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Precision measurement technology and application based on machine vision

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Abstract: *Presently, the precision measurement technology based on machine vision has applied to all kinds of fields such as electron, motorcar, weave, glass and metalworking. It can also work effectively in many occasions that many old methods are difficult to check and measure. The levels of production automation and intelligent detection system have been improved greatly. In this paper, the basic principle and application of the machine vision system is introduced firstly, and then the application of small modulus gear precision measurement technology based on machine vision is taken as an example to show the feasibility of this method in precision measurement. The results revealed the advantages of machine vision method that the measurement efficiency is improved and the artificial error is reduced.*
Key words: *machine vision, precision measurement, small modulus gear*

I. Introduction

Modern precision measurement technologyis a comprehensive cross subject which integrates optics, electronics, sensors, images, manufacturing and computer technology [1].The required measurement accuracy is from millimeter to micron and even to nanometer scale. The traditional detection technology and method cannot meet the needs of precision measurement absolutely [2]. It is extremely important to give machines the human visual function for modern precision measurement, and therefore forming a new subject -- machine vision. According to decades of development, machine vision measuring system has a good market application prospect because of its high degree of automation, high precision and speed.

In this paper, the precision measurement technology based on machine vision is introduced and analyzed. Firstly, the basic theory of the machine vision system is introduced firstly, and then the application of image detection technology based on machine vision is discussed. In addition, the superiority of machine vision method is shown using the application example of small modulus gear. The measurement methods are summarized and prospected at last.

II. Precision measurement technology based on machine vision

Machine vision, also known as computer vision, is a noncontact detection method based on computer, which includes the synthetic application of image processing, precision measurement, pattern recognition and artificial intelligence technology [3]. The basic principle is to obtain the image information of the object by using the machine vision method, and then comparing with the pre-approved standard to get the quality and information of the measured object, i.e. to determine the deviation.

2.1 machine vision system

As shown in Figure 1, the machine vision system is composed of a computer (as the center), a visual sensor, a high speed image acquisition system, a special image processing system and other modules [4]. The source information of the system (the original image) is acquired by the visual sensor, which consist of one or more image sensors, an optical projector and other auxiliary equipment. The high speed image acquisition system converts the analog video signal acquired from the visual sensor to digital image signal in real time and transmits the image to the computer for display or processing directly. As the assistant processor of computer,special image processing system can finish various primary image processing algorithms in real time and reduce the processing load of computer. Computer is the core of the whole machine vision system. In addition to control the normal operation of the modules in the whole system, the computer is alsoused to execute the calculation and output of final results of the visual system.

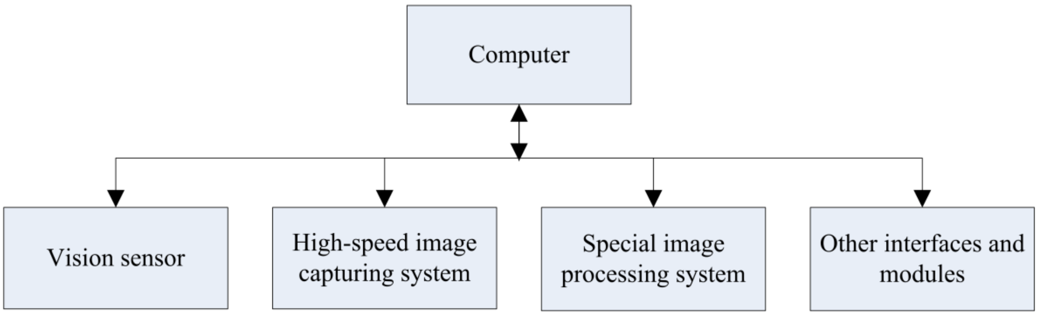

Figure 1. Composition of machine vision system

2.2 Factors affecting the accuracy of measurement system

The main factors affecting the optical measurement accuracy of digital images are imaging system resolution, geometric distortion, noise,etc. The system resolution refers to the smallest details resolution of the imaging system to the space optical image, and generally it is measured by the image resolution or the angular resolution of the image system. The geometric distortion includes lens aberration, pixel array error, perspective error,etc. The noisesare generated by the camera, CCD performance, illumination field of view, and pixel jitter of video image acquisition[2].

III. Application of imagedetection technology based on machine vision

After decades of rapid development, machine vision technology is widely applied in various aspects: from the industrial product testing to the clinical diagnosis, from remote sensing image analysis to national defense, military application, etc. Compared to traditional measurement technology, image detection technology based on machine vision has more obvious advantages in the measurement of micro size, large size, complex structure size and profiled surface [5]. The following is a concrete discussion.

3.1 Micro dimension measurement

With the development of science and technology and the development of manufacturing, the measuring requirements to micro/tiny size are increasingly urgent, for example, bearing in millimeter size, small hole and sphere in machining, small gap between magnetic head and disk in computer. The universal tool microscope or laser diffractionisalways used in traditional methods. However, the former is easily influenced by measuring head shape, size and force measurement; while the latter is required very harsh to the measuring environment, and can only measure relatively simple structure size, e.g. filament diameter, thin band width. For more complex micro structure size and optical fiber, the two methods are powerless to make a precision measurement.

Because of the characteristics of non-contact, the precision measurement technology based on machine vision is easy to implement large scale measurement (such as the magnitude from micron to millimeter) and guarantee high measurement accuracy at the same time. The detection accuracy and range is mainly determined by the resolution and magnification of the camera system.

3.2 Large size measurement

The traditional measurement methods for large structure size are mainly two: (1) the direct method, this method needs guides in large size or standard parts, which the cost is high butthe precision is low; (2) the indirect method, for example the bow altitude and chord length method, roller method and so on. These methods have the principle error in measurement and the reliability is not high.

However, the precision measurement technology based on machine vision can get many local overlapping images by shooting the different position of the parts. The complete structure and size of part can be obtained by analyzing the whole image, which is got by using image stitching. This method is simple, low cost and can achieve high accuracy.

3.3 Complex structure parts measurement

Because of the complicate shape and various parameters, the detection accuracy and efficiency are relatively low for the complex structure parts (such as gear, screw and cam) using conventional instruments. Although the special instruments, such as type 301 universal gear measuring machine, can achieve automatic and continuous measurement and the measurement accuracy is high, the measurement can only be carried out on the special test platform with a high cost and complicated process. Due to the carrier of “image” that the information is very rich, precision measurement technology based on machine shows great advantages. Only one or several images are needed, the outline information of complex structure can be obtained.

3.4 Special-shaped surface measurement

The detection methods of traditional special shaped surface are: manual measurement, robot measurement, three-coordinate measurement and the combined measurement of theodolite [5]. Due to its high cost, low speed and repetitive adjustment, manual measurement method has been eliminated in practice gradually. The robot measurement is widely used because of its fast speed, but, the accuracy is not high for precision measurement. The three-coordinate measurement is still an important method to special-shaped surface up to now. However, key shortcoming of this method is that the workpieces should be placed on the workbench, which will limit the size and weight of workpieces. The combined measurement of theodolite is flexible, and can realize the online noncontact precision measurement for large parts,but this method requires manual aiming and high working strength.

If the structural light and the precision measurement technology based on machine vision can be applied to the detection of special-shaped surface, the measuring speed and working strength are both better than the above methods, and the measuring accuracy is equivalent to three-coordinate measurement [5]. The basic principle is to project a certain type of structure light on the surface under test, and then analyzing and calculating the structural light image obtained by the camera to get the outline information of the special-shaped surface.

IV. Application example of small modulus gear

Generally, the small modulus gear refers to that the gear modulus is less than 1mm. It is widely used in precision optical instruments, aviation and radio instruments. Its accuracy can directly affect the performance and service life of the instruments. According to the national standard for the precision measurement of a small module gear, the mainly measurement projects including [6]: tooth profile deviation,helix deviation, tooth pitch deviation, ipsilateral tooth surface deviation, radial composite deviation and radial runout, etc. Due to the geometric and mechanical characteristics of small tooth clearance and poor tooth stiffness, small module gear is difficult to measure by traditional gear measuring instruments and contact measurement method. Appling the visual detection technology to the measurement of gear error can realize noncontact measurement, and can also solve many difficult problems in the traditional measurement. So, it has great significance for research. In this paper, a standard involute straight spur gear [6] is selected as an example to analyze the process of precision measurement based on machine vision.

4.1 image capture

The gear is placed on the universal tool microscope under normal lighting condition and then captures the image. As shown in Figure 2, the image is clear and the contrast ratio is good, but there are still some noises in the center position.

Figure 2.Image of macro size involute gear.

Figure 3. Pretreatment image of micro size gear.

4.2 Image processing

The image is inevitably affected by various signals in the process of collection and transmission. Due to the addition of these external noises, the resulting image has a certain degree of difference with the original image. Therefore, pretreatment is needed to filter the noise image and smooth the noise after capturing the image (In Fig. 3). Then, the edge detection and fitting can be carried out to find the edge of the gear image and prepare for subsequent gear parameter measurement.

4.3 Parameter measurement

After image capture and processing, the parameters' measurement can be carried out for geometry size, tooth pitch deviation, tooth profile deviation and so on. The basic parameters of geometry size for small module involute straight tooth cylindrical gear are mainly including tooth number *z*, the modulus *m*, the dividing circle diameter *d*,the addendum circle diameterd_a, the dedendum circle diameterd_f, etc. Firstly, the center of the gear (the center of the shaft hole) must be determined in the vision measurement system. Using this center as a reference, the other parameters can be determined and the calibration of the system can be carried out.

4.4 Data analysis and processing

The pixel size of calibration and the gear parameters can be calculated by the modulus *m*, the number of teeth *z*and the pressure angleα. The results between the universal tool microscope image method and the machine vision method are shown in Table 1 [7].

Table 1. Comparison between universal tool microscope measuring and machine vision measuring

Parameter	Modulus	Tooth number	Addendum circle diameter	Dedendum circle diameter	Shaft hole radius
Image method	0.4	16	3.6..3	2.6622	1.5045
Machine vision method	0.4	16	3.6032	2.6542	1.4968
absolute error	0	0	2.9μm	8.0μm	7.7μm
Parameter	Individual circular pitch deviation	Cumulative pitch deviation	Total cumulative pitch deviation	Left tooth profile total deviation	Right tooth profile total deviation
Image method	0.0099	0.0155	0.0273	0.0188	0.0131
Machine vision method	0.0127	0.0179	0.0266	0.0287	0.0124
absolute error	2.8μm	2.4μm	0.7μm	9.9μm	0.7μm

The results show that the measurement values between the two methods are very close to each other. The absolute error is less than one pixel. The absolute error of the left profile deviation of the maximum size is about 10 μm [7]. However, the measurement time of the small modulus gear based on machine vision method is only about 4-10 s, which is far less than the manual measurement. Therefore, the machine vision measurement methodshows the advantages of easy to operate, high efficiency, low working strength and measuring error, etc.

V. Conclusions

In this paper, the measuring principle and the visual system of precision measurement technology based on machine vision are introduced and analyzed. It has more advantages in the different measurement fields compared with the traditional measurement methods. The measuring example for small modulus gear shows that the efficiency is improved and the working strength is reduced. With the continuous development of modern precision manufacturing technology, the machine vision method with the characteristics of high measurement precision, high degree of automation, fast response will be more widely used in precision measurement.

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