A SIMPLE TECHNIQUE TO DETECT SURFACE DEFECTS BY INCORPORATING ROTATION-INVARIANCE IN A PATTERN MATCHING ALGORITHM

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Abstract An algorithm is presented here that empowers the simple template matching technique with the property of rotation invariance to make it suitable for detection of surface defects in products of both asymmetric and symmetric shape. The technique incorporating the algorithm can use the visual feedback into various robotic performances to achieve more flexible, adaptable and intelligent system under realistic, compact and robust aspect, with the help of a high performance computer and CCD camera. The algorithm tackles the problem of camera mounted on a stand to grab the image from the unstructured environment of products kept on conveyer belt in an assembly line and compares with the video data stored in CPU. After satisfactory matching, a robot is expected to utilize this information for performing various tasks as per requirement. Experimental results are included. Automating vision guidance is an issue of current interest in the context of flexible e-manufacturing, green manufacturing and efficient robot-operation. Our work is expected to assume additional importance as an effective tool against this backdrop.

Keywords: Multiple Template Matching, Correlation Coefficient, Hierarchical Search, Resolution Pyramid

INTRODUCTION

This paper presents a controlled, efficient algorithm used to automate vision guidance elegantly for the specific task of detecting surface defects in products of both symmetric and asymmetric shapes, finished and placed on the conveyer belt. Different algorithms and techniques have been reported in open literature [Fahantidis et al., 1997, Li and Lee, 1996, Cheng and Penkar 1995] on this. Here we present an algorithm based on the template matching technique, which is controlled, efficient and robust. While template matching inherently incorporates the property of translation invariance, we have developed, provided and tested the property of rotation –invariance in the context of pattern matching.

HARDWARE CONSIDERATION

This system uses a pair of CCD camera mounted, on stands and focused on the objects (including the defective ones) kept on a conveyor belt. The images obtained from the camera pair help in stereo vision, which can be used for finding the co –ordinates [Pal et al., 2001] of the defective objects for a possible robo pick –up and place kind of a job. But the present endeavor concentrates on grabbing the image and storing it in the CPU through the vision –card and the parallel port as described in Fig. 1.

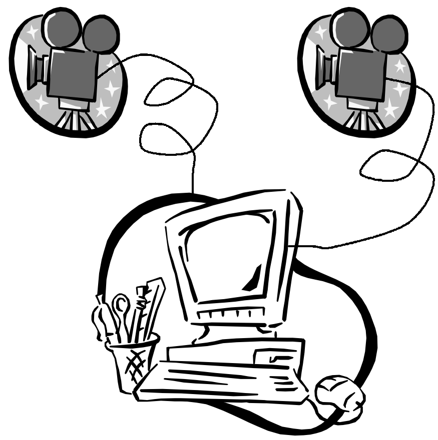

Fig. 1 CCD –Camera –Computer Section

For the kind of use planned in this text a Pentium III-PC with ~500 MHz clock speed can produce reliable real-time operation of controlling a robot-arm for pick and place job.

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TEMPLATE MATCHING

Fundamentals of Template matching
Template matching is a well-known method of detecting the presence or absence of objects and identifying them in an image. A template is itself an image that contains a feature or an object or a part of a bigger image, and is used to search a given image for the presence or the absence of the contents of the template. This search is carried out [Prasad and Iyengar, 1995, Fukuda et al., 1996] by translating the template systematically pixel-by-pixel all over the image, and at each position of the template the closeness of the template to the area covered by it is measured. The location at which the maximum degree of closeness is achieved is declared to be the location of the object detected. Fig. 2 presents the technique of template matching as applicable in pattern matching domain

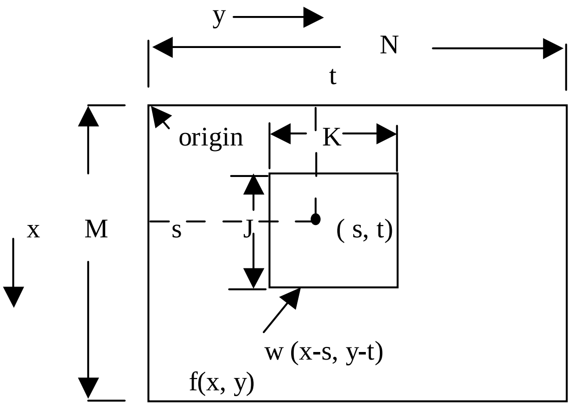

Fig. 2 Correlation of f (x, y) & w (x, y) at point (s, t)

Template matching which is matching by correlation, basically involves computation of correlation coefficient c (s, t) given [Gonalez and Woods, 2000] by

$$c(s, t) = \sum_x \sum_y f(x, y) \times w(x-s, y-t) \qquad \textbf{(1)}$$

where w (x, y) sub image of pixel-size $J \times K$ forms the template to be matched with the image f (x, y) of pixel-size $M \times N$, with s varying from 0 to M-1, t varying from 0 to N-1, J< = M, K< = N and the summation taken over the image range where f and w overlap, as shown in Fig. 2 above.

Normalized Correlation Unfortunately with ordinary correlation the accuracy deteriorates if the image gets uniformly brighter (with the function c (s, t) reaching a maximum when the image becomes completely white) or darker. The result therefore is sensitive to amplitude of f or w. To overcome this difficulty a normalized correlation coefficient r (s, t) defined [Gonzalez and Woods, 2000] by

$$r(s, t) = \sum_x \sum_y [f(x, y) - f'(x, y)] \times [w(x-s, y-t) - w'] \,/\, \{\sum_x \sum_y [f(x, y) - f'(x, y)]^2 \times \sum_x \sum_y [w(x-s, y-t) - w']^2\}^{1/2} \qquad \textbf{(2)}$$

is used, where w' is the average value of the pixels in w(x, y), computed only once, and f' (x, y) is the average value of pixels in f (x, y) in the region coincident with the current location of w, and the summations are taken over the coordinates common to both f and w. The normalized correlation coefficient r now varies between –1 and +1, where 1 indicates exact matching, 0 indicates no correlation and –1 indicates that the similarity is less than that might be expected by chance. In our design we are not interested in negative values and therefore the results are clipped to 0.

The Speed Barrier Additionally, for efficient and fast computation we find r^2 in place of r, in order to avoid the slow square root calculation. Finally the result is converted to a percentage given by

$$\text{Score} = \max(r, 0)^2 \times 100\% \qquad \textbf{(3)}$$

where 100% represents perfect matching. Thus with some of the terms in the normalized correlation function depending only on the model template and therefore needing computation only once, effectively the equation (2) needs computation amounting to two multiplications and three additions per template pixel. But even this for a typically modest application involving a 128×128 pixel template and a 512×512 pixel image, works up to $2 \times 512^2 \times 128^2$ or over 8 billion multiplications, taking over a few minutes of computer time for a typical PC. Clearly an efficient algorithm needs to be faster.

Problem of Template Matching

Rotation-Invariance While speed barrier is an inherent hardware problem and efficient algorithm can improve the situation within the limit of the hardware capabilities, as we shall discuss later, the absence of immunity to the feature of rotation-invariance is the real limitation of the conventional template matching technique that makes it completely unsuitable for recognizing the objects of asymmetric shape.

In the Fig. 3 we explain the problem pictorially. There we see that the template failed to recognize the pattern when the latter was placed with a different orientation with respect to the frame-boundary.

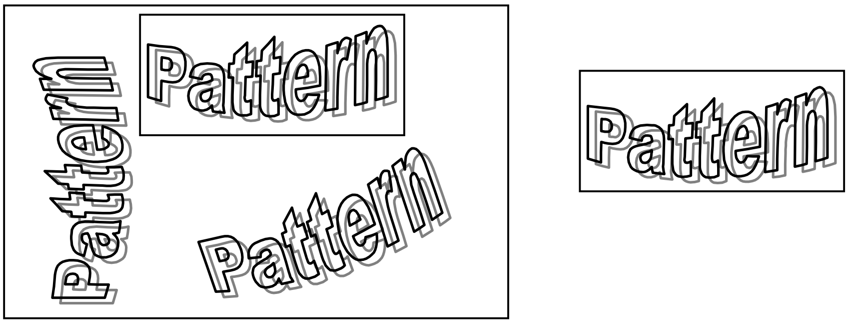

Fig. 3 Absence of Rotation Invariance (the template failed to recognize the rotated 'Pattern's)

Thus while translation invariance was an inherent property of the conventional matching technique as we verified from equations (1) and (2), the absence of rotation-invariance limits its applicability in recognizing asymmetric objects and hence the required robustness lacks.

PROPOSED ALGORITHM

The present endeavor automates following steps:

i. Grabbing an image from a CCD camera
ii. Converting the acquired image to its corresponding grayscale value
iii. Restoring the model into the memory of the computer for using the same as template
iv. Recognizing the presence of the object of interest in images grabbed hence by matching with the template already created in step (iii)
v. Calculating the number and level of matching and declare the result on the screen
vi. Provide rotation invariance to asymmetric objects

while improving speed and incorporating rotation-invariance.

Hierarchical Search to Overcome Speed Barrier

In our algorithm we have applied the method of hierarchical search to reduce the number of multiplications while keeping the reliability reasonably acceptable. The method produces a series of smaller, low-resolution versions of both image and the template. These sub-sampled images are termed resolution pyramid. A typical resolution pyramid is shown in Fig. 4. The search begins on a much-reduced scale. Each level of the pyramid is half the size of the immediate previous one and is produced by applying low-pass filtering before sub sampling. Thus if the resolution of an image or template is 512 $\times$512 at level 0, then at level 1 it is 256 $\times$256, at level 2 it is 128 $\times$128 and so on. The search starts at low resolution to quickly find likely match candidates. It proceeds to higher and higher resolutions to refine the positional accuracy and make sure that the matches found at low resolutions were actually occurrences of the template.

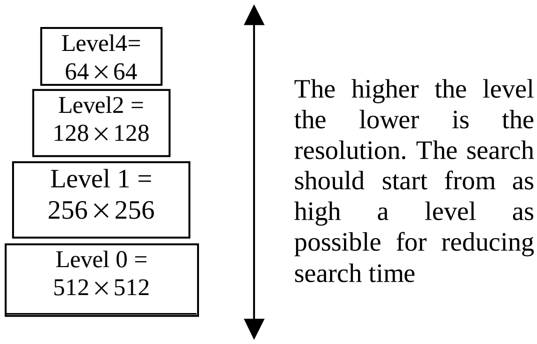

Fig. 4 Resolution Pyramid

Because the position is already known from the previous level to within a pixel or so, the correlation function need be evaluated only at very small number of locations. Since each higher level in the pyramid reduces the number of computations by a factor of 16, it is usually desirable to start at as high a level as possible. However the search algorithm must trade off the reduction in search time against the increased chance of not finding the pattern at very low resolution. In our algorithm we have introduced 4 – level searches.

Even though performed at very low resolution, the initial search accounts for most of the computation time if the correlation is performed at every pixel in the search region. Computing for typical matching applications in production environment using test templates on a Pentium-III PC with ~ 500 MHz CPU clock speed, the search time was found to be 5 m. second which is far less than the earlier search time of a few minutes as indicated above. The actual accuracy that can be obtained depends on several factors including noise and the particular pattern of the template (search time is higher for smaller templates). However if these factors are ignored, the absolute limit on the accuracy imposed by the algorithm itself and by the number of bits used to hold the correlation result, is about 0.025 pixel which is the worst case error measured in X or Y when an image is artificially shifted by fractions of a pixel. In real application accuracy better than 0.05 pixels typically, is achieved in low-noise images.

Rotation Invariance
To circumvent the problem of missing or failing to recognize the objects kept at different orientations we devised the method of matching with multiple templates, where each individual template of the multiple template space is obtained by rotating the first or original template by a definite angle. In other words the templates are rotated versions of the same pattern or image. The angles are so chosen as to cover almost all possible orientations with reasonable resolution levels. Usually for objects like screws, bolts, resistors, IC's of different sizes, we obtained reasonably robust recognition with 18 templates and very robust performance with 36 templates. As we increase the number of templates the robustness increases. Obviously the trade-off is between speed of search (or search-time) and robustness. There is no standard rule for finding what will be the optimum number of templates for a particular image to be recognized for different orientations. The choice more-often-than-not is made heuristically and varies with objects, required resolution level and the like.

Software Considerations
The algorithm for identifying and locating the objects with surface defects was developed using visual C++. Some of the library functions of a special pattern-matching package called Matrox Imaging Library (MIL) [Matrox Imaging Library (Version 6.0) User Guide, 1999] were declared in the main programme and were imported from the package with suitable control and linking instructions. This greatly simplified the programme size and substantially reduced the execution time.

The following steps were executed in the programme:

- Allocation of MIL application default **// *this links up with the MIL library and makes the functions accessible* //**
- Allocation of a two-dimensional BUFFER on the specified area to store the grabbed image using 8-bit unsigned form
- Grab data from an input device (CCD camera) and store into the BUFFER **// *grabbing is done using MIL-library function MdigGrab* //**
- For each object of interest do

1. Set expected number of occurrences **// *one/two/all etc.* //**
2. Pre-process the model // ***this operation trains the system to take-up the most efficient search algorithm – Heuristic Search*** //
3. Allocate a pattern matching result-buffer and store the match-result (e.g. Fig. 5)

Detection of Objects with Surface Defects In the frame the possible match candidates without any defects are detected first. The remaining items from the frame therefore are defective ones and the coordinates thereof are written in a file, which can be used by a robo-manipulator programme, to instruct the arm to do the separation job.

EXPERIMENTAL RESULT

The process of template matching is applied to both symmetric and asymmetric objects. For asymmetric objects, rotated versions of the model are created using MIL commands, and used as templates to incorporate failsafe identification and robustness. Search-time as low as ~2.5 seconds for up to 36 templates have been reported.

The computer-image of a number of asymmetric mechanical components objects kept at different orientations in the frame is presented in Fig. 5, which clearly exhibits the property of rotation-invariance developed in our algorithm.

At the time of this writing the proposed algorithm is undergoing experimentation on the aspects of scale invariance and search time as also the relation of the latter with the size of the template and number of levels used in the hierarchical search. Comparative study of neural network techniques for solving this problem also needs to be done to put the proposed algorithm in the right perspective.

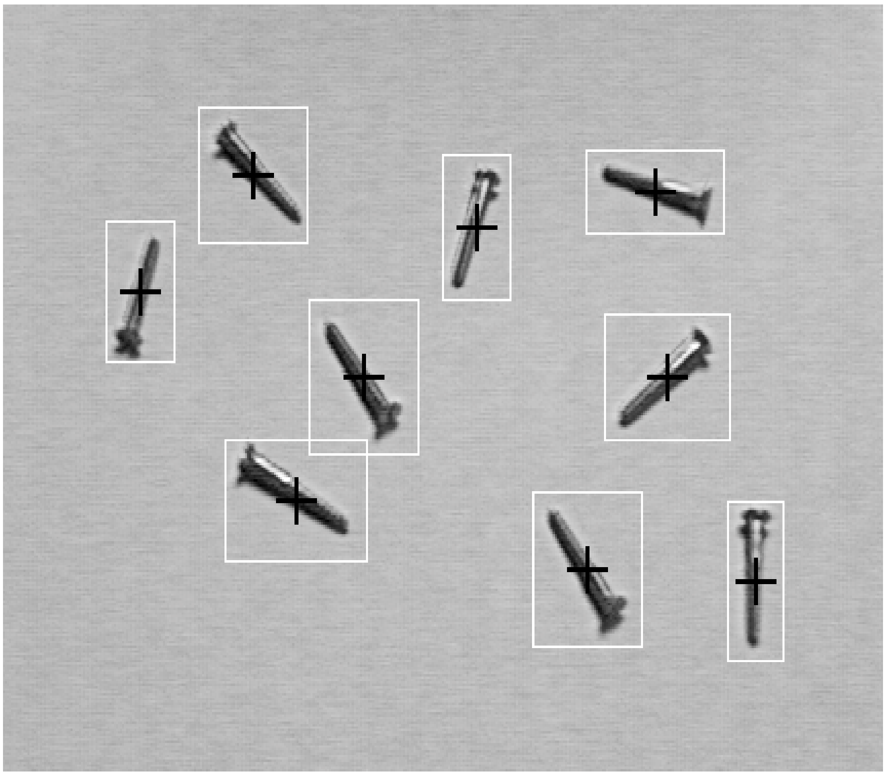

Fig. 5 Computer image of recognition of asymmetric object of various orientations – Exemplifies Rotation Invariance

CONCLUSION

In manufacturing industry the need to increase the production assurance is relentless. Automated visual inspection is introduced to increase the rate of repeatability and reliability. It adds the necessary machine intelligence and flexibility. In general, it has the aim of structuring product for different aspect. Pattern matching algorithms having application in robotics reported in literature [Martinez, 2000, Winters et al., 2000], use different techniques. In this paper we have presented one such technique and used it for automatic grabbing, restoring, recognition and identification in a manner that is ideally suitable for application in detection of surface defects in symmetric as well as asymmetric objects. The reliability and easy repeatability of the technique ensures successful robotic operation.

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