FAST LOCATION OF ROTATED OBJECTS

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ABSTRACT
Machine Vision Applications such as robotic assembly require rapid location of objects of unknown position, scale and rotation. This investigation is part of a systematic study of coarse to fine methods where the mismatch notch width is exploited to guide the coarse-fine search strategy and reduce matching calculations by a large factor. A multi-template matched filter method is used in which a series of templates covers a 100 degree range of rotation. The speed-up methods use a coarse/fine search, a sparse grid technique and a finite template rotational step technique to speed up the location of the image object rotational position. The extent to which these coarse-fine methods can be combined to achieve very large speed-ups is discussed.

INTRODUCTION

In flexible manufacturing, robotic systems that can locate objects of unknown rotational aspect quickly are essential. Previous papers have covered speed-up methods for location of objects of unknown position and scale in grey level and binary images. The methods of speeding up these operations discussed here are a coarse/fine search, a sparse grid technique and a minimal set of templates spaced at different rotational aspects based on a knowledge of the image object rotation versus matching error function. The relationship between matching error and rotational mismatch is investigated for the image object and the matching error versus rotation results are shown. From a knowledge of this function the maximum rotational step in degrees between templates can be found. Search time is clearly dependent on the number of templates required and therefore reduction in this number is of fundamental importance to fast location of image objects. This paper is one of a series which discusses coarse fine and sparse template speed-up methods for location of objects of unknown position and rotation. Results are given for the relationship between matching error and rotational mismatch for the image object allowing the maximum rotational step between templates to be used.

BASIC OBJECT LOCATION STRATEGY

A template of the object is traversed over the image and is deemed to be found if the template image mismatch function is below a certain threshold. For objects of unknown rotation, after evaluation of the matching error versus rotational position function, a decision may be made regarding the rotational step size and a series of template candidates calculated using standard graphical techniques starting with an unrotated template and rotating it in finite steps as discussed earlier. Image rotation is essentially a process of calculating the polar co-ordinates of the data point(s) to be rotated and then adding the weighted sum of the nearest neighbour data values, up to four in all to produce the rotated grey scale value. A rough rotated template may be formed by using integer values only. In this study, a weighted sum of two pixel values was used to reduce the calculation burden. The rotated templates are then translated over the image and the matching error calculated at each image position. The minimum error is stored after each complete search. Candidates are selected one after another to find which template gives the minimum error.

SPEED-UP LOCATION TECHNIQUES

Although we minimise the number of rotated candidates, the above strategy is basic and very slow, consuming large amounts of computational effort. Sparse templates reduce very significantly the computational effort required. A sub-grid of pixel points on rotated each candidate model may be used. These sparse templates may be, for example at every second row and column position giving a factor of four reduction in computation for each template. Depending on image noise and geometric distortion effects, this method may be extended to quite large sub-grids,

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a further combined speed-up factor of 4 for the coarse-fine search strategy

RESULTS

Unknown Rotation Results

A series of rotated templates were produced and the mismatch sums against the "correct" rotation calculated. The graphed results for the template mismatch sums at different rotational steps show the relation between the mismatch sum and rotational differences. In these diagrams, a matching calculation was made at every column position, ie a fine positional search The column for the correct match was column 100. This point shows up very clearly on the zero degrees mismatch graph.

ZERO ROTATION COARSE-FINE SEARCH RESULTS

Results for an unrotated template, ie a template at the correct rotational position are shown following. Coarse fine positional searches for the template taken from pebbles, shown on the diagram page, gave the results shown in the right hand table. The graphs shows a plot of the Chebyshev matching function, ie the sum of the absolute differences versus the image column number for the correct row number, namely the row where the template was actually found.

SPARSE TEMPLATE RESULTS

These results are given in the lower table. As discussed, image search times may be reduced by speeding up the mismatch calculation by a template/image sub-sampling method. For this test, a full search was made for all sets of results. Results are as expected, with search times dropping rapidly with greater and greater sub-sampling.

Table 1.
Sparse Template Results

Row,column spacing	search time seconds
1	25.05
2	6.70
3	3.19
4	2.03
8	0.74
10	0.61
16	0.32

For the key 256x256 image and 141x141 rotated key model, the above results were obtained:-

Table 2.
Coarse Fine Column Results

Column step pixels	search time seconds
1	24.99
2	12.63
3	9.11
4	6.98
5	6.04
6	5.22
7	4.53
8	3.83
9	3.96

Column step template results were for an exhaustive column and row search. Coarse/Fine column results were for a single row search at all template points.

Table 3
Combined Speed-Up Factors

Row, col spacing pixels	Coarse step pixels	Time seconds
1	1	25.01
2	2	3.52
4	2	1.10
8	2	0.44
8	4	0.24
10	4	0.18
16	5	0.11

DISCUSSION

Rotational Speed-ups

The graph of template object rotation versus mismatch shows that the mismatch function extends over a range of many degrees above and below the "correct" rotation. This information may be used to reduce the number of rotated templates required to cover one rotation, assuming no a priori knowledge of rotational limits. This also depends on the number of objects to be found. For only one object type, a minimal set of templates may be used. If two similar objects are to differentiated, further templates between the two minimal error templates may be required. By using sparse templates, the computational burden in say every sixteenth row and column giving a 16x16 sub-grid for a noise free image. Such a sub-grid would give a speed-up factor of 256 times.

COARSE-FINE COLUMN SEARCH

Computational effort may also be reduced by calculating the matching error sum at less than each image position. If the error sum could be calculated at every third column position for example a speed-up of three could be achieved. This can be achieved by monitoring the matching error and only conducting an exhaustive search, ie at every row when a significant reduction in matching error occurs.

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Coarse-fine Row Search

The principles of the coarse-fine column search can also be used to reduce the number of fruitless row searches by monitoring the inter-row error and using this measure to determine whether a coarse row search may be continued or if an exhaustive row by row search is required.

COMBINED SPEED-UP STRATEGY

By combining the speed-up techniques discussed previously for each template, very large speed-up factors can be obtained on noise-free data. Even on noisy images these techniques may be applied to give significant speed-ups. By using the sparse template technique and coarse-fine search together, speed-up factors of over a thousand for each template may be obtained using a 16x16 sparse grid and a coarse column and row step of three. Table 3 shows some of the results obtained with combined speed-up factors.

COARSE-FINE SEARCH WITH BACK-TRACKING

By allowing the search to reverse in direction, it is possible to approach the null from the far side nominally doubling of coarse step size for the row and column coarse search. This addition gives a 2 to 1 speed up in search time. By using sparse templates the time spent generating these template models may be greatly reduced. The coarse-fine row and column step technique gave good speed-up factors which could be doubled by allowing the search direction to be reversed allowing a match to be made from the far side of the null.

Combined Speed-up Factors

Table 3, showing combined speed-up factors shows the very large gains that can be made by combined speed-up methods. While these results were for an un-rotated template, results for a template at 5 degrees of mismatch still showed that the minimum was correctly identified.

Template Generation Speed-up.

By only generating sparse templates ie templates with non-zero pixel values at every second x,y position for example, template generation times are cut by a factor of four. With an 8x8 sparse grid, generation times are cut by a factor of 64. This means that only the corresponding sparse template spacing or a multiple can be used for matching calculations. It is important to note that in this work, templates were cut from the image containing the object and then rotated over a series of angles for investigative purposes.

CONCLUSION

Rotation Template Speed-ups

For each rotated template, two classes of recognition speed-up methods, known as a coarse fine search method and a sparse template techniques have been applied for a grey scale image with a template rotated over a 100 degree range. The methods apply at any degree of rotation but results were restricted to this range for convenience. For pebbles, the textured image, the matching effect extends well beyond 5 degrees above and below the nominal image rotation. These results show that finite steps of at least 5 degrees may be used for template rotation steps for rotated object searches for images of a certain texture, giving a 5:1 reduction in computation over steps of say, one degree in template rotation. For the room key image object, similar results are evident from the rotated key versus error results.

Template Speed-ups

For each rotated template, two classes of recognition speed-up methods, known as a coarse fine search method and a sparse template techniques have been applied For each template, the tabulated results given in this paper show that these methods give at least a 40 times sparse template speed up and a 5 to 1 coarse-fine column speed up for each template. Coarse to fine row search results gave a 4:1 speed-up factor. Using a 16x16 sparse template as well, each template search is speeded up by a factor of 1000 Rosenfeld and Vandenberg have used a block average template method [5] for a reduced search but their method requires the computation of image block averages which this method does not. These results are for noise-free images and templates. Practical cases, with appreciable noise will show reduced speed-up factors.

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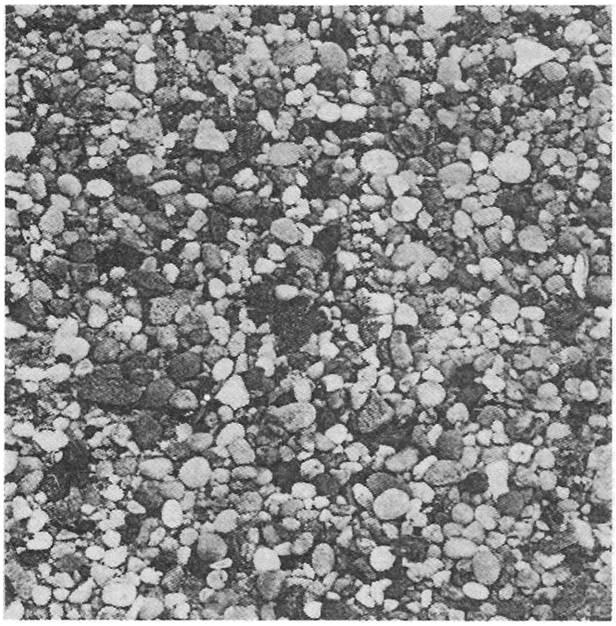

Fig 1. Pebbles Image.

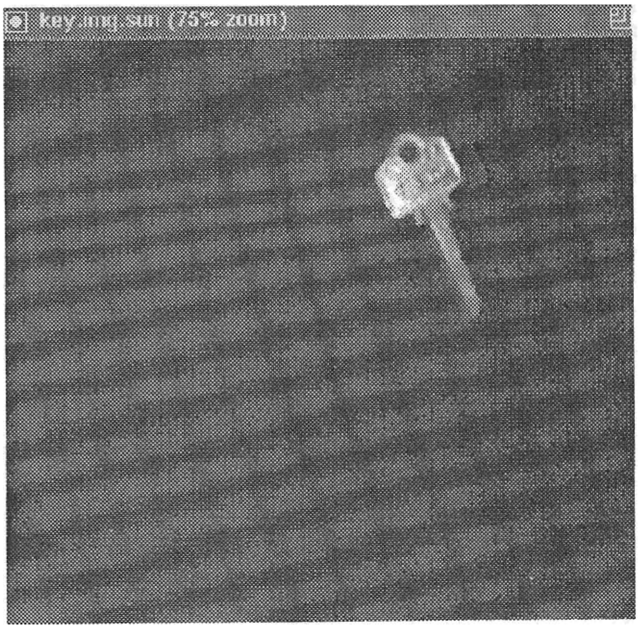

Fig 3 Key Image

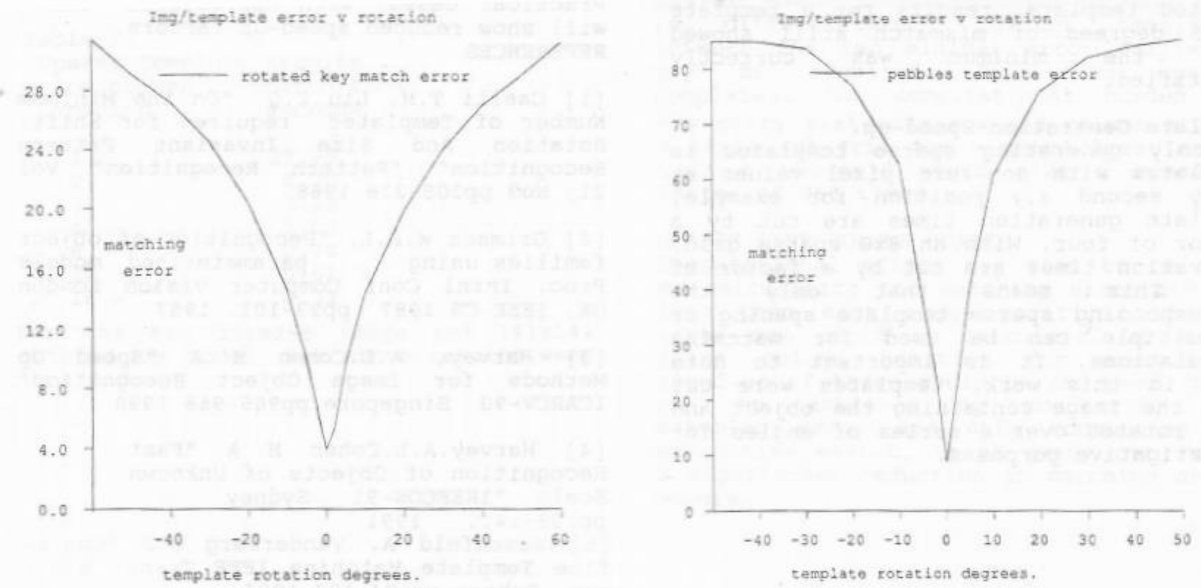

Fig. 3,6 Matching error versus template rotation

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