Abstract: Aiming at the low efficiency and low accuracy of traditional manual detection of workpiece circular features, a machine vision method is proposed to accurately detect circular features. By adopting algorithms such as iterative threshold segmentation, generating XLD contours, selecting feature contours and random Hough transforms, single or multiple circles on the workpiece can be quickly detected. Experiments show that the detection is efficient and accurate, and can meet the detection needs of industry.

1. Introduction
Circle detection is one of the important research contents in the field of digital image processing, and it has extensive and important applications in pattern recognition, artificial intelligence and automated detection[1-4]. In actual production activities, the production environment is relatively harsh and not suitable for manual operations. At the same time, traditional manual inspections are inefficient and prone to errors due to visual fatigue. Therefore, the Hough transform[5]is an effective method for detecting circles so far, especially for the detection of round features of workpieces in industrial production. For circle detection, commonly used techniques include shape analysis method, loop integration method[6], circle detection method based on existence probability[7], and genetic algorithm[8]. On the basis of Hough algorithm, Gong Xin et al.[9]introduced cluster analysis and merged circles with high similarity to improve the accuracy of circle detection; Cui Zhixun et al.[10]proposed a method based on gradient and prior knowledge. Improve the Hough transform method to accurately and quickly detect the installation of the anti-loose gasket in the part; Illingworth et al. [11-12]summarized many improved circle detection algorithms based on the Hough transform, which solved the problem of low local circle detection accuracy; Seluk Aslan [13]studied an improved artificial bee colony algorithm to solve the problem of multi-circle detection.

Based on the random Hough transform, this paper proposes an accurate and fast detection method for the circular feature of the workpiece, which can meet the detection requirements of industrial workpieces.
2. **Technical solutions**

The realization of this technical solution is composed of a computer system, a camera system, a workpiece to be detected and a press-part conveying system, etc. The image information of the workpiece is collected by the camera, and then transferred to the computer for image processing. After a series of image preprocessing operations, it is converted to XLD contour, and then contour features are selected to perform random Hough transform to find circle features, and parameters such as the position and radius of the circle are detected. Through the detection of the round features of the workpiece, and the operation of the robot arm, the unqualified products can be quickly detected. Figure 1 shows the overall design of the system.

![Diagram of the system](attachment:image.png)

**Figure 1.** The overall design of the system.

3. **Image processing and random hough detection algorithm**

3.1. **Image preprocessing**

Median filtering is an indispensable stage of image preprocessing. The detected workpiece is interfered by various noises during the collection process, so it is necessary to reduce or even remove such noise interference. The median filter replaces each pixel in the square neighborhood of the center pixel with an intermediate pixel, which can eliminate this interference well. The median value is defined as follows: an array of $x_1, x_2, x_3, \ldots, x_n$, the n numbers are arranged in ascending order as: $x_{(n+1)/2}$.

$$y = \text{med}(x_1, x_2, x_3, \ldots, x_n) = \begin{cases} x_{(n+1)/2} & \text{if } n \text{ is odd} \\ \frac{1}{2}(x_{(n+1)/2} + x_{(n+2)/2}) & \text{if } n \text{ is even} \end{cases}$$  \hspace{1cm} (1)

1) In order to segment the artifacts from the background, an iterative threshold processing algorithm is adopted. The steps are as follows:

- Choose an appropriate gray value T as the estimated value.
- Use the threshold T to divide the grayscale image into two regions: R1 and R2.
- Calculate the average gray values of the pixels in the gray areas R1 and R2: $\mu_1$ and $\mu_2$.
- Calculate the new threshold:
  $$T_{n+1} = \frac{1}{2}(\mu_1 + \mu_2)$$  \hspace{1cm} (2)

- Repeat steps 2–4 until the iterative threshold T is less than the previously estimated value.
2) After the threshold is processed, the connected domain operation in the neighborhood is performed on the area. The conversion mode is divided into two types: border mode and center mode. This technical solution selects the border_holes mode, and the edges of all holes form XLD.

3.2. Random hough transform detection circle

When detecting a circle, the image space is only the two-dimensional parameters of pixel coordinates \((x, y)\):

\[
\frac{(x-x_0)^2}{r^2} + \frac{(y-y_0)^2}{r^2} = 1
\]

(3)

At this time, the parameter space becomes larger, and the center \((x_0, y_0)\) and the radius \(r\) constitute a three-dimensional parameter space. Therefore, it is necessary to construct a function of these three independent variable \((x_0, y_0, r)\) and perform a peak search in this three-dimensional space. Take three points on the circle: \((x_1, y_1)\), \((x_2, y_2)\), \((x_3, y_3)\), and put the three points into equation (3) to get the equation system:

\[
\begin{align*}
(x_1 - x_0)^2 + (y_1 - y_0)^2 &= r^2 \\
(x_2 - x_0)^2 + (y_2 - y_0)^2 &= r^2 \\
(x_3 - x_0)^2 + (y_3 - y_0)^2 &= r^2
\end{align*}
\]

(4)

Solving the equations can get the center coordinates \((x_0, y_0)\) and radius \(r\). Select 3 points on the edge of the image to obtain the center coordinates \((a, b)\) and radius \(r_1\), and then at the fourth point \((x_4, y_4)\) and substitute (3) to obtain the radius \(r_2\), the calculation error can be obtained Value formula:

\[
\delta_1 = r_2 - r_1
\]

(5)

\(\delta\) is a preset error value, and only when \(\delta_1\) is less than \(\delta\), it is determined as a candidate circle. After the candidate circle is determined, all the points are taken into the calculation. When the value of the accumulator reaches a predetermined threshold, it can be determined as a true circle.

4. Experimental results

The workpiece picture information collected in this paper is realized by the joint programming of HALCON vision software and VS2013. What is collected is the kind of workpiece with eight round holes, and the characteristic parameters of the circle are the key factors for part inspection. Figure 2 shows the workpiece image information collected by the camera.

Figure 2. Original image

4.1. Iterative threshold segmentation of images and XLD feature selection

This paper adopts the maximum separability to perform iterative threshold segmentation, as shown in Figure 3(a), and then performs connected domain operations and generates XLD contours, and selects XLD according to the threshold, as shown in Figure 3(b).
Figure 3. (a) is the iterative threshold processing image, (b) is the XLD feature selection image

4.2. Random hough transform
The workpiece belongs to multi-circle feature detection. When the error value is less than the preset error value, it can be determined as a candidate circle. At the same time, according to the accumulator when the value reaches the predetermined threshold, it is considered to be a true circle, and the circular feature image of the workpiece detected by Hough transform is shown in Figure 5.

Figure 4. Hough detecting circle features

The statistics of the eight circles detected according to the random Hough transform are shown in Table 1 and Table 2:

| Circle number | Center coordinates/pixel | Detection radius/pixel | True radius/pixel | Absolute error/pixel |
|---------------|--------------------------|------------------------|-------------------|---------------------|
| C1            | (246, 552)               | 11.6                   | 11                | 0.6                 |
| C2            | (251, 245)               | 11.7                   | 12                | 0.3                 |
| C3            | (401, 533)               | 11.5                   | 11                | 0.5                 |
| C4            | (405, 268)               | 11.7                   | 12                | 0.3                 |
| C5            | (495, 495)               | 11.6                   | 11                | 0.6                 |
| C6            | (497, 308)               | 11.6                   | 12                | 0.4                 |
| C7            | (554, 557)               | 11.7                   | 12                | 0.3                 |
| C8            | (557, 250)               | 11.7                   | 12                | 0.3                 |

| Number | 1   | 2   | 3   | 4   | 5   | 6   | mean |
|--------|-----|-----|-----|-----|-----|-----|------|
| Time (s)| 3.14| 3.16| 3.12| 3.17| 3.13| 3.15| 3.145|

It can be seen from Table 1 that the maximum absolute error of radius detection in this paper is 0.6 pixel. It can be seen from Table 2 that the whole process of a single detection takes 3.15s on average, and it takes approximately 0.4s to detect a single circle. The time-consuming length is related to the step value selected by the detection, and also related to the configuration of the computer. Generally speaking, the smaller the step size, the more iterations and the longer the detection time. At the same
time, the smaller the step value is, the better the circle detection accuracy is. Therefore, the design of this detection scheme needs to take into account both the step value and the accuracy.

5. Concluding remarks
This paper adopts the RHT (Random Hough Transform) algorithm to detect the circular feature of the workpiece, and selects the step value and accumulator to determine the threshold during the transformation. By selecting the appropriate step length and controlling the number of iterations, the workpiece detection is satisfied. Precision and efficiency. This paper collects multiple sets of workpiece images to detect the circle feature. The maximum detection error is 0.6 pixel, the average time is 3.15s, and the detection effect is good, meeting the requirements of industrial workpiece detection.

References
[1] Li Dandan, Liu Jinfu, Yu Daren. Application of self-adjusting snake model to realize the extraction of Brinell hardness indentation circle [J]. Chinese Journal of Scientific Instrument, 2011, 32 (12): 2734-2739.
[2] Li Zhanli, Liu Mei, Sun Yu. Research on calculation method of center image point of circular target in photogrammetry [J]. Journal of Instrument and Meterology, 2011, 32 (10): 2235-2341.
[3] Tan Lei, Wang Yaonan, Shen Chunsheng. Obstacle visual detection and recognition algorithm for transmission line deicing robot [J]. Chinese Journal of Scientific Instrument, 2011, 32 (11):2564-2571.
[4] Qiao Naosheng, Ye Yutang, Huang Yonglin, etc. Research on the detection method of PCB microscopic image defect circle hole [J]. Optoelectronics-Laser, 2009, 20 (7): 964-966.
[5] Duda R O , Hart P E . Use of the Hough transformation to detect lines and curves in pictures[J]. Cacm, 1972, 15(1):11-15.
[6] Daugman J G . High Confidence Visual Recognition of Persons by a Test of Statistical Independence[J]. IEEE Transactions on Pattern Analysis and Machine Intelligence, 1993.
[7] Zhang Yunchu, Wang Hongming, Liang Zize, et al. Circle detection method based on existence probability graph[J]. Computer Engineering and Applications, 2006, 42(029):49-51.
[8] Ayala-Ramirez V , Garcia-Capulin C H , Perez-Garcia A , et al. Circle detection on images using genetic algorithms[J]. Pattern Recognition Letters, 2006, 27(6):652-657.
[9] Gong Xin,Zhang Nan.Improvement of circle detection algorithm based on Hough transform[J].Information Technology,2020,44(06):89-93+98.
[10] Cui Zhixun,Zhang Renjie. Installation detection of circular anti-loosening gasket based on improved Hough transform[J]. Electronic Measurement Technology, 2018, 41(22):95-98.
[11] Illingworth J, Kittler J. A survey of the Hough transform[J]. Computer Vision, Graphics, and Image Processing, 1988,44(1): 87-116.
[12] Illingworth J, Kittler J. The adaptive hough transform[J]. IEEE Transactions on Pattern Analysis and Machine Intelligence,1987;9(5):690-698.
[13] Aslan S. Modified artificial bee colony algorithms for solving multiple circle detection problem[J]. The Visual Computer, 2020:1-14.