Research Article

Noncontact Defect Detection Method of Automobile Cylinder Block Based on SVM Algorithm

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Based on the problems encountered in the gateway system, this article developed the SVM algorithm support vector machine auxiliary system based on the function of the hybrid network gateway to help the gateway dynamically adjust its operating status to ensure the stability of the gateway system and the real-time internal data. This paper studies the noncontact defect detection system of automobile cylinder block on the basis of the SVM algorithm. There are many thin holes in the wall of automobile engine cylinder block, the structure is complex, and the processing is easy to deform. In order to solve the problem of deformation of the automobile engine cylinder block during the milling process, this paper uses a combination of simulation and experiment to analyze the clamping deformation and milling deformation during the machining of the top surface of the automobile cylinder block and proposes the control of the milling deformation profile error measure. In order to solve the problem of backward detection technology, low detection efficiency, and low detection accuracy for the detection of defects on the inner surface of the master cylinder of automobile brakes, this paper uses the machine vision technology to choose the noncontact method of measurement. The use of laser nonultrasonic contact systems is not limited to workpieces having regular shapes, such as planes and cylinders. It is limited to workpieces with regular shapes such as planes and cylinders. In the automotive and other industrial fields, for various curved parts with free-form surfaces, nondestructive testing techniques of laser nonultrasonic contact systems are generally required to find defects. In the research of the noncontact defect detection method of the automobile cylinder block based on the SVM algorithm, this paper hopes that the detection efficiency and detection accuracy of the inner surface of the brake cylinder can be improved, and the defect location can be accurately found.

1. Introduction

With the development of automobiles, consumers have gradually increased their requirements for automobiles, and continuous breakthroughs in current technical barriers have become the core competitiveness of current auto companies. In this article, the gateway load prediction node is constructed to support the gateway system. Based on the SVM algorithm, the time attention mechanism, the space attention mechanism, and the recently strengthened network structure optimization model are designed to improve the prediction accuracy of the gateway load. In order to eliminate the influence of the fuzzy mode, the fuzzy samples are subdivided to further improve the prediction accuracy [1]. In the machining automation industry, affected by the characteristics of the workpiece material, mechanical vibration, and machining technology, various defects will appear on the surface of the parts. These defects not only destroy the appearance of the parts but also reduce the performance of the parts, mainly reflected in the loose sealing, easy wear, and fatigue strength reduction of the parts. These defects will not only affect the performance of the component but also affect the operation of the component’s equipment, thereby shortening the service life of the equipment and ultimately bringing greater safety risks. In order to ensure the quality of products in the industrial production process, the surface inspection technology of mechanical parts is widely used [2]. The research content of this article includes the compensation hole of the master cylinder of the automobile brake. When inspecting the automobile cylinder, the nondestructive detection of defects using the noncontact method is to use some
scientific treatment without damaging the performance of the inspected object and its microstructure, such as the method and special equipment for detecting the change of the characteristics of the object to be measured [3]. The noncontact method of defect detection occupies an important position in industrial production, and it has an irreplaceable guarantee for the safety of production and the reliability of products. As a new generation of nondestructive testing methods, the laser ultrasonic defect nondestructive testing technology has played an important role in industrial production [4]. Laser ultrasonic defect detection technology uses laser pulses to irradiate the surface of the test sample to excite ultrasonic waves and uses contact or noncontact methods to detect the ultrasonic waves that carry effective information about the test object. Through postsignal processing and analysis, the test object is finally realized [5]. Compared with traditional ultrasonic defect detection methods, laser ultrasonic defect detection technology has the advantages of noncontact, broadband, high time, and space resolution. In addition, the technology can be applied to harsh environments such as high temperature, high pressure, and severe corrosion [6]. Laser ultrasonic technology also shows more and more obvious advantages in nondestructive inspection of test objects with complex curved surfaces. This method overcomes the shortcomings of manual visual inspection and ultrasonic inspection methods, such as low detection efficiency, complex detection process, low detection accuracy, and high false detection rate, and realizes the high-precision, noncontact, high-speed measurement, and intelligentization required for modern measurement [7]. The characteristics provide a certain effect for improving production efficiency, controlling product quality, and testing automated production.

2. Related Work

The application of the SVM algorithm based on the statistical learning theory in classification and prediction was introduced. The penalty factor and kernel function parameters directly affect its accuracy. Usually, it is necessary to optimize the SVM parameter settings. It is carried out by combining optimization techniques, including genetic algorithms and particle algorithms. These methods have a good effect on improving the classification accuracy [8]. The simulation analysis of the top surface deformation of the cylinder block caused by the combined action of the milling force and the clamping force in the milling of the engine block and establishes the relationship between the top surface of the cylinder block and the profile [9]. Orthogonal experiment was used to calibrate the coefficients of each parameter in the cutting force model, and the cutting force model during the milling process of the top surface of the cylinder block was established to provide the required cutting force value for the simulation process of the top surface of the cylinder block milling deformation [10]. Through the simulation of milling deformation, the deformation law of the top surface of the cylinder body was analyzed, and the relationship between the milling deformation of the top surface of the cylinder body and the profile was established. In actual industrial production, the equipment under test often does not have a known contour model. To detect such a complex surface object, it is first necessary to obtain the contour information of the surface object under test [11]. The three-dimensional reconstruction of the object shell based on the monocular camera multicontour occlusion technology used in this paper can obtain the three-dimensional information of the measured surface object, extract the normal displacement of each detection point, and finally realize the automatic nondestructive laser ultrasound in the complex surface component [12]. The application in testing provides key technical achievements. The manual sampling visual inspection method is not only difficult to observe but also very exhausting after working for a long time, which leads to an increase in the false detection rate, and the detection quality cannot be guaranteed, and there are certain hidden safety hazards [13]. In view of this, some companies have tried to use ultrasonic, electromagnetic wave, and other measurement techniques for the research of new detection methods, but the effect is not very satisfactory [14]. This type of detection method has low accuracy and slow detection speed, but it has high requirements for environmental factors and is not suitable for rapid and accurate detection of compensation hole surface defects [15, 16]. The more and more important role of automobile braking system in the safe driving of vehicles was introduced. As the main component of the braking system, the processing quality of the inner surface of the master cylinder is particularly important. Therefore, the demand for braking is constantly increasing [17]. There are more stringent requirements on the quality of brakes. The development of technology provides a solid backing for this emerging detection technology and promotes the wide application of this technology in modern industrial production, especially for quality inspection and processing control products [18].

3. Car Network-Related Theories Based on SVM Algorithm

3.1. Optimization Principle of Support Vector Machine. The Volterra series model can effectively meet the description requirements and achieve a more accurate description process through the description of the nonlinear system. After the analog circuit fails, the core of the Volterra series will change accordingly. It can be described as

\[
y(k) = \sum_{m_1=0}^{\infty} \sum_{m_2=0}^{\infty} \cdots \sum_{m_n=0}^{\infty} h_k(m_1, m_2, \ldots, m_n) u(k - m_1), \ldots, u(k - m_n). \tag{1}
\]
The specific expressions of the first three-order time-domain kernels are

\[
\begin{align*}
  y_1 (k) &= \sum_{m_1=0}^{L_1-1} h_1 (m_1) u(k-m_1), \\
  y_2 (k) &= \sum_{m_1=0}^{L_1-1} \sum_{m_2=0}^{L_2-1} h_2 (m_1, m_2) u(k-m_1) u(k-m_2), \\
  y_3 (k) &= \sum_{m_1=0}^{L_1-1} \sum_{m_2=0}^{L_2-1} \sum_{m_3=0}^{L_3-1} h_3 (m_1, m_2, m_3), \\
  u(k-m_1) u(k-m_2) u(k-m_3).
\end{align*}
\]

Breeding: there is the lowest and highest fitness among all individuals in the population. When determining the seed, the expression number of seeds produced by each weed, in addition to the fitness value are processed by differential mutation. Realize the weed population completes the reproduction and then complete the generation of test individuals by cross-processing the original population and the intermediate population, complete the generation of the test population, and finally screen the test population. The expressions of these two functions are

\[
f(x) = \sum_{i=1}^{n} x_i^2, \quad (8)
\]

\[
f(x) = \sum_{i=1}^{n} (x_i^2 - 10 \cos(2\pi x_i) + 10). \quad (9)
\]

The convergence process of the DEIWO algorithm under the Rastrigin function is faster and more accurate in higher dimensions and effectively solves the problem of the IWO algorithm that is easy to fall into the local optimum and can obtain the global optimum solution.

3.2. Simulation Training of SVM Model. Although the simple two-way LSTM network has a more accurate prediction of the 0 and 1 load, the prediction performance of the 2 load is extremely poor. Compared with the two-way LSTM network, although the optimized network greatly improves the shortcomings of the former, the classification of load levels 1 and 2 is still relatively rough. According to analysis, this situation is said to be unable to resolve the boundary of fuzzy samples. The problem caused the error in the prediction result. Therefore, this article will perform simulation tests on the basic SVM model and the fusion model to verify its feasibility.

After training the input training set of the established SVM model, the confusion matrix diagram shown in Figure 1 can be obtained.

The SVM model roughly predicts the gateway load 0, 1, and 2. At the same time, combined with the ROC (Figure 2) after training, it can be seen that the SVM model has relatively general convergence for the prediction of load levels 0, 1, and 2. The prediction result is not bad. Although the actual gateway load forecasting does not satisfy people, it is enough that the fusion model eliminates the problem of fuzzy sample boundary. People are satisfied, but it is enough that the fusion model eliminates the problem of fuzzy sample boundaries.

After completing the training of all SVMs and optimized network models, it is necessary to determine the final weight ratio of the fusion model to achieve the best prediction effect. During the experiment, during the simulation data input process of the two models, the weight ratio of different combinations was continuously verified, and the actual prediction results of different combinations were recorded. Some weight combinations obtained after repeated training are shown in Table 1:

<table>
<thead>
<tr>
<th>Weight Combination</th>
<th>Prediction Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0, 1.0, 2.0</td>
<td>Poor</td>
</tr>
<tr>
<td>0.1, 0.8, 0.1</td>
<td>Fairly general</td>
</tr>
<tr>
<td>0.3, 0.5, 0.2</td>
<td>Good</td>
</tr>
<tr>
<td>0.5, 0.5, 0.0</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

As shown in Table 1, when the weight of \( W_0 \) is low and the weight of \( W_4 \) is high, the prediction success rate is significantly reduced; when the weight of \( W_4 \) is relatively high and the weight of \( W_0 \) is low, although the predicted gateway increases significantly, the forecast rate will remain at a fixed value without significant changes.
4. Research on Noncontact Defect Detection Method of Automobile Cylinder Block

4.1. Correlation Analysis of Automobile Cylinder Profile. The basic parameters of the process system of the cylinder block production line of a company’s production base are shown in Table 2.

Apply the correct contact pair in the finite element model by understanding the cylinder clamping process. This article will introduce in detail the OP190 station clamping layout and clamping force calculation and the establishment of the cylinder clamping deformation, which provides the corresponding clamping information and clamping force information for the finite element model.

“Profile” is used to evaluate the change between the actual measured profile and the ideal profile of the part. The contour tolerance zone is generally the upper and lower envelopes of a series of spheres with a diameter of \( t \), the center of which is in the reference plane. The area defined by the surface is shown in Figure 3.

The evaluation object of N12 cylinder block top surface contour is the cylinder block top surface. The defined tolerance is 0.1 mm, taking the bottom surface of the cylinder block as a reference, and the distance value is related to the actual shape of the top surface itself. Since the theoretical contour of the cylinder top surface is a plane parallel to the reference plane, the contour value of the cylinder top surface is only related to the distance between the top surface of the cylinder block and the bottom surface of the cylinder block and the reference plane. If the distance \( L \) between the top surface of the cylinder block and the bottom surface is too large or too small, the tolerance zone will not surround the actually machined top surface, resulting in contour error. In the machining process, the milling deformation of the top surface of the cylinder block is the main reason for the fluctuation of the distance \( L \) value. Therefore, the deformation of the top surface of the cylinder block can be used to reflect the contour error of the workpiece. The deformation of the top surface of the cylinder block is equal to the contour error, and the symbol is opposite.

In order to check whether the deformation of the top surface of the cylinder block can reflect the contour error of the top surface of the cylinder block, the actual statistical data Q-DAS data of op190 station of M1 and M2 production lines of engine cylinder block in a base are shown in Table 3.

In order to make the new tool processing more intuitively reflect the data law of the top surface profile of the N12 cylinder, the above data are drawn into a chart, as shown in Figure 4.

It can be seen from Table 3 and Figure 4 that when the T22096 turning needle mills the top surface of the N12 cylinder, the average profile data of point 1 is 236.0031 mm,
and the average profile error is 0.0031 mm; the average profile data of point 2 is 236.0209 mm, and the average profile error is 0.0209 mm; the average data of the point 3 profile is 235.9959 mm, and the average profile error is −0.0044 mm; the average data of the point 4 profile is 235.9818 mm, and the average profile error is −0.0190 mm.

4.2. Analysis of the Principle of Noncontact Defect Detection.
The measurement method based on pulse echo and the time-of-flight analysis method based on diffraction are two traditional methods that use ultrasonic laser technology to detect material defects. Taking surface defects as an example, when the depth of the sample defect is less than the center wavelength of the ultrasonic wave, most of the ultrasonic energy will be diffracted from the bottom of the defect, resulting in small changes in the reflected echo signal and transmitted surface wave signal, and it is not easy to find. Therefore, these two methods are not suitable for detecting surface defects whose depth is less than the wavelength of sound waves. Aiming at the problem that the defect is too small to be accurately detected, the researchers based on the characteristics of the ultrasonic laser technology proposed a method of scanning the laser source. This technology makes full use of the ultrasonic advantages of laser excitation, transforms the original detection mechanism based on the interaction of surface acoustic waves with defects into a detection mechanism based on the interaction of the laser source with the defects and the use of shape changes, and then analyzes the defects. The focal size of the laser source is much smaller than the wavelength of ultrasound. Therefore, the laser source scanning method can greatly improve the ability of laser ultrasound to detect small defects. At the same time, this method has high signal-to-noise ratio and response sensitivity.

The scanning process of the laser source scanning method is shown in Figure 5.

During the scanning process of the laser beam along the sample surface from the far field to the near field and then to the defect area, the laser beam gradually approaches the defect until it passes over the defect. In this process, the interaction between the laser beam and the defect causes the detected surface wave signal to change significantly in terms of amplitude, peak value, and frequency components. Small defects with a depth less than the center wavelength of the ultrasound can also cause significant changes in the ultrasound signal. The study found that when the relative position of the laser beam and the defect changes, the amplitude of the received surface acoustic wave signal also changes significantly. By analyzing the change of the ultrasonic signal during the laser beam scanning process, information such as the position and size of the defect can be obtained.

The laser ultrasonic excitation system and the ultrasonic signal detection system are the main components of the laser ultrasonic noncontact nondestructive testing system. The detection principle is shown in Figure 6.

The excitation system is mainly composed of a laser and a scanning mirror. The pulsed laser is used to generate ultrasonic signals on the surface of the material to be measured, and then the scanning mirror is used to instruct
the laser beam to scan. Ultrasonic laser detection system mainly includes focal Fabry–Perot interferometer, signal amplifier circuit, and other parts. Detect the ultrasonic surface displacement signal generated by the optical interference detection method. The ultrasonic detection system realizes the advantages of noncontact excitation, noncontact reception of ultrasonic signals, and good detection reliability and is suitable for rapid detection in industrial sites.

4.3. Image Acquisition System Design. MER-500-7UM/UC series digital camera is a newly developed digital camera with USB 2.0 interface developed by Daheng Imaging. It adopts 1/2.5 line exposure CMOS sensor chip. The appearance is extremely small and compact, only 29 × 29 × 29 mm, with built-in I/O interface. Cable locking device is provided, which can work stably in various harsh environments. The main performance parameters of the industrial digital camera with high reliability and cost performance are shown in Table 4. Its main performance parameters are shown in Table 4.

<table>
<thead>
<tr>
<th>Experiment number</th>
<th>Contour of point 1</th>
<th>Contour of point 2</th>
<th>Contour of point 3</th>
<th>Contour of point 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual value</td>
<td>Error value</td>
<td>Actual value</td>
<td>Error value</td>
</tr>
<tr>
<td>1</td>
<td>236.0034</td>
<td>0.0034</td>
<td>236.0284</td>
<td>0.0284</td>
</tr>
<tr>
<td>2</td>
<td>236.0096</td>
<td>0.0096</td>
<td>236.0178</td>
<td>0.0178</td>
</tr>
<tr>
<td>3</td>
<td>236.0023</td>
<td>0.0023</td>
<td>236.0166</td>
<td>0.0166</td>
</tr>
<tr>
<td>4</td>
<td>236.0058</td>
<td>0.0058</td>
<td>236.0285</td>
<td>0.0285</td>
</tr>
<tr>
<td>5</td>
<td>236.0108</td>
<td>0.0108</td>
<td>236.0217</td>
<td>0.0215</td>
</tr>
<tr>
<td>6</td>
<td>235.9937</td>
<td>−0.0065</td>
<td>236.0207</td>
<td>0.0207</td>
</tr>
<tr>
<td>7</td>
<td>236.0001</td>
<td>0.0001</td>
<td>236.0198</td>
<td>0.0198</td>
</tr>
<tr>
<td>8</td>
<td>236.0088</td>
<td>0.0088</td>
<td>236.0164</td>
<td>0.0164</td>
</tr>
<tr>
<td>9</td>
<td>235.9983</td>
<td>−0.0019</td>
<td>236.0205</td>
<td>0.0203</td>
</tr>
<tr>
<td>10</td>
<td>235.9983</td>
<td>−0.0019</td>
<td>236.0188</td>
<td>0.0188</td>
</tr>
<tr>
<td>Average value</td>
<td>236.0031</td>
<td>0.0031</td>
<td>236.0209</td>
<td>0.0209</td>
</tr>
</tbody>
</table>

Figure 5: Scanning laser source method.

Table 3: Profile data of the cylinder top surface.

The lens uses a 5-megapixel low-distortion zoom lens, model MG3Z1228FC-MP. Its main performance parameters are shown in Table 5.

The automatic rotating table adopted by the system is a precision electric rotating table, and the model is ZT300-X. The turntable adopts a precisely developed worm gear structure, which is convenient to move and can be rotated back and forth in any direction. Its main performance parameters are shown in Table 6.

The internal parameter model of the camera reflects the conversion relationship between the pixel coordinate system and the camera coordinate system. From the above model analysis of the camera internal parameters, it can be seen that the camera internal parameters mainly include the focal length, the pixel spacing along the X-axis and Y-axis directions. The origin coordinates are transformed from the image coordinate system to the pixel coordinate system and the first-order radial distortion coefficient.

The position of the world coordinate system can be selected arbitrarily, so for the convenience of calculation, the world coordinate system is defined to match the camera.
Table 4: Industrial camera performance parameter table.

<table>
<thead>
<tr>
<th>Model</th>
<th>MER-500-7UM/UC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>2592 (H) × 1944 (V)</td>
</tr>
<tr>
<td>Frame rate</td>
<td>7 fps</td>
</tr>
<tr>
<td>Sensor type</td>
<td>1/2.5 &quot; line exposure CMOS</td>
</tr>
<tr>
<td>Pixel size</td>
<td>2.2 μm × 2.2 μm</td>
</tr>
<tr>
<td>Spectrum</td>
<td>Black and white/color</td>
</tr>
<tr>
<td>Image data format</td>
<td>MONO8/RAW8 (Bayer)/MONO12/RAW12 (Bayer)</td>
</tr>
<tr>
<td>Data interface</td>
<td>Mini USB2.0</td>
</tr>
<tr>
<td>Power consumption</td>
<td>Rated &lt; 1 W (@5V DC)</td>
</tr>
<tr>
<td>Lens interface</td>
<td>C</td>
</tr>
<tr>
<td>Mechanical dimensions</td>
<td>29 mm × 29 mm × 29 mm, without connectors</td>
</tr>
<tr>
<td>Weight</td>
<td>41 g</td>
</tr>
</tbody>
</table>

Table 5: Lens performance parameter table.

<table>
<thead>
<tr>
<th>Model</th>
<th>MG3Z1228FC-MP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target surface size</td>
<td>2/3&quot;</td>
</tr>
<tr>
<td>Focal length</td>
<td>12~36 mm</td>
</tr>
<tr>
<td>Maximum imaging size</td>
<td>8.8 × 6.6 (Φ11) mm</td>
</tr>
<tr>
<td>Aperture range</td>
<td>F2.8~F360 C</td>
</tr>
<tr>
<td>Working distance</td>
<td>0.2~inf m</td>
</tr>
<tr>
<td>Aperture control</td>
<td>DC automatic aperture</td>
</tr>
<tr>
<td>Filter thread</td>
<td>M358 × P0.5 mm</td>
</tr>
<tr>
<td>Interface</td>
<td>C</td>
</tr>
<tr>
<td>Mechanical dimensions</td>
<td>Φ 41.6 × 52 × 53 mm</td>
</tr>
</tbody>
</table>

Table 6: Turntable performance parameter table.

<table>
<thead>
<tr>
<th>Model</th>
<th>ZT300-X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle range</td>
<td>360° around X, Y, Z axes</td>
</tr>
<tr>
<td>Resolution</td>
<td>0.005°</td>
</tr>
<tr>
<td>Positioning accuracy</td>
<td>0.005°</td>
</tr>
<tr>
<td>Table size</td>
<td>150 × 150 mm</td>
</tr>
<tr>
<td>Transmission ratio</td>
<td>180:1</td>
</tr>
<tr>
<td>E body material</td>
<td>Aluminium alloy</td>
</tr>
<tr>
<td>Center bearer</td>
<td>10 kg</td>
</tr>
<tr>
<td>Weight</td>
<td>25 kg</td>
</tr>
<tr>
<td>Mechanical dimensions</td>
<td>Φ 41.6 × 52 × 53 mm</td>
</tr>
</tbody>
</table>
coordinate system, and the plane of the calibration board is on the \( Zw = 0 \) plane of the world coordinate system. Use \( p_i \) to represent each column vector of the rotation matrix \( R \), and \( \sigma \) represents the scale factor (\( \sigma \) is a parameter introduced to facilitate matrix operations. For homogeneous coordinates, the existence of \( \sigma \) will not change the coordinate value). For any point on the plane, there are

\[
\begin{bmatrix}
u \\
v \\
1
\end{bmatrix} = M \begin{bmatrix} p_1 & p_2 & p_3 & t \end{bmatrix} \begin{bmatrix} x_w \\
y_w \\
0 \\
1 \end{bmatrix} = M \begin{bmatrix} p_1 & p_2 & t \end{bmatrix} \begin{bmatrix} x_w \\
y_w \\
1 \end{bmatrix}
\]

\[
A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\
a_{21} & a_{22} & a_{23} \\
a_{31} & a_{32} & 1 \end{bmatrix},
\]

(10)

If the space coordinates and image coordinates of some characteristic points on the calibration plate are known, the unique mapping matrix \( A \) can be solved. Substituting formulas (11) into (12),

\[
\begin{cases}
\sigma u = a_{11} x_w + a_{12} y_w + a_{13} \\
\sigma v = a_{21} x_w + a_{22} y_w + a_{23} \\
\sigma = a_{31} x_w + a_{32} y_w + 1
\end{cases}
\]

(12)

Let \( a' = [a_{11}a_{12}a_{13}a_{21}a_{22}a_{23}a_{31}a_{32}] \), then

\[
\begin{bmatrix}
u \\
v \\
1
\end{bmatrix} = \begin{bmatrix} x_w & y_w & 1 & 0 & 0 & -ux_w & -uy_w \\
0 & 0 & x_w & y_w & 1 & -vx_w & -vy_w
\end{bmatrix} a'.
\]

(13)

After obtaining the homography matrix \( A \), the internal parameters of the camera need to be further analyzed. Use \( ai \) to represent the column vector of \( A \), and then

\[A = [a_1, a_2, a_3] = \varepsilon M \begin{bmatrix} p_1, p_2, t \end{bmatrix}.\]

(14)

Substitute \( p_1 \) and \( p_2 \) into the combination of \( a_1, a_2 \), and \( M \) as an expression, that is, \( p_1 = a_1 M - 1 \), \( p_2 = a_2 M - 1 \). Based on these two constraints, the following two constraint equations are obtained:

\[
\begin{cases}
\begin{bmatrix} a_1^TM^{-1}M^{-1} A_2 \end{bmatrix} = 0, \\
\begin{bmatrix} a_1^TM^{-1} M^{-1} A_1 \end{bmatrix} = a_2^TM^{-1} A_2.
\end{cases}
\]

(15)

Order:

\[
G = M^{-1}M^{-1} = \begin{bmatrix} G_{11} & G_{12} & G_{13} \\
G_{21} & G_{22} & G_{23} \\
G_{31} & G_{32} & G_{33} \end{bmatrix}
\]

\[
= \begin{bmatrix}
\frac{1}{\alpha^2} & \frac{-\gamma}{\alpha^2 \beta} & \frac{\gamma \nu_0 - \beta \nu_0}{\alpha^2 \\
\frac{-\gamma}{\alpha^2 \beta} & \frac{\gamma}{\alpha^2 \beta^2} + \frac{1}{\beta^2} & \frac{-\gamma (\nu_0 - \beta \nu_0)}{\alpha^2 \beta^2} - \frac{\nu_0}{\beta^2} \\
\frac{\gamma \nu_0 - \beta \nu_0}{\alpha^2 \beta} & \frac{-\gamma (\nu_0 - \beta \nu_0)}{\alpha^2 \beta^2} + \frac{\nu_0}{\beta^2} & \frac{\nu_0^2}{\beta^2} + 1
\end{bmatrix}
\]

(16)

According to formula (16), \( G \) is a symmetric matrix. Let:

\[g = [G_{11} G_{12} G_{13} G_{22} G_{23} G_{33}]^T \]

Suppose the vector of \( A \) is \( ai = [ai1, ai2, ai3]^T \), then

\[a_i^T G a_j = V_{ij} g,\]

(17)

of which

\[V_{ij} = \begin{bmatrix}
a_{i1}a_{j1} + a_{i2}a_{j2} \\
a_{i1}a_{j1} + a_{i3}a_{j3} \\
a_{i2}a_{j2} + a_{i3}a_{j3} \\
a_{i2}a_{j2} + a_{i3}a_{j3} \\
a_{i3}a_{j3} + a_{i3}a_{j3} \\
a_{i3}a_{j3} + a_{i3}a_{j3}
\end{bmatrix}.\]

(18)

Using constraint conditions, the following equations can be obtained:

\[
\begin{bmatrix} V_{12}^T \\
V_{11}^T - V_{22}^T \end{bmatrix} g = 0.
\]

(19)

Suppose the number of calibration images is \( N \), and the equations corresponding to \( N \) images are superimposed, then:

\[V \times g = 0.
\]

(20)

Among them, \( V \) is a \( 2N \times 6 \) matrix. Perform coordinate conversion calculations: assuming that the translation transformation matrix from the camera coordinate system to the rotating coordinate system is TCA, the rotation transformation matrix is RCA, and the coordinate transformation matrix is MCA, then
Suppose the transformation matrix that rotates \( \theta \) counterclockwise around the \( O_Y A \) axis of the rotation axis coordinate system is \( R_{\theta Y} \), then

\[
R_{\theta Y} = \begin{bmatrix}
\cos \theta & -\sin \theta & 0 \\
\sin \theta & \cos \theta & 0 \\
0 & 0 & 1
\end{bmatrix}
\]  

(22)

Assuming that the translation transformation matrix from the rotating coordinate system to the initial camera coordinate system is \( T_{AC} \), the rotation transformation matrix is \( R_{AC} \), and the coordinate transformation matrix is \( M_{AC} \) then

\[
M_{AC} = T_{AC} \times R_{AC} = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} R_{AC}.
\]  

(23)

In this way, the point of the object \( P \) is rotated clockwise by \( \theta \) from the coordinates \( P_0 (x_0, y_0, z_0) \) in the camera coordinate system around the rotation axis, thereby obtaining the three-dimensional coordinates \( P_\theta (x_\theta, y_\theta, z_\theta) \) in the initial camera coordinate system. Assuming that the total conversion matrix is \( R_\theta \), then

\[
P_\theta = R_\theta \times P_0 = M_{AC} \left( R_{\theta Y} \left( M_{CA} \times P_0 \right) \right)
\]

\[
= \left( M_{AC} \times R_{\theta Y} \times M_{CA} \right) P_0,
\]

(24)

of which

\[
R_\theta = T_{AC} (R_{AC} \times R_{\theta Y} \times R_{CA}) T_{CA} = T_{AC} \times W \times T_{CA}.
\]  

(25)

And, the rotation transformation matrix \( R_{AC} \) and \( R_{CA} \) are orthogonal matrices; then, \( R_{CA} = R_{AC}^{-1} = R_{AC}T \).

Make

\[
\left[ \begin{array}{c}
\left( b_1^2 + (1 - b_1^2) \cos \theta \right) (X_0 - X_A) + (b_1 b_2 (1 - \cos \theta) + b_3 \sin \theta) (Y_0 - Y_A) \\
+ (b_1 b_3 (1 - \cos \theta) - b_2 \sin \theta) (Z_0 - Z_A) + X_A \\
\left( b_1 b_2 (1 - \cos \theta) - b_3 \sin \theta \right) (X_0 - X_A) + \left( b_1^2 + (1 - b_1^2) \cos \theta \right) (Y_0 - Y_A) \\
+ (b_2 b_3 (1 - \cos \theta) + b_1 \sin \theta) (Z_0 - Z_A) + Y_A \\
\left( b_1 b_3 (1 - \cos \theta) + b_2 \sin \theta \right) (X_0 - X_A) + (b_2 b_3 (1 - \cos \theta) - b_1 \sin \theta) (Y_0 - Y_A) + \left( b_3^2 + (1 - b_3^2) \cos \theta \right) (Z_0 - Z_A) + Z_A
\end{array} \right]
\]

(29)
It can be seen that given the unit direction vector \([b_1 b_2 b_3]\) \(T\) of the axis of rotation line \(L\) in the camera coordinate system and the three-dimensional coordinates of any point on the line, the three-dimensional coordinates of the object point in the camera coordinate system can be obtained by formulas. The three-dimensional coordinates in the initial camera coordinate system, which is the world coordinate system, after the rotating shaft rotates a certain angle, confirms the external parameter model of the image acquisition system.

4.4. Design of Noncontact Defect Detection Process for Automobile Cylinders. The detection system cannot be completely separated from manual participation, and the system must manually participate in the preparatory work before it works. First of all, the system cannot distinguish between different types of workpieces to be tested, or even if it can be automatically identified through programming, it is a complex and arduous task. Therefore, the system uses manual participation to change the positioning position and limit of the fixture according to different types of workpieces. Therefore, the system uses manual participation to change the positioning position of the fixture and the position of the baffle according to different types of workpieces. The system also needs to change the corresponding initial parameter settings in the system software.

Secondly, the clamping work of the workpiece also requires manual participation. Compared with the use of motor control to achieve workpiece clamping, manual participation is more convenient and faster. Finally, the initialization of many hardware devices also requires manual participation, such as the power supply of the motor and the turning on of the light source.

After the preparatory work is completed, the detection method of the detection system will be introduced in detail. The system function has been visually presented on the main interface of the inspection system. The specific inspection steps are as follows: fix the fixture for the rainbow, and enter the workpiece number in the corresponding position on the main interface of the inspection system. According to the model of the part to be tested, set the step length and stop position of the endoscope moving motor in the main interface and set the step length and stop position of the endoscope rotating motor according to the angle of view of the selected endoscope. People click the forward button on the endoscope motion motor module on the main interface, send the endoscope into the brake iris body, and stop moving forward within the maximum coverage of the endoscope. At the same time, the system cooperates with the grating ruler to calculate the position of the endoscope at this time. At this time, select the "capture image" command to take the image at this time. Click the forward button on the endoscope rotating motor module to make the endoscope rotate clockwise, and stop when it reaches the next step to perform the operation. In this process, the system will run the image processing program in the background to detect the image in the image and save the results. The rotating motor continues to rotate the endoscope and stops when it reaches the next step length, and the system runs the image processing program in the background. Repeat the operation until the moving motor reaches the initial stop position and stops. The moving motor pushes the oscilloscope forward and stops when it reaches the next set step. During this process, the rotating motor returns to its initial position in a counterclockwise direction. Repeat four steps until the running motor reaches the stop position and stops.

Checking the inner surface of the entire part, move the motor out of the brake cylinder and return to its initial position. At this point, the detection of defects on the inner surface of the entire part is completed, and finally the system saves the entire detection result for printing and reference. For defective parts, the system will also send out an audible and visual alarm, and the entire discovery process takes about two minutes.

There is a "measurement kit" command in the graphics menu of the main interface of the system. Clicking this command, the system will open a measurement suite dialog box; in this dialog box, you can directly manually manipulate the collected images. The picture has a small flaw. You can use the "ellipse" command in the "operation" menu to roughly wrap the fault area in an ellipse and then click the "measurement manager" command in the "measurement" menu to open the measurement manager dialog box and measure. The manager will list the measurement operations performed on the image, select the ellipse measurement operation, and click the "view" button, you can view the detailed information of the area, such as the center point coordinates, perimeter, and area. Of course, what operation is performed on a certain area of the defect in the image depends on the characteristic shape of the defect. The principle of selection is to ensure that the selected operation can be consistent with the shape of the defect, so as to minimize the error of the defect information of the detected defect. Through the measurement setting dialog box, you can intuitively and vividly obtain the general information of the defect, and at the same time, you can compare these data with the system measurement result to verify the feasibility of the system measurement.

5. Conclusion

This paper proposes a noncontact measurement scheme in view of the backward detection technology, low detection efficiency, and low detection accuracy of the surface defect detection of the automobile brake master cylinder. It is based on machine vision. It has done certain research on the clamping deformation, milling deformation, and contour error control of the top surface of the automobile engine cylinder, and has achieved some results. However, the machining process of the cylinder block of an automobile engine is very complicated, and the machining quality of the cylinder block is affected by many factors. The milling contour error of the top surface of the cylinder block is controlled; from the point of view of machining optimization, during the machining process, the contour error of the cylinder top surface can be controlled by optimizing the clamping force, multipass or variable path machining;
considering machining optimization and machining compensation comprehensively, through the joint optimization of clamping force and machining parameters, the contour error of the upper surface of the cylinder is controlled. Experimental results show that different optimization strategies have different error control effects. Among them, the upper surface contour error control effect based on the optimization of clamping force and processing parameters is the most ideal.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

References