euspen's 16th International Conference &
Exhibition, Nottingham, UK, May 2016
www.euspen.eu

A rotational stitching method for measuring cylindrical surfaces

Mingyu Liu[1,*], Chi Fai Cheung[1], Shanshan Chen[1,2]

[1]*Partner State Key Laboratory of Ultra-precision Machining Technology, Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Kowloon, Hong Kong, China*
[2]*School of Mechatronics Engineering, Harbin Institute of Technology, Harbin 150001, China*

**corresponding author, email: samuel.liu@connect.polyu.hk*

Abstract
It is difficult for traditional measurement instruments such as white light interferometers and coordinate measuring machines to measure cylindrical surfaces such as grinding wheels since most of these instruments only have 2.5D measurement capability so that the data may be missing in the bottom section of the workpieces. Moreover, the area near the edge where the surface gradient is high would be susceptible to large measurement uncertainty for some instruments. To address these shortcomings, this paper presents a method named Rotational Stitching Method (RSM) which attempts to measure the whole cylindrical surface. The method is used to measure a grinding wheel mounted on the shaft of a step motor which can be controlled and rotated with pre-set micro steps. A series of measurement experiments are designed to measure the top surfaces of the grinding wheel with a white light interferometer for every certain angle and the measurements are designed to have overlapped regions for registration. After the sub-measurements cover the whole cylindrical surface, the measurement datasets of the sub-surfaces are stitched and fused together to form the holistic surface of the grinding wheel. The motion errors of the grinding wheel including the rotation error of the motor, and alignment error can be eliminated or minimized by the stitching process. The capability of the method is realized by measurement experiments.

Keyowrds: Measurement, Cylindered surfaces, Grinding wheel, Rotational stitching method

1. Introduction

Most of the traditional surface measurement instruments such as white light interferometers, coordinate measuring machines, laser interferometers, confocal microscopes only provide a 2.5D measurement capability that the bottom surface cannot be measured [1]. This shortcoming largely limits the usage of these measurement instruments to relatively flat surfaces. For the measurement of the cylindrical surfaces, some commercial instruments such as the Alicona (InfiniteFocus Real3D) [2] and Werth (Axis of rotation/tilt) [3] provide a turnkey solution by adding a rotational unit to rotate the workpiece so as to form a completed measurement. This is usually purchased as an expensive optional device.

This paper presents a rotational stitching method for measuring of the cylindrical surfaces using the Zygo white light interferometer with the help of a low-cost additional step motor and a stitching method. The method is demonstrated with the measurement of a grinding wheel. The method and experimental setup are detailly explained and the result shows that the effectiveness of the proposed method. The successful establishment of this method provides a simple and low-cost method for the widely used 2.5D measurement instruments so as to enhance the measurement ability to a real 3D aspect.

2. Rotational stitching method

Fig. 1 shows the system diagram presenting the hardware of the rotational stitching method (RSM). The grinding wheel is mounted to the shaft of a step motor controlled by a micro-controller which is connected to the computer of the Zygo nexview white light interferometer. The grinding wheel is rotated for a certain angle and a whole 360° measurement is done by a series measurements. The Zygo machine is set to automatically measure and a software is developed and run on the PC connected with the Zygo machine to send a rotation command to the micro-controller once a single measurement is completed. For the whole cylindered surface measurement, a number of data files are generated.

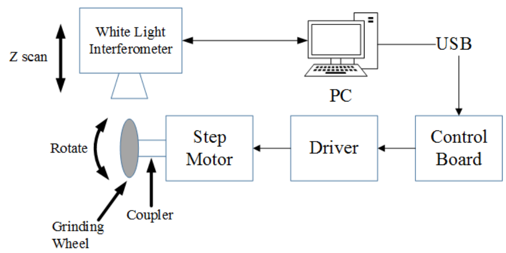

Figure 1. System diagram of the rotational stitching method.

After the original measurement datasets are generated, the next step is data processing. The flowchart of the data processing is shown in Fig. 2.

Figure 2. Flowchart of the data processing.

The original measurements are first processed by removing null data and determination of overlap region for every nearby measurements. Then every pair of the nearby datasets are registered using an iterative closest point (ICP) method [4] and the associated transformation matrixes are obtained. After that, all 200 measurements are pre-stitched together by transforming the datasets to the same coordinate with the method determined by

$$S_{t_i} = M_{t_i} S_{o_i} \tag{1}$$

where S_{o_i} is the ith original measured surface and M_{t_i} is the transformation matrix associated with the ith original measured surface and M_{t_i} is determined by

$$M_{t_i} = \prod_{1}^{i} M_i \qquad (2)$$

where M_i is the ith transformation matrix for the ith pair dataset.

It should be noted that, in present of registration error, there is misalignment in the wraparound (the first and the last) area result from the systematic error of the registration process and this will be studied thoroughly in the future work. To address this issue, the misalignment is determined and the error is compensated in the post-stitching process by evenly distributed the error to every registered pair.

3. Experimental setup and procedures

An experiment was conducted to evaluate the proposed RSM method and a RSM system was built. The experimental setup is shown in Fig. 3 and the design of the coupler is shown in Fig. 4. It should be noted that the coupler was purposely designed to make sure the runout of the grinding wheel was as small as possible so as to avoid data missing in the automatic measurement since the maximum vertical scan range of the Zygo machine is about 150µm. The rotational angle of the grinding wheel was set to be 1.8° and the number of the series measurement was 200. The software on the PC was written in VB.net and an Arduino UNO board was used to control the step motor. The data processing software was developed by using Matlab software package.

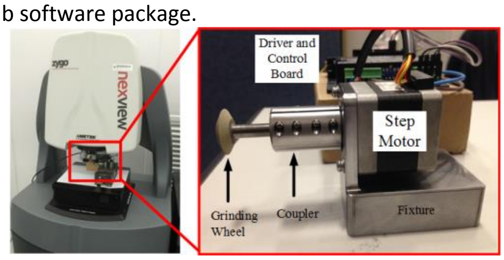

Figure 3. Experimental setup.

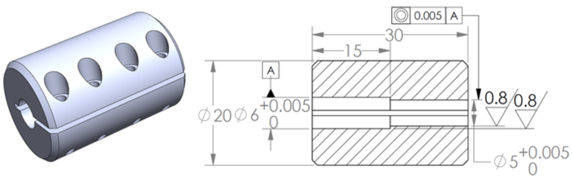

Figure 4. Design of the coupler.

4. Results and discussion

A pair of the original measurement result is shown in Fig. 5 and the overlap region is highlighted which is used for registration, the result shows that with a 20×1 magnification for the white light interferometer and 1.8° rotation for the grinding wheel, the overlap region is about 30% and the large overlap area ensures the accuracy for the registration process.

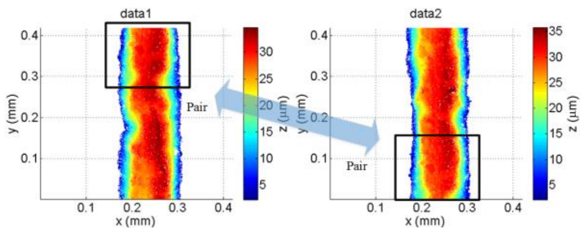

Figure 5. One pair of the original measurement datasets.

The registration result for a pair of the datasets is shown in Fig. 6. Fig. 6a is the initial datasets while Fig. 6b is the registered datasets. The result shows that the two datasets are well registered. It should be noted that some unwanted measurement noise is found in the measurement and this may introduce some registration error. Noise determination may be added in the future work.

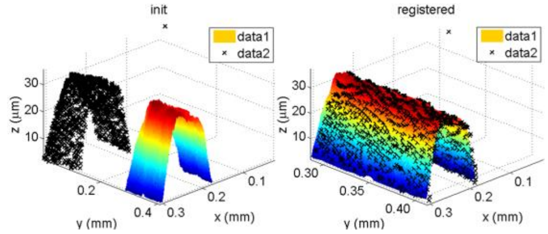

Figure 6. Registration result of one pair datasets.

The pre-stitching and post-stitching results are shown in Fig. 7. Fig. 7a shows that there is a large gap between the first dataset and the last dataset after pre-stitching. This misalignment was compensated and the result is shown in Fig. 7b. A section of the result is also enlarged for better illustration. The result shows that the datasets are well stitched together.

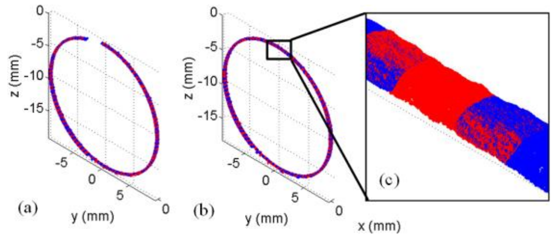

Figure 7. Stitching result of the whole measurement.

5. Conclusion

A simple and low-cost rotational stitching method (RSM) is proposed and a RSM system is built for measuring cylindrical surfaces and demonstrated with a Zygo white light interferometer. A series of 200 automatic measurements was conducted for measuring a grinding wheel and the measurement results were stitched together to construct a holistic cylindrical surface. The result shows that the method is effective and this provides an example for the measurement ability enhancement for the large amount 2.5D measurement instruments in the industry. Future work will focus on performance evaluation of the RSM method.

Acknowledgements

This work described in this paper was mainly supported by PhD studentships (project account codes: RTHC and RU3K) from The Hong Kong Polytechnic University. The work was also supported by a grant from the Research Grants Council of the Government of the Hong Kong Special Administrative Region, China (Project No. PolyU 152028/14E). The authors also thank Mr. Fan Tsz Hin for his help in the experiment.

References

[1] Weckenmann A, Jiang X, Sommer KD, Neuschaefer-Rube U, Seewig J, Shaw L, Estler T. Multisensor data fusion in dimensional metrology. CIRP Annals-Manufacturing Technology. 2009 Dec 31;**58**(2):701-21.

[2] www.alicona.com

[3] www.werth.de

[4] Besl PJ, McKay ND. Method for registration of 3-D shapes. InRobotics-DL tentative 1992 Apr 30 (pp. 586-606). International Society for Optics and Photonics.