ON THE GRAPH-BASED PANORAMA CONSTRUCTION FOR 2D LARGE-SCALE MICROSCOPE IMAGES

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ABSTRACT:

On analysis of existing images mosaicing methods, the conception of mosaicing graph is introduced and some principles to construct high quality panorama are presented in the paper. Image registration algorithm based on spatial relationship is applied to calculate the registration position and evaluate the registration error of a pair of images. Then three images mosaicing approaches based on spanning trees, including minimum cost spanning tree, shortest path spanning tree with media as root and minimum rouging cost spanning tree are proposed to calculate global optimum position of every images and to create the panorama. In the experiments, results of four methods are compared and the approaches based on shortest path spanning tree with media as rot and minimum routing cost spanning tree are proved to be appropriate to construct panorama with high quality and great efficiency.

1. INTRODUCE

Image mosaicing has already been an important subject in image processing and the technology has been applied widely in robotics, computer vision, virtual reality, surveillance, interactive TV, virtual tourism, medicine, remote sensing and so on(Brown, 1992, Chen, 1995, Gledhill et al., 2003, Zitova et al., 2003). Image mosaicing is the most difficult problem of panoramic image construction(Gledhill et al., 2003).

Image mosaicing is based on image registration. Existing methods of registration can be classed into area-based and feature-based approaches(Brown, 1992, Zitova et al., 2003,), which evaluate the similarity of images with several measurements to obtain the correct registration position(Škerl, 2006).Pyramid-based algorithm(Thevenaz, 1998), wavelet-based algorithm(Manjunath, 1996, Meijering et al., 1999), SSDA(Barnea et al., 1972) or combined algorithm(Xu et al., 1999) were proposed to fasten the image registration. While getting the registration in general, those methods could neither evaluate the quality of the registration result nor compare the results of different pairs of images.

Most of the mosaicing methods deal with 1-D sequence images, in which each image is only adjacent to its previous and following image and there is no cycle of the adjacent relationships. In 1-D sequence images mosaicing, global position of each image is calculated by transform parameter of two neighboring images. In order to construct high quality panoramic image, errors of neighboring images are reduced by recovering the camera focal length(Kang et al., 1999, Davis , 1998) or adjusting transform parameter(Kim et al., 2003, McLauchlan et al., 2002). In 2-D image mosaicing, each image not only has overlay area with its previous or following images, but also has neighbor relationships with some other images. In 2-D image mosaicing, some registration failures or errors of pairs of images may transfer to other images and accumulate more and more, which will induce gaps or overlaps of the panoramic image.

In order to reduce errors accumulated in 2-D image mosaicing, many improved methods, including topological relations among images(Hsu et al., 2002), gap closure of images sequence(Szeliski et al., 1997), least square method(Park et al., 2000) or integrated method(Shum et al., 2000) are proposed to adjust local registration errors or select global optimization solution to create high quality panoramic image.

According to the work above, a new type of mosaicing method based on graph theory was proposed, of which a vertex indicates an image and an edge indicates the registration relationships of pairs of images. For each edge, a weight by some criterion is attached. Registration graph are introduced to replace failed registered pairs by registering other pairs and reduce the registration error globally(Zhou, 2006). In(Nikolaidis et al., 2005), a object function is proposed to select the spanning tree of the graph, in which sub-graph spanning tree mosaicing is introduced to reduce the computation complexity. More approaches adopt shortest path spanning tree algorithm to calculate the global positions of each image and to build high quality panoramic image (Zhou et al., 2006, Kang et al., 2000, Marzotto et al., 2004). To avoid randomicity of reference frame, an improvement method, which take median as the root of the shortest path spanning tree(median is the root vertex with minimum routing cost from the root to other vertexes(Wu et al., 2003)), is provided to adjust local registration and confirm global position of all images(Choe et al., 2006).

Above method of image mosaicing is mainly used to construct panoramic image of natural scene for browse, and the amount of images is most about decade or several decades. In order to build panoramic image with high precision, the overlap rate between pair images is about 70%-80%(Zhang et al., 2004) . If the panoramic image is constructed from large scale images, for instance, hundreds of or thousands of images, registration failure or accumulate errors will lead to obvious gaps or overlaps though image registration error of pair images is little.

Large-scale microscope images are gathered by microscope apparatus, which cover the whole area of target. Each image has overlap area between conjoint images. In general, panorama of large-scale microscope images is applied in medicine, LSI etc. Mosaicing of Large-scale microscope images is different from general image mosaicing in: (1) Microscope images are gathered by special apparatus so that errors including distortion and rotation can be neglected. (2) The amount of images is large, commonly several hundred, for example, under 40 multiple magnifier an organization slice has several hundreds or several thousands images with 1600*1200 pixels. Therefore, local mosaicing error will accumulate and lead to gaps or overlaps of the panoramic image. (3) On the field such as medicine and LSI, panoramic image is build for further analysis, so the quality of the panoramic image is vital. Those panoramas with low quality will lead to unpredictable bad result.

In this paper, several mosaicing approaches based on mosaicing graph are presented and compared, e.g. minimum cost spanning tree, shortest path spanning tree and minimum routing cost spanning tree from the quality and efficiency point of view, and the most proper method to be selected under different situation is discussed.

The main contents of this paper is arranged as following: in section 2, the conception of mosaicing graph and some principles to construct optimal panoramic are provided; In section 3, method and algorithm to compute the weight of mosaicing graph, and methods based on three types of spanning tree of mosaicing graph are presented and compared to build panorama with high quality and great efficiency. In Section 4, experimental results of several methods are presented and compared. Finally, a conclusion is drawn in 5.

2. CONCEPTS AND PRINCIPLES

Mosaicing graph of image mosaicing is an undirected weighted graph, marked as G(V,E,w), in which V represents image set, E represents registration relation set among images and w is weight of edge. Microscope images arrange much regular, like M rows and N columns(M*N) matrix, and only neighboring images have registration relationship.

A micrograph mosaicing graph of 2 row 3 arrange is shown in Figure1(a). In the mosaicing graph, each vertex denotes an image, each edge denotes registration relation between two neighboring images, and each edge owns non-negative weight.

Among mosaicing graph, there always are some registration failures or errors, while one spanning tree of mosaicing graph may determine global positions of all images. If cycle existing in the graph, global position of some of the images may calculate by more than one route and conflicts emerge. Then, the most important problem to build a panoramic image is to select a proper spanning tree to minimize the global errors of the mosaicing graph.

Let mosaicing graph be G(V,E,w) where w>0, one of its spanning tree be T, weight of edge be radio scaling. The approaches to construct panoramic image based on spanning tree can be classified into two types: on the external errors and on the internal errors.

First we will discuss the approach based on the external errors. Let vertex i and j be pair of conjoint vertexes, (xi,yi),(xj,yj) be registration coordinate of vertex i and j of conjoint images, (xi',yi'),(xj',yj') be global coordinate of vertex i and j by spanning tree T respectively. As to spanning tree T of mosaicing graph G, the total errors of conjoint vertexes is marked as external errors summation, that is

$$E_{out} = \sum_{\substack{i,j \in V(G),\\ (i,j)\in E(G)}} \sqrt{((x_j - x_j') - (x_i - x_i'))^2 + ((y_j - y_j') - (y_i - y_i'))^2} \quad (1)$$

According to equation (1), the panoramic image will be in highest quality when E is smallest. If weight of pair image registration is considered, registration with high quality should take more rates in Eout. Let ai,j be the measurement of registration quality of image pair i and j. Spanning tree to build panoramic image with best quality should satisfy:

$$E_{\min} = \min\left\{\sum a_{i,j}\sqrt{((x_j - x_j') - (x_i - x_i'))^2 + ((y_j - y_j') - (y_i - y_i'))^2}\right\} \quad (2)$$

Although it is a good method to construct high quality panoramic image, unfortunately, to get all of the spanning trees of mosaicing graph imposes prohibitive computational requirements when the amount of the vertexes is large(Nikolaidis, 2005). Then we should consider from another point of view and discuss the method based on internal errors.

Supposed shortest path SP(u,v)=(u=r1,r2,…,rn=v)of vertex u,v of spanning tree T, thereinto ri V(T), routing cost dT(u,v) of SP(u,v) can be denoted as weight summation of all edges in the path on T:

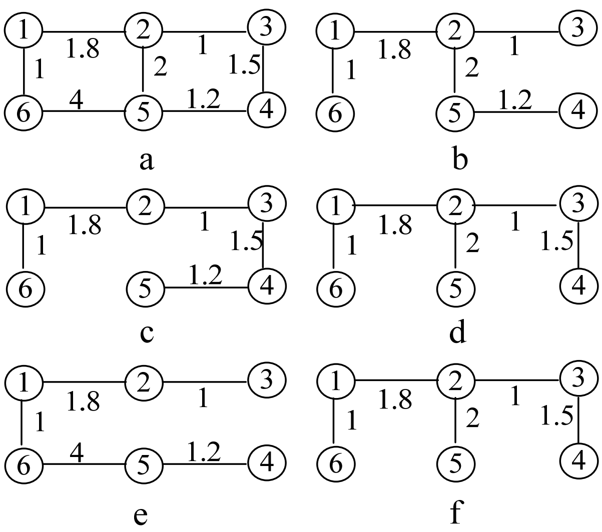
$$d_T(u,v) = \sum_{i=1}^{n-1} w(r_i, r_{i+1}) \quad (3)$$

For each pairs of neighboring images u and v, the result is best while the routing cost is minimized; for the mosaicing graph, the panoramic image is in highest quality while the routing cost's summation of all the adjacent vertexes in graph is minimized. This spanning tree is marked as Adjacent-Vertex -in-Graph Minimum Routing Cost Spanning Tree (AVGMRST), and the cost of AVGMRST is called Adjacent-Vertex-in-Graph Minimum Routing Cost(AVGMRC) of mosaicing graph:

$$AVGMRC(G) = \min\left\{\sum_{u,v\in V(G), e(u,v)\in E(G)} d_T(u,v)\right\} \quad (4)$$

So, the AVGMRST is the spanning tree of mosaicing graph to build high quality panoramic image; if it is difficult to build AVGMRST, the spanning tree which is closer to AVGMRST is preferred. For example, Figure1(a) is a mosaicing graph and its optimize spanning tree should make summation of route cost between vertexes (1,2),(2,3),(1,6),(2,5),(3,4),(5,6) and (4,5) minimized, and its AVGMRC is 32, as Figure1(b) shown. Figure1(c), Figure1(d), Figure1(e) and Figure1(f) shows minimum cost spanning tree, shortest path spanning tree of vertex 2, shortest path spanning tree of vertex 6 and minimum routing cost spanning tree of mosaicing graph in Figure1(a) respectively. From Figure1, we can see that not all of the shortest path spanning trees can reduce the global errors of the mosaicing graph effectively. Minimum cost spanning tree, one of the shortest path spanning trees and minimum routing cost spanning tree, especially the second and the third ones, are close to the optimal solution to create high quality panoramic image.

The second problem to be considered is how to select weight of edge in mosaicing graph. According to measure scale, data can be classified as nominal scale, ordinal scale, interval scale and radio scale. To construct spanning trees of graph, if only comparison weights of different edges is needed, data of interval scale or ordinal scale is enough. If the spanning tree is based on route, then the weight should be a type of radio scale. It is the second principle of image mosaicing based on mosaicing graph. For example, while constructing minimum spanning tree of mosaicing graph, the weight of the edge should be a type of ordinal scale, interval scale or radio scale. While constructing the shortest path spanning tree or minimum routing cost spanning tree of mosaicing graph, the weight of the edge should be radio scale



(a) Mosaicing Graph; (b) Adjacent-Vertex-in-Graph Minimum Routing Cost Spanning Tree (AVGMRC=32); (c) Minimum Cost Spanning Tree (AVGMRC=35.4); (d) Shortest Path Spanning Tree of Vertex 2 (AVGMRC= 33.2); (e) Shortest Path Spanning Tree of Vertex 6 (AVGMRC=49.6); (f) Minimum Routing Cost Spanning Tree (AVGMRC=33.2)

Figure 1. AVGMRC and Four Typical Spanning Trees of Mosaicing Graph.

In large scale mosaicing, error accumulation is a relative severity problem. Weight of edge is uncertainly and error is unavoidable. If routing cost of two routes is similar, the route with more edges will accumulate more errors. Therefore, the third principle is, in the spanning tree of mosaicing graph, the number of edge in the route should be reduced.

The final principle is that, a balance should be made between the quality of the panorama and the efficiency. For those with several images to be mosaiced, a more precise method can be considered to construct a panorama in high quality; but for those with hundreds of or thousands of images which are the most cases in the microscope images mosaicing, much time are consumed and a balance between the quality of the panorama and the efficiency should be made.

3. METHOD AND ALGORITHM

3.1 Local Registration Based on Spatial Relationships and Evaluation of the Registration

Image registration is a procedure to search the same image of standard image in the reference image. Existing image registration algorithm can not distinguish the registration precision of different pairs of images through the correlation coefficient.

We adapted a registration approach based spatial relationships, in which the standard image is divided into several block images to register with the reference image respectively and then the registration position is calculated by the spatial relationship of the block image registration positions through spatial clustering algorithm. Details of this method can be viewed in [].

In this method, the standard image is divided into n blocks denoted by $B_i(i=1,2\ldots n)$. Registrations of these blocks are carried out in reference image to get n coordinates of standard image in the reference image, marked as $L(B_i)$. Under ideal condition with non-distortion and non-circumvolve, each one in $L(B_i)$ will be same. However, in practice elements in $L(Bi)$ are different because of distortion and circumvolve. But in most cases, elements of the $L(B_i)$ distribute around a point and concentrate in a small region , while few points distribute irregularly. Therefore we can compute the position of the standard image in the reference image from those concentrated points.

Adopting image registration algorithm based on spatial relationships, not only the registration position can be calculated, but also the reliability of the image registration is computed. Suppose N is the amount of blocks divided from standard image, M is the amount of points in C_{max}, the class has more object than others, and the reliability P of registration is:

$$P = \frac{M}{N} \tag{5}$$

3.2 Weights of the Edges in Mosaicing Graph

Before constructing panoramic graph based on spanning tree of mosaicing graph, the weight of the edge should be calculated. Weight of edge should satisfy the principle 2 and 3 provided in section 2.

It is reasonable to take average error of the registration as the weight of the edge. As to registration result of a pair of images, let l(x,y) be the registration position, (xi,yi)(i=1,2…M) be the points in Cmax. The average error of the registration is:

$$\delta = \frac{\sum_{i=1}^{M} \sqrt{(x_i - x)^2 + (y_i - y)^2}}{M} \tag{6}$$

Now considering two situations, the first is high reliability with big average error, the second is low reliability with small average error. It is obviously that the latter is more precise than the former. As to the same pair of images in registration, the relationship between average error and reliability is inverse. Therefore, we can take the ratio of average error to reliability as weight of edge of mosaicing graph, that is

$$w = \frac{\delta}{P} \tag{7}$$

When $P=0$, the weight of the edge is infinite, that is to say, the registration of the pair of images is failure.

Errors always exist in the images registration and the average error calculated is an estimate value. If the path has a big amount of edges and the routing cost is 0, accumulative error always exists. The more edges in the path, the bigger the errors accumulate. Therefore, if there are several paths between two vertexes which have the same or similar routing cost, the path with fewer edges will be more precise than those with more edges. The method modeling with this type of error and selecting the path with fewer edges is to assign an inherent error θ to the weight. By the method, the weight of the edge is:

$$w = \frac{\delta+\theta}{P} \tag{8}$$

For the mosaicing graph, this method will decrease the amount of the edges of the all routs in the graph to reduce the global errors of the panoramic image. The weight can carry out comparative operations and accumulative operations, which also has clear physical meaning. So it can satisfy the principle 2 and 3 simultaneity.

3.3 Spanning Trees of the Mosaicing Graph

Let G=(V,E,w) be the Mosaicing Graph with a set of images of M rows and N columns(M*N), in which V is the vertex set denoting images and E is the edge set denoting registration relationship set which . As to those edges failing in registration, the weight is infinity. The spanning tree of mosaicing graph has |V|-1 edges, in which |V| denotes the amount of the vertexes. In mosaicing graph with M*N, the amount of the edges is 2*M*N-M-N (including edges failing in registration) and the spanning tree of this mosaicing graph has M*N-1 edges. Then, M*N-M-N+1 edges in the mosaicing graph are free and redundancy to construct some spanning tree with the minimum global errors of the panoramic image.

There are many types of spanning tree of graph, including minimum cost spanning tree(MCT) (Wu et al., 2003, Cormen et al., 2001), shortest path spanning tree(SPT) (Wu et al., 2003, Cormen et al., 2001) and minimum routing cost spanning tree(MRCT) (Wu et al., 2003).

As MCT and SPT are extremely discussed and widely used spanning trees of graph, we will introduce the MRCT of graph in brief. MRCT is one type of spanning trees of graph. Let T be a spanning tree of graph G, dT(u,v) be the routing cost of path(u,v) in T. Routing cost on T of graph G is the sum over all pairs of vertices of the routing cost for the pair in this tree:.

$$C(T) = \sum_{u,v \in V(G)} d_T(u,v) \tag{9}$$

The MRCT is the one with minimum routing cost among all possible spanning trees. Calculation of MRCT of G has been proved a NPC problem (Garey et al., 1979) .

As discussed in section 2, AVGMRST is the spanning tree with minimum global mosaicing errors of mosaicing graph, but to compute AVGMRST is a NPC problem too, as proved in the following. Actually, to construct AVGMRST of graph is to calculate the spanning tree with minimum routing cost of specific vertices pair set. MRCT is a special case of this kind of spanning trees. By (Garey et al., 1979), “an NP-completeness proof by restriction for a given problem Π NP consists simply of showing that Π contains a known NP-complete problem Π’ as a special case”. For AVGMRST, if the vertices pair set are restricted to the adjacent vertices, it is a MRCT problem. As proved by (Garey et al., 1979), MRCT is a NPC problem, so AVGMRST is a NPC problem too.

Then, how about to calculate all possible spanning trees and get the AVGMRST? For a complete graph with n vertices, the amount of the spanning trees is n^{n-2} (Wu et al., 2003) so that to compute the AVGMRST of a graph with many] vertices is really impossible. Even for graph with M*N, the number of the spanning trees grows exponentially when M*N is large(Wu et al., 1997).

So to seek spanning tree with least global errors is impossible for those with hundreds of or thousands of images in practice, and an optimal spanning tree should be adopted to balance between the quality of the panoramic images and the efficiency. We compare several kinds of spanning trees as following.

Minimum spanning tree is edge-selection based and only takes the sum of the weights in spanning tree into account, without considering routing cost in mosaicing graph. Obviously, the mosaicing graph for a series microscope images is a sparse graph. So Kruskal algorithm is better than Prim algorithm in our application and its time complexity is O(n2), where n is the number of the vertexes in the mosaicing graph.

Shortest path spanning trees consider the path and routing cost, so it is better than minimum cost spanning tree. The shortest path spanning tree with median as root of mosaicing graph is a better solution to construct panoramic image. What’s more, to build the shortest path spanning tree with median as root consumes few time. If the Dijkstra algorithm is adapted, the time complexity to construct a shortest path spanning trees is O(n2), where n is the number of the vertexes in mosaicing graph. There are n vertexes in the mosaicing graph, so the time complexity is O(n3).

As to minimum routing cost spanning tree, paths between all pairs of vertexes are taken into account and it is the most similar spanning tree to AVGMRST by means of routing cost. This is response to the first principle in section 2. To build MRCT is a NPC problem. Therefore it is unpractical to construct MRCT of mosaicing graph with large number of images and approximate algorithm has to be applied. A (1+ε) approximate algorithm in time complexity O(n2*ceil(2/ε)-2) is introduced in(Wu et al., 1999) were ε>0 and ceil(2/ε) denotes integers no less than 2/ε.

Compared the three spanning trees of mosaicing graph, we can find out that MST-based method does not consider the routing cost between pairs of images although it is very efficient. The panorama will not be in high quality. The quality of panorama based on MRCT is best among the three methods, but it would consume much time when there are a large amount of images to be mosaiced. So when high quality of the panorama is required and the amount of the images is to be mosaiced, it is a proper choice. The method based on SPST with median as root, which balance the efficient and the quality of the panorama, will be a practical choice for large scale microscope image mosaicing.

4. EXPERIMENTS AND RESULTS

In the experiments, microscope images are collected from tissue slice in 1600*1200 pixels under 40 amplification ratios. For images in the same row and between adjacent columns, the horizontal search range is from 70% to 92% and the vertical search range is from -10% to 10%. For images in the same column and between adjacent rows, the vertical search range is from 70% to 92% and the horizontal search range is from -10% to 10%.

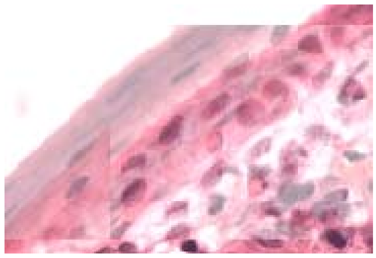
In general, number of microscope images from tissue slice in 1600*1200 pixels under 40 amplification ratios will arrive several hundred; some of them even are over one or two thousand. Images of a tissue slice with 22 rows and 17 columns are tested in this paper, which have 709 conjoint relationships and many blank and vague images.

In the local registration, 109 pairs of images fail and the right rate of registration is 84.635%, in which most of the registration failures come from blank images.

Based on local registration, we adopt three methods to construct spanning trees of mosaicing graph as described in section 3, including mosaicing method based on minimum cost spanning tree, mosaicing method based on shortest path spanning tree with media as root and mosaicing method based on minimum routing cost spanning tree of 2-star.

Image mosaicing method based on MST has some serious shadows in the panorama(Figure2). The method based on SPST and MRCT improve the quality much and there almost doesn't exist obvious mistake in the panoramas, but parts of panorama based on SPST are more blurry than that based on MRCT(Figure3).

The comparison of the four methods is shown in Talbe.1. From the table, we can see that the quality of panorama based on shortest path spanning tree with media as root is very similar to that based on minimum routing cost spanning tree but the algorithm of minimum routing cost tree is very complex and the method to construct panorama based on minimum routing cost tree consumes much more time than the method based on shortest path spanning tree with media as root does.



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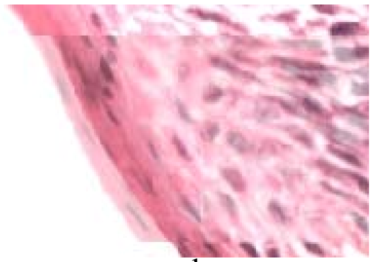

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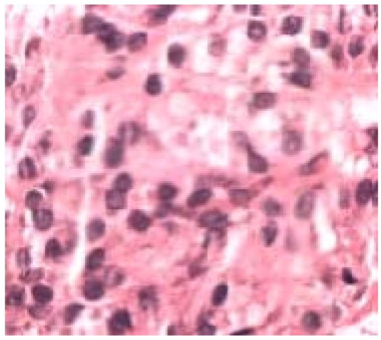
Figure 2. Mistakes in Panoramic Image Based on MST



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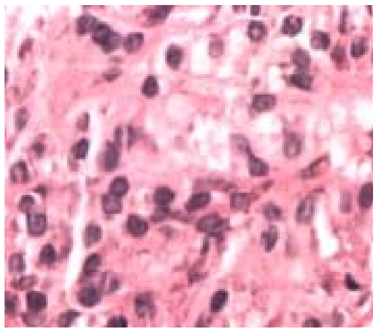

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Figure 3. Comparison the Same Parts from the Panoramic Image based on SPST and MRCT: (a) Part of Panorama Based on SPST; (b) Part of Panorama Based on MRCT.

Method	Effect	Time Complexity
MCT	Good. A few serious displacements in the panorama.	O(n2)
SPST	Better. No obvious displacement but some minor blurries in the panorama.	O(n3)
MRCT	Best. No obvious displacement and few minor blurries in the panorama.	$O(n^{2*ceil(2/\varepsilon)-2})$to construct a (1+ε) approximate MRCT

Table 1. Comparison of Four Mosaicing Methods

5. CONCLUSION

Because of limitation of the apparatus, in fields of medicine and LSI etc, microscope images of the target are gathered in many frames and should be mosaiced to construct the panorama. The amount of the microscope images is large and existing methods can not deal with the accumulated errors well. In this paper, the method based on graph theory is provided and several approaches based on spanning trees are compared, including minimum cost spanning tree, shortest path spanning tree with media as root and minimum routing cost spanning tree, which takes the registration results based on spatial relationships as the weights of the mosaicing graph. The experiments show that the methods based on spanning trees of mosaicing graph is much better than the method based on local registration. According to the comparison, the mosaicing method based on SPST as root and MRCT are appropriate to construct high quality microscope panorama, between which the latter is a little better but consumes much time, while the method based on SPST is more efficient than the method based on MRCT. Therefore, the method based on SPST is much proper to construct panorama with large scale microscope images and high quality.

For microscope images mosaicing, an improvement depends on the algorithm of the Adjacent-Vertex-in-Graph Minimum Routing Cost Spanning Tree, which will construct the panorama with less error.

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