An Algorithm for Fast Image Registration and Feature Matching for the Purposes of Image Stitching

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Abstract: *The paper is devoted to the problem of image alignment which is one of the most important in image stitching. The basic requirement of this stage is the high alignment precision. As a rule algorithms for image registration are time consuming. In the paper we propose a fast algorithm for image registration. We suggest only sets of specially extracted control points to be involved in computations. The basic feature of these points, named equipotential points, is that they outline closed contours around brightest and darkest objects in the scene. An algorithm for combining, grouping and reduction of selected control points is also presented. Results, obtained using proposed points and algorithm, are compared with the results, obtained using other control points like corner and edge points.*
Key words**:** *Image Matching, Image Alignment, Image Stitching, Representative Points, Control Points*

INTRODUCTION

Making panoramic images has become increasingly common nowadays. The process is known as image stitching. Stitched images are used not only in panoramas but in various other applications such as object insertion, architectural walk-through, texture synthesis, modelling the 3-D environment, etc.

The goal of image stitching is to produce a seamless end image using set of smaller images.

The main steps in producing a panoramic image are image registration and aligning and image merging.

Registration step is performed to establish correspondence between object from one image with the objects from the other image. During the step of image alignment a proper mathematical model, which connects pixel coordinates from one image with the pixel coordinates from another image has to be formulated. After that the right alignment between images must be established. Both steps can be made by two basic methods: pixel-to-pixel (or direct) comparison [2], [7], [8] and feature-based comparison [4], [5], [6], [7], [9], [11].

A great advantage of direct methods is the high precision of registration and alignment. The basic disadvantage of these methods is their high computational complexity.

A way to accelerate computations is to use sets of control points [5], [6], [11]. Corner points, edge points, contours and texture are usually used for image registration and alignment.

In this paper we propose specially selected control points to be used for image registration in order to decrease computational time instead of using direct pixel-to-pixel comparison. We also propose an algorithm for reduction, combining and grouping selected points.

CONTROL POINTS

In order to create invariant descriptions of the processed images it is necessary representative points to be selected. Our suggestion is to use for this purpose points, extracted with the method of equipotential planes, proposed by us earlier [10]. This

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method is based on the criterion of D-optimality, which means that the most informative points outline the protruded peripheral shape of an object and represent it in the best way. We use the three-dimensional representation of the image and cut the lowest and the highest parts of it, using parallel to *xOy* "potential" planes Pt_{min}, Pt_{max}.

Set of representative points EP is formed according to the following rule (Eq. 1):

$$
\textit{If}\;\left(\begin{array}{ll}
 & \left(\begin{array}{l}[(PI(i,j)\le Pt_{max})\cap(PI(i+1,j)>Pt_{max})]\cup\\ \cup[(PI(i,j)\ge Pt_{max})\cap(PI(i+1,j)<Pt_{max})]\end{array}\right)\cup\\
\cup & \left(\begin{array}{l}[(PI(i,j)\le Pt_{min})\cap(PI(i+1,j)>Pt_{min})]\cup\\ \cup[(PI(i,j)\ge Pt_{min})\cap(PI(i+1,j)<Pt_{min})]\end{array}\right)\cup\\
\cup & \left(\begin{array}{l}[(PI(i,j)\le Pt_{max})\cap(PI(i,j+1)>Pt_{max})]\cup\\ \cup[(PI(i,j)\ge Pt_{max})\cap(PI(i,j+1)<Pt_{max})]\end{array}\right)\cup\\
\cup & \left(\begin{array}{l}[(PI(i,j)\le Pt_{min})\cap(PI(i,j+1)>Pt_{min})]\cup\\ \cup[(PI(i,j)\ge Pt_{min})\cap(PI(i,j+1)<Pt_{min})]\end{array}\right)
\end{array}\right)
$$

$$
\text{Then} \qquad (i,j)\in EP \tag{1}
$$

where: $PI(i,j)$ is the intensity at point (i, j); Pt_{min}, Pt_{max} are intensity values, which determine the distance between the *xOy* plane and the planes, cutting lowest and highest parts of the relief ("valleys" and "hills"); EP is the set of points, outlining "valleys" and "hills".

These points outline closed contours of the local "valleys" and "hills" from the image relief, as it is shown in fig. 1.

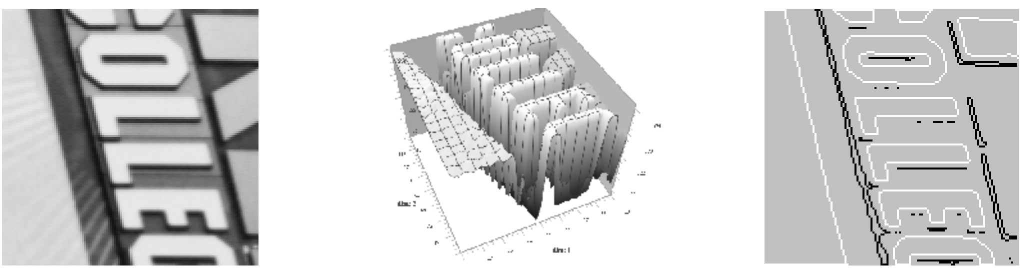

Fig.1. Input image (left), its three-dimensional representation (middle) and extracted control points (right), which outline objects – hills (white) and valleys (black)

It is well seen that selected control points mark the important parts of the image. The next step is feature matching based on the selected points from input images.

Standard strategy for feature matching used in algorithms for image stitching is analyzing a window of pixels around every selected point in the first image and correlating them with a window of pixels around every other selected point in the second image. Points which have maximum bidirectional correlation are taken as corresponding pairs. The computational complexity of this strategy highly depends on the number of control points. This fact determines the need to use only the most informative points and therefore corner detectors (SUSAN, Harris, Moravec, FAST [5, 6, 11]) are widely used.

The main disadvantage of corner detectors is that their computational complexity is significantly higher than standard edge detectors (Roberts, Sobel, Canny), and our method of equipotential planes. This problem is compensated with the smaller number of detected high informative control points.

The equipotential planes algorithm selects control points that mark high informative zones of images. The problem is that the number of detected points is much greater than corner detectors and this decreases the performance of feature matching stage. We describe here a modification of standard feature matching strategy using specific characteristics of equipotental planes, so the performance of the feature matching stage can be highly improved. The modification is directed to a preliminary reduction, combining and grouping the already selected points.

REDUCING, COMBINING AND GROUPING THE CONTROL POINTS

The number of equipotential control points can be reduced by removing the less informative points. Combining and grouping strategies can be used in order to easily find the most important points. Each point is combined with a neighboring point if the neighbor is already marked as a control point. For each point 8 neighbor points must be checked but if the combining algorithm is performed during the equipotential points' selection process these 8 points can be reduced to 4 depending on the scan direction.

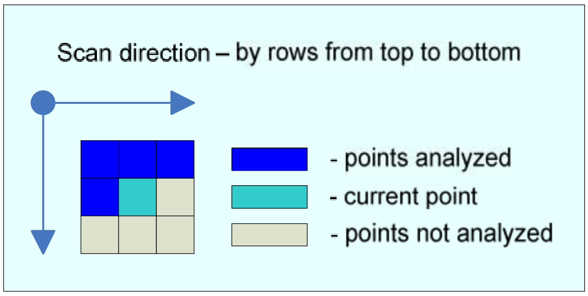

Fig.2. Based on scan direction there are always 4 neighbor points to check, only points that are already analyzed are checked

It is seen (Fig. 2) that only the analyzed neighbor points must be checked in order to form a combination. The points' relative locations depend on scan direction but they are always 4 instead of the initial 8. This optimization is achieved only if we apply combining during the point selection stage not as a second pass algorithm. Unnecessary access to image data could be avoided with caching the intensity values from last scanned line and previously checked point.

Point combinations form point groups. Each group contains a set of connected control points. Often these sets are object outlines. In order to increase the performance groups can be also formed dynamically during the point selection. This is possible after changing the logical representation of a point. Each point must contain a reference to its group and each group must contain a reference to its points. If the currently scanned point cannot form a combination with any of the points of existing groups the new group will be created for this point. After the point selection completes the groups will be formed.

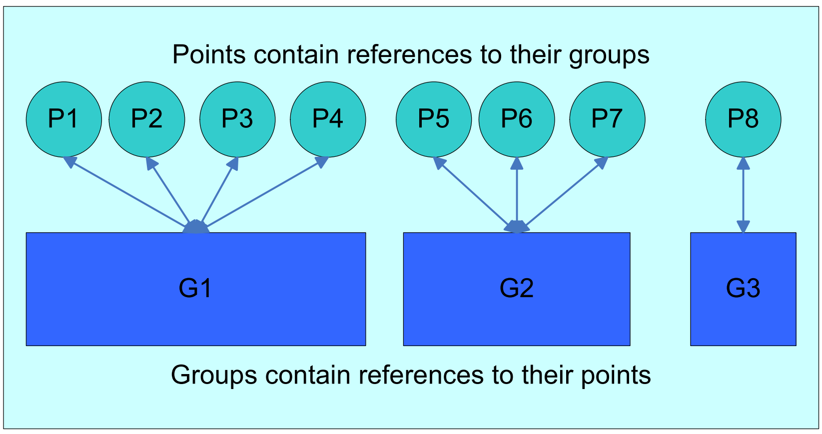

Fig.3. Points (marked with P) and groups (marked with G) are connected with references therefore the complexity of accessing a group of a point or the points of a given group is guaranteed to be a constant

The purpose of connecting groups and their points with bidirectional references is to guarantee a fast access from points to their groups and from groups to their points. If a given point forms a combination with an analyzed neighbor the group of this neighbor can be accessed directly without searching. This method of logical representations consumes more memory but it greatly improves the speed of point combination and grouping allowing these operations to be combined in a single pass with the selection of equipotential control points. The result is a modified version of Equipotential Points Selector algorithm [10].

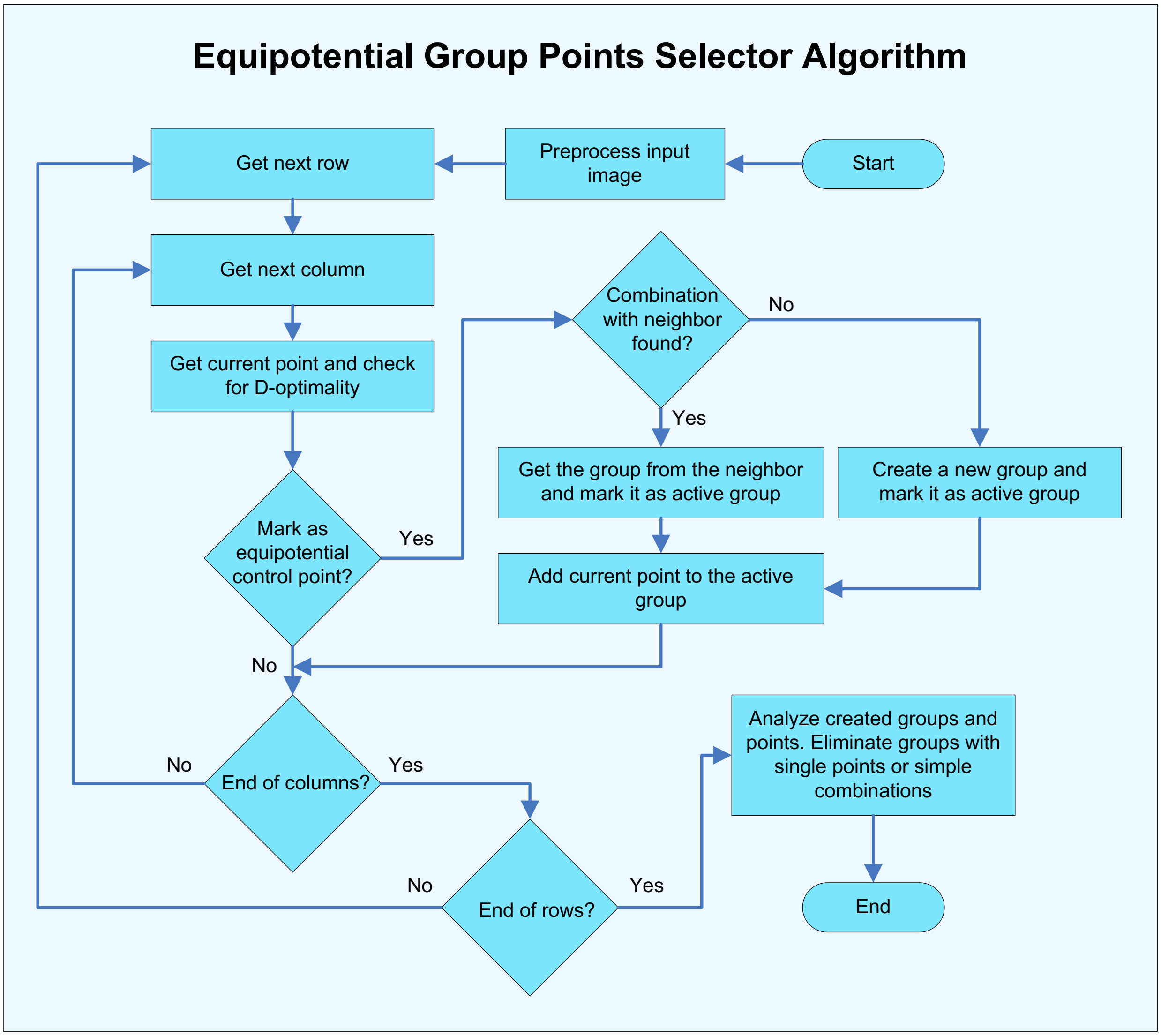

Fig.4. Block diagram of Equipotental Group Points Selector algorithm

The block diagram (Fig. 4) illustrates the idea of forming point combinations and groups directly during the control point selection process. This idea is combined with proper programming techniques which reduce the access to the image data to minimum.

The last stage of Equipotential Group Points Selector algorithm is analysis and reduction of the selected point and groups. After forming the groups the number of control points can be reduced by using a threshold technique - groups that contain simple combinations (combinations of less than N points, where N can be used as a threshold value for minimum point count in a group) should be removed. By applying this strategy the set of control points will be reduced and will contain only these points that outline important objects from the input image objects.

FEATURE MATCHING

As noted above, using the standard strategy for feature matching in image stitching tasks is efficient only if a small number of control points (the most informative points) are used. In order to reduce the number of selected control points we proposed a modification for our equipotential planes. This modification preserves the high speed of the control points selector algorithm and additionally combines points in a higher hierarchy – groups.

The feature matching step can be modified in order to take advantage from the specific characteristics of the point groups. The formed groups can be used directly for feature matching. Each group from the first image is compared with each group with second image in order to find the best match. The best match can be found by using any robust similarity measure like NCC, M-Estimators or Invariant Moments.

Usually the number of groups is significantly less than the number of corner points which improves the performance of the feature matching process. The Equipotential Group Points Selector is also greatly faster than corner detectors or standard edge detectors. In some cases even these speed improvements are not enough. For example, high quality photographic images with more than 10 megapixels image data will require further optimizations.

STRATEGIES FOR FURTHER OPTIMIZATIONS

If the proposed strategies for grouping the equipotential points and performing the feature matching step directly on these groups are still not fast enough there are some techniques that can be used for additional performance improvements:

- Groups can be labeled as 'white' and 'black'. The 'white' groups will consist of points that outline only the hills and the 'black' groups will consist of points that outline only the valleys. After this labeling a given group from the first image must be compared only with the groups with same label from the second image;
- Groups can be sorted based on the number of points they contain. After the sorting is performed a distance, based on the number of points, between the groups from the input images can be calculated. A given group from the first image can be compared only with the nearest groups from the second image, based on the calculated distance.

Strategies described above can be combined in order to achieve better performance results.

EXPERIMENTAL RESULTS

Speed comparison of Equipotential Points Selector, Equipotential Group Points Selector, Sobel Edge Detector and SUSAN Corner Detector is presented in Table 1. The speed comparison table contains execution times of different algorithms with different 24 bit color images.

Table 1 Speed comparison

	Execution Time [ms]			
Image Size [pixels]	**Equipotential Points Selector**	**Equipotential Group Points Selector**	**Sobel Edge Detector**	**SUSAN Corner Detector**
747 x 408	7,13	7,37	23,43	156,61
1242 x 1024	31,34	33,34	89,86	681,29
2904 x 2258	181,95	211,97	448,62	3205,67
3299 X 2549	220,49	224,42	539,78	3985,75
5256 X 3768	569,08	690,65	1392,76	9905,75
6048 X 4176	711,79	854,51	1665,55	12176,22

It is well seen that Equipotential Points Selector and Equipotential Group Points Selector are greatly faster than the other algorithms. It is important to note that the performance decrease in Equipotential Group Points Selector compared to Equipotential Points Selector is minimal, because point selection, combining and grouping are performed in a single pass.

Experiments have been made on the following PC configuration: Operating system: Microsoft Windows XP Professional SP2; CPU: Intel Core 2 Quad Q6600, 2400 MHz (9x267); System Memory: 2 x 1 GB DDR2-667 MHz; Video Adapter: Intel(R) Q33 Express Chipset Family (128 MB); HDD: Seagate ST3250820AS (250 GB, 7200 RPM, SATA - II).

CONCLUSIONS

The proposed algorithm for control points selection and optimization uses high-informative points for image representation. Due to the bidirectional relations between control points and groups unnecessary comparisons between all points are avoided. The Equipotential Group Points Selector is faster than corner detectors or widely used edge detectors.

In spite of the proposed speed improvements the Equipotential Group Points Selector is not fast enough in some cases. Additional optimization techniques are suggested. They can be used separately or together.

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