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

Design of a laser scanner system for sub-mm 3D shape measurement using commercial off-the-shelf components

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Abstract
Laser (profile) scanners (LS) have been widely used in industry for 3D shape measurement. However, commercially available scanners are costly. They are also less flexible as the components of the device are permanently fixed in a sealed housing, whereas altering setup geometry can improve the device's height resolution. This paper describes the design and construction of a LS setup from generic off-the-shelf components; a digital camera, laser line module, optical bandpass filter and a machine vision library software for image to 3D point cloud conversion. The performance of the setup is assessed by measuring a set of step height samples ranging from 50 µm to 1 mm. LS measurement performance is determined by comparing measurements of the step heights with those taken from a Coordinate Measurement Machine (CMM). Average measurement difference between the setup and CMM is 20.29 µm with repeatability of 0.60 µm. The highest percentage error for the smallest tested step height suggests the setup can measure objects with feature variation down to 0.1 mm.

Keywords: Three-dimensional shape measurement, laser scanner, height resolution, CMM

1. Introduction

Various makes and models of commercial laser scanner (LS) are now available to meet the demand of 3D shape measurement in industry. At least 30 companies have been identified as laser scanner (LS) suppliers for industrial shape measurement [1]. LS offer some advantages compared with other shape measurement technologies; high acquisition rates can be achieved whilst maintaining acceptable accuracy. The sensors are compact as they typically only consist of a 2-D sensor array, lens, bandpass filter, laser line module and a control board. With current technology, it is common to see palm-sized industrial LS units. The compact size of LS units enables them to be integrated in machines for in-situ measurement of manufacturing process. For example, LS can be mounted at a robot tool centre point (TCP) along with the end effector and other sensors.

However, commercial sensors are not low in cost, and the permanent geometry of scanner components fixes the depth resolution and accuracy. However, in some applications it may be required to compromise depth resolution for compactness or depth of field, which typically requires the purchase of a new scanner. A custom design scanner where components can be independently selected according to space and performance constraints is beneficial in this situation.

This paper describes the design and evaluation of a custom LS unit built from commercial off-the-shelf components and the Halcon machine vision library for shape measurement applications. Section 2 describes the sensor design. The tests to evaluate design performance and the comparison of scanning results with CMM measurements are described in Section 3, and an overall discussion of the results is given in Section 4.

2. The setup

A generic design of a LS consists of two major elements; a camera and laser line source. The camera in the setup is a Basler CCD acA1600-20gm, 1626 (H) pixels × 1236 (V) pixels, with pixel size of 4.4 µm × 4.4 µm. A Tamron 8 mm focal length f/1.4 CCTV lens is used to image the laser profile onto the sensor array. In front of the lens is an optical bandpass filter with centre wavelength 660 nm and transmission width of 10 nm. The filter is chosen to match the 660 nm laser wavelength emitted from a 1 mW laser line module with a beam fan angle of 45°focused at working distance of 133 mm. Using the Rayleigh spot size criterion [2] the wavelength yields an ideal lateral spatial resolution of 2.23 µm. The vertical resolution of the scanner can be calculated as $p_y/\sin(\theta)$ [3] where p_y is the pixel size in the vertical direction and θ is the triangulation angle i.e. the angle between camera and laser axes (Fig.1). In this setup the triangulation angle is set to 38°, thus the maximum vertical resolution of the setup is 7.42 µm. These resolution figures however are for ideal circumstances [2] and real performance will be inferior.

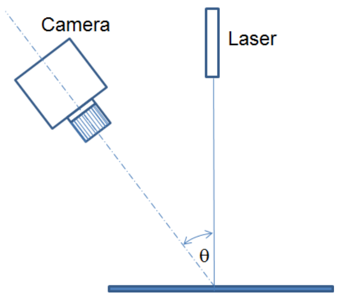

Figure 1. Custom laser scanner system.

The conversion process from the acquired image of a laser profile to a point cloud requires calibration, which has been explained in detail in various literature [4,5]. In this experiment, the Halcon machine vision library is used to perform the LS calibration as well as conversion of the images to point cloud data.

3. Performance evaluation

Evaluation of the setup performance was carried out by measuring a set of step height profiles, formed using slip gauges of different thicknesses (Fig.2).

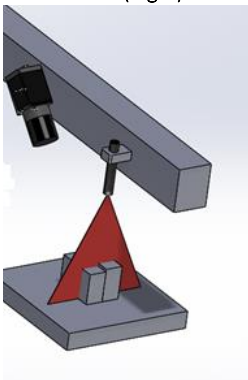

Figure 2. Step height measurement to assess scanner performance.

Step heights of 1000, 500, 300, 200, 100 and 50 µm were each measured five times to assess repeatability. Despite being calibrated objects, the slip gauges were re-measured on a Nikon Metrology CMM Ultra. The CMM is traceable to a UKAS national calibration standard. As the CMM resolution (0.5 µm) is smaller than the theoretical limit of the laser scanner, the CMM results can be considered as true values. Similarly, CMM measurements were repeated five times. The performance of LS was assessed by comparing the results with CMM measurements.

4. Results and discussions

Average CMM and laser scanner measurements are presented in Table 1. For each height profile, the mean and standard deviation values are calculated on both upper and lower sides of the profile. Measured step height is calculated as the difference between the mean values of upper and lower sides, or $m_U - m_L$, as illustrated in Fig.3.

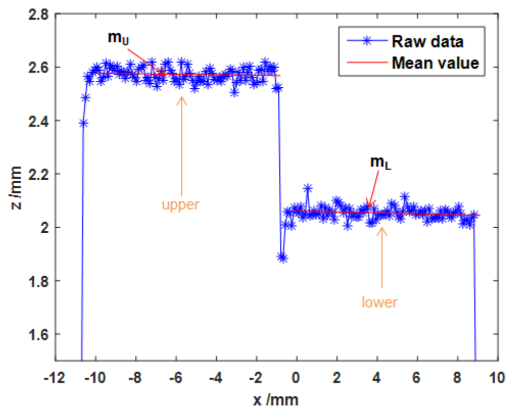

Figure 3. Height profile calculation from laser scanner output.

The percentage errors from Table 1 are plotted in Fig.4. The smallest height difference tested, 50 µm, shows the largest percentage error. Average error and percentage error for all step heights above 50 µm is 21.6 µm and 4.4%, respectively.

Table 1. CMM and laser scanner measurement results.

Nominal step height /µm	Measurement /µm		Absolute Error /µm	Percentage Error
	CMM	Laser scanner		
1000	1002.7 ± 0.1	1066.0 ± 0.4	63.3 ± 0.4	6.0
500	510.4 ± 0.0	526.9 ± 0.4	16.5 ± 0.4	3.1
300	301.7 ± 0.2	311.8 ± 0.8	10.1 ± 0.8	3.2
200	201.0 ± 0.1	216.2 ± 0.9	15.2 ± 0.9	7.0
100	102.4 ± 0.1	106.0 ± 0.4	3.6 ± 0.4	2.7
50	49.5 ± 0.2	63.2 ± 0.6	13.7 ± 0.6	21.7

Overall system repeatability is 0.6 µm. The results also show that LS measurement is consistently higher than the CMM, which indicates possibility of systematic error in the measurement.

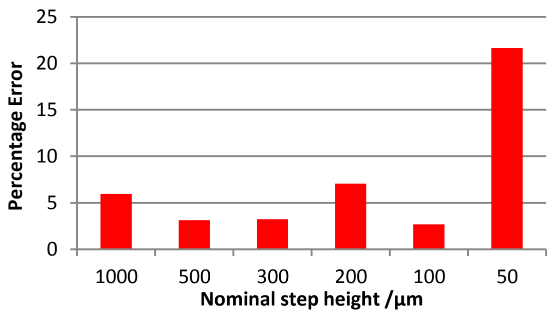

Figure 4. Percentage error of scanner measurement of the step profiles.

The evaluation results show the custom laser scanner is suitable for measuring objects with feature variation down to 0.1 mm. This is higher than the ideal vertical resolution calculated in Section 2, as well as the accuracy typically offered by commercial scanners of comparable size [6]. However, this capability is sufficient for most shape measurement activities in manufacturing industries. Furthermore, due to the advantages of a custom scanner described in Section 1, this type of scanner remains competitive for shape measurement in industries with medium to low resolution requirements. Future work includes the investigation on the sources systematic error in the measurement process.

Acknowledgements
We acknowledge support from the EPSRC Centre for Innovative Manufacturing in Intelligent Automation, in undertaking this research work under grant reference number EP/IO33467/1.

References
[1] Blais F 2004 *J. Electron Imaging* **13** 231-43
[2] Smith W 2008 *Modern optical engineering* McGraw-Hill 160-163
[3] Dorsch R G, Hausler G and Hermann J M 1994 *Appl. Opt.* **33** 1306-14
[4] McIvor A 2002 *Opt. Eng.* **41** 205-12
[5] Gan Z and Tang Q 2011 Ch 3 *Visual sensing and its applications: integration of laser sensors to industrial robots* (Springer Heidelberg) 41-89
[6] Micro-Epsilon GmbH scanControl 2D/3D laser scanner (laser profile scanner) http://www.micro-epsilon.co.uk/download/products/cat--scanCONTROL--en.pdf (accessed on 31 January 2016 22:36)