A method of detecting the feature of cylindrical pin based on machine vision

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Abstract. As a common mechanic part, cylindrical pin is mainly used for positioning the parts in assembling process. Chamfer angle is an important feature of cylindrical pin, which guides the pin into the pin hole. Manual method is used by cylindrical pin manufacturer to detect the chamfer feature and so as to filter the defective products. But it is found that many problems including inevitable subjective error, high intensity of labor, and low detection efficiency exist during manual operation. A new method based on machine vision is proposed in this paper to detect the chamfer feature and size of cylindrical pin. Contour of cylindrical pin is obtained by camera, chamfer feature and size is then extracted through image analysis. Experiment result proves that the method is feasible.

1. Introduction

The first paragraph after a heading is not indented (Bodytext style). Cylindrical pin is a common mechanical part, its is mainly applied to part positioning in mechanical industry, so it is also called dowel. In the assembly positioning of the parts, the relative position of the parts is determined by the geometric features of the cylindrical pin. Therefore, the relative assembly positioning accuracy of parts largely depends on the geometric accuracy of the cylindrical pin [1], [2]. The geometric characteristics of the cylindrical pin are mainly composed of the cylindrical revolving body and the chamfer at both ends. Machining accuracy of the cylindrical diameter and its dimensional consistency determine the assembly accuracy. The straightness of the cylinder generatrix determines the positioning accuracy of the parts. The chamfer feature at the end of pin help the pin get into the pin hole. Therefore, the geometric characteristics of the cylindrical pin directly determine the assembly accuracy.

Due to the refinement of social division of labor, cylindrical pins are often outsourced to small or medium-sized enterprises as consumable standard parts. Most of these enterprises use semi-automatic method to produce cylindrical pin to reduce the cost. In quality inspection of cylindrical pin products, most of them use manual method to check whether the geometric characteristics of cylindrical pin satisfy the technical requirement. Quality inspection of cylindrical pin mainly includes length and chamfer inspection. The length of the cylindrical pin is inspected by the metal mold with holes, and the inspector shall visually inspect whether there is any cylindrical pin with abnormal length under the fluorescent lamp. The inspector grabs a certain number of pin workpieces to check whether the
There are many problems in manual inspection of the quality of the cylindrical pin. Firstly, the subjective judgment and the proficiency varies from person to person, which affect the efficiency and the precision of the inspection. Meanwhile, working in the environment full of oil for long time influences the healthy of the inspector, and working on the inspection workbench under the fluorescent lamp causes a great burden on the workers’ eyesight. In addition, with the rise of labor cost and the increase of personnel mobility, inspection cost has gradually become one of the economic burden of enterprises. Looking at the inspection methods of cylindrical pin in many enterprises, it is found that manual inspection is a common inspection method of cylindrical pin, which is only slightly different in mold shape and sampling proportion.

In recent years, the ability of machine vision becomes stronger than before. Machine vision technology has been used in more and more practical cases. Through consulting the domestic and foreign papers, it is found that there is few relevant research on the key dimension detection of cylindrical pin. Relevant research contents mainly concern the detection of large-scale shaft parts, such as Qi et al. [3] proposed a detection method of stepped shaft outline dimension with machine vision, Wei et al. [4] studied the detection of transmission shaft diameter based on machine vision, Yang et al. [5] studied the precisely detection method of circumference diameter using machine vision, Zhu et al. [6] studied the piston pin diameter estimation based on Hough transform. It can be seen that the existing research is related to the detection of the key dimensions of the cylindrical pin using machine vision to some extent, but there is few systematic research on cylindrical pin detection, and machine vision mostly focuses on the detection of the outer diameter of the shaft parts, and the detection content of the small features such as the small chamfer and the small part diameter can be rarely seen.

Aiming at the problems in the manual detection of the size and chamfer feature of cylindrical pin, an automatic detection method based on machine vision is proposed in this paper. Firstly, the image processing algorithm used in this method is described, then the chamfer feature of the cylindrical pin is analyzed, and the detection method proposed in this paper is described. Through the contour extraction and image analysis of the cylindrical pin image, the size and chamfer feature are detected.

The proposed method offers a theoretical foundation for the development of the key feature detection equipment of the cylindrical pin.

2. Machine vision

2.1. Binary image extraction

A machine vision based feature detection technology for cylindrical pin is proposed in this paper. Feature detection is realized by acquiring the image of the cylinder pin, analyzing the image features, extracting the chamfer features. Firstly, the color image from industrial camera is transformed into gray image which is then transformed into binary image.

The original image of industrial camera is in YUV format which needs to be converted into RGB format, and RGB format needs to be converted into gray-scale image for further analysis. Yuv-rgb psychological formula is utilized for conversion:

\[
V_{\text{Grey}} = V_R \times 0.299 + V_G \times 0.587 + V_B \times 0.114
\]  
(1)

Here, \(V_{\text{Grey}}\) is the value of grey; \(V_R\), \(V_G\), and \(V_B\) are the component value of red, green, and blue of the origin image. Considering the presision and computing cost, the fast formula of (1) can be applied:

\[
V_{\text{Grey}} = (V_R \times 0.38 + V_G \times 0.75 + V_B \times 0.15) >> 7
\]  
(2)
The value of each pixel ranges from 0 to 255, in which 0 means black and 255 means white, and the values between 0 and 255 represent the depth of grey in gray-scale image. As to binary image, the value of each pixel can only be 0 or 1. According to proper threshold, binary image can be generated by gray-scale image. And then the contour of image can be extracted using binary image.

2.2. Contour extraction
Chamfer feature can be detected according to the image contour, so whether the contour of the cylindrical pin can be obtained accurately directly determines the chamfer detection effect. The essence of contour extraction is edge recognition. In algorithm processing, contour operator is used to achieve contour extraction. The common contour operators are Canny operator, Sobel operator, Prewitt operator and so on. These operators generate contour features by constructing n-order operator matrix and plane convolution. Sobel operator is selected to extract the contour in this paper as it has a certain smoothing effect on the noise and a better denoising effect.

Sobel operator is composed of two 3x3 matrices $G_x$ and $G_y$. $G_x$ is the horizontal template used to detect the horizontal edge and $G_y$ is the vertical template used to detect the vertical edge. The two templates are convoluted with the image in the plane, and the approximate values of the horizontal and vertical luminance difference are obtained.

$$
G_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad G_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}
$$

The contour not only extracts the main image features of the object, but also replaces the image information with a large amount of data by the contour coordinate data with a small amount of data, which helps to feature information extraction and compression.

3. Feature detecting method

3.1. Illumination method
Illumination is needed to separate the object from the background, the separating effect depends on illumination methods. There are two kinds of lighting methods: direct lighting and backward lighting. The material of pin is metal. The finished surface is highly smooth and the reflectivity of light is high. It is found that the imaging effect is not good if the light source is placed facing to the pin directly, because the metal circle surface of cylinder pin will reflect some light to make the image bad. Under the existing experiment condition, backward LED array illumination is more conducive to contour extraction. Figure 1 shows the illumination of two kinds of light sources together.

It can be seen from the figure that the light perpendicular to the pin surface forms reflection stripes on the surface, and the gray level of the reflection area is similar to that of the background. The backward light makes the gray level of the cylindrical pin and the gray level of the light area form a significant difference, which is conducive to get a better binary image and better contour data.
3.2. Size calibration

Camera lens distortion needs to be tested and the relation between the pixel and actual size needs to be confirmed for size estimation and chamfer detection. The unit of image size from the camera is in pixels. The resolution of the original image is 640x480. According to the measured size of the view field, the actual size of each pixel can be obtained as 0.068599mm.

Figure 2 shows the image of a coin of 19mm diameter which is used to verify the size calibration. The black circular area is the coin image, and the data displayed in the picture is the calibrated value. Length 0-1 represents the length of the line between corner 0 and corner 1 of the circular external rectangle, and length 1-2 represents the length of the line between corner 1 and corner 2 of the external rectangle.

It can be seen from the figure that the values of length 0-1 and length 1-2 are equal, indicating that:

1. The rectangle is square, so the inscribed circle is a positive circle, which is in line with the actual situation;
2. The diameter measured in the circular area is 19.01472mm. The absolute error between the estimated size and the actual size is 0.01472mm, the relative error is 0.078% which is within the acceptable range. Through calibration, it is verified that the camera lens has no distortion.
3.3. Chamfer detect
The end chamfer is one of the important characteristics of the cylindrical pin. Whether the chamfer exists or not affects the assembly performance of the cylindrical pin, and the size of the chamfer affects the assembly mechanical performance to a certain extent. Corner detection, line fitting and other methods are generally used to evaluate the contour index in machine vision. However, most of cylindrical pins are small, and the chamfer size of both ends is relatively smaller, which makes it difficult for machine vision recognition. The chamfer size is very small and the number of pixels in chamfer area is fewer, so corner detection method and line fitting method can hardly detect the feature. After compared the contour features of cylindrical pins with and without chamfers, the influence weights of chamfer on the whole contour and local contour are analyzed, and a chamfer detection method based on local contour features is proposed.

The detection steps of chamfer feature are as follows: (1) Extract the binary image of the cylinder pin image; (2) Obtain the pin contour and the external rectangle according to the binary image; (3) Draw 4 certain size rectangle areas based on the corner points of the external rectangle; (4) Extract the overlapped part of binary image and the 4 rectangles; (5) Calculate the area ratio of each overlapped part and the small rectangle, and then 4 ratios can be obtained for each pin, then calculate the average of the ratios at the same end to get 2 parameters; (6) After calculated many ratios of different pins, threshold of quality testing can be obtained.

![Figure 3. Different condition of chamfer on cylindrical pin](image)

In quality inspection, the quality of a pin can be estimated by 2 area ratio parameters of the pin and the threshold. The algorithm will decide whether the pin is good or bad automatically.

With the above steps, the quality inspection of the chamfer of the cylindrical pin at any angle can be realized. In practical application, according to different detection requirements, detection rules can be formulated freely, such as:

1. Check whether the chamfer exists: establish the threshold value of area ratio (e.g. ≥ 0.9), the chamfer does not exist if the ratio is larger than the threshold;
2. Check whether the chamfers at both ends are consistent: calculate the area ratio of the four corners in the image to determine whether the values are consistent;
3. Check whether the chamfer dimension is qualified: first, calculate the area ratio value of qualified parts as the evaluation basis, and then evaluate the cylindrical pin using this basis.

4. Experiment

4.1. Main steps
Chamfer detection and dimension estimation experiments of the cylindrical pin are carried out using the proposed method. The image sensor of industrial camera used is CMOS, its pixel resolution is 640x480, and the output format is YUV. LED backlight is used for illumination, the focal length of camera lens is 6-60mm. Three kinds of stainless steel cylinder pins are used for detection.
Firstly, the dimension of the cylindrical pin is estimated to evaluate whether the dimension meets the requirements; secondly, the chamfer feature of the cylindrical pins are detected to analyze the difference between the measured chamfer feature of the qualified part and the unqualified part. According to the previous test, it is found that the difference of chamfer area ratio of both ends of qualified cylindrical pin is less than 1%, so the unqualified threshold is set to be 2%. If the difference of measured area ratio is greater than 2%, it is considered as unqualified.

4.2. Test on size and chamfer detection

Figure 4 is the screenshot of the inspection result of one cylindrical pin. The black rectangular area in the figure is the image of the pin. After pre calibration, the unit of the measured target dimension is millimeter, where length 0-1 and length 1-2 represent the diameter and length of the measured cylinder pin respectively. The actual dimension, measured dimension and error of the cylindrical pin are shown in Table 1.

![Figure 4. Feature detection of a cylindrical pin](image)

| Table 1. Estimation results |
|-----------------------------|
| Actual size(mm) | Estimated(mm) | Absolute error(mm) | Relative error |
| Diameter      | 8.2           | 8.2368             | 0.0368          | 0.46%          |
| Length        | 22.5          | 22.5754            | 0.0754          | 0.34%          |

Rate of 0-1 represents the average area ratio of the local contour near corner 0 and corner 1 of the external rectangle of pin image, and rate of 2-3 represents the average area ratio of the local contour near corner 2 and corner 3. Because the position of the part in the field of view is uncertain, which couple of corner belong to the same end will be confirmed according to the length of lines between the corners.

In the cylindrical pin image shown in Figure 3, the average area ratio of chamfer at one end is 71.20%, while that at the other end is 76.65%, and the difference between the two chamfers is 5.45%. The tested cylinder pin is known as an unqualified part. The reason is that the chamfer size at both ends is inconsistent, and the measured situation is consistent with the actual situation.

4.3. Result analysis

It is found that the absolute value of the difference between the local characteristic area ratio of the two ends of the qualified part is no more than 2% through the multiple tests of the qualified and unqualified cylinder pins. Based on this criterion, the chamfer features of different cylindrical pins are detected, and the screenshots of detection results are shown in Figure 5 and figure 6. The detection target is chamfer feature, so the pixel size is not calibrated.
The chamfer local contour area ratio, error at both ends, judgment results and other information of the cylindrical pin are shown in Table 2.

It can be seen from the table that the result judged according to the threshold value is consistent with the actual situation. It is reasonable to set 2% as the threshold value because the maximum difference between the ratios of two ends of the qualified cylinder pin is 0.93%, and the minimum difference between the two ends of the unqualified cylinder pin is 3.42%.

|   | End A ratio (%) | End B ratio (%) | Abs. diff. between two ends (%) | Estimate result | Actual result | Estimate quality |
|---|-----------------|-----------------|---------------------------------|-----------------|---------------|-----------------|
| 1 | 86.82           | 87.20           | 0.38                            | good            | good          | ✓               |
| 2 | 85.02           | 85.95           | 0.93                            | good            | good          | ✓               |
| 3 | 89.61           | 85.78           | 3.83                            | bad             | bad           | ✓               |
| 4 | 86.37           | 86.98           | 0.61                            | good            | good          | ✓               |
| 5 | 86.12           | 89.54           | 3.42                            | bad             | bad           | ✓               |
| 6 | 87.28           | 86.77           | 0.51                            | good            | good          | ✓               |
| 7 | 85.89           | 85.32           | 0.57                            | good            | good          | ✓               |
| 8 | 87.38           | 86.95           | 0.43                            | good            | good          | ✓               |
| 9 | **85.57**      | **89.48**      | **3.92**                        | **bad**         | **bad**      | ✓               |
|10 | 85.62           | 86.38           | 0.76                            | good            | good          | ✓               |

### 4.4. Extended application

The proposed method in this paper is also suitable for similar demand, in addition to solving the problem of chamfer feature detection at the end of cylindrical pin, it can also be used for feature detection of other products. For example, in the manufacturing process of sports shoes, it is necessary to spray glue on the sole so that the upper part of shoe can be firmly combined with the sole. Information including position, direction, inspection etc. is needed in glue spraying process.

In the semi-automatic glue spraying period, before the conveyor belt transmits the sneaker sole to the gelatinizing station, it is necessary to observe manually whether the sole is in the right position, whether the direction is correct, whether the model is correct, whether the sole is damaged, and so on. The glue spraying line has a strong dependence on labor. At the same time, long-term visual inspection is extremely harmful to the health of workers and has a more obvious impact on their eyesight.

Therefore, an automatic detection technology which can replace human recognition is needed. Using the detection method proposed in this paper, the automatic detection of sole characteristics can be realized.
In order to get the proper spray track, it is necessary to determine the sole specification. By extracting the edge of the sole image, the minimum circumscribed rectangle is calculated. The length and width of the rectangle can represent the length and width of the sole.

In order to spray glue accurately, the sole position needs to be determined. By obtaining the center of gravity of the sole binary image and calculating the coordinates of the center of gravity in the coordinate system of the platform, the detection of the sole position can be realized. The figure below shows the measured image and coordinates when the sole is in two positions.

After the glue spraying track is confirmed, the left and right feet of the sole and the toe orientation can be determined. Using the local area method used in chamfer detection in this paper, small rectangles are generated at four corners of the external rectangles, and the area ratio parameters of the sole image are calculated, four parameters can be obtained. The process of sole binary image is shown in Figure 8 above which are 4 parameters of local area ratio. Comparing the sum of parameter 1 and parameter 2, and the sum of parameter 3 and parameter 4 can determine the left and right of the sole; comparing the sum of parameter 1 and parameter 4, and the sum of parameter 2 and parameter 3 can determine the toe orientation.
5. Conclusion
Facing to many problems in quality estimating of cylindrical pin via manual work, a method for feature detection of cylindrical pin based machine vision is proposed in this paper. Image feature is obtained using machine vision technique, local contour of chamfer is regarded as research object. The area ratio of local contour is used to judge whether chamfer exists and whether the chamfer size is correct.

The capability of camera len is tested through length calibration, and then 4 kinds of cylindrical pins are detected using the proposed method according to local area ratio. The experiment results shows that the proposed method is able to discriminate the good and bad pins, which proves the proposed method is feasible. The proposed method can replace the manual work in chamfer detecting of cylindrial pin, it will help the pin manufacturer promote the production efficiency. Furthermore, the example of sole feature detection shows that the proposed method can also be applied in similar condition.

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