Visually Optimal Seam-Line Determination in Image Mosaicking

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ABSTRACT

A optimal seam-line determination algorithm is proposed to determine the image border-line in mosaicing using the transformation of gray value differences and the dynamic programming (DP). Since a visually good border-line is the one along which pixel differences are as small as possible, it can be determined associated with an optimal path finding algorithm. A well-known effective optimal path finding algorithm is the dynamic programming. Direct application of the dynamic programming for the seam-line determination causes the “distance effect”, in which seam-line is affected by its length as well as the gray value difference. In this paper, an adaptive cost transform algorithm with which the “distance effect” is suppressed has been proposed utilizing the dynamic programming on the transformed pixel difference space. The performance of the proposed algorithm has been tested in both quantitatively and visually on various kinds of images.

1. INTRODUCTION

Image mosaicing techniques creating an image mosaic in a large range from small images can be used in many different applications, such as satellite imagery mosaics (USGS Hurricane Mitch Program Project), the creation of virtual reality environment (Szeliski, R.,1996), medical image mosaics (Chou *et al.*, 1997), and video compression (Standard MPEG4).

One of main processes of image mosaic construction by the image mosaicing techniques is to create well-aligned image mosaics among overlapping images. The algorithms of creating a well-aligned image mosaic fall into three categories: histogram matching, image blending, and seam-line detecting. The algorithm of the histogram matching carries out in an overlapping area of radiometric equalization across image mosaics (Yong *et al.*, 2001). The image blending algorithms, such as weighted (Nicilas, 2001 and Uyttendaele *et al.*, 2001) and frequency (Adelson *et al.*, 1984) blending methods are commonly used to create well-aligned panoramic and spherical mosaics from a pan/tilt camera. With the first two techniques from the images with stereoscopic effect, it is very difficult to create the well-aligned image mosaics, because basically the techniques have been studied about the geographical corrected images. Even if we use ortho-satellite imagery, which are generated by using the direct linear transform, equations of warping one pixel to several pixels or less one pixel, with the digital element model and the ground control point, since we cannot reconstruct the real data of 3-D objects, there are also existed the miss-alignment problems.

In this point of view, algorithms of seam-line detection are very efficient to stereoscopic images. The algorithms are using twin snakes (Martin, 2001) and dynamic programming (Efros *et al.*, 2001). Martin developed the twin snakes algorithm to detect an optimal seam-line on ortho-satellite imagery. The twin snakes often miss global minimum areas and stop local or global maximum areas on the pixel difference map of overlapping images. The problems are originated that the algorithm of the snake has problem of passing local minimum or maximum areas on the cost map and it is sensitive to snake constants to control the relationship of the control points of snake. The dynamic programming (DP) finding a global optimal path, which is a curve linking starting and goal points, is very efficient to detect a seam-line and it is not facing with the problems of the twin snakes. If a direct application of DP for detecting the seam-line causes the "distance effect", the seam-line will be affected by its length. For example, the seam-line detected by only DP. DP operates in a point of view of minimizing accumulated cost only and it does not have any concern with visual sensitivity. To solve the drawbacks, an adaptive cost transform algorithm with which the "distance effect" is suppressed has been proposed utilizing DP on the transformed pixel difference map of overlapping images.

2. OPTIMAL SEAM-LINE DETERMINATION BY ADAPTIVE COST TRANSFORMATION

As stated in the introduction, when start and goal points, global optimal path finding by DP is very efficient in detecting a seam-line. It is because the algorithm of DP only operates in a point of view of minimizing accumulated energy and it is also because that the algorithm has no concern with visual sensitivity. If direct application of DP for the seam-line determination causes the "distance effect", a detected seam-line will be affected by its length. It is quite probable that the seam-line will be included pixels with the highest pixel difference. To detect a seam-line avoiding pixels of the highest pixel difference, this paper proposed the adaptive cost transform algorithm with which the "distance effect" is suppressed by using DP on the transformed pixel difference space. To create a cost map suppressed "distance effect", as the low and high costs of the cost map are reduced and emphasized more respectively, we can obtain a new cost map suppressed "distance effect". That is, if the cost of each seam point of seam-line detected by DP on the new cost map is smaller than arbitrary threshold, the accumulated cost does not increase, even if the length of the seam-line is long. But the reference threshold of cost, which can be ignored and is invisible value by human, is changing according to each different pair of images. Thus we proposed a method of automatic determination of the reference threshold of the cost transform function to the correlation of overlapping images.

In the process of the evaluation of the least accumulated cost function, the arbitrary threshold t_{ref} transforms the correlation map of overlapping images into a binary cost map and the least accumulated cost ϕ of a seam-line detected by DP on the binary cost map is then calculated. In the process, if the threshold t_{ref} is very high, the accumulated cost of the seam-line will be around zero, because the cost of the most nodes of the cost map might be set as zero. On the other hand, if the threshold t_{ref} is very low, which is the highest value in cost values, the accumulated cost of the seam-line will be high, since the cost of the most nodes of the cost map might be set as one. When changing the threshold t_{ref} from the highest value to the lowest value, the least accumulated cost ϕ will be changed from zero to high value as shown in Fig. 1(a). To calculate this curve, the threshold t_{ref} (Fig 1(a)) changing from one to zero at interval of ΔT, which is a small interval value, is defined as follows:

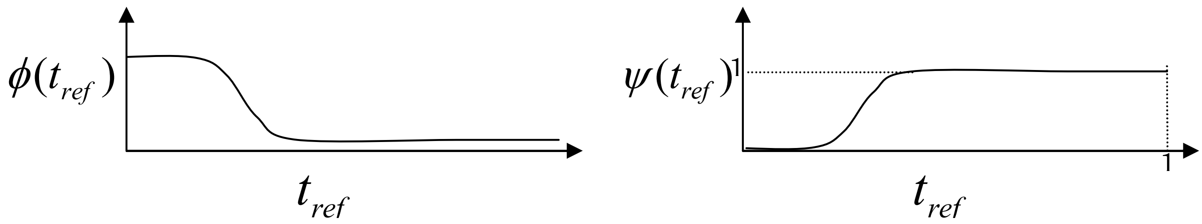
$$t_{ref} = 1 - n\,\Delta T, \qquad (1)$$

where *n* is changing as 1,2,3, and …. Let a seam-line detected on a cost map transformed by each *n* be l_n and the cost of the k^{th} seam point of l_n be $cos t_k$. The least accumulated cost ϕ_n on this l_n is calculated as follows:

$$\phi_n = \sum \{\text{cost}_k, \quad k \in l_n\} \cdot \tag{2}$$

The function $\phi_n(t_{ref})$ calculated by the repeated calculation of Eq. (2) about the each *n* will be released in Fig. 1(a). We use the normalized function $\hat{\phi}_n(t_{ref}) = \phi_n(t_{ref}) / max\{\phi_n(t_{ref})\}$ about $\phi_n(t_{ref})$ as the badness function. The curve in Fig. 1(a) means the state of the badness of seam-lines, while the curve in Fig. 1(b) means the state of the goodness of seam-lines. Let the goodness curve be called as the cost transform function $\psi(t_{ref})$. The cost transform function $\psi(t_{ref})$ is calculated as follows:

$$\psi(t_{ref}) = 1 - \hat{\phi}_n(t_{ref}) \tag{3}$$



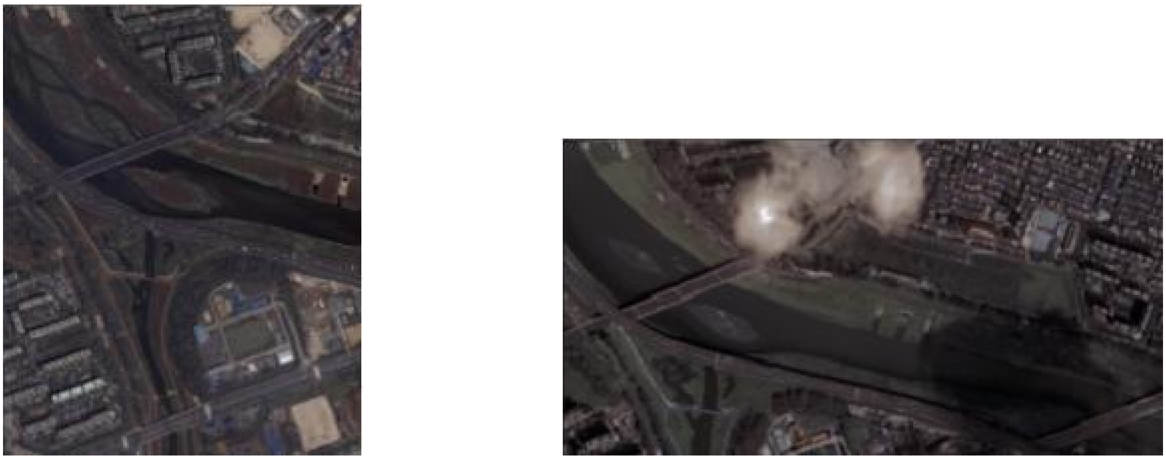
(a) (b)

Fig. 1. An example of cost mapping function composition, (a) minimum sum of cost function $\phi(t_{ref})$ about a threshold value, (b) cost mapping function obtained using (a).

3. EXPERIMENTAL RESULTS AND DISCUSS

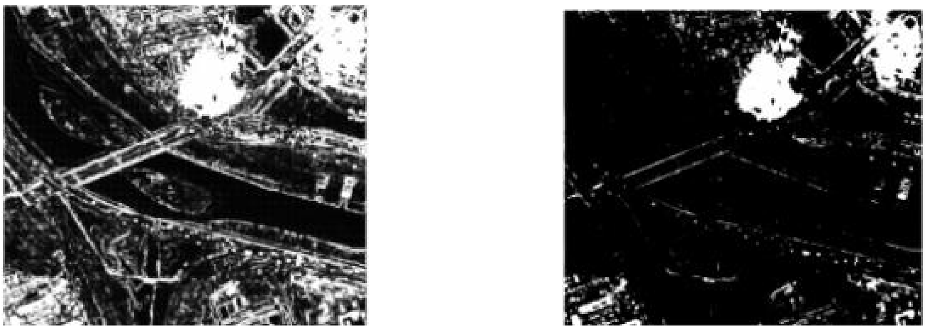
To evaluate and compare the performance of the proposed method with DP only and the twin snakes, the image mosaics have been tested on ortho satellite images. The images in Fig. 2 are the ortho satellite images with different shooting time, photographing angle, and sun light angle. Figure 3(a) is a cost map created by normalize cross correlation (*NCC*) with overlapping images. In the cost map, the dark and the light areas mean the high and the low similarities of the pixels of overlapping images, respectively. In Fig. 3(b) that is a binary image created by applying threshold $t_{ref} = 0.3$ to Fig. 3(a), the seam-line will be obtained a curve passing the dark areas that are low costs. If the threshold t_{ref} becomes to reduce gradually from 1.0 at intervals of ΔT, the light areas get to be extended gradually. Figure 4(a) is a function $\phi(t_{ref})$ presenting the accumulated cost of each seam-line detected by DP while changing the threshold t_{ref}. This function $\phi(t_{ref})$ has a dependent characteristic associated with the input images because of difference of the correlation of each pair of overlapping images. The cost transform function $\psi(t_{ref})$ is calculated as shown in Fig. 4(b) by applying Eq. 3 to the function $\phi(t_{ref})$. Using this function $\psi(t_{ref})$, we can obtain a cost transformed image Fig. 5. When comparing the cost transformed image Fig. 5 and the original correlation image Fig. 3(a), we can easily know that the high and the low cost areas are extended and reduced more respectively. Image mosaics Fig. 6(a) and (b) are created by using seam-lines detected by applying DP to the two cost maps. Figure 6(c) presents the detected two seam-lines on the correlation map Fig. 6(a). The two vertical lines around both boundaries in Fig. 6(d) are the initial control points of two snakes and the two curves around central area are the twin snakes after a few iterations. The dotted squares ① and ② in Fig 6(a) are represented at right side of Fig. 6(a) as an original size. The two original images are showing misaligned problems that are originated from the distance effect. The twin snakes did not be one seam-line. In case of setting higher value to the pulling constant of the twin snakes for docking one seam-line, the twin snakes easily miss the global or the local minimum cost areas on the cost map Fig. 3(a). From the result by the algorithm of the twin snakes, we know that the algorithm of the twin snakes can only detect a good seam-line in case of using overlapping images of which the texture similarity is high.

As contrasted with the results by the previous methods, we know that the image mosaic Fig 6(b) created by the seam-line, which detected by the proposed method, avoiding discordance areas and turning far away is a well-aligned image mosaic.



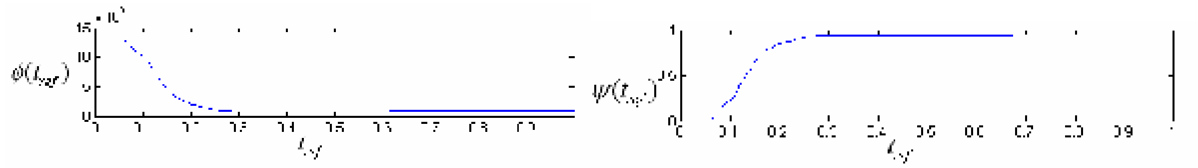
(a) Left image (b) Right image

Fig. 2. Two images for mosaicing (ortho-satellite imagery) (a) left image (b) right image.



(a) (b)

Fig. 3. (a) Cost image and (b) Binary image using the threshold t_{ref}=0.3.



(a) (b)

Fig. 4. (a) $\phi(t_{ref})$ and (b) $\psi(t_{ref})$ functions (ortho-satellite image).

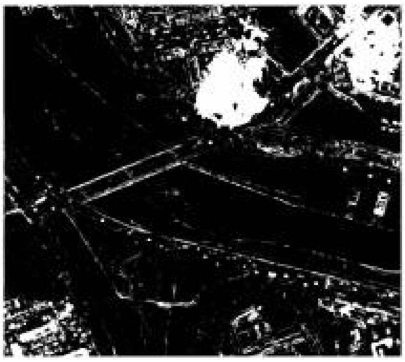
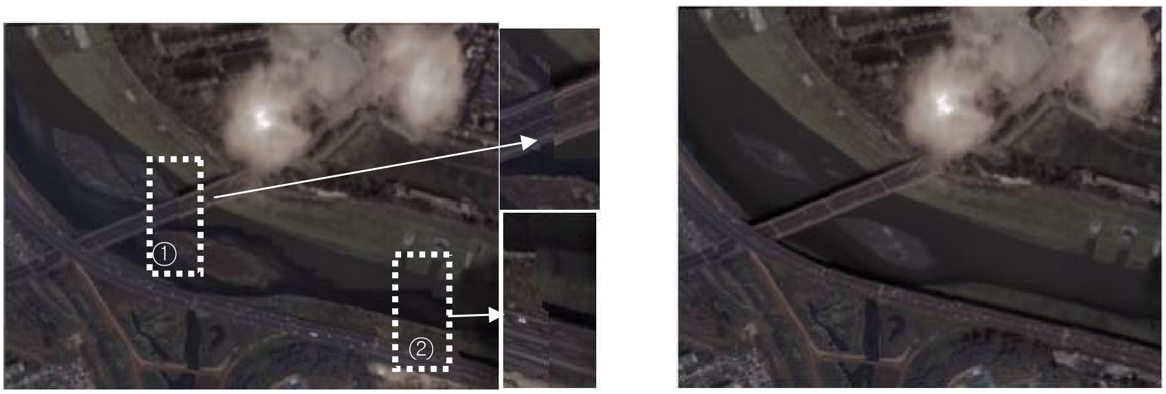
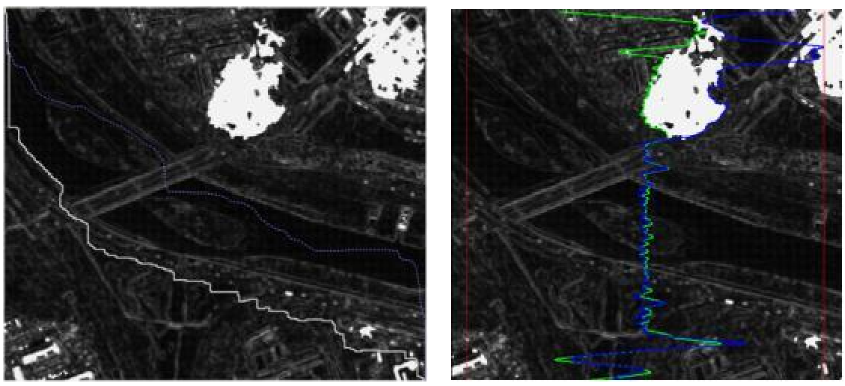


Fig. 5. Mapped cost image using the function $\psi(t_{ref})$ of 7(b) (ortho-satellite image).



(a) (b)



(c) (d)

Fig. 6. Mosaicked images (ortho-satellite image) with the dynamic programming only 、 seam points with miss alignment are shown in dotted squares (b) with the proposed algorithm (c) seamlines on the cost image in the overlapped area (dotted line: DP, solid line: proposed algorithm) (d) seam-lines by twin snakes algorithm.

4. CONCLUSION

If an image mosaic is created using a seam-line that is the one along which the pixel differences of overlapping images are as small as possible in the image mosaicing process, the visual discordance around border-line in mosaiced images will be very small. Since the visually good seam-line is determined associated with an optimal path finding algorithm, well-known effective optimal path finding algorithm is the dynamic programming. The algorithm of the dynamic programming only operates in a point of view of minimizing accumulation and it does not have concern with visual sensitivity. But the visual sensitivity of human has not concerned with the length of a seam-line and has only concerned with high costs.

We proposed the visually optimal seam-line determination algorithm that determines an image border-line in mosaicing using the transformation of gray value differences and the dynamic programming. Because the transformation makes high costs to higher costs and low costs to lower cost, the seam-line detected by the dynamic programming on the transformed cost map will be a visually optimal seam-line ignoring its length. For processing the cost transformation, we use the least accumulated cost curve calculated by changing the threshold. The seam-line is detected by using the dynamic programming on the cost map transformed by the curve. We know that the proposed method can create a good seam-line visually and numerically.

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