ABSTRACT
In Vision guided robotic operations, the rapid location and identification of image objects for assembly is essential. The image object data taken with a ccd camera may be in the form of a grey level, binary or colour image. This paper discusses our work on new speed up methods for object recognition in binary and grey level images. These are a coarse/fine stepping method and a sparse template technique. An extension of the coarse fine technique to give larger speedups is discussed.

INTRODUCTION
Searches for objects within images are extremely computationally expensive when scale, position and orientation of objects within the image is unknown. This paper reports results of a comprehensive coarse-fine object location program in which the criteria for coarse to fine switching have been investigated. These methods can speed up the column and row position search by a factor of 64. A matching error function is used to switch between coarse and fine search modes. Also a sparse template technique is used to give a further 64 fold speed up even more a for larger templates. This paper reports position search speed up times obtained on a number plate reading project. This work is of importance in vision guided assembly operations where machine vision techniques are used for locating parts and was first applied to a vehicle number plate location system.

COARSE FINE COLUMN SEARCH
By applying a reduced column search technique to object location in an image, a large reduction in computation may be made. A basic approach is to move the template over the faster scan image, computing the mismatch function at each pixel location. Clearly if the matching calculations could be made at a reduced number of locations, ie a coarse search at say every fourth or fifth, pixel then a large speed up in the matching operation could be made. If a check is made by comparing the current matching error with the error calculation at the previous pixel position, then a decision can be made to move along say four or more columns, if the error is not moving towards a match. Alternatively, if the matching error is decreasing rapidly, from A to C in Fig 5, then the template pixel array will be moved along column by column after each calculation. Investigations showed that the template map may be moved along six columns for the coarse search and still find the matching position. A five to one speed up was obtained in this way. It is important to note that speedup factors are image dependent.

APPLICATION TO OBJECTS OF VARYING SCALE
If a plot is made of matching error versus image size or scale a finite correlation region typically of the order of 10 pixels will be found for all but completely random images. On the diagrams page, diagrams two and three 2 and 3 on the last page of the paper for the pebbles image. This result indicates that a finite set of templates may be used to find the object of unknown scale by making coarse steps in the template scale to form a finite template library. Again it is not necessary to perform a matching calculation over the entire template and sparse template techniques can also be used to reduce the number of matching calculations for each template. Sparse template techniques may also be used to reduce the calculation burden for each template. The number of competing template candidates in the image will also influence the template scale step required to differentiate between the template objects. Also see reference 5.
OBJECTS OF VARYING ROTATION
Of all the image processing geometric operations, image rotation is one of the most computationally expensive. The plot of matching error versus image rotation at a fixed location will again produce a finite correlation notch of the order of 10 pixels or so. This correlation region will be finite for all but random images. See the diagram below for the pebbles image. This result indicates that a finite set of templates may be used to find the object of unknown rotation by making coarse steps in the template angle to form a finite template library. Again it is not necessary to perform a matching calculation over the entire template and sparse template techniques can also be used to reduce the number of matching calculations for each template. Sparse template techniques may also be used to reduce the calculation burden for each template. Again the number of competing template candidates in the image will influence the template rotation step required to differentiate between the template objects. A paper covering this aspect will be presented at ICIP-92 in Singapore. See reference [5].

BINARY IMAGES
If the brightness of corresponding points of the image and the model or template differ, due to changes in illumination for example, then the matching error will not drop to zero even when the template is correctly positioned. To reduce this problem, images may be thresholded to black and white, ie a binary image. The grey level threshold may be chosen globally or by calculation of a local measure. As a large amount of information is thrown away by thresholding, it can be expected that the scope of the speed up techniques will not be as great with binary images. However, significant speed up factors are still attainable. The use of weighted templates has been investigated for binary images. The results show that greater discrimination and hence greater speedups are attainable using suitable weighting factors.

RESULTS
Sparse Template results for a template object of correct scale are given in the left hand 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 at all image column/row locations. Results are entirely predictable, with search times dropping rapidly with greater and greater sample spacing. Coarse/Fine Row Search results below illustrate the speed up factors obtained by varying the coarse row step for a template of correct scale but unknown position. Coarse fine positional searches for the template taken from pebbles, shown on diagram four, gave the results shown in the right hand table. The graphs shows a plot of the Chebyshev matching function, the sum of the absolute differences versus the image column number for the correct row number, ie the row number where the template was actually found.

<table>
<thead>
<tr>
<th>Sparse Template Results</th>
<th>Coarse Fine Column Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>row, column spacing</td>
<td>search time</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.31</td>
</tr>
<tr>
<td>2</td>
<td>3.57</td>
</tr>
<tr>
<td>4</td>
<td>11.64</td>
</tr>
<tr>
<td>8</td>
<td>22.1</td>
</tr>
</tbody>
</table>

Sparse template results were for an exhaustive column and row search. Coarse/Fine results were for a five row search and all template points.

Varying Scale Results
The graph in diagram 6 for error versus varying scale shows the effect on the mismatch dip of scale errors. Scales gives are size information, so that 50% scale is actually .25% of the area. This diagram shows that a finite set of templates may be used for objects of varying scale and the object found reliably. If there are a large number of possible object candidates, the template scale step must be reduced in order to give greater discrimination. Sparse template techniques may be used in the preparation of the images to speed template preparation.

CONCLUSION
Two recognition speedup methods, known as a coarse fine search method and a sparse template technique have been proposed and tested for grey scale and binary images. Tabulated results given in this paper show that methods give up to a 64 times coarse/fine search speed _ factor and a similar speed up for the sparse template method for grey scale image translation searches. For binary images, translation searches can give at least a 16 fold: sparse template and a 4 to 1 coarse-fine column speed respectively. The coarse-fine row search was not reliable for coarser templates. Rosenfeld and Vandenberg have used a block average template method [10] but their method requires the computation of image block averages which this method does not. This study has shown the significance of the width of the dip in the mismatch function in coarse-fine template matching. In particular, for a direct switch from coarse to fine search the coarse step size must be less than half the mismatch notch width. Using the extended coarse-fine strategy which uses back-tracking, the coarse step may be doubled to slightly less than the full notch width. While this paper covers translation and scale object searches, these methods will speed up of orientation searches as well. This work was first used in a vehicle number plate location investigation but has also been used for natural scenes involving textured images. These methods will still work is the presence of noise with some reduction in speed ups depending on the signal to noise ratio.

REFERENCES
Figure 1 Car Image

Figure 2 Fine search. Car image template matching error Line 90.

Figure 3 Coarse fine search Car image. Line 90.

Figure 4 Beach pebbles.

Figure 5 Proposed sequence of search for the coarse fine search technique.

Figure 6 Minimum error v scale