Chapter 6
Novel Image Stitching Technique

6.1 Introduction

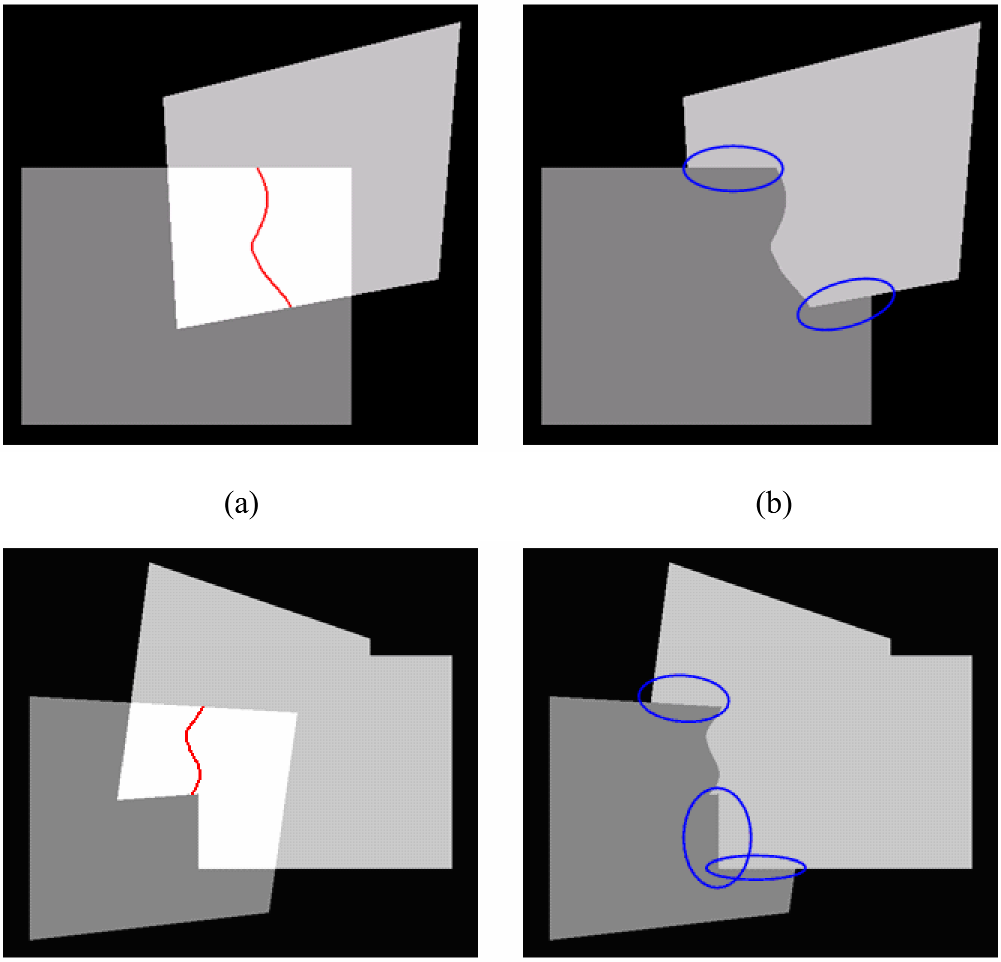
In this chapter, the defects of the previous researches for image stitching techniques are described first and then a novel image stitching technique is proposed to improve the performance of image stitching. There are two preprocessing steps of the novel image stitching technique in this thesis called determination of main cut line direction and brightness normalization are applied to automatically choose the better way of stitching and reduce the brightness difference between the mapped source image and the target image. Furthermore, the band-type optimal partition based on multiple cut lines is proposed to combine two input images successfully in general stitching cases. Finally, the image blending method is employed to smooth the border between the mapped source and the target image such that the higher resolution combined image with almost invisible image artifacts can be obtained.

6.2 The Defects of the Previous Researches

From the Section 5.3, the previous image stitching methods called minimum error boundary cut and optimal partition are simply introduced. However, these methods aim to some particular conditions and consequently have some defects in general stitching cases. In this section, the defects of the previous researches for image stitching are described and the novel image stitching technique is proposed to improve these defects in next section.

First, in the image quilting algorithm [3], the image stitching technique called minimum error boundary cut successfully synthesizes a new image by stitching small patches from an input texture. The fixed stitching direction and single cut line can deal with all the conditions since the overlap region is predetermined and the shape of the overlap region is always rectangular as shown in Figure 5.3(c). However, in general stitching cases, the source image will change its original rectangular shape to match up the target image from its appropriate direction and the target image will become arbitrary shape after the first image stitching process is done. Therefore, the defects would occur when the overlap region is not in a rectangular form or when two images are combined with different size or not in horizontal or vertical direction. In order to described the defects easily, the final cut line will be drawn as the red line to separate the combined region into two parts for the mapped source image and the target image shown in Figure 6.1(a) and Figure 6.1(c). Furthermore, it can be seen from Figure 6.1(b) and Figure 6.1(d) that there are some discontinuous edges within the blue circles needed to be compensated after using the image stitching technique stated above and region assignment technique.

Second, in the eliminating structure and intensity misalignment algorithm [9], the image stitching technique called optimal partition directly choosing a smooth and little color difference path through the overlap region as the optimal partition line in the first step and then the image registration technique is applied along it. Finally, the deformation propagation is applied to blend two images together. The image stitching technique stated above saves a lot of calculation time since the image registration technique is only applied along the optimal partition line. However, reference to Figure 5.5 and Figure 5.6, the direct partition in the first step works only the overlap region is predetermined or known prior to make sure the reasonable matching pairs can be found along the partition line. Moreover, the less feature points lead the inaccuracy of the image mapping. Therefore, in the general automatic image stitching cases which the overlap region can't be predicted and predetermined, the stated technique still has some defects to be improved.



(a) (b) (c) (d)

Fig 6.1 The minimum error boundary cut line in the overlap region of the combined region (left), and the combined image after region assignment (right)

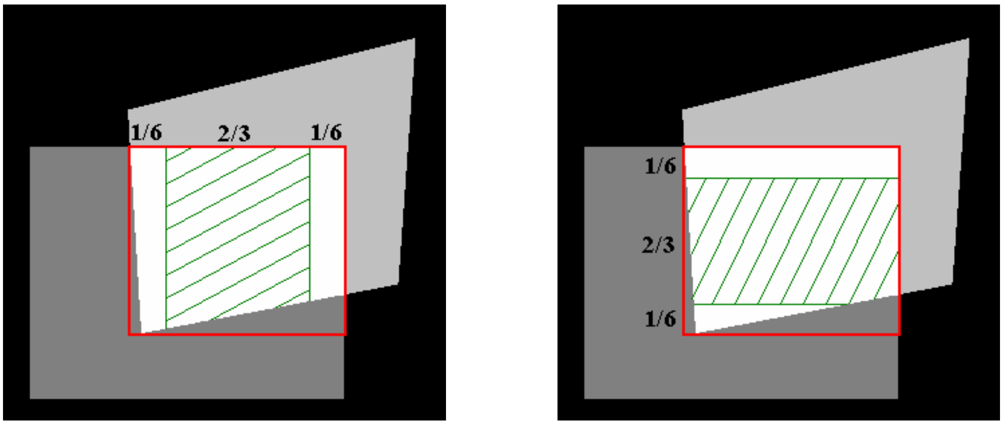
6.3 Novel Image Stitching Technique

6.3.1 Determination of Main Cut Line Direction

The previous section introduces two image stitching techniques which use single cut line as the border between two images. Because the overlap region is predetermined, the direction of the cut line can be set before to benefit the image stitching process. In order to achieve the goal of stitching images automatically, the direction of the main cut line through the entire overlap region must be robustly determined according to the information obtained from the overlap regions of the mapped source image and the target image. Therefore, a technique is proposed in this thesis to determine the direction of the main cut line based on the amount of vertical and horizontal edges.

Since no matter how similar the mapped source image and target image are within the overlap regions, the position mismatch between them still exists unavoidably. In particular, even a little mismatch will result in the obvious broken edges whose artifacts can be seen easily. Therefore, if there are many horizontal edges on the possible path of the vertical main cut line, it may divide these edges into two parts for two images and even a little position mismatch will cause obvious artifacts, so as in the condition of the horizontal cut. The technique called determination of main cut line proposed in this thesis utilizes the edge information to determine which direction is better for the main cut line.

Consider the combined region in Figure 6.2(a), where the red lines are the rectangular boundary of the overlap region determined from Section 5.2 and the region drawn in green obliques with two third width is the possible region for the vertical main cut line passing through. Afterward, change $\boldsymbol{V}_{ct}$ and $\boldsymbol{V}_{cs}$ to gray-level and then employ the Sobel masks $\boldsymbol{S}_x$ and $\boldsymbol{S}_y$ respectively to obtain the gradient domain images. Further, the binarilization described in Section 3.2 is applied to calculate the total amount of vertical edges N_{vc}^{v} and horizontal edges N_{vc}^{h}. Similarly, the amount of vertical and horizontal edges in the possible path region for the horizontal main cut line such as Figure 6.2(b) can be obtained as N_{hc}^{v} and N_{hc}^{v} respectively in the same way. Because the purpose is to make the main cut line cross less edges, the vertical cut line should have less horizontal edges an the horizontal cut line should have less vertical edges. Subsequently, three judgment steps are used to determine which direction is better for the main cut line. First, if $N_{vc}^{h} < N_{vc}^{v}$ and $N_{hc}^{v} > N_{hc}^{h}$, and then the direction of the main cut line is chosen as vertical direction. Second, if $N_{vc}^{h} > N_{vc}^{v}$ and $N_{hc}^{v} < N_{hc}^{h}$, and then the direction of the main cut line is chosen as horizontal direction. Otherwise, let the percentage of N_{vc}^{h} and N_{hc}^{v} make the decision of the direction. That means the vertical direction of the main cut line is chosen for $\frac{N_{vc}^{h}}{N_{vc}^{h} + N_{vc}^{v}} < \frac{N_{hc}^{v}}{N_{hc}^{h} + N_{hc}^{v}}$, while the horizontal direction is chosen for $\frac{N_{hc}^{v}}{N_{hc}^{h} + N_{hc}^{v}} < \frac{N_{vc}^{h}}{N_{vc}^{h} + N_{vc}^{v}}$. After the main cut line direction is determined, the proposed image stitching method has a better path region to obtain the main cut line crossing fewer edges and enhance the stitching performance.



(a) (b)

Fig 6.2 The possible path region for (a) the vertical main cut line, and (b) the horizontal main cut line to do the edge detection

6.3.2 Brightness Normalization

In general, it is impossible to acquire the source and target images with the same brightness, which might be in a different light condition or a result of automatic brightness compensation by the camera. The physical problem described above would cause severe artifacts such as Figure 6.2(a) and Figure 6.2(c) even if the image stitching process is successfully applied. Besides, the white balance compensation by the camera would also cause unwanted color difference between two neighbor images, but fortunately its influence is not serious. Hence, this thesis will focus on the problem of brightness difference and the normalization process is proposed as a preprocessing step to regulate the brightness of the mapped source image and the target images according to the brightness information of their overlap regions.

At the beginning of the normalization, the canvases $\boldsymbol{V}_{ct}$, $\boldsymbol{V}_{cs}$ and $\boldsymbol{V}_{cb}$ are taken as the process inputs, each respectively containing the mapped source image, the target image and the combined region. By the information of the combined region, it is easy to recognize the overlap regions of the mapped source image and target image according to their different pixel values defined in Section 4.4. Then, change the color space of $\boldsymbol{V}_{ct}$ and $\boldsymbol{V}_{cs}$ from RGB to YC_bC_r by

$$\begin{bmatrix} Y \\ C_b \\ C_r \end{bmatrix} = \begin{bmatrix} 0.257 & 0.504 & 0.098 \\ -0.148 & -0.291 & 0.439 \\ 0.439 & -0.368 & -0.071 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix} \tag{6.3-1}$$

where Y contains the required brightness component and both C_b and C_r are related to the chrominance color components. Further, calculate the average values of the brightness Y_o^s and Y_o^t acquired from $\boldsymbol{V}_{cs}$ and $\boldsymbol{V}_{ct}$ respectively within the overlap region. Subsequently, take the brightness difference Y_d^s and Y_d^t for the source and target images as

$$\begin{cases} Y_d^s = Y_o^s - \dfrac{Y_o^s + Y_o^t}{2} = \dfrac{Y_o^s - Y_o^t}{2} \\ Y_d^t = Y_o^t - \dfrac{Y_o^s + Y_o^t}{2} = \dfrac{Y_o^t - Y_o^s}{2} \end{cases} \tag{6.3-2}$$

Then, the normalized Y components can be obtain as

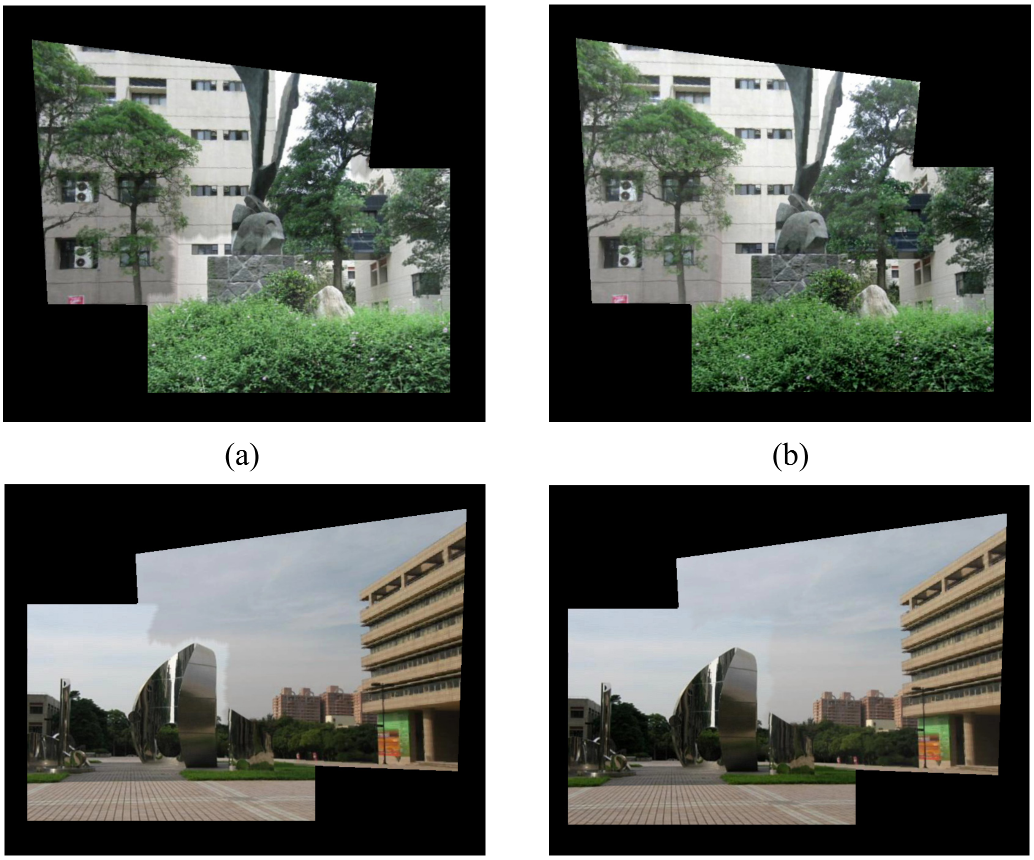
$$\begin{cases} Y_n^s(i,j) = Y^s(i,j) - Y_d^s \\ Y_n^t(i,j) = Y^t(i,j) - Y_d^t \end{cases} \tag{6.3-3}$$

where $Y^s(i,j)$ and $Y^t(i,j)$ represent the original Y components in the mapped source image and the target image respectively, and $Y_n^s(i,j)$ and $Y_n^t(i,j)$ are the Y components of two images after brightness normalization. Finally, recover the color space of $\boldsymbol{V}_{ct}$ and $\boldsymbol{V}_{cs}$

from YC_bC_r to RGB with normalized Y component and original C_b and C_r components according to the equations as

$$\begin{cases} R = 1.164\cdot(Y-16)+1.596\cdot(C_r-128) \\ G = 1.164\cdot(Y-16)-0.813\cdot(C_r-128)-0.392\cdot(C_b-128) \\ B = 1.164\cdot(Y-16)+2.017\cdot(C_b-128) \end{cases} \qquad (6.3\text{-}3)$$

where Y can be $Y_n^s(i,j)$ or $Y_n^t(i,j)$. As shown in Figure 6.3, the left images show the combined images after applying the novel image stitching method without doing the brightness normalization and the right images show the combined images with the brightness normalization preprocessing step. Clearly, the proposed image stitching method with the brightness normalization can successfully combine the mapped source image and the target image together without any visible border like Figure 6.3(a) and Figure 6.3(c).



(a) (b) (c) (d)

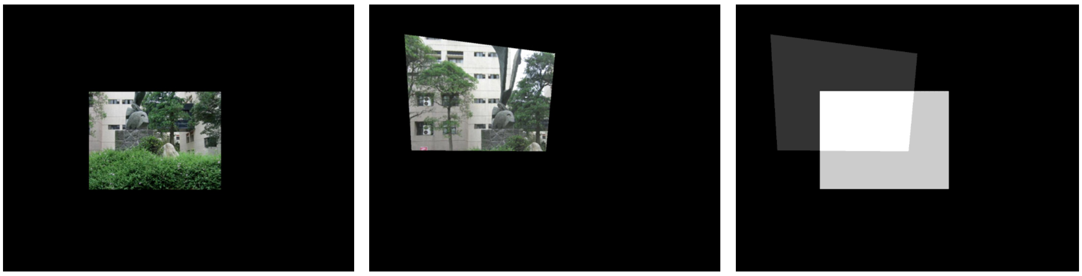
Fig 6.3 The image stitching without brightness compensation (left images), and with brightness compensation (right images).

6.3.3 Band-type Optimal Partition Based on Multiple Cut Lines

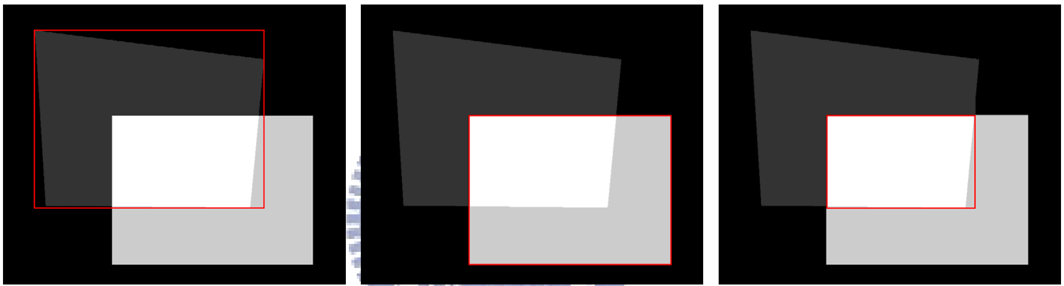
In this section, a novel image stitching method called band-type optimal partition based on multiple cut lines is proposed to generate five cut lines by band-type optimal partition method. More information are considered and used to obtain the cut lines between two images to deal with any stitching case and efficiently reduce the discontinuous edges needed to be compensated.

In Section 5.3, two previous researches of the image stitching techniques called minimum error boundary cut and optimal partition are introduced. Unfortunately, these image stitching techniques can be only used under some particular conditions or predeterminations, such as using fixed stitching direction or the overlap region predetermination by a single cut line described in Section 6.2. To improve those defects and enhance the performance of image blending, the image stitching method proposed here is based on choosing multiple band-type cut lines to compensate the discontinuous edges such as Figure 6.1 and it indeed improves the image stitching performance. Unlike the single cut line image stitching methods, the multiple cut lines method has to consider the entire possible stitching cases that where the mapped source image may come from and analysis them to find out where the discontinuous edges will happen after the region assignment and then compensate these edges to improve the image stitching performance. The images in Figure 6.4 containing all the information obtained from the previous sections will be taken as an example to completely describe the procedures of the proposed method.

In general image stitching cases, the source and target regions are not all in the rectangular form such as the right image in Figure 6.4(a), thus the relative positions between two images must be determined according to the center of the rectangular boundaries of the source region and the target region respectively. Take Figure 6.4(b) as example, the source region is in the upper left side of the target region. Further, the direction of the main cut line determined in Section 6.3.1 can be applied to do the band-type optimal partition method. Because the locations where discontinuous edges happen are related to the relative positions between two images and the direction of the main cut line, the position and direction of other two sub cut lines should be determined according to these information.



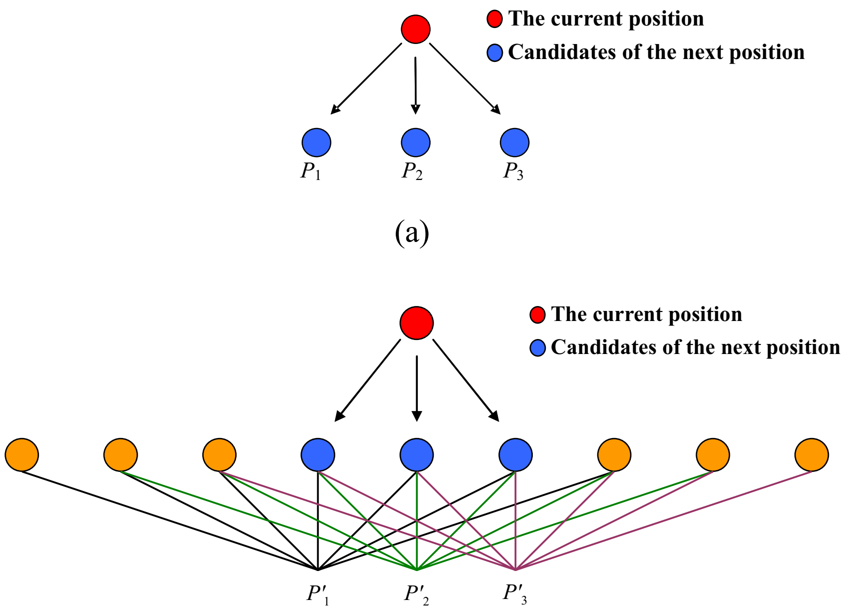
(a)



(b)

Fig 6.4 The example for the proposed stitching method (a) three canvas, and (b) the rectangular boundaries of each region in the combined region

Based on the spirit of the line-type optimal partition [9], all it has to do is find an almost invisible cut line passes through the overlap region as a border to separate it into two parts for two images. However, there are still some edges resulted from little brightness and color difference or position mismatch can be seen along the border. Therefore, the image blending method is applied to smoothly transit one image to the other to eliminate these edges. Figure 6.5 shows the difference between the traditional line-type optimal partition and the novel band-type optimal partition. The tradition line-type optimal partition just calculate the cost of the similarity and smoothness at each candidate point, P_1, P_2 and P_3, and choose one whose cost is minimum as the next current point circularly to obtain a cut line avoiding the condition of crossing edges but usually along them. Although it is still a suitable cut line for the region assignment, other artifacts such as ghost image would occur by image blending method since the transition band for image transition contains the mismatching edges. Therefore, the improved partition method called band-type optimal partition is proposed to consider not only the cost values of each candidate point but also the pixels neighbor to them such as P'_1, P'_2 and P'_3. The number of the considered neighbor pixels as the width of the transition band which is set to be 7 in this thesis.

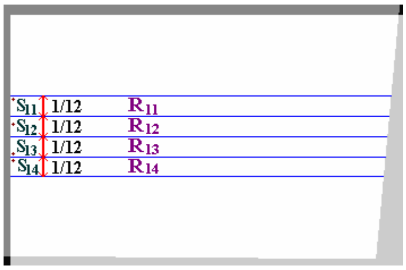


(b)

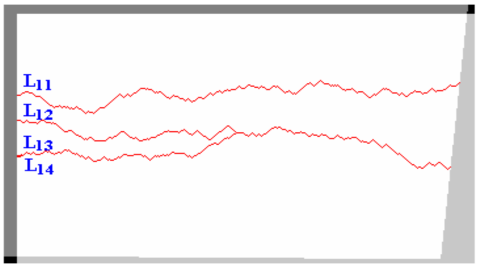
Fig 6.5 (a) Traditional line-type optimal partition, (b) novel band-type optimal partition

After the concept of band-type optimal partition are stated, employ it to the physical case shown is Figure 6.4. First, the direction of the main cut line is set to be the horizontal based on the determination in Section 6.3.1. Because it is needless and time consuming to calculate the cumulative error values of all the possible paths, the center of the overlap region are separated into four equal parts each contains one twelfth width in the horizontal direction as R_1, R_2, R_3 and R_4. Afterward, choose four points whose cost of the similarity and smoothness are minimal at the beginning of each region as the start points called S_{11}, S_{12}, S_{13}, and S_{14}

respectively as Figure 6.6(a). Subsequently, the band-type optimal partition method is applied to generate four candidates of the main cut lines L_{11}, L_{12}, L_{13} and L_{14} with their cumulative error values as Figure 6.6(b). Finally, choose one of the candidates with minimal cumulative error value as the main cut line. As shown in Figure 6.7(a)-(c), it is clear that the cut line L_{12} crosses through the less edges and passes through smoother region and thus has the minimal cumulative error value to be chosen as the main cut line as Figure 6.7(d).

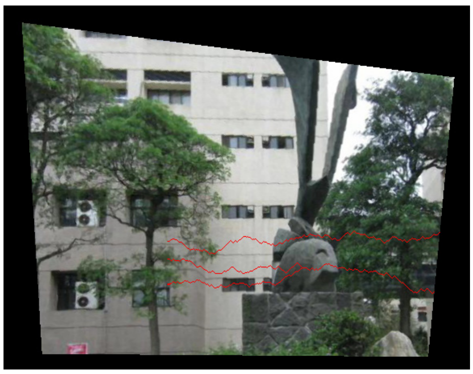


(a)



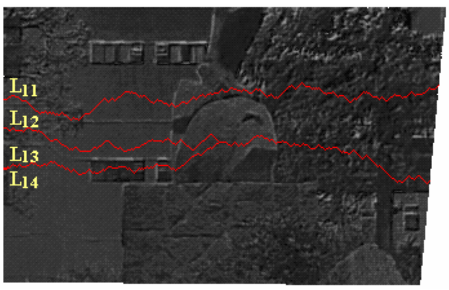
(b)

Fig 6.6 (a) The four sub regions and start points for optimal partition method, and (b) four candidates of the main cut lines

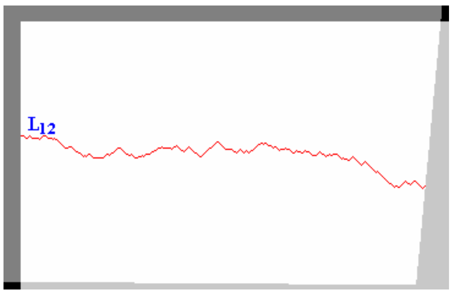


(a)

(b)



(c)



(d)

Fig 6.7 Draw the candidates of main cut lines on (a) the mapped source image, (b) the target image, and (c) the averaged color difference on the overlap region. (d) The chosen one as the main cut line

After determining the appropriate main cut line, the overlap region is separated into the upper and lower parts by the horizontal main cut line. According to the information given from the combined image the upper and lower regions are assigned to the mapped source image and the target image respectively and then the discontinuous edges within the blue circles are shown in Figure 6.8. Therefore, the first sub cut lines are applied still base on the band-type optimal partition method to deal with these discontinuities.

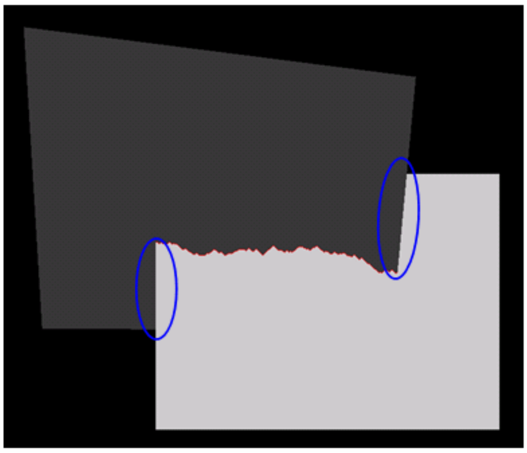
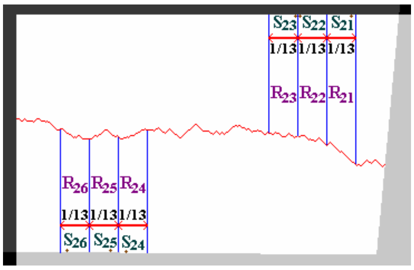
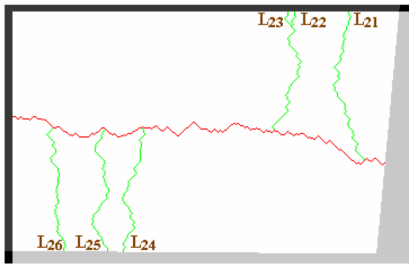


Fig 6.8 The region assignment after the main cut line determination

Similar to the determination of main cut line, the first sub cut lines use the same technique but in different regions according to the direction of the main cut line and the relative position between two images. In the example case, because of the horizontal cut line and the mapped source image is in upper left side of the target image, the discontinuities occur at the upper right side and lower left side of the overlap region as shown in Figure 6.8. In order to compensate these discontinuities, the first sub cut lines are applied based on the band-type optimal partition. Because the sub cut lines that too close the boundaries may generate the cut lines along the boundaries and become the helpless ones, the regions for partition should a little away from the boundaries. As shown in Figure 6.9(a), choose three regions on the upper right side and lower left side of the overlap region as R_{23} to R_{26} and each region contains one thirteenth width of the rectangular region in the vertical direction without crossing the main cut line. Furthermore, choose the start points as S_{21} to S_{26} from the costs of similarity and smoothness such like the way of choosing those in the determination of main cut line. Finally, the band-type optimal partition method is applied to generate L_{21} to L_{26} as Figure 6.9(b) and Figure 6.10(a)-(c), and then the cut lines which have cumulative error value in the upper right side and lower left side each are chosen as the first sub cut lines as shown in Figure 6.10(d).



(a)

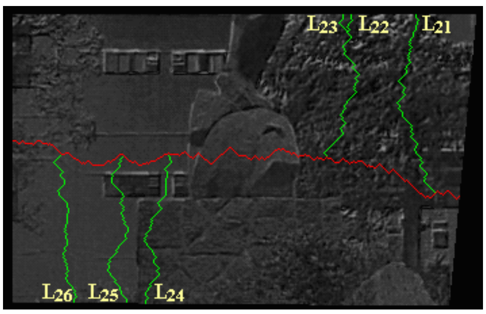


(b)

Fig 6.9 (a) The six sub regions and start points for optimal partition method, and (b) six candidates of the first sub cut lines


(a)


(b)



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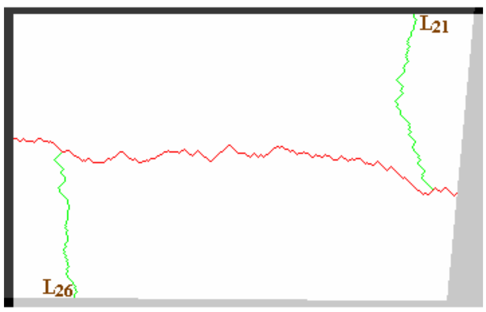


(d)

Fig 6.10 Draw the candidates of first sub cut lines on (a) the mapped source image, (b) the target image, and (c) color difference on the overlap region. (d) The chosen ones as the first sub cut lines

In Figure 6.11, it can be seen that the discontinuous edges are lower after the appropriate first sub cut lines are chosen and region assignment. Therefore, the second sub cut lines are applied to furthermore make the discontinuities much lower and enhance the image stitching performance.

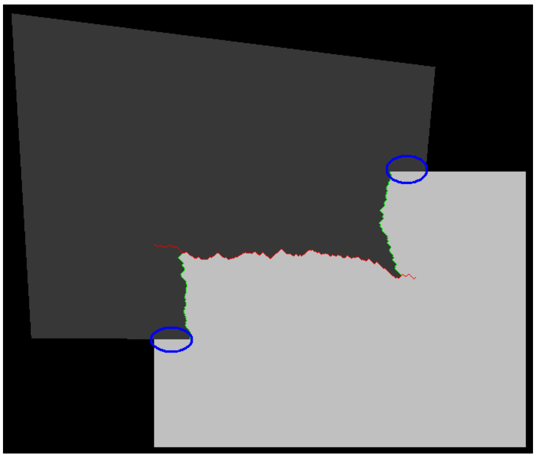
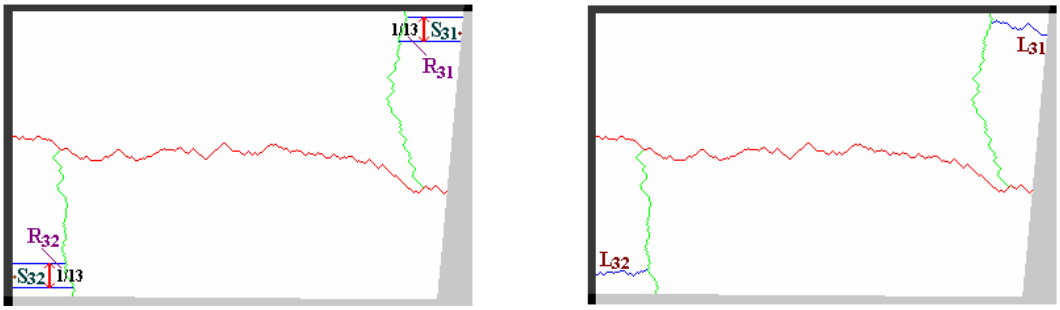


Fig 6.11 The region assignment after the first sub cut lines determination

The determination of the second sub cut lines is similar to the first ones. Because the main purpose of the second sub cut lines is to lower the discontinuities, only one appropriate region which close to the boundaries are chosen as R_{31} and R_{32} and the start points are selected based on the costs of similarity and smoothness as S_{31} and S_{32}, as shown in Figure 6.12(a). Afterward, the band-type optimal partition is applied to generate L_{31} and L_{32}, and then directly chose them as the second sub cut lines, as shown in Figure 6.12(b). After the region assignment shown in Figure 6.13, the discontinuous edges still exist but much lower than those uses only a single cut line shown in Figure 6.8. In the next section, the image blending method is employed to find out the border between two images and smooth it by dealing with the multiple cut lines determined in this section and the last discontinuous edges.



(a) (b)

Fig 6.12 (a) The two sub regions and start points for optimal partition method, and (b) the second sub cut lines

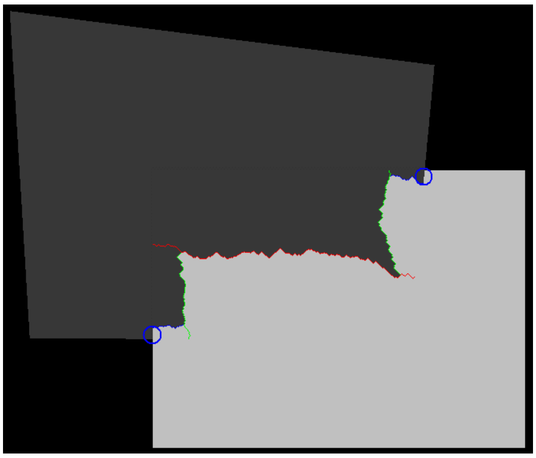


Fig 6.13 The region assignment after the second sub cut lines determination

6.3.4 Image Blending

In the sections above, the five cut lines are determined to divide the overlap region into two parts and reduce the discontinuous edges which without compensated based on the relative position between two images and band-type optimal partition method. Thank to the proposed novel band-type partition, the transition band which has the edges within it can be successfully detected and avoided. Therefore, the purpose of the image blending method proposed in this section is to find out where the border is and then smooth it such that the border between two images is almost invisible.

From the combined region of the example case in Figure 6.14(a), it can be seen that the overlap region are separated into two parts according to the information of the five cut lines determined above. However, it still can be seen that some discontinuous edges must be the border but undetermined and some parts of the cute lines are not the border. Therefore, the border needing to be smoothed must be determined first from the cut lines and boundaries of the overlap region.

In order to determine the border between two images, all the cut lines and the boundaries of the overlap image must be marked first as shown in Figure 6.14(b). If the marked pixel is part of the border between two images, the neighbor pixels excepting the marked pixels must have different pixel values corresponding to different region. Otherwise, if the marked pixel is not part of the border, the neighbor pixels excepting the marked pixels must have the same pixel value. Figure 6.15 clearly shows the judgment rules described above, the marked pixel maintain its original pixel value if it is part of the border or change its pixel value the same as it neighbor pixels if it's not part of the border. After applying the judgment rules, the useless parts of cut lines are eliminated and the undetermined edges are marked to derive a border. Finally, separate the overlap region into two parts along the border for each image as Figure 6.16 and the do the image blending process to smooth the border successfully.

(a) (b)

Fig 6.14 (a) Show the useless parts of cut lines and the undetermined border and (b) mark the combined region by all cut lines and boundaries of the overlap region

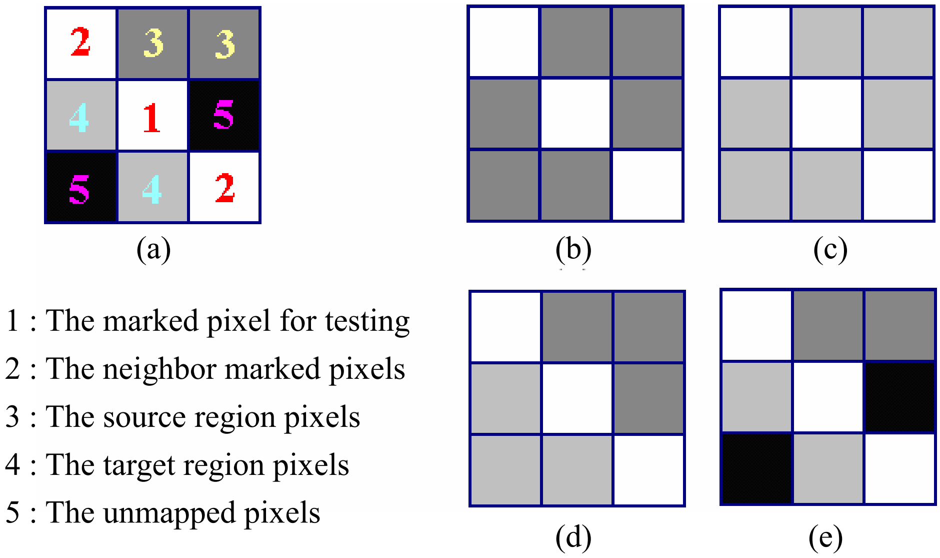


Fig 6.15 (a) The meaning of each pixel value and the examples that (b) and (c) the center marked pixels are not parts of border, (d) and (e) the center marked pixels are parts of border

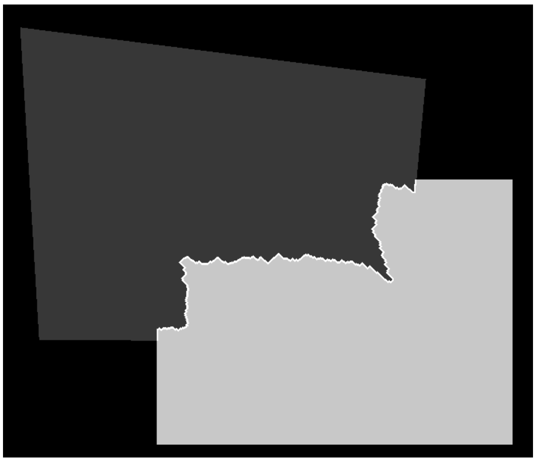


Fig 6.16 The combined region with the border after border determination

After the border determination, the mapped source image and the target image can combine together according to the information from the combined region. Afterward, the image blending techniques are applied to the acquired border to enhance the stitching performance. Thanks to the band-type optimal partition method proposed in the previous section, all the cut lines preserve the smoother and lower color difference region as transition band for image blending. Hence, Figure 6.17 shows that the weighting of the mapped source image in the transition band decrease from 1 to 0 to smoothly decrease the color intensity from the mapped source image to the target image and so as the weighting of the target image. Furthermore, the decreasing step is set to be 0.125 because the width of the transition band is set as 7 in this thesis. However, there are still some pixels which are originally the undetermined border shown in Figure 6.14(a) needing to be smoothed. Because these pixels are the boundaries of the overlap region without both two images color information in its neighbor pixels, the color transition method can not be used for smoothing. Therefore, the general Gaussian smoothing method is employed to smooth these pixels by convolution them with smoothing masks such like (3.2-1) to make these pixels smoother. After the image blending, all the procedures of image stitching process are done and the results of the final combined images are shown in Figure 6.18.

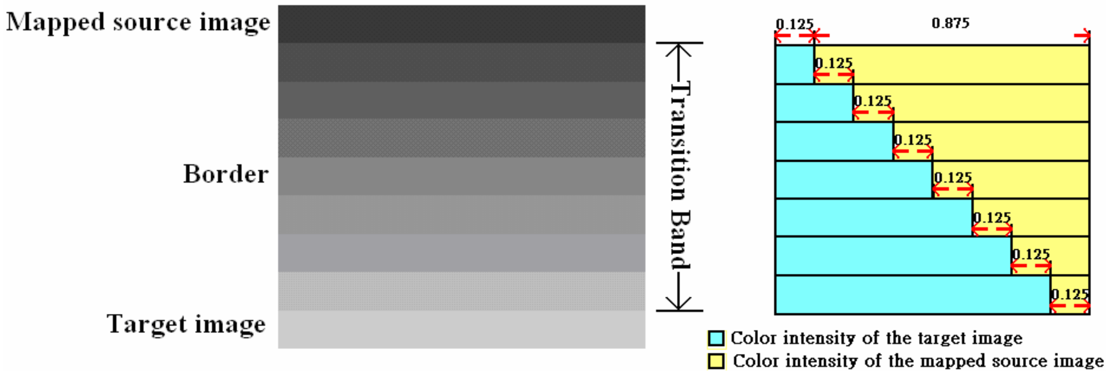
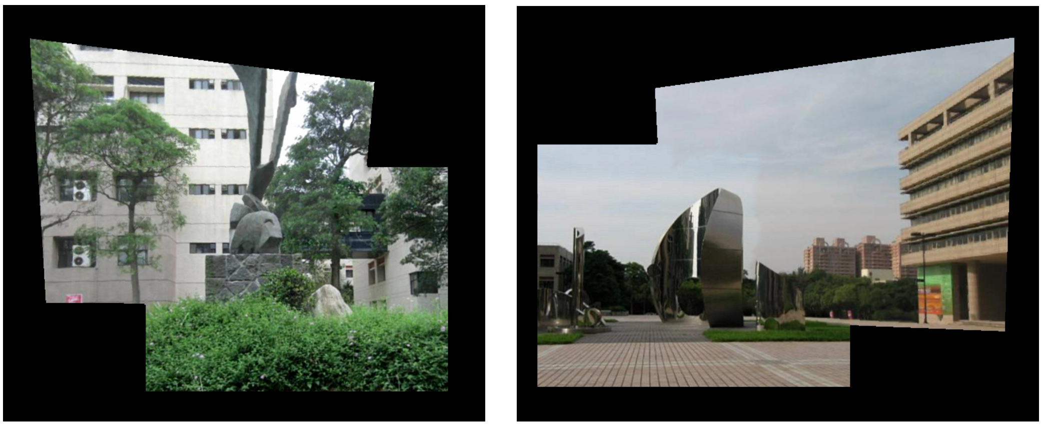


Fig 6.17 The color transition from the mapped source image to the target image



(a) (b)

Fig 6.18 The final stitching results after all the image stitching processes