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Universal Tool Microscope Computer Aided Measurement System Based on Machine Vision Technology

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Abstract
With the rapid development of China's manufacturing industry, the requirements of measurement technology in the fields of aviation, aerospace, shipbuilding and vehicles are getting higher and higher, especially in the precision measurement of geometric quantity. The advanced nature of measurement technology determines the advancement of product. However, most of the geometric measurement systems currently used in many industries have problems such as low measurement accuracy and poor system stability, which seriously affect the application of precision geometric measurement technology in industrial manufacturing and restrict the development of the manufacturing industry. In order to solve these problems, this paper designs a geometric precision measurement system based on machine vision technology. The system is composed of two tools: image processing and raster signal processing. In order to verify the relevant performance of the measurement system, the parameters of the reading, measurement accuracy and other parameters were verified experimentally. The results show that the measurement system has the characteristics of accurate reading and high measurement accuracy, especially for the measurement of standard parts, and its accuracy is completely higher than other similar products. The results show that the universal tool microscope computer-aided measurement system designed in this paper has good performance in measurement and can be applied to the precision parts measurement in the manufacturing industry.

Key words: Machine Vision, Precision Measurement, Image Processing, Measurement System

1. Introduction

Today, with the rapid development of science and technology, modern precision measurement technology plays an important role in the development of a country. In modern industrial manufacturing technology and scientific research, with the continuous development of manufacturing industries such as large-scale precision machinery and ultra-large-scale integrated circuits, measuring instruments have a trend of precision, integration, and intelligence, and various manufacturing industries are highly accurate and high. The demand for efficiency, large-scale and microscopic instruments and their measurement methods is increasing, and the precision measurement technology for geometric quantities is beginning to occupy an increasingly important position in the field of metrology and testing. According to the industry demand and the development trend of products, the development of geometric precision measurement system can effectively make up for the shortcomings of China's measurement technology, and at the same time promote the development of China's manufacturing industry [1].

In recent years, as the manufacturing industry has become more and more demanding for measurement technology, many scholars and related institutions at home and abroad have conducted research on precision measurement systems. For example, the CONTURA G2 three-coordinate measuring instrument produced by Zeiss, Germany, can measure the shape error of large and complex workpieces and maintain stable measurement accuracy during the measurement. Professor Takamatsu of the University of Tokyo developed the Nano.CMM two-dimensional measurement platform, which uses the grating ruler for displacement measurement. The coplanar design of the platform is based on the traditional reduction principle, and the structure uses a symmetric mobile bridge CMM to reduce the design and Friction transmission mechanism design, this structural design greatly reduces the straightness error of the platform. In addition, due to the use of the grating scale, the displacement repeatability accuracy and overall accuracy are relatively high. The UK NPL has designed the SCMM measuring machine, a three-dimensional measuring mechanism that attaches a high precision micro-workbench to a traditional high-precision CMM table with an uncertainty of nanometers, but the table still has motion error. The high-precision three-dimensional measuring machine 3D-CMM developed by the University of Eindhoven in the Netherlands has an uncertainty of less than 100 nm. The three-point symmetry machine structure design effectively reduces the coupling error in motion [2]. The Ultra precision CMM developed by METAS in Switzerland, the measuring line of the axis interferometer intersects the measuring head at one point, and the measuring head suspension adopts a flexible mechanism. The repeatability error of each axis is 5nm, and the overall accuracy can reach 30nm [3]. Domestic research on precision measurement started late, but in recent years, under the efforts of various universities, it has also made great achievements. Feng Li of Xi'an University of Technology designed a micro-part precision measuring device based on flexible guide rail. The measuring device has the advantages of simple structure and convenient operation. The guiding mechanism based on flexible structure in the device can basically achieve micro-scale motion precision in the measuring surface and measurement accuracy. However, due to the improper arrangement of the stylus and the sensor, it is easy to cause measurement error [4]. Hao Huadong et al. studied the precise measurement method of small-axis coaxiality based on structured light three-dimensional scanning technology [5]. Bi Chao and Fang Jianguo, based on the three-axis motion platform, installed sensors such as linear displacement sensors and multi-axis motion controllers to design a measuring mechanism for measuring the cone angle of the fuel nozzle [6]. From the perspective of measurement principle and measurement accuracy, Du Fuzhou and Wenke analyzed the current digital measurement equipment and studied large-scale precision measurement technology.

After reviewing the historical literature and analyzing the existing research, it is found that the current precision measurement system has the following problems: (1). When reading the measured values, the reading process is not only cumbersome and error-prone; (2). Multiple times When measuring the workpiece, the measurement system needs to be calibrated frequently; (3). Although the precision measurement system is high, the reading of the value is still traditional manual reading, and the relative error is large; (4). The intelligence degree of the measurement system Lower, the measurement efficiency is low.

Machine vision mainly uses computer to simulate human visual function, extract information from the image of objective things, process and understand it, and finally use it for actual detection, measurement and control. At present, machine vision technology has been widely used in many industries. Machine vision processes, analyzes, and understands images to identify targets and objects in a variety of different modes. It can achieve traceability and collection of data, and is widely used in auto parts, food, medicine, etc. [7]. Laser processing is a widely used industrial processing technology. With the upgrading of laser processing technology, traditional technology can no longer meet the requirements of industrial processing for high precision and high speed, which makes machine vision technology and laser processing technology begin to merge, through visual Positioning and guiding to achieve high-precision machining, reducing the need for high-cost precision fixtures, improving equipment accuracy and reducing processing costs. In the pharmaceutical industry, recognition uses machine vision to process, analyze, and understand images to identify targets and objects in a variety of different modes. Through the machine vision means to achieve quality control and management control of the pharmaceutical production process, can improve the quality of medicines and packaging, and ensure the safety of patients [8].

In summary, machine vision can be regarded as the eye of the machine, and the analysis and judgment of the target object can be realized through the program, and specific precise information is provided for the specific action of the machine. Therefore, machine vision technology can be applied to the research of computer-aided measurement systems for universal tool microscopes. Based on machine vision technology, this paper designs a universal tool microscope auxiliary measurement system. The system has an automatic reading function, which can stably and effectively read measurement data, greatly improving measurement efficiency. In the experiments of measuring the glass ruler and the standard gauge, the system showed a high measurement accuracy, which indicates that the measurement system has good practical application performance.

2. Method

2.1. Machine Vision for the Basis of Dimensional Measurements

Machine vision systems can be divided into: image sensors, image acquisition cards, and image processing sections. The general vision system is composed of several parts as shown in Figure 1. The basis of machine vision technology applied to geometric dimension measurement is edge detection [9]. The so-called edge refers to the edge of the bright part and the dark part of the image. The image sensor can display the inspection object on the plane, and measure the geometric dimensions such as length, circle and angle through edge detection.

(1) Edge Acquisition

In image processing, the edges can be obtained by the following three processes.

1) Projection processing is performed on an image in a measurement area. The projection process is a vertical scan with respect to the inspection direction, and then the average density of each projection line is calculated. The projected line average density waveform is called a projected waveform. By calculating the average concentration of the projection direction, it is possible to reduce the inspection error caused by noise in the area.

2) Perform differential processing based on the projected waveform. A part that may become an edge with a large change in shading has a large differential value. For example, the differential value of the portion where

there is no shading change is zero. The value when white (255) changes to black (0) are -255. The effect of the change in the absolute value of the concentration in the region can be eliminated by the processing of the change in the density (level). In the actual measurement, in order to achieve a stable state of the edge, appropriate adjustments are usually made to make the absolute value of the differential reach 100%. The peak value of the differential waveform exceeding the “edge sensitivity (%)” set in advance is taken as the edge position. According to the detection principle of the peak value of the shading change, the edge can be stably detected on the production line where the illuminance often changes.

3) Sub-pixel processing, in which three pixels near the center of the largest portion of the differential waveform are subjected to correction calculation based on the waveform formed by the three pixels. The boundary position (sub-pixel processing) is measured in units of 1/100 pixels.

(2) Representative Detection Application of Edge Detection

Edge checking has the following derived patterns. The representative applications of geometric information measurement are described below.

1) The X-coordinate or Y-coordinate of the detection object is measured by various inspections of the edge position, that is, the edge position mode is set at a plurality of locations.

2) Using the “outer size” mode of the edge width, the width of the metal plate, the X-direction/Y-direction aperture of the hole, and the like are detected by various inspections of the edge width.

3) Using the various inspections of the circumferential area of the edge position, the circumference is used as the detection area, and the angle (phase) of the cutout portion is detected.

4) The trend edge position (width) mode refers to detecting the edge position while scanning a narrow edge window in the inspection area. With this inspection mode, edge position (width) inspection can be performed for multiple points within a window, thus ensuring small changes in the captured workpiece. For example, using various inspections of the trend edge width, the inner diameter of the annular workpiece, the flatness is evaluated, etc. using the “trend edge width” mode of the circumferential region.

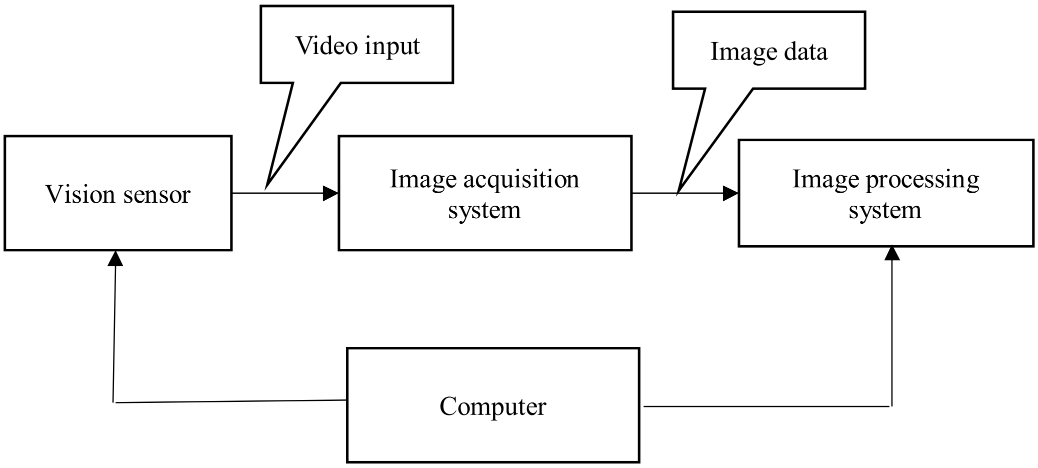

Figure 1. Machine vision system composition

2.2. System Design Overview

In the computer-aided measurement system of the universal tool microscope designed in this paper, the mechanical structure is selected from the domestic 19JA universal tool microscope [10]. The 19JA universal tool microscope is suitable for precision measurement of length and angle. At the same time, it is easy to make simple modification design because it is equipped with a variety of accessories, which is in line with the design requirements of the measurement system. A grating scale is respectively mounted on the rear side of the X guide rail of the 19JA universal tool microscope and the right side of the Y guide rail, and the two grating scales are respectively provided with a grating signal processing card for collecting and processing the grating signals of the X guide rail and the Y guide rail. The illumination system of the measurement system follows the illumination system of the universal tool microscope itself, and uses the objective lens of the microscope and the CCD image sensor to form three new imaging systems for aiming and reading X- and Y-direction readings, respectively. In the imaging system, the function of the CCD sensor is equivalent to the human eye in the conventional measurement, and the acquired image information can be transmitted to the computer via the image acquisition card [11]. Aiming is done by adjusting the point to be measured and the “meter” on the computer screen.

The measurement principle framework is shown in Figure 2. Before the measurement, the aiming is first, that is, the point to be measured on the workpiece is adjusted to coincide with the center point of the "meter" line. The imaging system consisting of the objective lens and the CCD image sensor is used to image the workpiece to be measured, and the image is transmitted to the computer through the image acquisition card, and the image is grayed out, smoothed, and edge detected. The grating signal obtained by the grating ruler is collected and processed by the FPGA in the grating signal processing module, and the counting data outputted by the FPGA is controlled and managed by the single chip microcomputer, converted into relative displacement amount and sent to the computer for integer reading; the image acquired by the CCD image sensor is The millimeter line on the glass scale, the image is sent to the computer through the image acquisition card for image processing, and the algorithm can determine the position of the reticle to obtain the decimal position reading. The integer bit reading is added to the decimal place reading to obtain the coordinate value of the measuring point and recorded, and the next point to be measured can be measured. In the plane geometry, two points can determine a straight line, and three points can determine a circle. Therefore, the length information can be known by measuring the coordinate values of the two points, and the diameter information can be known by measuring the coordinate values of the three points. For the angle measurement, two points can be taken on the two boundaries of the angle to be measured to measure the coordinate values, and the angle information can be obtained. After the measured coordinate point information is analyzed by the algorithm, the obtained geometric information such as length, angle and diameter are imported into the Auto CAD software, and the graphic size of the measured workpiece can be obtained.

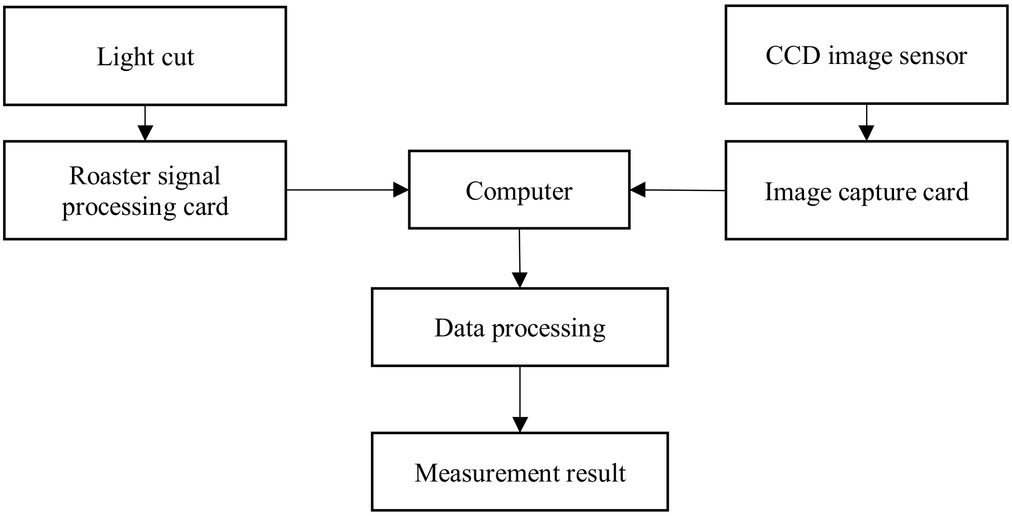

Figure 2. System measurement principle

2.3. Image Processing

The millimeter line image acquired by the image sensor is a color image. In the image processing, the image image processing system is slowed down due to the excessive amount of data, so the image needs to be grayed out. In addition, in the image transmission process, image distortion occurs due to the presence of noise, so a series of image preprocessing such as noise reduction, smoothing, and filtering is required.

(1) Image Graying

The process of converting a color image into a grayscale image becomes a grayscale process of the image. The color of each pixel in the color image is determined by three components: R, G, B (red, green, blue), and each component has a median value of 255, so that one pixel can have more than 16 million (255*255*255) the range of color variations. The grayscale image is a special color image with the same components of R, G and B. The range of one pixel is 255. Therefore, in the digital image processing, the images of various formats are first converted into gray [12]. The degree image is such that the amount of calculation of subsequent images becomes less. There are several ways to deal with image graying:

1) The component method, that is, the luminance of the three components in the color image is used as the gray value of the three grayscale images, and a grayscale image can be selected according to the application requirements:

$$\mathrm{Gray}_1(i,j) = R(i,j) \quad (1)$$

$$\mathrm{Gray}_2(i,j) = G(i,j) \quad (2)$$

$$\mathrm{Gray}_3(i,j) = B(i,j) \quad (3)$$

2) The maximum value method is to use the maximum value of the three-component luminance in the color image as the grayscale value of the grayscale image.

$$\text{Gray}(i,j) = \max\{R(i,j), G(i,j), B(i,j)\} \tag{4}$$

3) The average method is to average the three component luminances in the color image to obtain a gray value:

$$\text{Gray}(i,j) = \frac{R(i,j)+G(i,j)+B(i,j)}{3} \tag{5}$$

4) The weighted average method, based on importance and other indicators, weights the three components by different weights. Since the human eye is most sensitive to green and the least sensitive to blue, the weighted average of the RGB three components can be used to obtain a more reasonable grayscale image.

$$\text{Gray}(i,j) = 0.299 * R(i,j) + 0.578 * G(i,j) + 0.114 * B(i,j) \tag{6}$$

In the formula, 0.299, 0.578, and 0.114 are weighting coefficients based on experience.

(2) Image Smoothing

Image filtering, that is, suppressing the noise of the target image under the condition of retaining the image details as much as possible [13], is an indispensable operation in image preprocessing, and the processing effect will directly affect the effectiveness of subsequent images. Eliminating noise in an image is called smoothing the image. Typically, the energy of a signal or image is concentrated primarily in the low and mid bands of the amplitude spectrum, so this article is selected from low pass filtering for image smoothing [14]. Low-pass filtering is a frequency domain smoothing method that smoothes high-frequency components and preserves low-frequency components. Its filtering formula is:

$$G(U,V) = H(U,V)F(U,V) \tag{7}$$

Where F (U, V) is the original image spectrum, G (U, V) is the smoothed image spectrum, and H (U, V) is the transfer (transfer) function. The steps are as follows: fourier transform the original image f(x, y), transform the image from the spatial domain to the frequency domain, and obtain the image spectrum F(U, V), and then pass the transfer function H(U, V) with low The pass filter formula changes F(U, V), and finally the inverse-Fourier transform of the filtered spectrum G(U, V) is performed to obtain the filtered image g(x, y).

2.4. Discrete Point Fitting

In image processing analysis, by fitting the grayscale or coordinates of the target in the discrete image [15], a continuous function form of the target can be obtained, thereby determining various parameter values describing the object. In this paper, the least square method is used to fit the curve of discrete targets. In the following, this paper deduces the optimal solution method of the least squares method.

Given n discrete points $x_1, x_2, \cdots, x_n$, it can be expressed as a linear function as follows:

$$y = \beta_0 + \beta_1 x_1 + \beta_1 x_2 + \cdots + \beta_n x_n \tag{8}$$

For m samples, it can be represented by the following linear equations:

$$\beta_0 + \beta_1 x_{11} + \beta_1 x_{12} + \cdots + \beta_n x_{1n} = y_1 \tag{9}$$

$$\beta_0 + \beta_1 x_{12} + \beta_1 x_{22} + \cdots + \beta_n x_{2n} = y_2 \tag{10}$$

$$\beta_0 + \beta_1 x_{m1} + \beta_1 x_{m2} + \cdots + \beta_n x_{mn} = y_m \tag{11}$$

If the sample matrix x_{ij} is denoted as matrix A, the parameter matrix is denoted as vector β, and the true value is denoted as vector Y, the above linear equations can be expressed as:

$$\begin{pmatrix} 1 & x_{11} & x_{12} & x_{13} & \cdots & x_{1n} \\ 1 & x_{21} & x_{22} & x_{23} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & x_{m1} & x_{m2} & x_{m3} & \cdots & x_{mn} \end{pmatrix} \begin{pmatrix} \beta_0 \\ \beta_1 \\ \vdots \\ \beta_n \end{pmatrix} = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_m \end{pmatrix} \tag{12}$$

That is $A\beta = Y$. For the least squares, the final matrix expression can be expressed as:

$$\min ||A\beta - Y||_2^2, A \in R^{m*(n+1)}, \beta \in R^{1*(n+1)}, Y \in R^{m*1} \tag{13}$$

Where $m \geq n$, since the constant term is considered, the number of attribute values is changed from n to n+1. Solve the above equation:

$$||A\beta - Y||_2^2 = (A\beta - Y)^T(A\beta - Y) \tag{14}$$

$$= (\beta^T A^T - Y^T)(A\beta - Y) \tag{15}$$

$$= \beta^T A^T A\beta - 2\beta^T A^T Y + Y^T Y \tag{16}$$

Using $\beta^T A^T A\beta - 2\beta^T A^T Y + Y^T Y$ to obtain β:

$$\frac{\partial(\beta^T A^T A\beta - 2\beta^T A^T Y + Y^T Y)}{\partial\beta} = \frac{\partial(\beta^T A^T A\beta)}{\partial\beta} - 2A^T Y \tag{17}$$

According to the matrix's derivation rule:

$$\frac{\partial(\beta^T A^T A\beta)}{\partial\beta} - 2A^T Y = 2(A^T A\beta - A^T Y) \tag{18}$$

Let the above formula be equal to zero, you can get:

$$(A^T A)\beta = A^T Y \Leftrightarrow \beta = (A^T A)^{-1} A^T Y \tag{19}$$

The above formula is the analytical solution of the least squares method, which is a global optimal solution.

2.5. Grating Measurement and Signal Processing

The measurement of the grating combines the absolute measurement in one cycle with the incremental measurement outside the cycle. The absolute measurement is performed by subdividing the pitch in the interval of one cycle, and the range exceeding the cycle is measured using continuous increment. In order to ensure the accuracy of the measurement, in addition to the grating quality and motion accuracy requirements, it is necessary to have certain requirements on the moire signal quality of the grating, because this will affect the accuracy of the grating. The subdivision quantity and spacing accuracy also affect the accuracy and measurement step size of the grating measurement system. The requirements for the moire fringe signal quality are mainly the sine and quadrature of the signal; the signal DC level drift is small. The photoelectric conversion circuit in the read head and the subsequent digital interpolation circuit require good frequency characteristics to ensure high measurement speed.

In the measurement system designed in this paper, the raster signal processing module is responsible for the reading of integer bits, which is the core module of the system to achieve automatic reading. The grating signal processing module is mainly composed of a shaping filter circuit, an FPGA, a single chip microcomputer and a power source. The shaping filter circuit is to eliminate the influence of the sharp pulse in the grating signal on the system, and transform the output signal into a standard square wave signal through filtering; the FPGA is to output, select, count and count the output of the raster signal; the main function is to control and manage the FPGA logic circuit, convert the output count data into displacement amount and send it to the computer for processing; the function of the power supply is to supply power for the entire module. The block diagram of the grating signal processing module is shown in Figure 3.

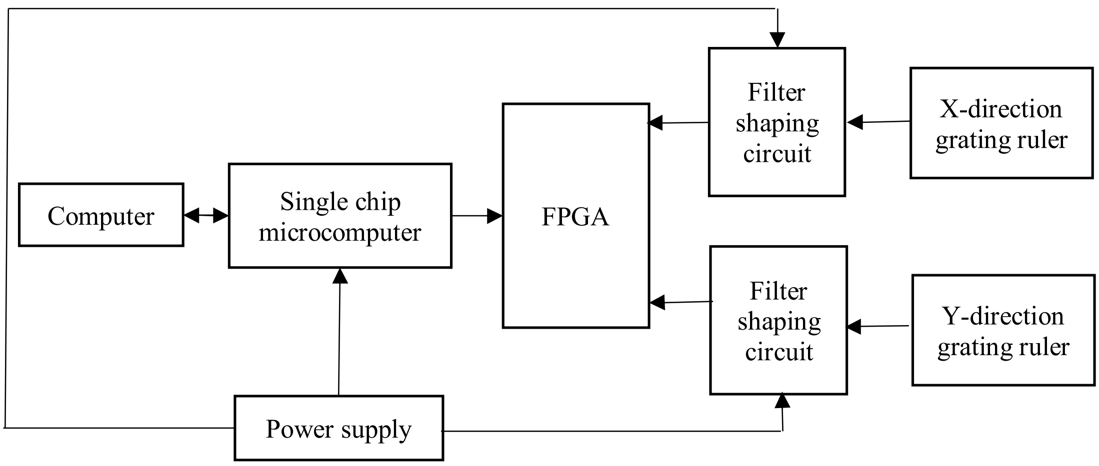

Figure 3. Raster signal processing module structure

3. Experiment

3.1. Experimental Design

In order to verify the measurement accuracy of the universal aid microscope computer-aided measurement system, this paper designs the following experiments:

(1) Collect 5 mm reticle images at intervals of 10 mm in the Y direction, and collect a total of 50 images, with a range of 0 to 100 mm. Use the measurement system designed in this paper to make readings to verify the accuracy of the system's automatic readings;

(2) Measure the scale of the glass line scale to verify the accuracy of the measurement system in length measurement. A glass ruler with a range of 100 mm was selected and measured at scales 0, 10, 20, 90, 100, each scale was measured twice, and the average value was taken as the measured value at that point. Set the control group, that is, use the traditional measurement method to perform the second measurement at the same scale, and compare the accuracy of the two measurement methods;

(3) Measure the ring gauge and the angle gauge to verify the accuracy of the measurement system in diameter measurement and angle measurement. The ring gauge is an outer diameter ring gauge with a diameter of 35.002 mm, and the angle of the angle gauge block is 15° 7'. Perform 10 measurements on the selected ring gauge and angle gauge, and record the readings to calculate the error. The system measurement process is shown in Figure 4.

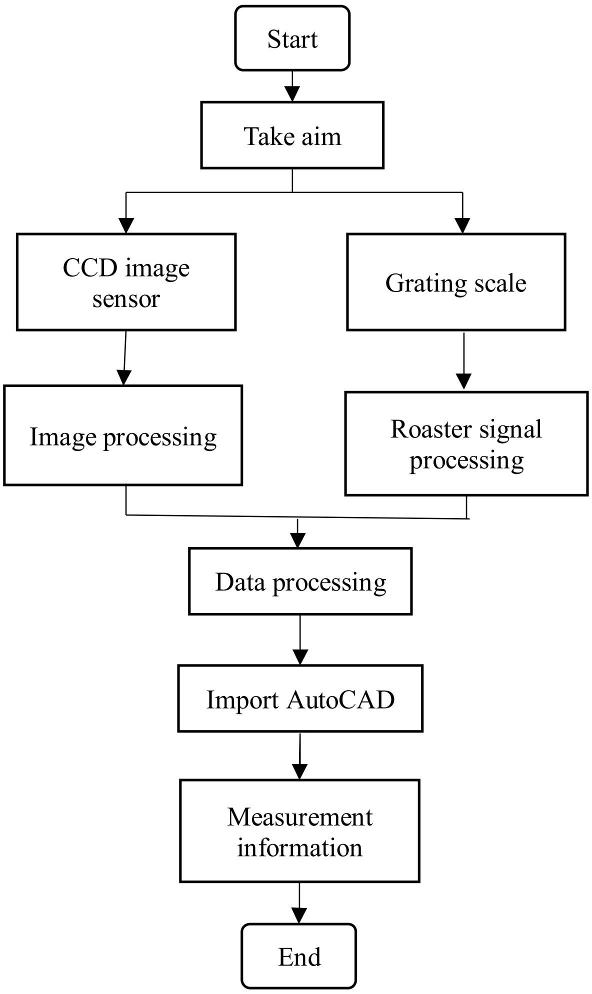

Figure 4. Measurement process

3.2. Experimental Evaluation

(1) For the reading experiment, observe whether the accuracy of the read measurement data reaches the micrometer level, and evaluate the accuracy and time of the reading;

(2) In the measurement of the scale of the glass line scale, calculate the error of each reading and the final cumulative error, and analyze the source of the error;

(3) Calculate the average value and standard deviation of the 10 measurements of the ring gauge and the

angle gauge respectively, and evaluate the accuracy of the measurement system in diameter and angle measurement.

4. Results and Discussion

4.1. Accuracy of Readings

The measured values are shown in Table 1 and the readings are shown in Figure 5. As can be seen from Table 1, the accuracy of these 50 measurements has reached the micron level, and no abnormal readings have occurred. This indicates that the measurement system has a stable automatic reading function. It can be seen from Figure 5. That the reading time at each measuring point isn’t longer than 39 ms, and the average time is 32.6 ms, indicating that the measuring system has high measurement efficiency.

Table 1. Readings of measured values

Serial number	System reading (Unit: mm)	Serial number	System reading (Unit: mm)	Serial number	System reading (Unit: mm)
1	0.0005	18	36.5788	35	69.7872
2	2.0218	19	37.8795	36	72.1453
3	3.1023	20	39.4557	37	72.4520
4	6.7019	21	40.9737	38	73.3424
5	7.2496	22	44.4534	39	77.2483
6	11.9026	23	45.3472	40	78.6824
7	12.2218	24	47.7837	41	82.9794
8	14.2546	25	49.5353	42	84.3164
9	15.4551	26	51.3573	43	87.0243
10	18.1211	27	53.4837	44	87.4786
11	22.8154	28	54.8728	45	89.1434
12	23.8518	29	57.3573	46	92.5477
13	26.5854	30	58.0084	47	93.4837
14	28.4545	31	61.7862	48	96.1457
15	29.9542	32	62.2543	49	96.2245
16	33.5453	33	63.1587	50	99.4437
17	35.8756	34	67.4823		

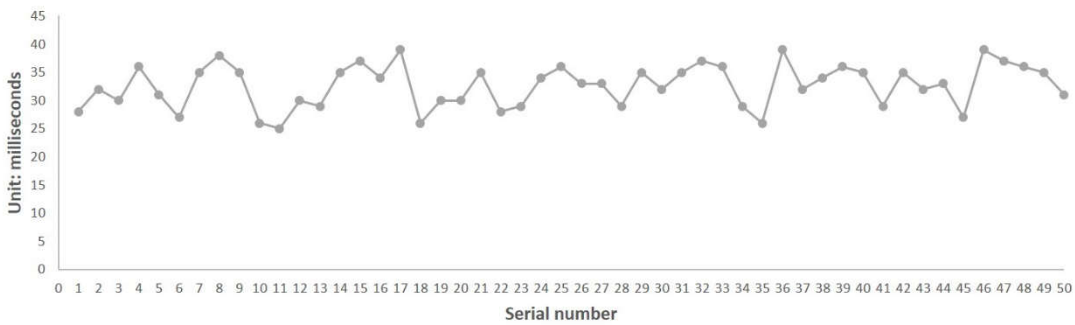

Figure 5. Reading time

4.2. Measurement Accuracy

The measurement results of the glass line scale by the traditional method and the measurement system designed in this paper are shown in Table 2. It can be seen from the table that the measurement accuracy of the measurement system designed in this paper is significantly higher than the traditional measurement method. However, the measurement system designed in this paper still measures the error. After analysis, the error should come from two aspects: (1) The installation position of the grating ruler does not fully comply with the Abbe principle (collinear principle); (2) During the measurement process, the glass ruler is moved by the mechanical guide. The mechanical guide itself has mechanical errors.

Table 2. Accuracy measurement results

Standard value (mm)	Traditional method measurement(mm)	System measured values (mm)
0	0.0023	0.0002
20	20.0035	19.9995
40	39.9967	40.0008
60	60.0051	60.0002
80	80.0036	79.9998
100	99.9943	100.0004

4.3. Diameter and Angle Measurement

The measurement results of diameter and angle are shown in Table 3. After calculation, in the diameter measurement, the maximum deviation is 0.0004 code, the average deviation is 0.00026mm; in the angle measurement, the maximum deviation is 13, “and the average deviation is 9”. This level of accuracy indicates that the measurement system designed in this paper can be applied to measurements of diameter and angle.

Table 3. Diameter and angle measurement results

Serial number	Diameter Measurement(Mm)	Deviation (Mm)	Angle Measurement	Deviation
1	35.0022	0.0002	15°7′7″	7″
2	35.0020	0.0000	15°7′10″	10″
3	35.0021	0.0001	15°7′13″	13″
4	35.0023	0.0003	15°7′8″	8″
5	35.0016	0.0004	15°7′9″	9″
6	35.0024	0.0004	15°7′11″	11″
7	35.0019	0.0001	15°7′7″	7″
8	35.0015	0.0005	15°7′12″	12″
9	35.0017	0.0003	15°7′6″	6″
10	35.0023	0.0003	15°7′7″	7″

5. Conclusions

In the manufacturing industry, processing technology is constantly moving in the direction of precision, the size of machined parts is getting smaller and smaller, and the influence of machining errors on product performance is also increasing. It can be said that precision measurement technology determines the development of processing and manufacturing technology. At present, most of the domestic precision measurement systems have problems such as insufficient measurement accuracy and low measurement efficiency. Combined with the high cost of imported equipment, precision measurement has not been popularized in the domestic manufacturing industry, which seriously restricts the development of China’s manufacturing industry. In this paper, based on machine vision technology, an auxiliary measurement system for universal tool microscope is designed. Experimental verification shows that the measurement system has the advantages of high measurement accuracy and high measurement efficiency. However, due to the limitation of the mechanical structure of the universal tool microscope, the Abbe principle is not fully obeyed during the installation of the grating sensor, and the systematic error of the mechanical structure itself leads to the improvement of the measurement accuracy of the measurement system, but its performance has exceeded other similar products. This paper provides ideas for the transformation of traditional measuring instruments to intelligent precision measuring instruments. It is hoped that later researchers can make in-depth research on this and promote the further development of precision measuring technology in China.

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