A fast on-line two-dimensional sizes measurement method for micro part

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Received 8 October 2013, www.tsi.lv

Abstract

In order to meet the manufacturing process of micro part, where the space is small，the production speed, temperature and vibration frequency are high, a novel method, which is used to measure the two-dimensional (2-D) sizes of the micro part fast and on-line, was proposed based on optical fibre image bundles and CCD camera. Double parallel lights were projected on the part symmetrically. The outline information of the part image on CCD camera through optical fibre image bundles and the part 2-D sizes can be obtained from the CCD camera. The optical fibre image bundles can be embedded into tool-set or fixed in limited space due to its small size, flexibility and bendability. Therefore, the method overcomes the bad influences from the part hard processing conditions effectively. Experiments were carried out to measure workpiece with dimensions of 6.124 mm x 0.424 mm. The results show that the measurement time was less than 0.2 second and the accuracy was up to 25um.

Keywords: On-line Measurement, Micro-part, Optical Fibre Image Bundles, Two-dimensional Sizes, CCD

1 Introduction

Micro parts have been used widely in recent years due to its various advantages such as less consumption of energy and material, low costs, small size and light-weight and so on. The typical fields of the application of the micro parts include the industries of military, automobile, electric, aerospace as well as medical equipment. There are all kinds of techniques which can be used for the manufacture of micro parts. Micro-manufacturing is mainly categorized as micro-electromechanical systems (MEMS)-based manufacturing and non-micro-electromechanical systems (non-MEMS)-based manufacturing. MEMS-based manufacturing involves techniques such as photolithography, LIGA, plating, chemical etching, laser fabrication, etc. While non-MEMS-based manufacturing often involves techniques such as mechanical machining, injection molding, forging, extrusion, stamping etc. [1]. Although fundamental issues relates to materials, processes and analysis of micro-manufacturing have been studied intensively in past two decades [2-7]. But still have some challenges on the dimensional measurement for micro part, especially fast on-line dimensional measurement. Firstly, compared with the traditional macro-manufacturing, the micro-manufacturing available space is smaller, so location of sensors is a very difficult task. Secondly, the production speed of the micro-manufacturing is fast. Some equipments manufacture’s speed up to 1000 workpieces per minute. Thirdly, the temperature and vibration frequency of the micro-manufacturing processing site are often high [8].

Currently, many techniques of micro part dimensional sizes measuring have been proposed. Yang etc. have developed a high precision micro coordinate measuring machines (M-CMM) with measurement uncertainty up to 50 nm in a measuring volume of 30mm x 30mm x 10mm (XYZ) [9]. Tosello G etc. use optical coordinate measuring machines (OCMM) to obtain the dimensional of micro channels and the surface roughness [10]. S Ontiveros proposes a dimensional measurement method of micro moulded parts by computed tomography (CT) [11]. In addition, scanning electron microscopy (SEM), atomic force microscopy (AFM) and scanning tunnelling microscopy (STM) are all widely used in micro and nano part surface analysis techniques capable of very high accuracies [12].

However, all these methods are off-line measurement. Each of them demands large space for allocation and enough time to analysis the data. To the best of our knowledge, it is not a fast on-line two-dimensional sizes measurement method for micro part has been reported.

In order to meet the manufacturing process of micro part, especially (non-MEMS)-based manufacturing, where the space is small, the production speed and vibration frequency are high, we propose a novel fast on-line 2-D sizes measurement method for micro part in this paper. Double parallel lights are projected on the micro part symmetrically, passing through optical fibre image bundles and the telecentricity modules at its both ends. The micro part 2-D sizes information can be obtained

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from the CCD camera. The front-end probe consists of telecentric lens and the optical fibre image bundles, both of them volume is smaller significantly compared with the normal camera, and the optical fibre image bundles have the merits of flexible, bendable and long distance signal transmission. Therefore, the front-end probe can be embedded into tool-set or fixed in limited space. This paper is organized as follows. Section 2 gives a basic measurement principle of 2-D shape for micro part based on the optical fibre image bundles. In section 3 the measurement experiment and results of the micro part 2-D shapes are presented. Section 4 the resolution and mainly error sources of the system are analysed. Finally, the conclusion and further study are also described in the end.

2 Principle of the measurement

The fast on-line measurement system of 2-D shape for micro part consists of double lights, two telecentric lens, optical fibre image bundles, charge coupled device (CCD), frame grabber and computer, as shown in FIGURE 1.The 2-D contour of micro part is imaged on the CCD through the optical fibre image bundles, then frame grabber and image acquisition software process the data and the 2-D sizes of micro part can be obtained.

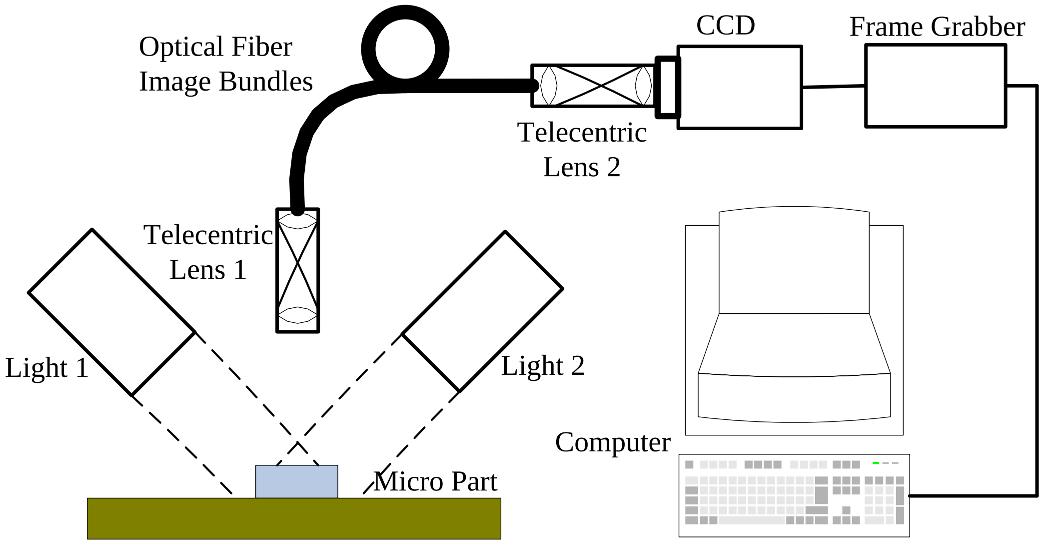

FIGURE 1 Schematic diagram of the measurement system

2.1 THE OPTICAL FIBER IMAGE BUNDLES AND TELECENTRIC LENS

Optical fibre image bundles have the merits of flexible, bendable and long distance image-transmission, so it used a wide range of applications, including medicine for endoscope, industrial remote vision systems, ordered array detectors, hazardous environment imaging, defence and research. The major technique parameters of the optical fibre image bundles used in this paper as shown in table 1.

TABLE 1 The major parameters of the optical fibre image bundles

Item	Parameters	Unit
Quality area	6 x 6	mm
Single core fibre size	17 (element 6x 6array)	um
Numerical aperture	0.56	
Resolution	34	Lp/mm
Temperature resistance	-40 to +125	℃
Diameter	12	mm
Length	800	mm

Telecentric lens have the unique property of purely orthographic projections of scene points and maintaining a constant magnification over a specific range of object distances, and show very low distortion degree, normally less than 0.2%. So they are being widely used in many machine vision applications especially for accurate dimensional measurement of 2-D parts and components of different heights [13]. In this paper, the size and weight of the telecentric lens 1 decide the front-end probe whether it can be installed in compact space. The major parameters of the telecentric lens 1 as shown in table 2.

TABLE 2 The major parameters of telecentric lens 1

Item	Parameters	Unit
Maximum diameter	20	mm
Length	43	mm
Weight	40	gram
Magnification	0.75X	
Distortion	Less than 0.2%	
Depth of field	16	mm

We can find that the volume and weight of telecentric lens 1 is reduced significantly compared with the normal camera (In this paper, the type of camera is WAT-535EX2. The length, width and height are 53.5mm, 43.5mm and 44mm, respectively, and the weight is approximate 125 gram.) The schematic diagram of the optical fibre image bundles mounting with telecentric lens shown as in figure 2.

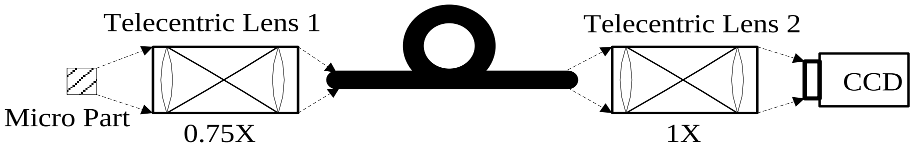

FIGURE 2 Schematic diagram of the optical fibre image bundles mounting with telecentric lens

2.2 ILLUMINATION OF THE MEASUREMENT SYSTEM

A singular light might meet some problems in practical measurement system, such as blind area and uneven illumination, etc. Symmetrically placed double lights can deals with them and the measurement precision can be improved. The telecentric lens 1 is vertically fixed upon the part and two parallel lights are symmetrically placed on both sides of it, as shown in figure 1. The illumination condition of the measurement system will be improved by placed on double lights.

3 Experiment and results

To verify this method performance, an experiment system is established to evaluate the accuracy of the measurement system. Besides the earlier mention that the optical fibre image bundles mounting with two telecentric lens to image micro part on the CCD, the WAT-535EX2 camera with resolution 768 x 494 and MV4000 frame grabber are employed. The size of a pixel is 6.35um x 7.4um. We use a pin of Microcontroller Unit (MCU, the type is STC89C51RC+) which the pins packaging with dual-in-line for measurement. The outside view of the MCU is as shown in figure 3. The pins are made by micro stamping. A pin dimension was measured through ZYM-500GS measuring microscope, the length and maximum width of the measurand are 6.124mm and 0.424mm, respectively, as shown in figure 4.

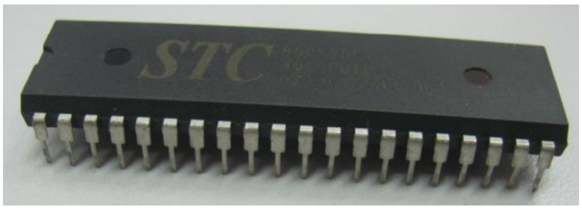

FIGURE 3 The outside view of the MCU

The micro part is placed at the working distance of the telecentric lens1, and an image is taken by the frame grabber, then software Matlab combined with VC++ to process the obtained image. The boundary of the micro part is extracted as using image processing algorithms Canny with threshold 0.6, as shown in FIGURE 5. The measurand has been measured ten times repeatedly. Time consumption is less than 0.2 second in every time, and the experiment results are shown in TABLE 3. It is clear that both of the length and maximum width of the micro part errors are less than 25um.

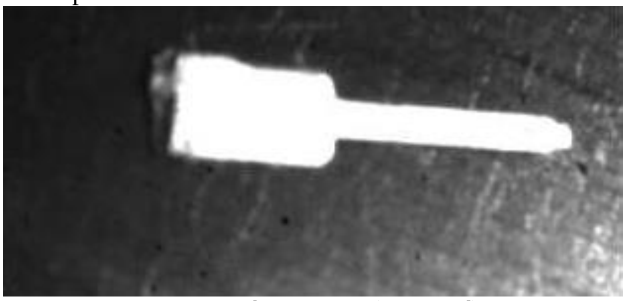

FIGURE 4 The micro part (measurand)

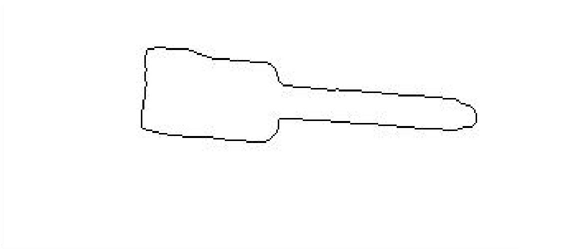

FIGURE 5 Boundary of the micro part

TABLE 3 Experiment results (unit: mm)

Number	Length(6.124)	Error	Maximum width(0.424)	Errors
1	6.103	-0.021	0.413	-0.011
2	6.148	0.024	0.408	-0.016
3	6.140	0.016	0.437	0.013
4	6.115	-0.009	0.415	-0.009
5	6.129	0.005	0.417	-0.007
6	6.118	-0.006	0.433	0.009
7	6.132	0.008	0.420	-0.004
8	6.128	0.004	0.411	-0.013
9	6.104	-0.020	0.430	0.006
10	6.126	0.002	0.439	0.015

4 Discussion

4.1 RESOLUTION OF THE MEASURE SYSTEM

The system resolution is mainly restricted by following factors, resolution of the optical fibre image bundles and CCD, magnification of the telecentric lens 1 and the telecentric lens 2. The optical fibre image bundles resolution is principally depend on the diameter of single core fibre and it arrangement mode. There usually are hexagonal and square arrangement mode, the corresponding calculate their resolution formulas are described by equations (1) and (2), respectively.

$$r_{oh} = \frac{\sqrt{3}}{2} d \,, \quad (1)$$

$$r_{os} = d \,, \quad (2)$$

where d is diameter of the single core fibre, r_{oh} and r_{os} are resolution of the hexagonal and square arrangement mode, respectively. In this paper, the core fibres are arranged by hexagonal mode, the diameter of the single core fibre is 17um, according to equation (1), we have r_{oh} is about equal to 14.7um.

The solution of the CCD is described by

$$r_c = \max\{\frac{W}{t_{pw}}, \frac{H}{t_{ph}}\} \,, \quad (3)$$

where W and H are the width and height of the CCD, t_{pw} and t_{ph} are the total effective pixels on the width and height direction, respectively. The WAT-535EX2 camera dimensions is 1/3 inch, the $W \times H$ of the CCD are 4800um × 3600um, the total effective pixels on the width and height direction are 768 x 494, so r_c is about equal to 7.3um.

As mentioned above, the image of the measurand is coupled into the optical fibre image bundles through telecentric lens 1, then imaging on the CCD through telecentric lens 2. We set the magnification of the telecentric lens 1 and telecentric lens 2 are m_1 and m_2, respectively. Here the value of m_1 is equal to 0.75X and m_2 is equal to 1X. So the resolution of this measure system is expressed by the equation (4):

$$r = \max\{\frac{m_2 r_{oh}}{m_1}, r_c\} \,. \quad (4)$$

Combining equations (1) to (4), the resolution of the whole system can be acquired, and the value is equal to 19.6um. It is obvious that the resolution of the system is mainly impacted by the optical fibre image bundles and magnification of the telecentric lens 1 and telecentric lens 2.

4.2 MAIN ERROR SOURCES OF THE MEASURE SYSTEM

There are mainly three aspects contributing to the error of the measure system, including image-transmission errors of the optical fibre image bundles, distortion of the telecentric lens and CCD noises. The principal error of system is caused by the first one, low resolution of the optical fibre image bundles lead to the result that obtained image is not clear, the arrangement errors and break of the some single fibres also cause the errors. The distortions of the telecentric lens including radial, decentring and thin prism distortions. The first one is caused by imperfect lens shape and manifests itself by radial positional error only, while the second and third types of distortions are generally caused by improper lens assembly, and the distortion of the telecentric lens is less than 0.2 percent. Photo noise, dark current noise jamming signal have influence on the resolution of the CCD image, which also reduces the measure precision of the system.

5 Conclusions

Manufacturing process of micro part features limited space, high of the production speed, temperature and vibration frequency makes fast on-line 2-D sizes measurement using common method difficult. This paper proposes a new method of fast on-line two-dimensional sizes measurement to solve this problem, and the corresponding equipment has been designed. Different from the conventional machine vision measurement system, CCD camera through optical fibre image bundles with two telecentric lens obtained image is presented. The volume and weight of the front-end probe is reduced significantly compared with only taking CCD camera directly. Experiment results prove the errors are less than 25um and time consumption is less than 0.2 second. Thus, the method is very suitable for fast on-line two-dimensional sizes measurement with space limited, especially fits well for micro-manufacturing. Although this method can solve the problem of fast on-line 2-D sizes measurement for micro part, it is not limited to this area. According to its principle, the method may also be used to measure other objects with demand for small space and high speed. The drawbacks to this method are as follows: (1) the precision of the measurement system is mainly depended on the precision of optical fibre image bundles and the magnification of telecentric lens, and improve of them will cost expensive. (2) The threshold is used in extract the boundary of micro part, at present, the threshold is confirmed through many times test that is effectively distinguishing the border.

Future work must address the above drawbacks. The higher resolution of optical fibre image bundles and bigger magnification of telecentric lens will be employed to improve the precision of the system. Further, more micro part will be tested in order to conclusion about the rule of threshold confirm. Finally, optimize the image processing algorithms to reduce the total time consumption.

Acknowledgements

The authors would like to appreciate the financial support from the Doctoral Program of Higher Education of China grant 20110181110084.

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