Development of leakage test system of cartridge valve based on NI vision

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Abstract. In order to realize the leakage test of cartridge valve, an automatic test system based on machine vision is designed, and the working principle of the system is described. Through the analysis and processing of the leakage image obtained by industrial camera, the leakage flow of the valve are obtained to determine whether they meet the national standards. Finally, the feasibility of the test system is verified by theoretical analysis and experiment.

1. Introduction

As a specific application of machine vision, vision measurement obtains the geometric dimension of the object and the position coordinates of the measured object by analysis the target image. Compared with the inherent shortcomings of traditional measurement methods the vision measurement technology based on machine vision has the advantages of non-contact, high precision, fast speed and good stability. So the vision measurement will become a new trend in industrial inspection$^{[1,2]}$.

The traditional cartridge valve test system is to judge whether the liquid level of each transparent tube is within the qualified range by human eye. The accuracy of human eye recognition is greatly affected by objective factors, and the efficiency is low. Based on this situation, this paper proposes a cartridge valve leakage test system based on machine vision measurement technology, which applies machine vision technology to the traditional hydraulic test bench and replaces human eye recognition. By comparing several machine vision algorithms, the accuracy of the test system is improved.

2. System principle analysis

In order to simulate the actual operating conditions of the cartridge valve, the test system uses hydraulic pressure to provide oil source for the tested cartridge valve. The electrical system realizes the control of electrical components through industrial control computer and the Siemens programmable logic controller. The real-time performance of the control system is improved by the
incremental PID control algorithm.

2.1. Hydraulic system analysis

The hydraulic schematic diagram of the control system is shown in Figure 1. The oil source is provided by the gear pump 2 with a displacement of 12ml/r. The impurities in the oil are removed by the superimposed high-pressure filter 4. By controlling the three-position four-way electromagnetic directional valve 5, it is selected whether the system pressure is supercharged by 4:1 through the superimposed supercharger 6. The two-position three-way reversing valves 10.1 and 10.2 are used to switch between station 1 and station 2. The system pressure is regulated and controlled by the direct-acting proportional relief valve 7. Two pressure sensors 11.3 and 11.4 are used to test the inlet pressure of the valve under test. The system safety valve 3 plays a protective role to prevent the system pressure from being too high.

![Figure 1. Hydraulic schematic.](image1)

![Figure 2. Logic diagram of control system.](image2)

2.2. Analysis of electric control system

The electronic control system mainly uses industrial control computer, and develops a set of automatic measurement and control program based on Labview. The program mainly realizes the real-time signal acquisition of the test bench, the acquisition of high-definition pictures taken by the industrial camera, and the control of the programmable logic controller to realize the digital control and analog control of the test bench, as shown in Figure 2.

In the process of pressure control, through comparative analysis, we choose incremental PID algorithm. The advantage of incremental PID algorithm control is that only output control increment each time, and the determination of control increment is only related to the last three sampling values, so it is easy to obtain better control effect. The control formula is:

\[ \Delta u[n] = K_p \{ e[n] - e[n-1] \} + K_i e[n] + K_d \{ e[n] - 2e[n-1] + e[n-2] \} \]

(1)
3. Visual inspection

Visual detection technology is a kind of new detection technology for specific visual tasks, which is based on computer vision and image processing, and carries out qualitative detection and quantitative measurement for the target object. It has the advantages of high efficiency, high precision, non-contact, rich information and other advantages, involving the theories and methods of image processing, image analysis and image understanding at all levels.[3]

According to the requirements of the test system, we choose COMS camera with 8 million pixels, optical size 1/2.5 inch, C interface, effective pixels: 2592h*1944v, and the main parameters of lens are focal length: 2.8-12mm, imaging size: 1/2", aperture range: F1.6-c, viewing angle: 98°-30°, interface: C.

3.1. Image acquisition

The image acquisition program based on NI vision calls the pre-edited ActiveX control. ActiveX is the name of Microsoft for a series of object-oriented program technologies and tools. The main technology is the Component Object Model (COM). COM is an industrial standard, which is more suitable for industrial automation.

The block diagram of image acquisition program based on ActiveX in Labview is shown in Figure 3. Directly call the method mv Camera Save Jpg or mv Camera Save Bmp of the ActiveX control, and enter the corresponding path and file name to save the collected image in JPG or BMP format. The speed of the collected image is calculated as 50ms by Labview program, which meets the test functional requirements.

![Figure 3. Program diagram of image acquisition based on ActiveX.](image)

3.2. Image pre-processing

Image pre-processing is mainly to filter the image to make the image smoother. Image filtering in spatial domain is realized by convolution of original image \( f(x, y) \) and impulse response \( h(x, y) \):

\[
g(x, y) = f(x, y) \otimes h(x, y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x', y') h(x-x', y-y') \, dx' \, dy'
\]

(2)

After discretization, it can be seen that the convolution of the image becomes the weighted calculation of the pixel points, and the output is a new image pixel value matrix obtained by

\[
g[i, j] = f[i, j] \otimes h[i, j] = \sum_{k=-m}^{m} \sum_{l=-n}^{n} f[i-k, j-l] h[k, l]
\]

(3)
translating the convolution template to the weighted average of each pixel. In this paper, a 3*3 Gauss operator is used to carry out weighted smoothing filtering on the image. After Gauss filtering, the grayscale histogram of the image and the grayscale histogram of the original image are shown in figure 4 and figure 5.

3.3. Morphological operation and threshold segmentation

Although the image obtained by the industrial camera has been subjected to Gaussian filtering and noise reduction, its image quality does not meet the requirements of edge detection, as shown in Figure 6. Therefore, this paper first performs morphological operations on the image and then performs threshold segmentation to ensure the quality of image processing.

The mathematical morphological processing of the image is mainly used to enhance the contrast of the target boundary of the grayscale image, including three basic operation forms: Erosion, Dilation and Hit-Miss. Corrosion operation on the image can eliminate isolated pixels with relatively high background brightness in the image. The corrosion operation formula is as follows:

$$U(X \ominus B) = \{(x, z) | U(B_{x \ominus z}^1) \subset U(X)\}$$  \hspace{1cm} (4)

The dilation operation can eliminate holes inside the particles in the image. The expansion operation formula is as follows:

$$U(X \oplus B) = \{(x, z) | U(B_{x \oplus z}^1) \subset U^c(X)\}$$  \hspace{1cm} (5)

After three times of open operation, the image is segmented by IMAQ threshold VI to get the result shown in Figure 7.

Figure 4. Histogram of Gaussian filtered image.  Figure 5. Histogram of the original image.

Figure 6. Gaussian filtered image.  Figure 7. Morphology and threshold segmentation image.
3.4. Calibration of measurement coordinate system

The calculation of image needs to be done based on coordinate system. The calibration of coordinate system is an essential step before the measurement of machine vision system.

IMAQ find coordsys (2 rects) 2 VI is provided in NI vision. This VI Computes a coordinate system based on the position of an object in two search areas of an image. The location and orientation of the coordinate system found is used to create the reference position of a Coordinate System or to update the current location and orientation of an existing Coordinate System. The two search regions are given by the IMAQ Convert Rectangle to ROI VI. By specifying two ROI regions, two search regions of the coordinate system are specified. The block diagram of the coordinate system calibration in Labview is shown in Figure 8. The result is shown in Figure 9.

Figure 8. Program for Coordinate System.

Figure 9. Program running results.

3.5. Edge detection

Edge extraction is the core part of the image processing of the test system. It can calculate the liquid level of the test tube by edge extraction to determine whether the leakage is within the qualified range. Many edge detection operators are provided in NI vision, such as Roberts operator, Sobel operator, Prewitt operator, sigma operator and Canny operator. After comparing the advantages and disadvantages of various operators, Canny operator is selected for edge detection. Canny algorithm has good SNR and detection accuracy. The liquid level edge is detected by IMAQ Canny edge detection, and the result is shown in Figure 10.

The essence of Canny algorithm is to use a quasi-Gaussian function as smoothing operation

\[ f_s(x, y) = f(x, y) \times G(x, y) \]

Then locate the maximum value of the derivative with the first-order differential operator with direction. Gradients of \( f_s(x, y) \) can use first-order finite difference approximations.

Figure 10. Canny algorithm results.
\[ P[i, j] \approx (f_x[i, j + 1] - f_x[i, j] + f_x[i + 1, j + 1] - f_x[i + 1, j]) / 2 \]  
(6)

\[ Q[i, j] \approx (f_y[i, j] - f_y[i + 1, j] + f_y[i, j + 1] - f_y[i + 1, j + 1]) / 2 \]  
(7)

The magnitude and direction of gradient can be expressed by \( M[i, j] \) and \( \theta[i, j] \). \( M[i, j] \) reflects the edge intensity of the image. \( \theta[i, j] \) reflects the direction of image edge. The strength and direction can be transformed from the rectangular coordinate system, and the formula is as follows:

\[ M[i, j] = \sqrt{P[i, j]^2 + Q[i, j]^2} \]  
(8)

\[ \theta[i, j] = \arctan(Q[i, j] / P[i, j]) \]  
(9)

Then, NMS is applied to the gradient amplitude, and the pixels with the largest gradient are extracted. Finally, the edge of the image is detected by double threshold method.

4. **Experimental verification**

Through the above image processing algorithm, the liquid level of the test tube can be clearly identified. The image processing algorithm is applied to the actual test process in Labview to verify the feasibility of the vision system. In order to improve the test efficiency, the automatic leakage test is carried out for six cartridge valves at the same time in the actual test. In the visual processing part, the liquid level heights of six transparent tubes are identified at the same time and converted into the leakage amount of the cartridge valve. The test results are controlled by Siemens PLC to turn on the red and green signal lights of the corresponding plug-in valves and inform the test operator whether the test results of the corresponding plug-in valves are qualified.

The main interface of the test system is shown in Figure 11. The interface mainly includes the signal display area, the image processing effects display area, the parameter information area of the current test products in the database, the input area of the test information, and the tested results display area.

![Test system main interface](image)  
**Figure 11.** Test system main interface.
In order to verify the accuracy and reliability of the system, we distinguish the flow value of multiple test tubes through the program and compare it with the accurate flow value measured by the measuring cup. The data is shown in Table 1.

Table 1. Test data comparison table.

| Detection value (ml) | 70.94 | 92.88 | 78.25 | 66.01 | 75.89 | 86.30 | 73.65 | 75.68 |
|---------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Exact value (ml)    | 70.5  | 92.7  | 78.1  | 65.9  | 75.7  | 86.2  | 73.5  | 75.4  |

According to the data in the table, the flows detected by machine vision meet the requirements in accuracy.

5. Conclusion

In this paper, a set of automatic cartridge valve leakage test system based on machine vision technology is developed. The hydraulic principle and control principle of the system are described. Through the analysis of the machine vision algorithm in NI vision, the most appropriate algorithm is found. Finally, through the experiment, it can be concluded that the machine vision technology based on NI vision can be well applied to the leakage test of cartridge valve. The accuracy of the test data meets the requirements. The problems of manual testing are effectively improved, and production efficiency is improved.

References

[1] Zhu S, Gao Y, Non-Contact 3D coordinates measurement of cross-cutting feature points on the surface of large-scale workpiece based on machine vision method[C], Instrumentation and Measurement Technology Conference 2005, Proceedings of the IEEE,2005,2:1255-1259.

[2] Li M, Zhang X, Wang Y, Software design of machine vision detection system for micro-geometry parameter[C], Intelligent Control and Automation, WCICA 2006, The Sixth World Congress on IEEE,2:5294-5298.

[3] Guang-jun Zhang, Vision measurement[M], Science Press, Beijing, 2008.

[4] Cheng Gao, Matlab image processing and application[M], National Defense Industry Press, Beijing, 2007.

[5] Er-dong Gong, Yun-feng Ding, Research on Machine Vision Inspection System Based on Labview, Journal of Changchun University of Science and Technology(Natural Science Edition), Vol.40, No.2, 2017.

[6] Xuan-ming Lu, Chang-rong Yuan, Xiao-ning Li, Improvement Research on the Measurement of Air Leakage and Minimum Working Press in Air Cylinder’s Life Test, Machine Tool & Hydraulics, Vol.40, No.21, 038-3, 2013.