A HIERARCHICAL IMAGE MATCHING SCHEME BASED ON THE DYNAMIC DETECTION OF INTERESTING POINTS

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ABSTRACT

This paper presents a parallel approach to a hierarchical image matching scheme using the Hausdorff distance for object recognition and localization in aerial images. Unlike the conventional matching methods in which edge pixels are considered as image feature pixels in distance transform and the blind pointwise comparison procedure in terms of the Hausdorff distance is applied, a guided image matching system is developed by the hierarchical detection of interesting points via a dynamic thresholding scheme for the search of the best matching between two image sets. Furthermore, the concept of remote procedure call (RPC) in distributed systems is introduced for the parallel implementation to achieve the speedup without specific software and hardware requirement.

Key words and phrases: Image matching, distance transform, edge detection, interesting point, parallel implementation, remote procedure call (RPC).

1. INTRODUCTION

Object detection and recognition is an important task for aerial image analysis. To recognize objects reliably, a key problem is to find an efficient approach to image matching for object search and identification. The matching operation can be viewed as a measurement to determine the degree of resemblance between two objects that are superimposed on one another. Based on the level of image feature extraction, the matching algorithms developed in the past can be summarized in three categories: pixel-based method, low-level feature based method and high-level feature based method. Once the image feature description is determined, a match evaluation function is required to show the mapping between two descriptions with the degree of similarity in their attributes. Usually the similarity of two descriptions is defined in the form of a cost function or a distance function, where these costs are expected to be minimized and are zero only if both descriptions are identical. As far as real-time is considered, the low-level feature based methods seem to be more applicable.

* This work was supported in part by 1994 French Foreign Ministry International Postdoctoral Fellowship

When edge points are selected as image features, Chamfer matching was first proposed by Barrow *et al* in the 70's[1] for finding the best fit of edge points from two different images based on distance transform and distance minimization. Such a technique was further extended by Borgefors[2] by introducing a hierarchical matching scheme. However, the application of Borgefor's method is limited to well-defined object recognition and cannot be directly applied to aerial images where the objects to be detected will not satisfy being represented with a polygon sketch. The Hausdorff distance transform is reported to be powerful for shape comparison by measuring the similarity between two objects that are superimposed on one another. The study performed by Huttenlocher *et al*[3] shows that the Hausdorff method is highly tolerant of perturbations in the locations of pixel points and applicable to aerial images. However, the directed comparison method using the Hausdorff distance is time-consuming because it considers every possible translation of the model within the given test image. Even though Huttenlocher *et al* have developed some speed-up techniques for the computation of the Hausdorff distance, further improvement is highly desired.

In this paper we present the parallel implementation of a hierarchical image matching scheme guided by the dynamic detection of interesting points. The matching measurement in terms of Hausdorff distance based on interesting points is introduced in Section 2, the detection of interesting points is detailed in Section 3, and the parallel implementation using remote procedure call (RPC) is detailed in Section 4. The initial test results are presented in Section 5 followed by our conclusion

2. THE HAUSDORFF DISTANCE IN IMAGE MATCHING

The Hausdorff distance is a non-linear operator which measures the mismatch of the two sets. In other words, such a distance determines the degree of the mismatch between a model and an object by measuring the distance of the point of a model that is farthest from any point of an object and vice versa. Therefore, it can be used for object recognition by comparing two images which are superimposed on one another. The key points regarding this technique are summarized as below.

2.1. The Concept

Given two finite point sets $A = \{a_1, ..., a_m\}$ and $B = \{b_1, ..., b_n\}$, the Hausdorff distance D_H between these two sets is defined as

$$D_H = \max(d_{AB}, d_{BA})$$

where d_{AB} is the distance from set A to set B expressed as

$$d_{AB} = \max_{a_i \in A}(d_{a_i B})$$

while $d_{a_i B}$ is the distance from point a_i to set B given by

$$d_{a_i B} = \min_{b_j \in B}(d_{a_i b_j})$$

Obviously the Hausdorff distance D_H is the maximum of d_{AB} and d_{BA} which measures the degree of mismatch between two sets A and B.

2.2. The Computation of Hausdorff Distance

In general, image data are derived from a raster device and represented by grid points as pixels. For an edge detected image, the characteristic function of the set A and B can be represented by a binary array $A[i,j]$ and $B[i,j]$ respectively, where the $(i,j)th$ entry in the array is non-zero for the corresponding edge pixel in the given image. Therefore, distance array $D[i,j]$ and $D'[i,j]$ are used to specify for each pixel location (i,j) the distance to the nearest non-zero pixel of A or B respectively, where $D[i,j]$ denotes the distance transform of A and $D'[i,j]$ denotes the distance transform of B. Consequently, the Hausdorff distance as a function of translation can be determined by computing the pointwise maximum of all the translated D and D' array in the form of:

$$F[i,j] = \max(\max_a, \max_b)$$

where

$$\max_a = \max_a D[a_i - i, a_j - j]$$
$$\max_b = \max_b D'[b_i + i, b_j + j]$$

There are many methods of computing a distance transform. It is essential to find an efficient algorithm to convert a binary image to an approximate distance image. The method used in our test was based on the 3-4 DT algorithm proposed by Borgefors[2], where the global operation is simplified to use a local mask (3*3 in our test) to propagate distance values through the array. The traditional implementation of distance transform are based on the detection of edge pixels as image feature points. In order to reduce the number of feature points in image without losing information for distance transform, we propose that the detection of edge points can be replaced by the detection of interesting points associated with a dynamic thresholding selection procedure. Such an operation can be significantly speeded-up by parallel implementation.

3. THE DETECTION OF INTERESTING POINTS

It should be pointed out that the original approach to determine the Hausdorff distance by computing $F[i,j]$ is very time-consuming because it considers every possible translation of the model over the test image by pointwise. Thus techniques to decrease this running time are essential. Huttenlocher *et al* proposed some rules to improve the performance which include ruling out circles, early scan termination and skipping forward. Unlike the conventional matching methods which are based on edge detection for distance transform and blind pointwise comparison, in this paper we propose to reduce the computation burden by introducing interesting points as feature pixels to avoid redundant pointwise comparison and guide the serach for the best matching.

The detection of interesting points is based on the measure of how interesting a point is. *Interesting* here has its own special meanings depending on different applications. In order to reduce the number of points used for matching while still preserving the features of the original image, such points must be distinguishable from immediate neighbours, which excludes points sitting on the same edge. Moravec[4] suggested that a point is considered interesting if it has local maximum of minimal sums of directional variances. For a local window ranging from 4*4 to 8*8, the directional variances can be expressed as

$$I_1 = \sum_{i,j} (I(i,j) - I(i,j+1))^2$$
$$I_2 = \sum_{i,j} (I(i,j) - I(i+1,j))^2$$
$$I_3 = \sum_{i,j} (I(i,j) - I(i+1,j+1))^2$$
$$I_4 = \sum_{i,j} (I(i,j) - I(i+1,j-1))^2$$

where (i,j) represents the elements in the window. The interestingness of a point is then given by

$$I(i,j) = \min(I_1, I_2, I_3, I_4).$$

Thus a point whose local maximum is over a pre-set threshold will be considered good as an interesting point, where the pre-set threshold can be chosen based on the image histogram. In our test, the threshold is determined dynamically for optimal performance based on the interestingness histogram of the filtered image after Moravec operation.

4. THE PARALLEL IMPLEMENTATION

Image matching, when used for practical applications, requires considerable computational resources in order to execute a reasonable time. Typically these would be supplied by fast supercomputers or by special-purpose fine-grained parallel processors. However these approaches are expensive. The emergence of general-purpose distributed systems, consisting of relatively modest computers communicating via networks, promises the ability to perform the image matching task at considerably less cost. The innovation of this paper is to introduce some techniques used in distributed systems for the parallel implementation of the proposed hierarchical image matching scheme. A divide-and-conquer policy is adopted in such a scheme, where a complex task is divided into a number of sub-tasks and each of them is assigned to a computer (processor) for simultaneous implementation. More specifically, execution time can be reduced by utilizing distributed processors to perform multiple matching tasks in parallel. In our initial test stage, both data parallelism and functional parallelism was applied to the detection of interesting points, where the calculation of I_1, I_2, I_3 and I_4 within a local window was performed simultaneously while the whole image was divided into sub-regions for the same operation. Due to the nature of parallel processing used in this scheme, the speedup is achieved by introducing remote procedure call(RPC) to share information between different processors. The parallel detection of interesting points based on Moravec operator involves two procedures – servers and client. Figure 1 shows the system structure between server and client.

The operation for each server can be summarized as below:

- registers with its local name server
- sits and waits for RPC call
- performs Moravec operation when calls received and sends reply on completion

On the other hand, the client is the master which controls the parallelism in the following way:

- reads in original image data
- divides the image into sub-regions with some pixel overlap essential for data parallelism
- calls the four servers to perform Moravec operation
- receives replies from the servers
- combines the results to obtain the final image with detected interesting points

It should be emphasized that the RPC mechanism provides function-call semantics for local or remote interprocess communication which enables us to write application programs consisting of a set of procedures that do not all reside on a single computer but on different computers. Therefore, resources available to an application are no longer limited to a single computer and computing power can be added incrementally to the system.

5. THE EXPERIMENTAL RESULTS

Our initial test results shown in Figure 2 confirms that interesting points reduce the redundant image feature pixels for efficient matching by eliminating simple edge points which have no variance in the direction of the edge. Figure 2(a) is the original aerial image of size $256 * 256$, Figure 2(b) shows edge pixels after DRF edge detection, and Figure 2(c) and 2(d) are interesting points at two different threshold values by means of Moravec operator.

The performance of both sequential and parallel detection of interesting points based on Moravec operator is compared as well. Table 1 lists the performance evaluation in terms of the average execution time on different images with various sizes ranging from 128*128 to 512*512.

Table 1: The comparison of execution time

image size	execution time (in sequential)	execution time (in parallel)
128*128	1.53 sec.	1.15 sec.
256*256	7.24 sec.	5.23 sec.
512*512	26.34 sec.	19.11 sec.

Our test data shows that the processing speed is increased by parallel detecting interesting points to remove redundant edge pixels without any specific architecture requirement for parallelism. It is clear that the speedup will be more effective when the image size is larger, the algorithm is more complicated and more processors are used for the parallel implementation.

6. CONCLUSION

The Hausdorff distance provides the powerful basis for image matching including aerial images as it is tolerant of perturbations in the locations of points. The conventional matching process with blind pointwise comparison in terms of Hausdorff distance is simplified and extended by introducing the use of interesting points to guide the search for the best fit between two image sets. The number of image feature pixels can be reduced without losing information for distance transform by detecting interesting points via an adaptive threshold selection procedure. The calculation burden can be further reduced by means of RPC for parallel implementation while no dedicated software and hardware architectures are required. When fully developed, the RPC mechanism for local or remote interprocess communication can be applied to various areas in image processing by sharing and transferring information on different machines for fast processing even in a heterogeneous system. Thus a guided image matching system can be established by the hierarchical detection of interesting points for the matching measurement.

7. REFERENCES

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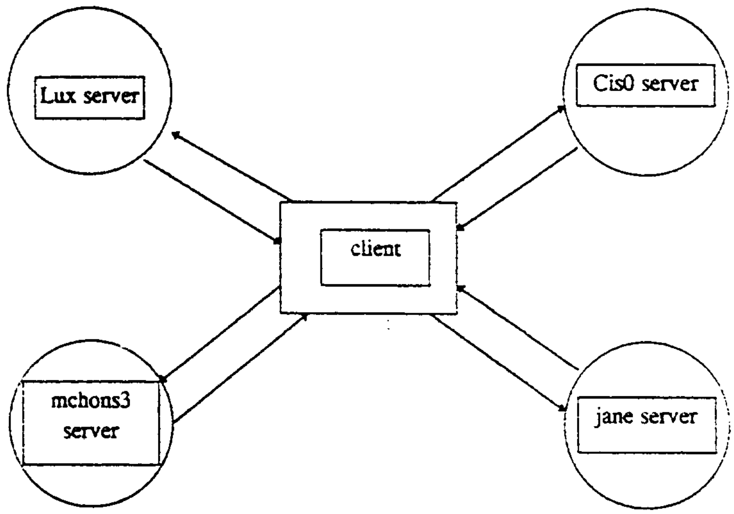
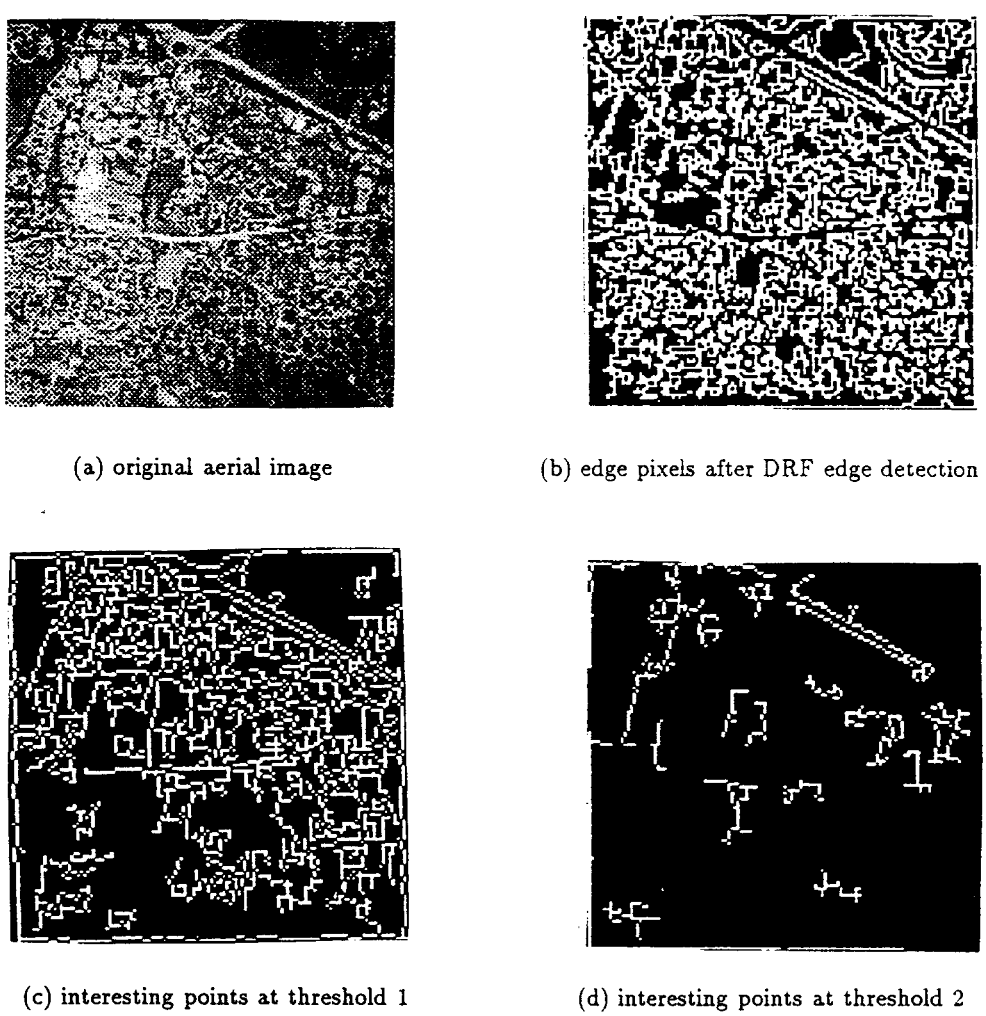


Fig. 1: The communication structure between client and servers during RPC calls



(a) original aerial image

(b) edge pixels after DRF edge detection

(c) interesting points at threshold 1

(d) interesting points at threshold 2

Fig. 2: The comparison of edge pixels and interesting points