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Research on the Recognition and Location of Screw Cap on Steel Drum Cover Based on Machine Vision

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Abstract— *In order to realize the robot automatic screw cap system, the recognition and location method of screw cap on steel drum cover based on machine vision is researched in this paper. Machine Vision System was established to acquire images from the screw cap and locate the workpiece based on coordinates of the screw cap center after digital image preprocessing. The corner detection algorithm based on Harris operator was used to obtain the rotating angle of screw cap with a stable key point. The experiment and simulation results showed that the method proposed in this paper has a good performance. This method can effectively improve the automation and flexibility of the steel drum production line.*

Keywords— *Corner detection: image processing: machine vision: workpiece localization.*

I. INTRODUCTION

Since the 80s of last century, Chinese modern coopery industry has introduce foreign advanced equipment and technology of cooperage in order to improve the manufacturing efficiency and quality of steel drums[1]. In recent years, with the rapid development of Chinese economy, Chinese steel drum's manufacturing enterprises are sparing no effort to improve product technology and the level of automation in order to face the customers' expectations of higher product quality. Screwing control system of the screw cap on steel drum cover is designed according to steel production line requirements of time and quality and used for automatically catching and screwing the screw cap. Industrial robot needs to identify and locate the screw cap before completing the capture. The traditional industrial robots generally use teaching methods to complete the capture and placement of on the production line[2]. But the location and angle of the target workpiece can't be guaranteed to be consistent, which may affect subsequent assembly tasks. In this paper, the technology of locating and identifying the screw cap based on machine vision is studied. According Lu's method[3], the procedure of the screwing control includes, getting information of workpiece and its surrounding environment, getting the location and rotation angle of the screw cap and guiding the manipulator to complete the accurate operation of the workpiece. The results of simulation experiment showed that the structure of the system was stable and accurate. It can effectively improve the level of the steel production line automation and flexibility.

II. THE STRUCTURE OF THE MACHINE VISION SYSTEM

The machine vision system is mainly composed of the image acquisition module, the light source module and the image processing module and so on[4]. The system for screw cap testing based on machine vision as shown in Fig.1. The main working process of this system is as follows:

a. The workpiece is moving on the conveyor belt. When it reaches the predetermined position, the photoelectric sensor triggers and the image is acquired by industrial camera.

b. The computer performs image enhancement, image segmentation, matching recognition and measurement for the captured images and gets the position and pose coordinates of the workpiece.

c. Transforming the coordinates into the other coordinates that can be identified by a robot by calibration. And sending this coordinates to the robot controller for grasping and tightening the workpiece [5].

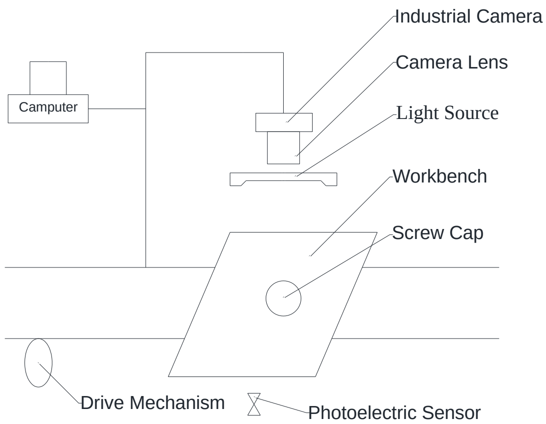

Fig. 1. The overall scheme of system.

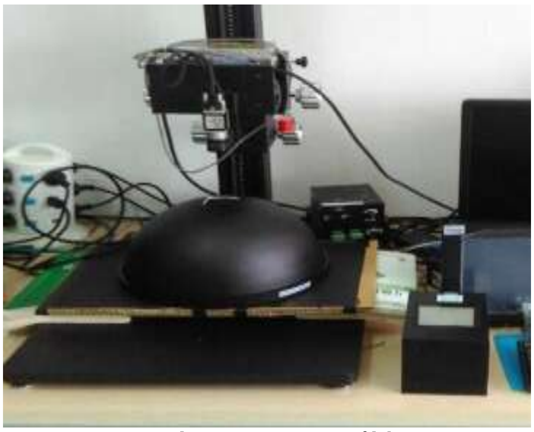

Fig. 2. Visual inspection system of laboratory.

In this paper, the machine vision system, as shown in Fig. 2, is set up in the laboratory, including the worktable, the industrial camera and the bowl shaped light source.

III. IMAGE PROCESSING AND POSITIONING

A. Image preprocessing

Because the image collected by machine vision system can't fully reflect all the information of the original image, we need to preprocess the image, such as suppressing unnecessary deformation or enhancing useful information in order to help subsequent image segmentation and image registration. In this paper, main preprocessing is sharpened filtering[6].

Image sharpening is a spatial domain filtering enhancement method. The Laplacian operator is a common linear two order differential operator[7]. The Laplacian transformation of $f(x,y)$ as:

$$\nabla^2 f(x,y) = \frac{\partial^2 f(x,y)}{\partial x^2} + \frac{\partial^2 f(x,y)}{\partial y^2} \quad (1)$$

For two dimensional discrete functions, the two order difference is commonly used to approximate the two order partial derivative. Therefore, the Laplacian transformation of the digital image is defined as:

$$\nabla^2 f(x,y) = \Delta^2 f_x(x,y) + \Delta^2 f_y(x,y) \quad (2)$$

In this expression, $\Delta^2 f_x(x,y)$ represents two order difference in the direction of X, $\Delta^2 f_y(x,y)$ represents two order difference in the direction of Y. They are defined as:

$$\Delta^2 f_x(x,y) = f(x+1,y) + f(x-1,y) - 2f(x,y) \quad (3)$$

$$\Delta^2 f_y(x,y) = f(x,y+1) + f(x,y-1) - 2f(x,y) \quad (4)$$

The Laplacian transformation of the digital image can be expressed by bringing (3) and (4) to (2).

$$\nabla^2 f(x,y) = [f(x+1,y) + f(x-1,y) + f(x,y+1) + f(x,y-1)] - 4f(x,y) \quad (5)$$

At the same time, two diagonal directions are added to Laplacian's definition. The corresponding two order difference template is 8 neighborhood. And the center coefficient of Laplacian operator is positive.

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix} \quad (6)$$

Using this template does convolution operation for the image to get the image of Laplacian linear filtering. Then the image is superimposed on the original image. The result after processing is shown in Fig. 3. It can be seen that the image of the screw cap is apparent from the background, and the purpose of image preprocessing is achieved.

(a) Original image (b) The image after sharpening

Fig. 3. Sharpening of the image.

B. Image Segmentation

The purpose of image segmentation is to get the separation and extraction of special features from the target pattern in the image[8]. The Fig. 4. is the gray level histogram of the screw cap. It has two obvious climaxes. The target area and background in the image are distributed on different wave peaks. Therefore, the gray value of the bottom of the two peaks is set as the threshold value[9]. The foreground of the image can be separated from the background by using the gray threshold segmentation method[10]. The function of the gray threshold segmentation method is defined as:

$$g(x,y) = \begin{cases} 0, & f(x,y) > T \\ 255, & f(x,y) \le T \end{cases} \quad (7)$$

In this expression, $f(x,y)$ is pixel values of the original image, $g(x,y)$ is the pixel value of the processed binary image. The Fig. 5. shows the binary image.

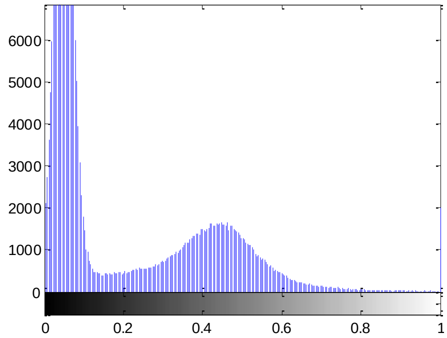

Fig. 4. The gray level histogram.

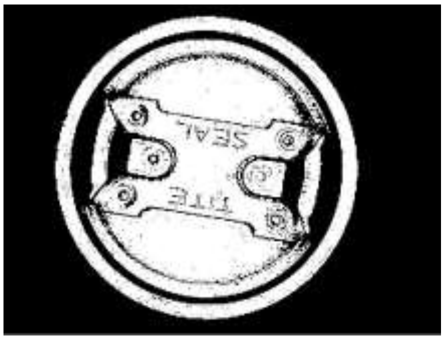

Fig. 5. Binary image.

C. Image Location

Because the outer contour of the screw cap is round, it can be accurately located by determining the center coordinates of the circular outline. The outer contour can be extracted by fundamental operation of mathematical morphology. Fundamental operation of mathematical morphology includes dilation and erosion. Open operation is the first erosion again dilation. Close operation is the first dilation again erosion. In this paper, the binary image is processed by morphological filling. The morphological filling algorithm can be expressed as:

$$\chi_k = (\chi_{k-1} \oplus B) \cap A^c, \chi_0 = \{p\}, \quad k = 1, 2 \cdots \quad (8)$$

Where A is binary image, B is structure element and χ_k is the final result of morphological filling algorithm. The Fig. 6.

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is the result of mathematical morphology processing.

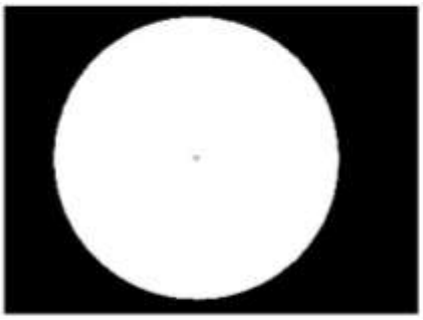


Fig. 6. Mathematical morphology processing.

The centroid can be obtained from the image of mathematical morphology processing by geometric moment. Two-dimensional image moment formula is defined as:

$$\mu_{m,n} = \iint (x - c_x)^m (y - c_y)^n f(x, y) dx dy \tag{9}$$

Because of the pixel value of the image is discrete, we need a discrete way to describe the moment of the image. It is defined as:

$$m_{m,n} = \sum \sum x^m y^n f(x, y) \tag{10}$$

The pixel coordinates of the workpiece center are:

$$O\left(\frac{m_{1,0}}{m_{0,0}}, \frac{m_{0,1}}{m_{0,0}}\right) \tag{11}$$

The target is cut out in the original image with the centroid as the center, as shown in Fig. 7.

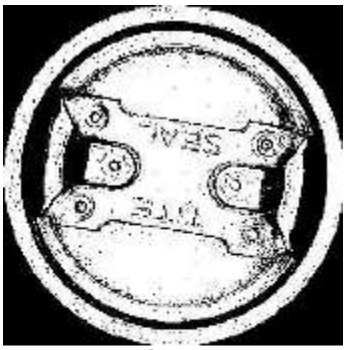


Fig. 7. Clipping image.

IV. Image Registration Based on Feature Points

Image registration is the alignment of the same target in the spatial position of two or more images[11]. Image registration based on feature has two important portions. They are feature extraction and feature matching. In this paper we use Harris corner detection method to image registration. This method has three main advantages.

a. The corner points after detection are much smaller than those of the original image. So it can greatly reduce the amount of calculation in the image matching process.
b. The detection process of the corner points can reduce the influence of noise points, and can be well adapted to the image deformation and the change of gray level.
c. The Harris corner detection operator has rotation invariance and is sensitive to the change of position, which can greatly improve the accuracy of matching[12].

A. Harris Corner Detection

The implementation steps of the Harris corner detection algorithm are as follows[13]:

a. Calculate the gradient I_x 、I_y in two directions of X and Y in the image :

$$I_x = \frac{\partial_I}{\partial_x} = I \otimes \begin{bmatrix} -1 & 0 & 1 \end{bmatrix}$$
$$I_y = \frac{\partial_I}{\partial_y} = I \otimes \begin{bmatrix} -1 & 0 & 1 \end{bmatrix}^T \tag{12}$$

b. The product of the gradient of the image in both directions.

$$I_x^2 = I_x \cdot I_x;\ I_y^2 = I_y \cdot I_y;\ I_{xy} = I_x \cdot I_y \tag{13}$$

c. The Gauss function is used to weigh I_x^2, I_y^2, and I_{xy}. And the elements A, B, C of matrix M are generated.

$$A = g(I_x^2) = I_x^2 \otimes \omega$$
$$B = g(I_y^2) = I_y^2 \otimes \omega \tag{14}$$
$$C = g(I_{xy}) = I_{xy} \otimes \omega$$

d. The Harris response value R of each pixel is calculated. And the response value R which is less than the threshold value sets to zero.

$$R = \{R:\ \det M - \alpha(traceM)^2 < T\} \tag{15}$$

e. No maximum suppression in 3×3 or 5×5 fields, and the local maximum point is the corner point in the image.

In this paper, the detection result of the image through corner points algorithm is shown in Fig. 8.

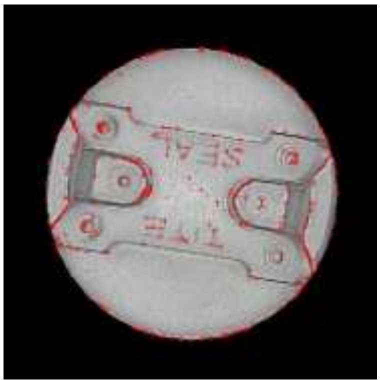


Fig. 8. Corner detection results.

B. Matching of Key Points

After the corner detection, it is necessary to determine a stable key point based on the feature of the image[14]. Because of the moving process on assembly line, the image of structure features of the image will appear subtle deformation which can result in the loss of the candidate point angle. We need to find a stable key point in a group. The key point is not missed when the geometry of the image changed. From the image of the screw cap, it can be found that the vertex of character 'A' in the image is a stable key point. The center coordinates of the screw cap have been calculated. The distance L between the vertices of the 'A' and the center 'O' is fixed. So a majority of corner points are removed by the distance to the center 'O' of the screw cap. The result is shown in Fig. 9.

Fig. 9. Candidate points.

It can be seen from the Figure 9 that it is possible to detect that the distance between the individual points and the 'O' point are exactly equal to the distance L. And these points can greatly interfere with the correction of the angle. These points can be removed by similarity threshold. The gray values of the 3 × 3 window region with the candidate corner coordinates as the center pixels are calculated as the feature vector. The feature vector and the key point of the template are used to calculate the similarity degree. The formula is as follows:

$$r = \frac{\sum_m \sum_n (A_{mn} - \bar{A})(B_{mn} - \bar{B})}{\sqrt{\{\sum_m \sum_n (A_{mn} - \bar{A})^2\}\{\sum_m \sum_n (B_{mn} - \bar{B})^2\}}} \quad (16)$$

$where\ \bar{A} = mean2(A),\ and where\ \bar{B} = mean2(B)$

By removing the candidate corners points which less than the threshold, the coordinates of the vertex of character "A" can be obtained. The result is shown in Fig. 10.

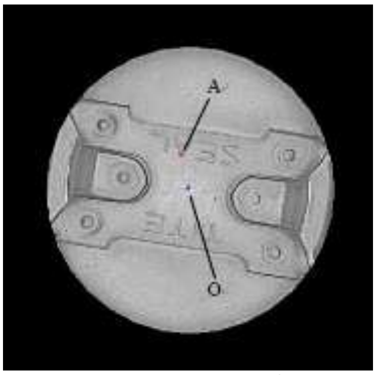
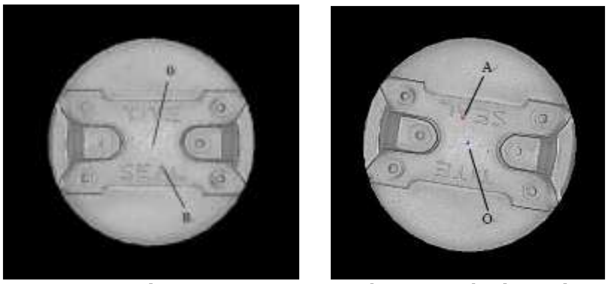


Fig. 10. Accurate localization of key point.

After obtaining the coordinate of key point A, the rotation angle of the screw cap can be determined by calculating the point B of template image and the point A of real image and the center point O of the image. As shown in Fig. 11. The calculation formula is as follows:

$$\vec{OA} = (x_A - x_o, y_A - y_0)$$
$$\vec{OB} = (x_B - x_o, y_B - y_0) \quad (17)$$
$$\cos\theta = \frac{\vec{OA} \cdot \vec{OB}}{|\vec{OA}| \times |\vec{OB}|}$$



a. Template image b. Image to be detected

Fig. 10. Rotation angle determination.

V. Results and Analysis of Simulation Experiment

Table I shows the position coordinate and angle which are obtained according to the above method.

TABLE I. Results of experiment.

n	X/pixel	Y/pixel	Angle/°	Real Angle/°
1	258.70	214.71	151.95°	152°
2	236.90	202.81	87.30°	87°
3	230.48	207.60	17.09°	17°
4	298.21	202.49	325.87°	325°
5	316.82	224.84	355.30°	356°

Pixel precision is 0.158mm/pixel. From the Table I, we can see that the position can be obtained by this method in this paper and the difference of actual measured rotation angle and the real rotation angle are within 1 degree. It can basically meet the precision requirements of the robot grasping the screw cap. It shows that the detection method can be used to determine the position and posture of the screw cap.

VI. Summary

This paper focuses on the research about recognition and location of the screw cap on steel drum cover based on machine vision. The position coordinates and placement angles of the screw cap are obtained and meet the actual requirements. On the image processing, because of the low contrast, high requirement of light source and complicated concave and convex structure of the screw cap, the image sharpening, mathematical morphology treatment and other methods are used to process the image and locate the position of it. The rotation angle of the screw cap is confirmed by using rotation invariance of the Harris corner detection operator. The experimental result shows that this detecting system keeps high detection precision when the workpiece rotates at any angle. The system is stable and reliable and meets the actual production requirements.

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