Grinding Workpiece Error Evaluation Based on Non-contact 3D Point Cloud Metrology

Po-Nien Tsou[1,a*], Po-Huang Shieh[1,b], Ming-Cheng Tsai[1,c]

[1] Mechanical and Mechatronics Systems Research Laboratories, Industrial Technology Research Institute, 195, Sec. 4, Chung Hsing Rd., Chutung, Hsinchu 310, Taiwan

[a] BernieTsou@itri.org.tw, [b] TabShieh@itri.org.tw, [c] GregTsai@itri.org.tw

Keywords: Point Cloud, Non-contact measurement, Geometric dimensioning and tolerancing (GD&T)

Abstract

For the purpose of measuring complex free-form surfaces of grinding components, a datum alignment technique and a tolerance evaluation algorithm based on point cloud data were developed. The CAD model was introduced to these algorithms as a measurement reference. The filtered parameters of input point cloud raw data were selected to eliminate noises. The datum alignment method was applied for minimizing the datum alignment error of the difference between CAD model and measured point could data. The tolerance evaluation method based on Geometric dimensioning and tolerancing (GD&T) was proposed for free-form surface quality inspection. It was also integrated into a non-contact 3D rapid measurement system with a high-precision laser line scanner system and a positioning stage.

The simulated and experimental results show that the non-contact 3D rapid measurement system with datum alignment method and tolerance evaluation method had significantly improved the efficiency of grinding workpiece tolerance inspection.

Introduction

Inspection of grinding workpiece is often carried out on conventional coordinate measuring machine (CMM). The CMM has the flexibility to measure a wide variety of workpiece geometries with high accuracy and precision. However, the efficiency of conventional coordinate measuring machines is relatively low in terms of measuring time and measuring speed. Thus, some studies are discussed on enhanced performance of CMM inspection process such as planning probe movement path and using different algorithms for minimization of inspection time [1-4].

As the demands for free-form surface measurements have increased in recent years, non-contact measurement machine is widely used for inspection due to its high efficiency. Moreover, non-contact measurement machine based on laser triangulation can capture large number of measuring points within a reasonable amount of time. However, some problems including digitizing errors have been discovered in non-contact laser scanning system and improved by some studies [5-7]. Despite the digitizing errors, there are still a lot of research focused on development of applicable non-contact laser scanning measurement systems. Bhat and Smith [8] presented a laser scanner for volume measurements used in medical applications. Gao et al. [9] applied 3D non-contact measurement on aerospace component repair. Henselmans et al. [10] developed non-contact measurement machine on free-form optics inspection.

In this paper, a non-contact measurement system is introduced about the tolerance inspection for free-form surface of grinding workpiece, and two methods are introduced in the following sections.

Experiment Methods and Results

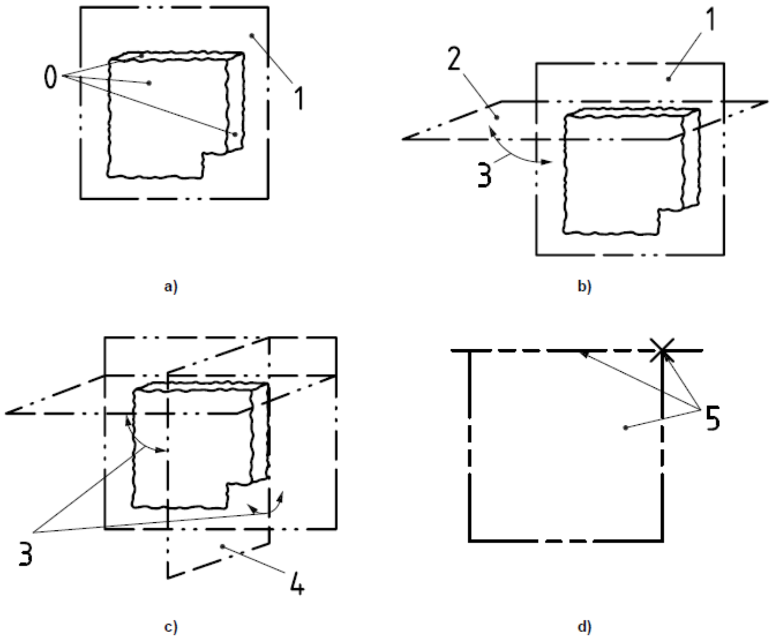
The non-contact 3D laser measuring system for this study was introduced and shown in Fig.1. This system consists of a laser line scanner and a high precision positioning stage. In this research, two major methods was developed: automated datum alignment method and tolerance measuring method.

Fig. 1 Pitcture of the non-contact 3D laser measurement system

Automated Datum Alignment Method

Datum alignment method is developed based on ISO 5459 Datum and datum systems standard [11]. The purpose of automated datum alignment is not only to ensure the consistence between coordinate system of measuring point cloud and 3D CAD model but also to avoid part fixturing manually. Take ISO 5459 specified three perpendicular planes datum system for example, as shown in Fig. 2, the primary datum is a plane which associates to the specific point cloud. The secondary datum is a plane that associates to the specific point cloud with an orientation constraint from the primary datum. The tertiary datum is a plane which associates to the specific point cloud with first orientation constraint from the primary datum and second orientation constraint from the secondary datum. Therefore, the datum system generated by three perpendicular planes includes a plane which is primary datum, a straight line which intersects between the primary datum and secondary datum and a point which intersects these three datums.

In this research, datum alignment method has been verified by following steps. Firstly, create two sets of point cloud with same data and position. Secondly, rotate and translate one set of point cloud to another space shown in Fig. 3 (a). Then, build the datum systems respectively based on ISO 5459 datum system standard and input them to the datum alignment method. In this case, Fig. 3 (b) shows the result of datum alignment. The alignment error on three axis are 14.0 nm, 3.28 nm and 31.6 nm respectively.



Key

0 datum features: real integral features

1 associated plane (primary datum in this case) to the datum feature identified by the datum letter A

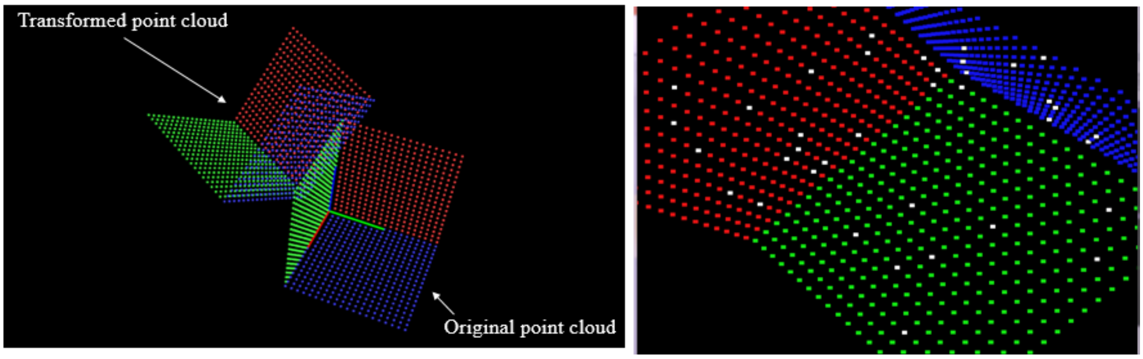
2 associated plane (secondary datum in this case) identified by the datum letter B, with orientation constraint from the primary datum

3 orientation constraint (perpendicularity)

4 associated plane (tertiary datum in this case) identified by the datum letter C, with orientation constraints from the primary datum and secondary datum

5 datum system: plane (primary datum), straight line (intersection between the primary and secondary datum) and point (intersection of the three datums)

Fig. 2 ISO 5459 three perpendicular planes datum system[11]



(a) (b)

Fig. 3 (a) Before and (b) After alignment for point cloud datum alignment verification

Tolerance evaluation method

In this study, several geometric dimensioning and tolerancing(GD&T) measuring methods have been developed such as straightness, flatness and position. For verification purpose, an experiment has been set up. Firstly, define a plane with normal vector (0, 0, 1) and locate this plane on z=0.1 mm. Secondly, build a set of point cloud based on this plane. Then, put the stochastic z-value for every point of the point cloud between ±0.5 mm, as shown in Fig. 4. In this case, Fig. 5 shows that the upper limit of deviation is 0.49370 mm and lower limit of deviation is -0.49936 mm, and the total deviation is 0.99306 mm. These results are consistent with the experiment setting.

These two methods have been demonstrated for propeller surface inspection machine that exhibit a high inspection efficiency, as shown in Fig. 6.

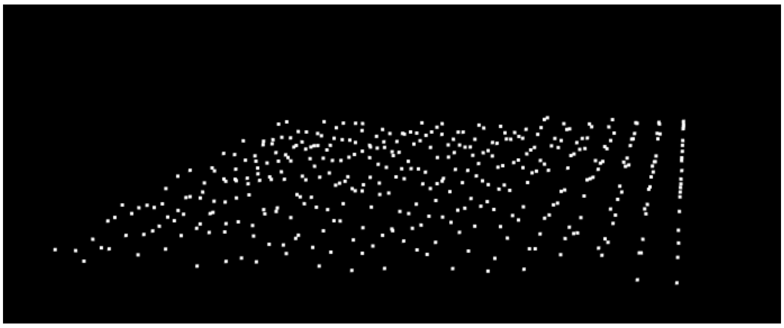


Fig. 4 Point cloud set on the plane parameters are a=0, b=0, c=1 and d=0.1mm ($ax + by + cz = d$) and with stochastic z-value for every point between ±0.5mm

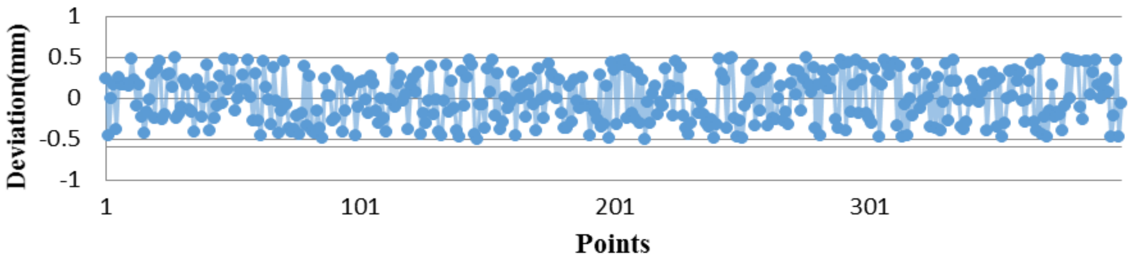


Fig. 5 Tolerance evaluation result for system deviation

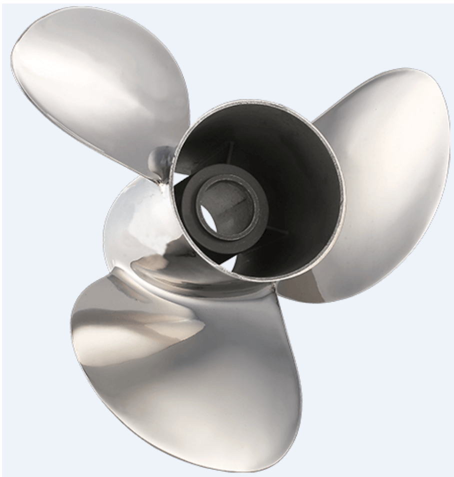


Fig. 6 Propeller for surface inspection

Summary

A non-contact 3D laser measurement system was developed in this study for free-form grinding surface profile measurements. The datum alignment method was proposed to not only avoid part fixturing manually but also enhance the datum alignment accuracy. It has been demonstrated that the datum alignment errors can be controlled to the nanometer scale. The GD&T based tolerance evaluation method which provides various GD&T measurement functions has been verified. In addition, these two methods have been employed for the free-form surface inspection of propeller. The inspection time is reduced by 100% compared to conventional coordinate measuring machine.

References

[1] W.S. Kim, S. Raman, On the selection of flatness measurement points in coordinate measuring machine inspection, International Journal of Machine Tools and Manufacture, (2000) 427-443.

[2] S.D. Jones, A.G. Ulsoy, Optimization strategy for maximizing coordinate measuring machine productivity, part 2: Problem formulation, solution, and experimental results. Journal of engineering for industry (1995) 610-618.

[3] M.M. Dowllng, P.M. Griffin, K.L. Tsui, C. Zhou, Statistical Issues in Geometric Feature Inspection Using Coordinate Measuring Machines, Technometrics (2012) 3-17.

[4] S.H. Mian, A. Al-Ahmari, Enhance performance of inspection process on Coordinate Measuring Machine, Measurement (2014) 78-91.

[5] K.B. Smith, Y.Z. Zheng, Multi-Laser Displacement Sensor Used in Accurate Digitizing Technique, ASME. J. Eng. Ind (1994) 482-490.

[6] H.Y. Feng, Y.X. Liu, F.F. Xi, Analysis of digitizing errors of a laser scanning system, Precision Engineering (2001) 185-191.

[7] N. Van Gestel, S. Cuypers, P. Bleys, J.P. Kruth, A performance evaluation test for laser line scanners on CMMs, Optics and Lasers in Engineering (2009) 336-342.

[8] S. Bhat and D.J. Smith, Laser and sound scanner for non-contact 3D volume measurement and surface texture analysis in wound healing, Proceedings of the 15th Annual International Conference of the IEEE Engineering in Medicine and Biology Societ (1993) 1608-1609.

[9] J. Gao, J. Folkes, O. Yilmaz, N. Gindy, Investigation of a 3D non-contact measurement based blade repair integration system, Aircraft Engineering and Aerospace Technology (2005) 34-41.

[10] R. Henselmans, L.A. Cacace, G.F.Y. Kramer, P.C.J.N. Rosielle, M. Steinbuch, The NANOMEFOS non-contact measurement machine for freeform optics, Precision Engineering (2011) 607-624.

[11] Geometrical Product Specifications (GPS) - Geometrical Tolerancing - Datums and datum systems, ISO 5459:2011.