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# Design of Large Size Axle Diameter Measurement System

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## Abstract

In this paper, a new method based on micro array LED dynamic axle diameter measurement system is proposed, which can achieve dynamic, rapid, accurate and non-contact measurement of the diameter of the axle, and combine the latest high-tech non-contact measuring method with the diameter measurement of shaft parts. In this paper, the measurement method is analyzed, and the characteristics of machine vision technology are described in detail, it introduces the working principle of the non contact CCD outer diameter measurement system and the method for measuring axle diameter. And the hardware design of the electronic control system is studied in depth, finally carries on the test to the detection system, in the diameter measurement range of 0~Φ300 mm, the system detection accuracy is less than or equal to ±2 μm, the data meet the detection precision index of the system requirements.

**Key words:** Non-contact measurement; CCD detection; Detection accuracy; Machine vision

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## INTRODUCTION

Machinery industry is an important foundation for the development of national economy, the measurement and testing technology is one of the prerequisites for the development of mechanical industry. Especially at present, the products of the machine industry are becoming more and more precise, so the requirement of the measurement and testing technology and instruments are getting higher and higher. In the process of manufacturing and installation of mechanical equipment, the measurement and quality control of geometric dimension and shape error of main work piece. It is one of the key factors to ensure the quality of equipment, but also the main gap between China's machinery manufacturing technology and abroad. Shaft part is one of the most widely used parts in all kinds of mechanical devices, with the progress of technology, the requirement of the precision and speed of the mechanical device is more and more highly. In the process of mechanical processing, often have to high precision machining of the shaft parts, then the parameter measurement of shaft parts directly affects the machining accuracy, and measurement of the diameter of the shaft parts become more important. At present, there are many methods to measure the diameter of shaft parts, but it is difficult to obtain high precision measurement. Especially for the measurement of the diameter of the shaft in the rotating motion and the complicated condition, there is still some bottleneck. How to improve the measurement accuracy of the shaft diameter is an important subject in machining and installation.

In order to meet the requirement of measuring the diameter of the axle, a non contact measurement method based on machine vision is proposed. It has become a new development trend and direction of modern product quality detection and parameter measurement that combine the latest technology for non contact measurement and the measurement of the diameter of shaft parts more effectively. On line measurement based on machine vision technology, not only can improve the real-time performance of the shaft diameter measurement, but also can ensure the machining accuracy of shaft parts, and has a good application prospect.

# 1. PRINCIPLE OF NON CONTACT MEASUREMENT OF AXLE DIAMETER

## 1.1 Analysis and Selection of Measurement Methods

Based on the analysis of theory, the classification of the diameter of shaft parts is various, according to the interactive relationship between the measuring head and the measured workpiece, the measuring method is divided into two categories, namely contact measurement and non-contact measurement.

(a) Contact measuring method

The contact measurement is defined as the direct contact between the head of the measuring instrument and the measured surface. The typical device with traditional vernier caliper, micrometer, in addition to the inductive principle of the inductance probe. The contact type measuring instrument has many advantages, for example, the operation is simple, reliable, strong versatility, etc.. These characteristics can meet the needs of general measurement, however, there are some deficiencies in the contact measurement: a) because of the contact measurement will be in contact with the measuring workpiece, when measuring high precision components and soft metal, on the surface of the measured workpiece will produce a certain extrusion, so that the accuracy of the measurement results will be affected; b) the result is one-sided and contingency, and it can’t be completely described and reflected; c) as a result of contact measurement, it requires human direct intervention to complete the operation, so it will bring more subjective factors and errors; d) due to the limitation of the contact measurement speed, it is not suitable for online real-time detection and measurement.

(b) Non contact measurement

Non contact measurement is based on the optical and electrical technology, and the development of optical mechanical and electrical integration of measuring equipment. In case of no contact with the surface of the object being measured, that is to say, measuring instruments and the measured surface did not force each other, so as to realize the measurement of a method. This measuring method is the trend of development at present, its application is a very wide range, and the biggest feature is the high precision, high efficiency, does not damage the parts processing surface, and can realize the dynamic measurement. According to the principle of the photoelectric sensor is different, non contact measurement can be divided into the following, mainly have CCD outside diameter detection method, laser scanning diameter method, laser triangulation displacement detection method, eddy current method, machine vision measurement and so on.

In recent years, machine vision technology has been widely used in the measurement of the diameter of shaft parts. Machine vision is a new technology in the field of precision measurement technology, which uses computer to simulate human visual function. The machine vision technology uses a number of cameras to capture the actual image of the measured object, and the required feature information is extracted by the method of image processing, and the final realization of the industrial production process of target detection, size measurement and control and other functions. A typical machine vision application system, its hardware mainly includes lighting, lens, camera, image acquisition card, computer and other components and its software mainly includes image acquisition software, digital image processing software (such as MATLAB) and so on. A lot of techniques have been applied to machine vision, including machinery, electronics, optical imaging, image processing and computer technology and other related technologies, Machine vision technology is very wide, almost can be applied to all testing industry, in terms of detection accuracy, speed and stability are much more than artificial detection. This method of measurement is the organic combination of optical technology and computer image processing, CCD imaging system was used to take the image of the object being measured, and then it is processed and analyzed and recognized by the computer, finally get the measurement data.

The concept of machine vision in industrial applications is different from that of common computer vision, pattern recognition and digital image processing, its characteristics are: a) machine vision is a comprehensive technology, including digital image processing technology, mechanical engineering technology, control technology, electric light source lighting technology, optical imaging technology, sensor technology, analog and digital video technology, computer software and hardware technology, human-computer interface technology, and so on. These technologies in the machine vision is the coordinate relations, mutually coordinated application can constitute a successful industrial machine vision application system. b) Machine vision more emphasis on practicality, the requirements can be adapted to the harsh environment of industrial production, to have a reasonable price, there is a general industrial interface, the machine vision technology can be operated by ordinary workers, there is a high fault tolerance and security, will not damage the industrial products, must have a strong versatility and portability. c) For machine vision engineers, not only to have the ability to study the mathematical theory and the preparation of computer software, but also need more light, machine, electrical integration of the comprehensive ability. d) Machine vision technology has high requirements for real-time, speed and accuracy, so many techniques in computer vision and digital image processing are difficult to be applied in machine vision, and their development speed is much faster than their actual application in industrial production.

 

Simple structure is the basis of the reliability and convenience of the equipment, technology maturity is the premise of the stability and service life of equipment, considering all factors, the diameter measurement system of train axle with non contact measurement method based on machine vision.

### 1.2 Working Principle of CCD Outer Diameter Measuring Instrument System

In this system, we need to detect the diameter of the high precision CCD scanner. CCD scanner system mainly consists of high intensity LED, special diffuse reflection device, collimating lens, telecentric optical system, optical device, CCD image sensor, and used for measurement of HL-CCD and control part. The schematic diagram of the detection system is shown in Figure 1.

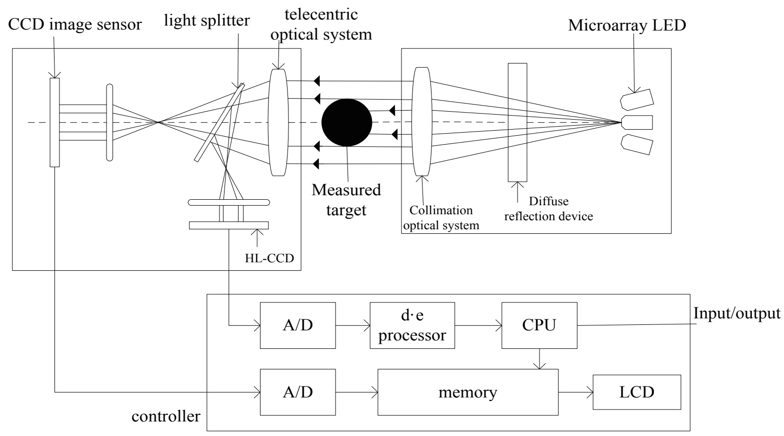


**Figure 1**
**Principle Block Diagram of Detection System**

As is shown in Figure 1. There is a beam of high intensity green LED through a special device and a diffuse collimating optical system. The light that comes out of the collimation optical system is turned into parallel light, because of the existence of the measured object. One part of the light is blocked by the measured target, and the other part of the light is not blocked, the light that has not been blocked, is divided into two parts after the far heart optical system and the optical splitter, part of the imaging in the CCD image sensor, the other part of the imaging to the HL-CCD photosensitive surface. When the light is illuminated to the CCD device. The part that is exposed to light will produce light generated charge, acquisition of light generated charge through the rear circuit, the collected CCD signal output to analog signal processing module; the analog signal processing module converts the collected analog signals into digital signals, and the collected signals are filtered and processed, after processing, the digital signal of the measured target size can be obtained; and then the front and back edges of the digital signals are extracted by the computer. The digital signal is converted to the size of the pulse count value, after the software is processed, the results of the measured workpiece size are given.

### 1.3 Axle Diameter Measuring Method

The output signal of linear array CCD contains the distribution of light intensity received by each pixel of CCD and pixel location information. It is shown in the object size and position detection is very important application value. When light is irradiated to the object, the object is imaged to the CCD image sensor by the objective lens, the charge packet of the measured object size information is stored on the corresponding image sensing unit. The charge packet carrying the size information is converted to a time sequence voltage signal through the conversion circuit, according to the output voltage waveform, the size of the object can be measured, then according to the relation between object and image of the objective lens, find out the optical imaging system magnification $\beta$, and use the following formula to calculate the object's actual size $d$:

$$d=d'/\beta\ . \qquad (1)$$

Obviously, from the Formula 1, we can see that it is very important calculate $d'$, it is not difficult to determine the actual size of the object as long as calculated $d'$. Because of the limited measurement of a single CCD, so we need to use a combination of measurement mode. The combination of measurement mode can measure the large diameter of the object, and does not require complex calculations and other settings.

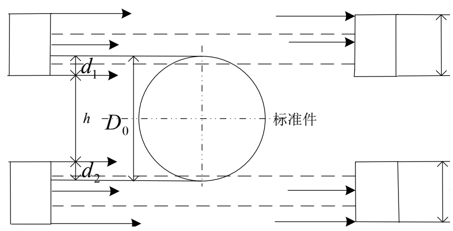


**Figure 2**
**Distance Calibration of Sensor**

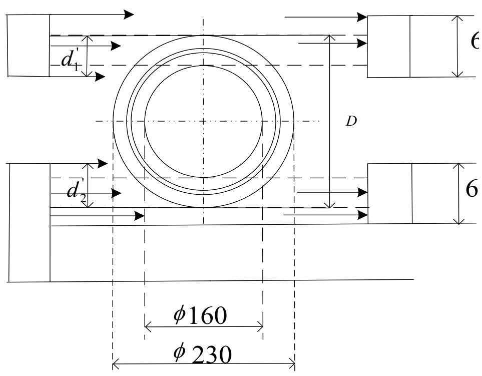


**Figure 3**
**Measurement Principle Diagram**

First of all, as shown in Figure 2, the standard part of the diameter of $D_0$ is placed in the corresponding position. At the same time, recording two sensor data $d_1$ and $d_2$, the distance between the two sensors is $h$:

$$h=D_0-d_1-d_2\,. \tag{2}$$

As shown in Figure 3, remove the standard part and place the measured object in the same position, at the same time, sensor data changes, respectively as $d_1'$ and $d_2'$, so the width of the light that is blocked by the test piece is $d_1'$ and $d_2'$, and the distance between the two sensors is known, therefore the diameter of the measured piece is:

$$D=h+d_1'+d_2'\,. \tag{3}$$

So:

$$D=D_0-d_1-d_2+d_1'+d_2'\,. \tag{4}$$

The axle rotation + 120 degrees, and repeat the measuring axle diameter steps, the sum of every measurement results, divided by the number of measurements, it can be concluded that the average value of the axle diameter, the average value is the diameter of the measuring object.

## 2. AXLE DIAMETER DETECTION SYSTEM AND DRIVE GUIDE MECHANISM

High precision CCD detection of the scanner schematic diagram shown in Figure 4. In the figure we can see, the system is made up of two pairs of CCD to detect the scanner to form a diameter measuring head, the CCD testing scanners are placed on both ends of the shaft so that the diameter of the axle can be measured.

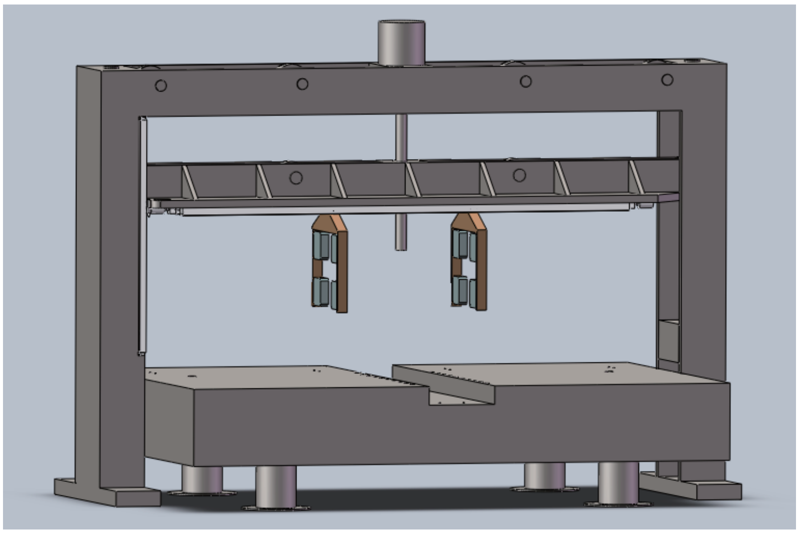

**Figure 4**
**Schematic Diagram of High Precision CCD Scanner**

Axle diameter measurement system based on high precision CCD scanner, the system is mainly composed of two pairs of performance consistent with the CCD scanner, support bracket, connecting plate, grating ruler, drive wire rod and so on. Each pair of CCD detecting scanner is connected with the grating ruler and the screw rod nut through the connecting plate, the position between each pair of CCD detecting scanner is constant. When the servo motor rotates, because of the transmission function of the screw nut, the CCD detects the direction of the scanner to move back and forth along the axis, the grating ruler can control the position of the diameter of the axle and play a guiding role in the axle diameter measurement system. Because of the train axle maximum diameter of 230 mm and minimum is 160 mm, the difference between the diameter of the single side is 35 mm. and CCD scanner emits a laser beam width of 10 mm, 20 mm, 50 mm and 100 mm four kinds of specifications, different specifications of the beam width can measure the diameter range is different. And the width of the laser beam emitted by the CCD scanner has four specifications, which are 10 mm, 20 mm, 50 mm, 100 mm, different specifications of the beam width can be measured in the diameter range is also different. In order to meet the measurement range of the axle 160 mm to 230 mm and the measurement accuracy of the parameters. We choose the self-designed

 

CCD detection scanning and measuring head, and its transmitting beam width is 50 mm, the measured range of the single measuring head for 0.5-65 mm and measuring accuracy is ±0.003 mm.

Servo motor as shown in Figure 5, the servo motor selection model for the 42BYG250C stepper motor. This kind of stepping motor is a kind of actuator which transforms electric pulse into angular displacement, when the stepper driver receives a pulse signal, it drives the stepper motor to rotate a fixed angle in the set direction, this angle called the step angle. The rotation of the stepper motor is running at a fixed angle step by step, and by controlling the pulse number to control the amount of angular displacement, so as to achieve the purpose of accurate positioning. At the same time by controlling the pulse frequency to control the motor rotation speed and acceleration, so as to achieve the purpose of speed. Stepper motor can be used as a control with special motors, with its high accuracy, high reliability, fast dynamic response, widely used in a variety of industrial control systems.

(a) The angular displacement of stepping motor is directly proportional to the input pulse. Therefore, when it is transferred to a week, there is no cumulative error, and with good follow;

(b) The open loop numerical control system composed of stepping motor and drive. It is very simple, cheap and reliable, at the same time, at the same time, it is combined with the angle feedback to form a high performance closed-loop digital control system;

(c) The dynamic response of stepping motor is fast. It is easy to start and stop, forward and reverse, and variable speed;

(d) Stepper motor rotation speed is stable, can be in a wide range of smooth adjustment speed. Under low speed can still guarantee to obtain large torque. Therefore, the general can not speed reducer can directly drive the load.

**Figure 5**
**42BYG250C Type Stepping Motor**

## 3. HARDWARE DESIGN OF AXLE DIAMETER MEASUREMENT SYSTEM

The basic tasks of this measurement system are as follows, first of all, control of the process of scanning and the drive of the scanning motor, high speed real time acquisition of a large amount of information generated by high speed scanning, the signal processing in order to obtain a large amounts of data. Second, the data are processed by the method of real-time data, the measurement of intermediate data set is given, then send these data to the superior computer for calculation, and give the result of the measurement. The measurement system has the following characteristics, fast scanning speed, large amount of information and data processing complex, high real-time and so on. Therefore, we choose single chip microcomputer as the central processor of the system control, it has many advantages, such as large memory, strong function, hardware and software resources rich. At the same time, the measurement system not only realizes the train axle diameter data acquisition, but also realizes the function of data display, storage and printing.

The overall design of the electric control includes four parts, which are composed of motion control system, data acquisition system, data processing system and auxiliary system composition, the following is a brief introduction to the functions of each part. The motion control system mainly completes the control of the linear motor, the rotational torque motor and the hydraulic cylinder, realization of the installation, positioning and measurement of waiting for the measurement of the axle; the data acquisition system mainly completes the acquisition of the diameter data from the output of the CCD scanner; the data processing system is based on the formula and calculation model, converting the photoelectric signal output by the CCD detecting scanner to the diameter data of the measured axis, and the measured data are calculated, displayed, stored and printed. In the whole measurement process, the function of the auxiliary function system, include online monitoring the working state, power protection, fault alarm, fault diagnosis and prompt operation. The block diagram of the system is shown in Figure 6.

 

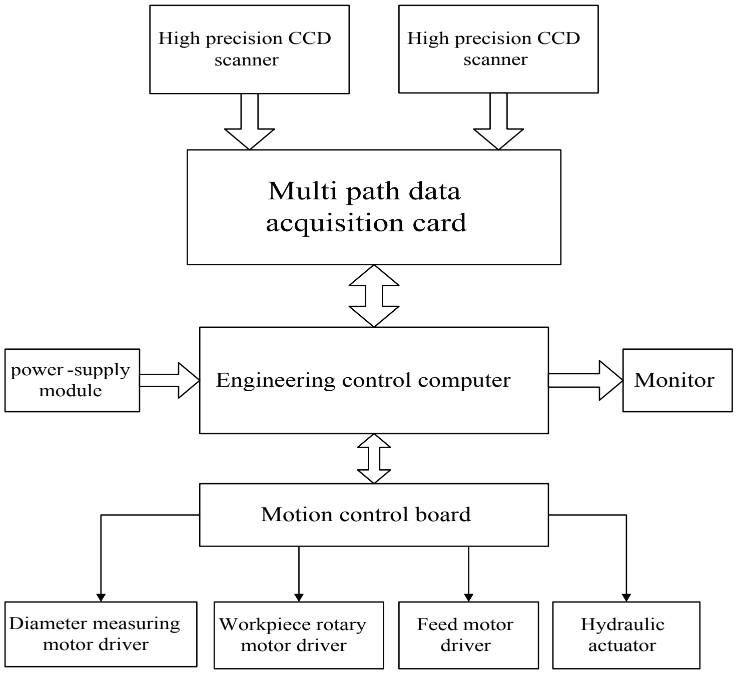


**Figure 6**
**Block Diagram of System Composition**

### 3.1 Motion Control System

Axle parameters measurement system needs to complete the two movements of linear motion and rotational motion. Linear motion is driven by servo motor, simplify the transmission mechanism so that the overall system has the advantages of compact structure and stable movement. In order to make the electronic control system in high precision, high efficiency and has a good man-machine interface, the motion control system using motion control card to realize the control communication between computer and motion control servo driver. As shown in Figure 7.

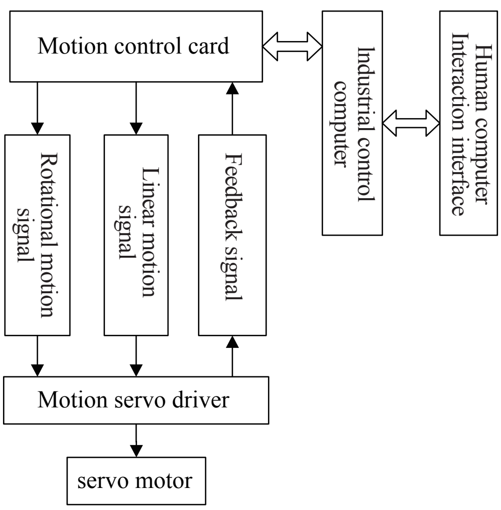


**Figure 7**
**Communication Principle Between Computer and Motion Control Servo Drives**

### 3.2 Diameter Data Acquisition System

The data acquisition system mainly completes the acquisition of the output diameter data of the CCD scanner. Generally speaking, measuring accuracy and measuring range are the main basis for selecting devices, CCD is a discrete sampling device, spatial resolution is one of the most important parameters of it, according to Nyquist sampling theorem, a device is able to distinguish between the highest spatial frequency equal to half of its spatial sampling frequency. The pixel of CCD is made of photosensitive diode, therefore, we should choose the devices with low uniformity and good linearity. Because it is the diameter of the workpiece to be measured is tested in laboratory conditions, on the spectral response and integral time without special requirements, is mainly based on the measurement accuracy to determine the CCD resolution. C omprehensive consideration of the above, in this measurement system, according to the requirement of the measurement accuracy is less than ±2 μm, we choose the production of Toshiba Co TCD1501D. It is a kind of high sensitivity, low dark current, 5000 pixel built-in sampling holding circuit of the linear CCD image sensor. The device works in the 5V pulse driver, 12V power supply conditions, the maximum sampling frequency of 20MSPS.

Spatial resolution is one of the most important parameters of CCD, CCD is a discrete sampling device. According to the Nyquist sampling theorem, half the highest spatial frequency of a device to distinguish equal to its spatial sampling frequency. The pixel of CCD is made of photosensitive diode. Therefore, it should be used in response to non-uniformity of low and good linearity of the device. For measuring the diameter of the workpiece to be measured under laboratory conditions, there is no special requirement for spectral response and integral time, mainly according to the measurement accuracy to determine the resolution of CCD. Comprehensive consideration of the above, and to improve the measurement accuracy of the system is less than ±2 μm, the production of Toshiba Co TCD1501D. It is a kind of high sensitivity, low dark current, 5,000 pixel built-in sampling holding circuit of the linear CCD image sensor. The device works in the 5V pulse driver, 12V power supply conditions, the maximum sampling frequency of 20MSPS.

Data acquisition card selection Art science and technology PCI bus data acquisition card, PCI2326 is a 8 channel digital input and output card. Provide 8 way TTL digital input and 8 way TTL digital output. The minimum voltage of the high level of the digital input channel is 2V, the maximum voltage of the low level is 0.8V. Board 8MHz clock frequency, the operating temperature range of 0~+50 degrees.

Hardware block diagram of the control system of non contact CCD scanner, as shown in Figure 8.

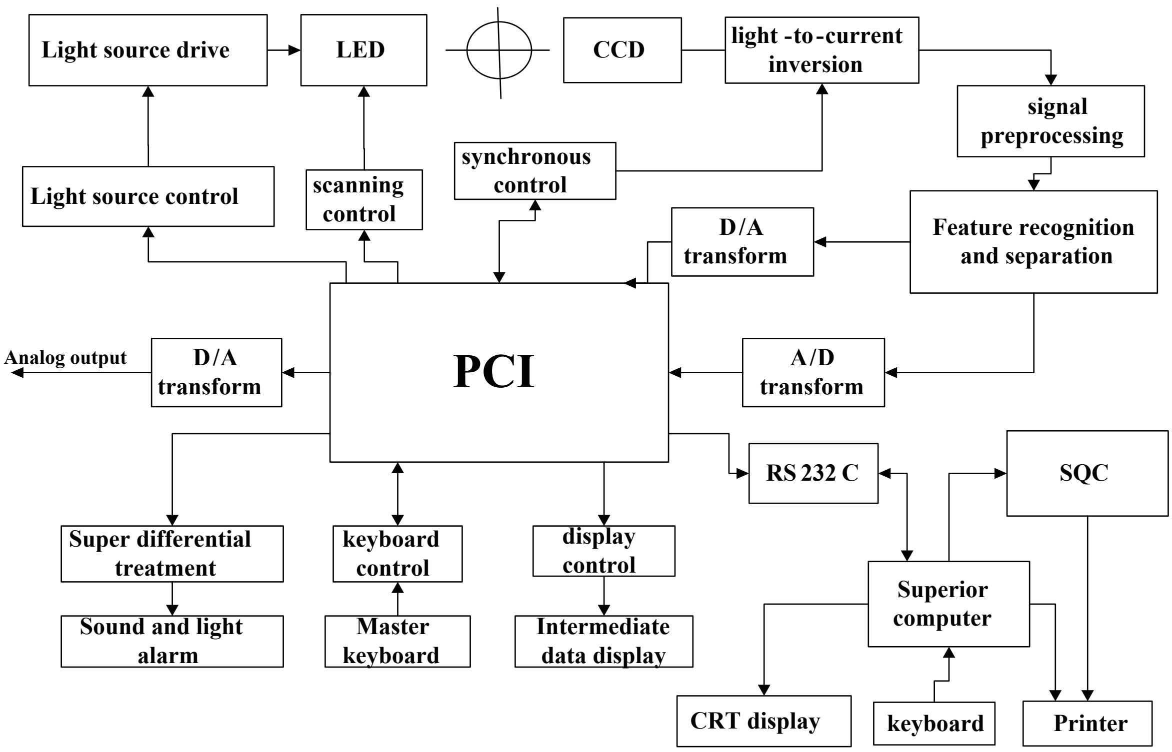


**Figure 8**
**Hardware Block Diagram of the Control System of Non Contact CCD Scanner**

## 4. AXLE DIAMETER MEASUREMENT

The diameter measurement process is shown in Figure 9. Firstly, the system is self checking, and the grating sensor returns the sensor position data of diameter measurement *Sx*, then judge whether the measuring head is located on both sides of the axle according to the position data *Sx*. If the test head is not located on both sides of the axle, the system drives the linear motor to rotate, and the motor drives the screw rod to rotate through the gear box, so that the two measuring diameter sensors are respectively returned to the two sides of the axle, at the same time collecting location data *Sx* from grating sensor. If the position data *Sx* is equal to the initial position data on the both sides S0, and judging the sensor has been homing, then make the measurement of the diameter of the sensor at a uniform speed from both sides to the middle of the run. In the process of diameter measuring sensor movement, the sensor scans a diameter data in a collection period, the sampling frequency is 392KHz and a collection period is about 2.5 ns, the diameter of the collected data is recorded as Di, which i represents the measured diameter data of the i acquisition cycle. And real time observation of the diameter data of the next instruction cycle, and the diameter data collected at this time is subtracted from the diameter data collected in the last period, if the difference is less than or equal to 1 mm, it is indicated that the position of the sensor is not located in the transition point in the instruction cycle, the motor continues to drive the lead screw to drive the diameter of the sensor movement, and constantly collect the diameter data. If the difference is greater than 1mm, it shows that the cycle is the transition point of the shaft diameter, namely the transition position of different diameter shaft.

The first jump point is located in the thimble and shaft position of the transition, the second jump point is located in the shaft neck and dust proof plate of the transition position of two segment of different diameter shaft,the third jump point is located in the dust proof plate seat and wheel seat of the transition position of two segment of different diameter shaft, the fourth jump point is located in the wheel seat and shaft of the transition position of two segment of different diameter shaft. When the jump point is detected, it is necessary to judge whether the jump time is 4 times. Because when the jump is 4 times, it is proved that the diameter of the sensor through the shaft neck, dust version, wheel seat and shaft four jump points. If the number of jumps is not 4 times, it means that the diameter measurement is not over, and the measurement of the diameter of the sensor to continue to run at a constant speed from both sides to the middle, at the same time the displacement data Si returned by the grating ruler is stored. Drive the measurement of the diameter of the sensor to run, and a grating ruler data is detected in a collection period, determine whether the diameter data Si is measured position. If not, the next acquisition cycle will continue to be scanned, and record the data of the grating ruler, then determine whether the position is measured, repeat the above steps. If the diameter data Si is measured position, the memory will store the diameter data Di at this time. When the jump is 4 times, the spindle motor will rotate 120 degrees, and determine whether the rotation of the spindle motor is 3 times, because once rotated 120 degrees, 3 times just rotated a week. If not, the lead screw is driven by a linear motor, drive the two diameter measurement sensor to continue to run at a constant speed from the middle to both sides, repeat all of the above measurement process, or the end of the measurement.

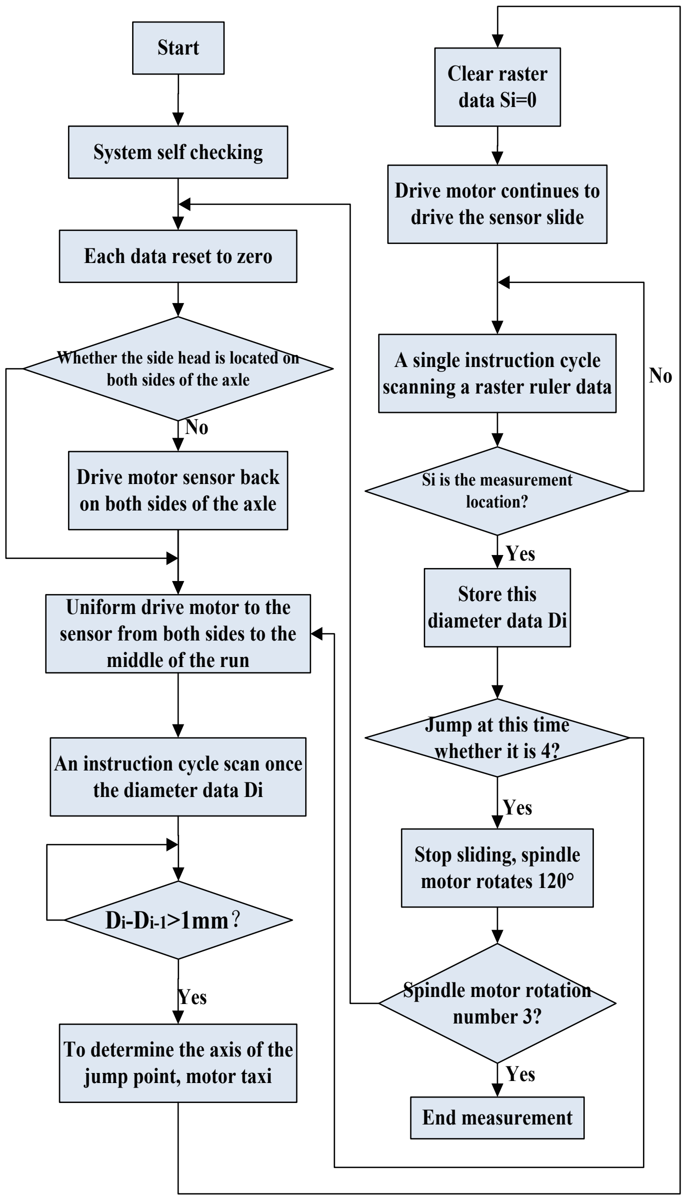


**Figure 9**
**Flow Chart of Diameter Measurement Control**

 

## 5. TEST RESULTS AND ERROR ANALYSIS

### 5.1 Test Data

Large diameter detection experimental system consists of a PC module, keyboard control, liquid crystal display module, diameter detection controller and double probe diameter measuring instrument and a power supply module composition. As shown in Figure10.

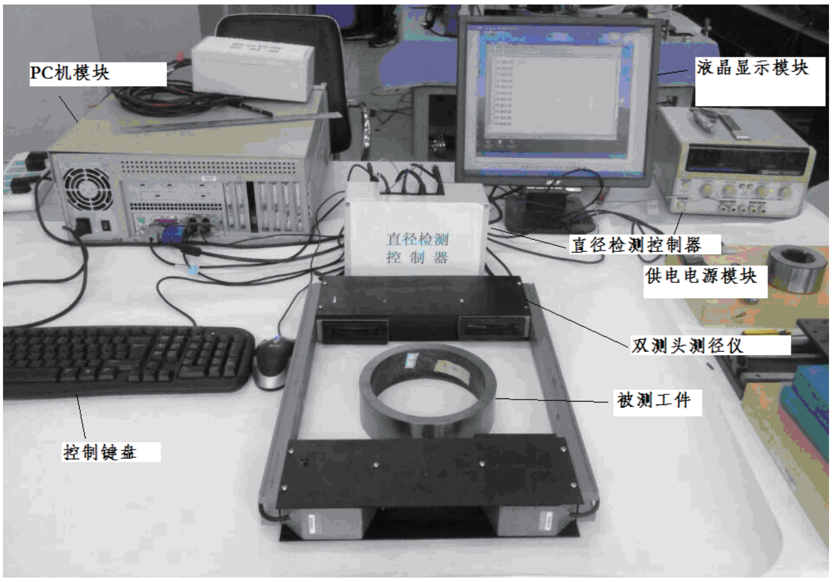


**Figure 10**
**System Device for Detecting Experiment of Large Diameter**

Choose a few standard parts, several experiments on standard samples, after the test statistics are shown in Table 1.

**Table 1**
**Experimental System Diameter Measurement Data**

| Test item name | Standard sample diameter(mm) | Test value (mm) | Required precision (mm) | Error |
|---|---|---|---|---|
| Diameter measurement of 0-25.000mm standard parts | 8.000 | 8.00060 | ±0.002 | 0.00060 |
| | 8.000 | 8.00050 | ±0.002 | 0.00050 |
| | 8.000 | 8.00045 | ±0.002 | 0.00045 |
| | 8.000 | 8.00040 | ±0.002 | 0.00040 |
| | 8.000 | 8.00040 | ±0.002 | 0.00040 |
| Diameter measurement of 0-25.000mm standard parts | 11.991 | 11.99100 | ±0.002 | 0.00000 |
| | 11.991 | 11.99110 | ±0.002 | 0.00010 |
| | 11.991 | 11.99115 | ±0.002 | 0.00015 |
| | 11.991 | 11.99105 | ±0.002 | 0.00005 |
| | 11.991 | 11.99100 | ±0.002 | 0.00000 |
| Diameter measurement of 25.000-50.000mm standard parts | 25.101 | 25.10115 | ±0.002 | 0.00015 |
| | 25.101 | 25.10095 | ±0.002 | -0.00015 |
| | 25.101 | 25.10100 | ±0.002 | 0.00000 |
| | 25.101 | 25.10105 | ±0.002 | 0.00005 |
| | 25.101 | 25.10100 | ±0.002 | 0.00000 |
| Diameter measurement of 150.000-175.000mm standard parts | 172.048 | 172.0481 | ±0.002 | 0.0001 |
| | 172.048 | 172.0484 | ±0.002 | 0.0004 |
| | 172.048 | 172.0486 | ±0.002 | 0.0006 |
| | 172.048 | 172.0487 | ±0.002 | 0.0007 |
| | 172.048 | 172.0484 | ±0.002 | 0.0004 |
| Diameter measurement of 225.000-250.000mm standard parts | 226.755 | 226.7548 | ±0.002 | -0.0002 |
| | 226.755 | 226.7549 | ±0.002 | -0.0001 |
| | 226.755 | 226.7550 | ±0.002 | 0.0000 |
| | 226.755 | 226.7549 | ±0.002 | -0.0001 |
| | 226.755 | 226.7550 | ±0.002 | 0.0000 |

Can be seen from table 1 data analysis, the measurement system can meet the system axle detection system with the proposed diameter detection precision is less than or equal to ±2 μm index requirements.

### 5.2 Diameter Measurement Error and Precision Analysis

Diameter measurement formula:

$$D = D_0 - d_1 - d_2 + d_1' + d_2' . \quad (5)$$

The measurement is an indirect measurement, so there is a formula for the uncertainty of the synthetic standard:

$$u_c(y) = \sqrt{\sum_{i=1}^{m} \left(\frac{\partial F}{\partial \boldsymbol{x}_i}\right)^2 u^2(\boldsymbol{x}_i) + 2\sum_{1\le i<j}^{m} \rho_{ij} \frac{\partial F}{\partial \boldsymbol{x}_i}\frac{\partial F}{\partial x_j} u(\boldsymbol{x}_i)u(x_j)}$$

$$= \sqrt{\sum_{i=1}^{m} a_i^2 u^2(\boldsymbol{x}_i) + 2\sum_{1\le i<j}^{m} \rho_{ij} a_i a_j u(\boldsymbol{x}_i)u(x_j)} \cdot \quad (6)$$

The synthetic uncertainty formula for diameter measurement is:

$$\Delta D = \sqrt{\Delta D_0^2 + \Delta d_1^2 + \Delta d_2^2 + \Delta d'^2_1 + \Delta d'^2_2} . \quad (7)$$

Because the sensor head side good consistency, so you can take $\Delta d_1 = \Delta d_2 = \Delta d_1' = \Delta d_2'$, which form (8):

$$\Delta D = \sqrt{\Delta D_0^2 + 4\Delta d_1^2} \quad (8)$$

The standard block length 150 mm to 200 mm, the standard part of grade 1, and its uncertainty is 0.001 mm. The accuracy of the CCD scanner is 0.003 mm, and the uncertainty of the diameter $\Delta D$ =0.0061 mm.

## CONCLUSION

In this paper, a new method for measuring the diameter of axle of axle based on machine vision is presented, which improves the precision of the shaft diameter measurement. The research of the shaft diameter measurement is improved to a new level, and the measurement system of multiple tests, measuring accuracy of less than ±2 μm, meet the requirements of precision.

## REFERENCES

Barreto, D., & Alvarez, L. D., & Abad, J. (2005). *Motion estimation techniques in super-resolution image reconstruction. A performance evaluation* (pp.254-268). Sveučilište u Zagrebu.

Fan, F. Y. (2008). D*esign of a portable non-contact diameter measurement system based on linear array CCD*. Changchun University of Science and Technology.

Fei, Y. T. (1998). *Error theory and data processing*. Beijing: Machinery Industry Press.

Ghosal, S., & Mehrotra, R. O. (1993). Moment operators for subpixel edge detection. *Pattern Recognition, 26*(3), 295-306.

Guo, L. (2006). *Research and implementation of fast and accurate measurement method for shaft parts based on CCD* (pp.9-12). University of Chongqing.

Heath, M., Sarkar, S., Sanocki, T., & Bowyer, K. (1998). Comparison of edge detectors. *Computer Vision and Image Understanding, 69*(1), 38-54.

Jiang, Z. N., & Yi, Q. S. (2013). Data processing of non contact diameter measurement experiment based on CCD. *Journal of Guangxi Normal University for Nationalities, 30*(3), 22-23.

Jiang, X. Y., & Bunke, H. (1999). Edge detection in range images based on scan line approximation. *Computer Vision and Image Understanding, 73*(2), 183-199.

Jin, T., & Luo, B. (2011). High speed transmission and control design of CCD photoelectric measurement signal. *Modern electronic technology, 34*(18), 142-145.

Li, S. X. (2012). *Design and research of industrial camera data acquisition system for linear array CCD*. Nanjing University of Science and Technology.

Li, Y. S., Young, T. Y., & Magerl, J. A. (1988). SubPixel edge detection and estimation with amicroprocessor-controlled line scan camera. *IEEE Transactions on Industrial Electronies, 35*(1), 105-112.

Liang, S. J. (2011). *Research on non contact diameter measurement system based on linear array CCD.* Nanjing University of Science and Technology.

Ma, D. J., Zhu, N., & Wang, C. J. (2006). Application of linear array CCD in high precision measurement system. *Computer Measurement and Control, 14*(2).

Ma, H. (2009). *Instrument accuracy theory* (pp.109-113). Beijing: Beijing University of Aeronautics and Astronautics Press.

Shin, M. C. (2001). Comparison of edge detector performance through use in an object recognition task. *Computer Vision and Image Understanding, 84,* 160-178.

Sun, N. (2003). *Research on non contact measurement system using CCD's relative position* (pp.7-9). Beijing: Graduate School of the Chinese Academy of Sciences.

Szafarczyk, M., & Misiewski, M. (1983). Automatic measurement and correction of workpiece diameter on NC center lathe. *Annals of the CIPP, 32*(1).

Tang, T. S., Li, H., & You, Q. X. (2013). A new method to improve the measurement accuracy based on CCD. *Optical Technology, 39*(1), 82-83.

Tsai, R. Y. (19987). A versatile camera calibration teehnique for high-accuracy 3D machine vision metrology using off-the-shelf TV cameras and lenses. *IEEE Journal of Robotics and Automation, 3*(4), 323-344.

Wang, X. L., Duan, C. X., & Zhou, Y. (2011). Research on the method of high precision non-contact automatic measurement of outside diameter. *Instrument Technique and Sensor,* (8), 79-81.

 

Weng, J. Y., Cohen, P., & Hemiou, M. (1992). Camera calibration with distortion models and accuracy evaluation. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 14*(10), 965-980.

Wu, M. H. (2011). *Research on non contact micro displacement measurement system based on linear array CCD*. Changchun University of Science and Technology.

Xu, X. Y. (2009). The working principle and application status of CCD. *Audio Visual Radio and Television Technology,* (5), 81-85.

Yan, L. W. (2008). *Research on the measurement method and key technology of high precision large shaft parts* (pp.1-2). Shanghai University.

Ye, J., Fu, G. K., & Poudel, U. P. (2005). High-accuracy edge detection with blurred edge model. *Image and Vision Computing, 23*(5), 453-467.

Zeng, L. J., Matsumto, H., & Keiji, K., et al. (1997). Two-directional scanning method for reducing the shadow effect in laser triangulation. *Measurement Science & Technology, 8,* 262-266.

Zhang, G. Y., An, Y., & Zhang, C. Z., et al. (1997). A dimension measuring system using semiconductor laser. *Acta Armamntarii, 18*(2), 125-128.

Zheng, W. X. (1992). *The instrument accuracy design* (pp.22-43). Beijing: The Publishing House of Ordnance Industry.