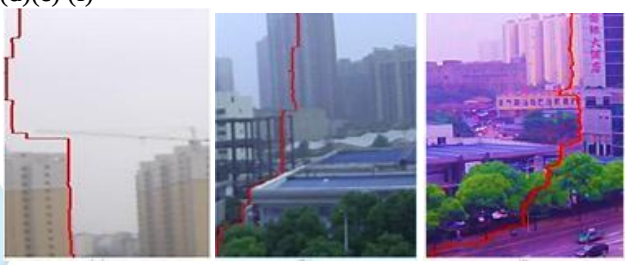
(a) (b) (c)

Figure 6: Cost Value of Overlapped Images I_1, I_2 and I_3



(a) (b) (c)

(d)(e) (f)



(g) (h) (i)

Figure 7: Comparison of Ridge Searching Results (a)-(c), (d)-(f), (g)-(i) are the Ridge Searching Results of Dynamic Programming, Improved Dynamic Programming, and the Proposed Algorithm

(a) (b)(c)

Figure 8:Merging Results of the Proposed Algorithm

The Table 1 indicate that the proposed ridge searching algorithm overcomes conventional methods in terms of computing time and the accuracy of this algorithm is also satisfactory. Although the value of accumulated cost of stitching seam is slightly higher than that of enhanced dynamic programming due to information loss in the down-sampling process, it achieves better real-time performance and hardly influences the stitching quality.

Table 1 show that the computing time of ridge searching and the accumulated cost of stitching seam are sensitive to the settings of parameters r and K. Less accumulated cost of stitching seam corresponds to higher visual quality of the stitched image. Considering both computing time and accumulated cost, the combination r = 4, K = 50 generates the best result and the corresponding ridgesearching results are shown in Fig. 8 (g-i). Compared with enhanced dynamic programming, the computing time of the proposed method is

reduced by 68.6 % on average for the input images, while the ridge searching performance is maintained.

Algorithm			Accumulated Cost of Stitching Ridge		
Camera Image			I_1	I_2	I_3
Dynamic Programming			3396	5532	6050
Improved Dynamic Programming			2785	4027	5198
Proposed Algorithm	r = 3	K=10	2936	4284	5275
		K=20	2867	4129	5214
		K=30	2774	4165	5240
		K=40	2747	4112	5230
		K=50	2734	4110	5210
	r = 4	K=10	2907	4296	5238
		K=20	2838	4221	5276
		K=30	2746	4187	5231
		K=40	2774	4152	5290
		K=50	2754	4110	5240
	r = 5	K=10	3131	4216	5208
		K=20	3049	4253	5295
		K=30	2915	4230	5263
		K=40	2851	4264	5272
		K=50	2709	4123	5212

Table 1: Accumulated Cost of stitching Seam is Sensitive to the Settings of Parameters r and K

With the increase of sampling interval r, the computing time of stage 1 drops dramatically because of the decrease of pixels to be processed. However, the accumulated cost of stitching ridges are also on the increase due to the error of the initial seam in stage 1, which is caused by information loss in the down-sampling process. A larger value of K contributes to the decrease of accumulated cost and the descent speed declines due to the increasing accuracy for ridge optimization. The computing time of stage 2 is proportional to the choice of K.

Smooth transition can be achieved using the ridge-based local color transfer model. The two source images are shown in Fig 9. Segmentation is implemented using Mean shift algorithm and the result is shown in Fig. 10(a), with the different colors indicating labels for regions. Fig 10(b) illustrates the ridge searching result. Based on the results of segmentation, the ridge based local color transfer model is applied to the local regions passed through by the seam. Compared with results of traditional smooth transition methods in Fig. 11 (a), (b) and (c) are more natural and smooth transition result is obtained using the proposed model. Blurring and visible seams in the overlapped region are eliminated.

(a) (b)

Figure 9: Source Images for Smooth Transition

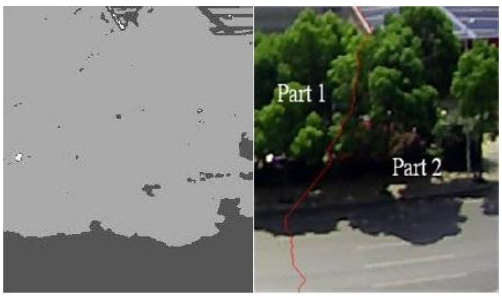


Figure 10: Segmentation and Ridge Overlapped Area

(a) (b) (c)

Figure 11: Comparison of Smooth Transition Methods

Figure 12: The Final Results of Video Stitching with Moving Objects

IV. CONCLUSION

In this paper, an effective novel video stitching method for multi-camera surveillance systems is prepared. To achieve better real-time performance for ridge searching process, a two-stage ridge searching method based on enhanced dynamic programming is proposed and satisfactory seam searching result is obtained. A local update scheme for stitching seams is proposed to eliminate deformation results. A ridge-based local color transfer model is constructed to achieve smooth transition between different images. Experiments have shown the effectiveness of the proposed method. For future research, hardware implementation of this method will be designed to accelerate the process of video stitching. Other efficient stitching algorithms will be further explored.

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