A New Method of Rotation, Scale and Translation Invariant Point Pattern Matching Applied to the Target Acquisition and Guiding of an Automatic Telescope

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Abstract: *There are many applications in the field of computer vision for a technique that can be used to find a matching set of points in two separate point patterns. One such application is the automatic telescope, where the telescope image can be compared to a finder chart in order to acquire or track a particular star. The problem of matching the CCD image from a telescope with a star finder chart reduces to that of matching two point patterns. With this in mind a new point pattern matching technique has been developed. In order to develop a technique which was rotation, scale and translation invariant, features were extracted from the point patterns which are independent of orientation, scale and position. This paper describes this new technique for point pattern matching and shows how the technique will be applied to an automatic photoelectric telescope which is currently under development at the South African Astronomical Observatory.*

I. Introduction

Image processing techniques have been in use in astronomical observation for some time for the enhancement and analysis of telescope images. However, with the increasing intelligence required of new automatic telescopes, new applications for these techniques have surfaced. In particular, computer vision techniques have recently been proposed for use in software controlled star acquisition and tracking as a less costly, but more reliable alternative to using telescopes with very high pointing accuracies [1,2,3,4].

An intelligent automatic photoelectric telescope (APT) is being developed at the South African Astronomical Observatory [5]. This APT will be different from similar systems that are presently in use in that it will be able to operate for long periods of time without human intervention. It will have built in intelligence which will allow it to make decisions based on weather conditions, time of the year and the lunar cycle. It will prioritize the observation of different stars and will have separate programs for the observation of different stellar events. In addition, acquisition and tracking of target stars will be completely automatic.

The subject of this paper is the subsystem that controls the position of the telescope, and in particular a new point pattern matching algorithm which is central to its operation.

Recent work in point pattern matching has yielded a number of different techniques. Techniques currently in use [1,6,7] were evaluated and found to be unsuitable. Other new rotation, scale and translation invariant techniques [8,9,10,11] are still to be compared to the technique presented in this paper on the basis of capability, performance and flexibility.

II. Automatic Star Acquisition and Tracking

Computer vision techniques are to control the guiding of the telescope. That is: the acquisition of a particular star in the center of the telescope aperture and its subsequent tracking.

With an ordinary telescope this is done as follows: The operator sets the telescope to point at the target star. The telescope then moves to this position, but does not have enough pointing accuracy to center the target in its aperture. The operator then consults star charts and manually positions the telescope to center the target in the aperture. This process has to be repeated during the observation session in order to track the star.

In the automatic system the operator is replaced by a charge coupled device (CCD) camera, support hardware and a computer. The same procedure is followed as described above, but the CCD camera is the 'eyes' of the system and the image is compared to electronic star charts which are stored in computer memory. Figure 1 shows a simplified schematic of the CCD image capture.

A thermoelectrically cooled CCD camera is used to capture the area of the sky seen by the telescope. This image is sent to the telescope control computer along a fibre optic link. Transputers are used to control the high speed communication between the computer and the telescope. A transputer card in one of the expansion slots of the computer loads the image into the memory of a VGA adapter in the computer via a DMA transfer. This image has an 8 bit pixel depth.

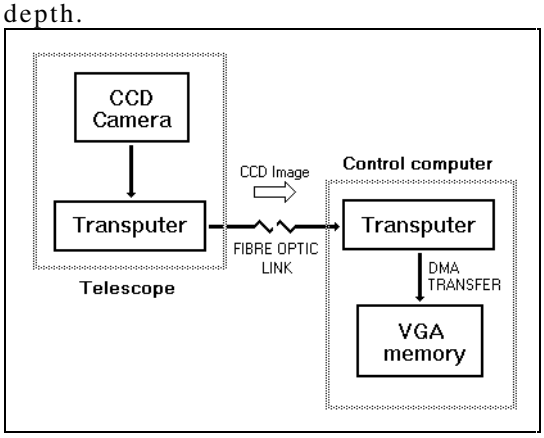

Figure 1:CCD image capture.

The software processing begins by setting all the pixel values below a threshold value to zero intensity. Region growing is then used to find all the objects in the image. The radius, centroid and average intensity of each object is stored. Stellar objects are found by filtering out objects that fall within a preset range of size and intensity. The result is a set of points that represent stars in the original image.

Point pattern matching is used to find a matching subset of points that is common to the CCD image and the finder chart of the target star. The offset for the correct telescope position is calculated using the transformation parameters between the point patterns, and the appropriate motor control commands are sent to the telescope. Figure 2 is a block diagram of the image processing software.

III. Point Pattern Matching

A new point pattern matching technique was developed for comparing the point pattern of stars found in the CCD image with the star chart. This technique is rotation, scale and translation invariant.

An important property of the technique is that it detects the largest matching subset of points in the two point patterns. This is necessary because not all of the stars in the star chart will be in the telescope image, and the telescope image may have additional stars, noise and other non-stellar objects that were not eliminated by previous processing.

The fact that the technique is unaffected by additional or missing points and rotation, scale or translation differences between the point patterns makes the preparation of the computer star charts more convenient. Charts created for a different telescope, or the star charts available on CD-ROM can be automatically converted to the required format.

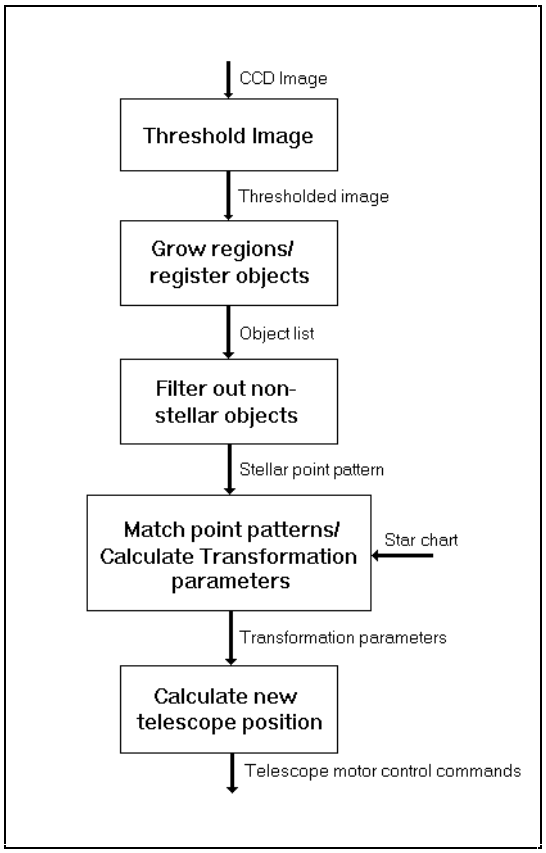

Figure 2: Image processing block diagram.

The technique can allow for perturbations in the positions of the points. There is a tradeoff between the size of the perturbations that can be allowed for and the number of points that can be matched.

The point pattern matching algorithm

Features that are rotation, scale and translation invariant are extracted from the point patterns. These features are the interior angles of every triangle that can be formed by the points in the pattern. It is believed that the angle information of these triangles completely and uniquely characterizes the point pattern. The point patterns are expressed in terms of these angles and compared to each other. Because the angles in the triangles are not affected by rotation, scaling or translation, the matching technique is independent of these properties.

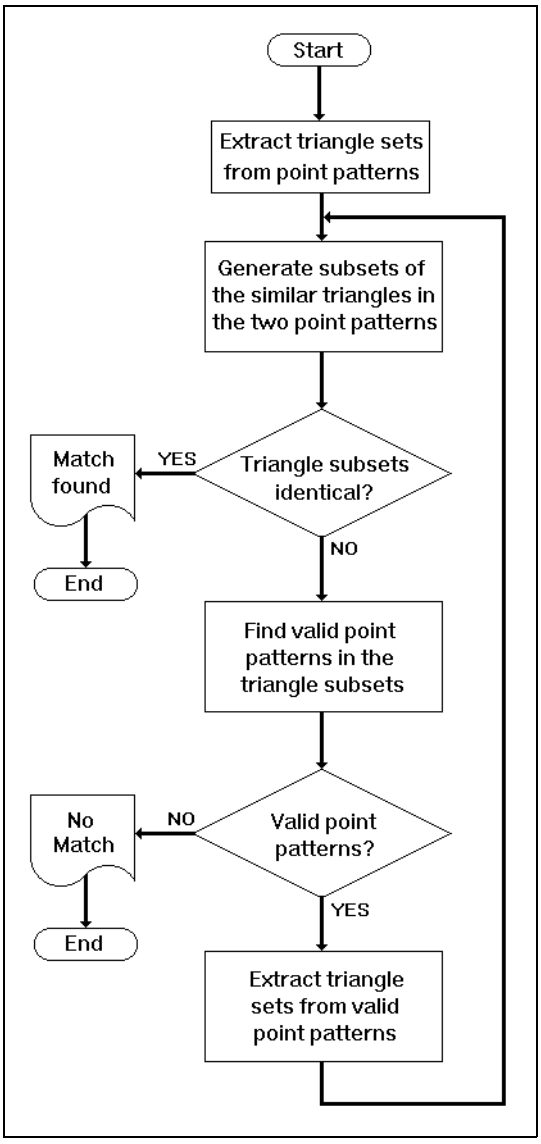

Figure 3: Point pattern matching flow diagram.

The matching process begins by calculating the sizes of the interior angles of all the triangles formed by each point pattern. These sets of triangles are compared, and any class of triangle that only appears in one of the patterns is discarded. Both of the remaining subsets of triangles are searched for a valid point pattern. If both of the triangle subsets have valid point patterns, the process begins again with these new point patterns. If either of the triangle subsets does not contain a valid point pattern, the process is aborted with matching unsuccessful. A match is found when the triangle sets of the point patterns are

identical. Figure 3 is a flow diagram of this algorithm.

The transformation parameters (rotation, scale and translation) between the two point patterns can be found by calculating these parameters for two corresponding triangles in the two patterns.

Comparing triangle sets: The Triangle Accumulator

Only two of the angles of a triangle are necessary to characterize that triangle completely. The triangle accumulator uses this fact to facilitate comparison of the triangle sets of two point patterns. It consists of a two dimensional array of values that is indexed by the smallest and largest angles of the triangles.

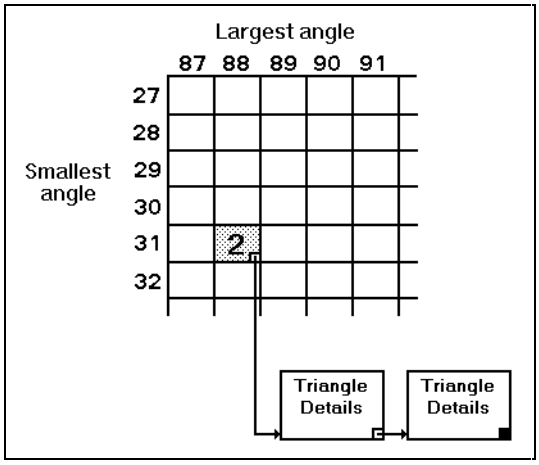

Figure 4: The Triangle Accumulator data structure.

The number of triangles with a particular set of angles in a point pattern can be found by examining the value in the appropriate accumulator cell. That is: A cell in the accumulator array contains the number of triangles in the point pattern with a particular smallest and largest angle. Each accumulator cell also specifies the points forming the vertices of each triangle. Figure 4 shows an implementation of a data structure for the triangle accumulator.

Note that if the smallest/largest angle coordinates are plotted on a Cartesian plane then they will be bounded by the following lines:

$$L + 2S = 180$$
$$2L + S = 180$$
$$S = 0$$

Where S and L are the smallest and largest angles of a triangle respectively. In order to make efficient use of the accumulator array these coordinates can be mapped to a rectangle on a different plane before they are stored in a discrete array. Figure 5 illustrates this transformation.

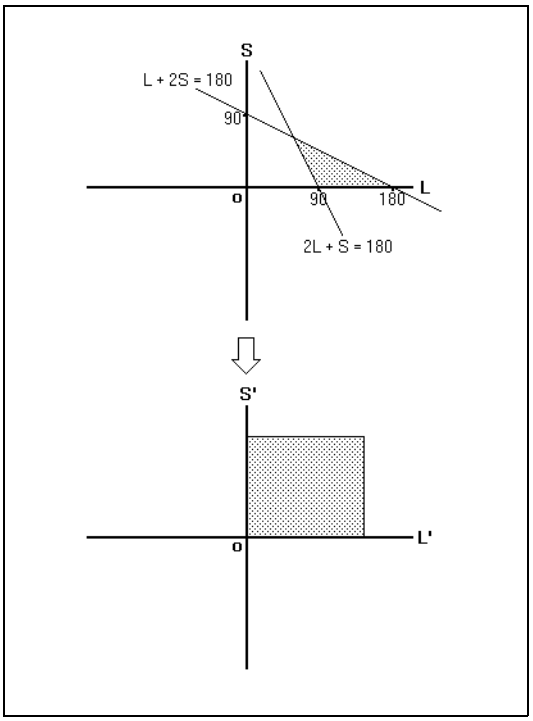

Figure 5: Transformation to make more efficient use of the Triangle Accumulator. The shaded area represents valid (largest,smallest) angle coordinates.

Finding valid point patterns: The Vertex Counter

Finding valid point patterns in the vertices of the triangles in the triangle subset is facilitated by the Vertex Counter. This data structure consists of a list which contains an entry for each point in the original point pattern. Each entry in the list contains the number of times a particular point is represented as a vertex in the triangle subset, and details of the other vertices in each of these triangles.

In the discussion that follows the notation $({}^{a}_{b})$ is used to indicate the

statistical combination function. That is: $\binom{a}{b} = a!/(b!(a-b)!)$

The vertex counter is used to find whether a valid point pattern with a particular number of points N is possible with a given set of triangles. The list is searched for points which cannot possibly be part of a valid point pattern of size N. Such a point would be represented by less than $\binom{N-1}{2}$. triangles, since in an N point point pattern each point is a vertex in $\binom{N-1}{2}$ different triangles. These invalid points and the triangles they belong to are discarded. This in turn affects the points in the list that were the other two vertices in discarded triangles, and their entries are adjusted accordingly.

This process is repeated until there are either no points (no valid point pattern), or N or more points remaining. The latter case indicates that these remaining points in the vertex counter are a valid point pattern of size N or greater. The case of multiple separate patterns with N points is ignored here.

This process can be extended to find a valid point pattern with an unknown number of points. The points discarded while searching for a pattern with N points would also be discarded when searching for a pattern with N+1 points. Therefore by searching first for the smallest expected point pattern, and incrementing N and searching again each time more than N points are remaining, the largest valid point pattern will be found. This will be when N points are remaining, each represented $\binom{N-1}{2}$ times in the vertex counter.

Point pattern matching in three dimensions

This point pattern matching technique could be extended to three dimensions. As such it could be used for matching or recognition of three dimensional objects, where the vertices have been represented by points in three dimensional space.

IV. Results

Figure 6 shows an example of a matching subset of points that was found in two point patterns using the technique described here. A program was written which accepted as input two lists of points and their coordinates. The test shown was performed with two point patterns generated as follows: The first pattern was created by randomly generating twenty points. Fifteen of the points in this pattern were then duplicated and the resulting second pattern was shifted, rotated and scaled. Five more points were generated randomly and added to the second point pattern. The entire matching process took less than one second on a computer based on the Intel 33Mhz 80386 and 80387 processors, using the MS-DOS 5.0 operating system.

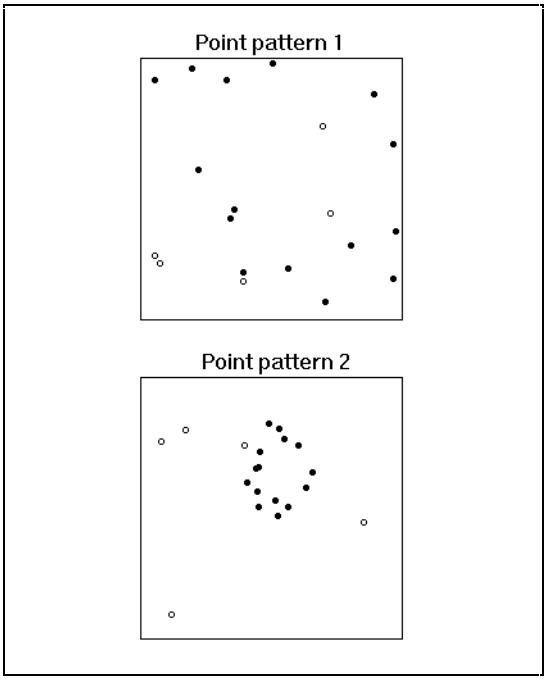

Figure 6: The point pattern matching technique demonstrated. The points belonging to the matching subset are solid and the remaining points are hollow.

The effect of random perturbations in the positions of the points in the patterns can be dealt with by reducing the precision of the triangle accumulator array. However, this will reduce the number of points that can be matched. For example: With an increment of five degrees on the smallest/largest angle

indices the maximum number of points in each point pattern, where 75 percent of the points were in the matching pattern, is about fourteen.

V. Conclusions

The point pattern matching technique described in this paper satisfies the requirements as the means of comparing a processed CCD image to a star finder chart when acquiring a particular star in the center of the telescope aperture.

This rotation, scale and translation invariant technique can find the matching subset of points in two point patterns, despite noise and small random perturbations in the positions of the points.

The technique could also be extended to match point patterns in three dimensions.

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