Areal Surface Measurement Using Multidirectional Laser Line Scanning

Kwame. D.B. Akowua, Simon Fletcher, Andrew Longstaff,
Naeem. S. Mian
Centre for Precision Technologies, University of Huddersfield, UK,

Abstract

The overall quality of a machined component has an important association with the quality of its surface finish. To obtain adequate data for the surface metrology of machined components, areal scanners are often preferred over stylus based profile scanners due to their ability to acquire surface data over a relatively large area. To further improve efficiency, there is a desire to perform on-machine measurement, and recently, high-resolution areal surface scanners have been integrated as an on-machine measurement device. Due to the limited areal coverage, these scanners can require multiple scans to capture data from surfaces produced on machine tools which requires a sufficient amount of time to complete a full surface scan. In addition, since these scanners are very sensitive, scanning delays often cause areal scanners to capture data contaminated with noise which may arise from within the machining environment such as axes vibrations, temperature effects, dust, etc. These factors mean such instruments are typically used in metrology laboratories.

This paper presents a new methodology referred to as multidirectional scanning (MDS) which is a technique that exploits characteristics of a 2D laser line scanner (profilometer). The device is used in two directions to scan the overall component surface ensuring the coverage of a wider surface area compared to typical areal scanners. Since the scanner is robust and integrated onto a machine tool, controlled axes feed rates in the orthogonal directions ensure high spatial resolution which in turn helps to identify and reduce the noise levels in the data. This methodology has been validated to be both accurate and rapid to scan the component surface, reducing the cost associated with machine downtime and also having a wider coverage of 6x6 mm^2 for a single scan, compared to 1 mm^2 for most conventional areal surface measurement instruments having comparable spatial and vertical resolution.

1. Introduction

Surface metrology plays a very significant role in modern manufacturing industries. This is due to the fact that 90 % of all engineering workpiece failures are linked to the surface quality of the component [1]. Hence, depending on the application of the component, most manufacturing industries aim to achieve a predefined surface quality of components before machining. Profile and Areal measurements are the two main methods for characterisation of surface texture

[2]. Areal characterisation is often preferred over 2D profile measurement due to its accuracy and comprehensiveness [3].

Due to the high demand of manufacturing components within a short space of time, a lot of research has been geared towards the use of on-machine surface areal instruments for quick data capture [4, 5], to acquire sufficient surface data that can be used to diagnose, monitor and control the manufacturing process [6]. However, the majority of currently available areal measurement techniques which provide high accuracy are limited to cover an approximately 1mm^2 without field-stitching. In order to cover much wider area, such instruments are often limited in the accuracy of the results as magnification levels are changed [7].

In this paper, a new methodology is presented which uses a laser line scanner to obtain accurate data. It covers a wider measurement area; enough to detect any irregularities as a result of the machining process. The new methodology will be quick in providing sufficient amount of data; ensuring a reduced machine downtime while not compromising on the accuracy.

2. Methodology

Laser line scanners, sometimes referred to as profilometers, have traditionally been used for in process dimensional inspection. Recent advances in the application shorter wavelengths such as blue light systems have enabled such devices to be used for spatial measurement over a variety of surfaces such as highly specular machined surfaces with much lower noise levels. This research uses a Keyence LJ-V7020k, a 2D blue laser optical profilometer which is designed for on line measurement [8]. The resolution in the X-axis (scan direction) is 10µm, and the resolution in y-axis depends on the sampling frequency of the instrument and the speed of travel during the measurement. The resolution in the measurement direction (Z-axis) is 0.1 µm.

A small 5 axis CNC machine tool is used to facilitate automated cycles and provide a constant lateral speed across the workpiece during measurement.
A single line scan provides data in < 1 ms (depending on settings), minimising the effect of machine vibration. Subsequent scans are also unaffected relative to the line scan but are affected in an absolute sense over a scanned surface comprising many lines. By rotating the sample, the direction which was susceptible to vibration, is now measured by the line scan and thus is now immune. By combining the data, it was envisaged that a robust 2D result could be obtained.

2.1. Procedure

The area on the machined surface to be measured was first demarcated with three registers. The registers help in the identification of the 6 mm^2 sample area under study on each block as shown in figure 1. The registers are holes with a diameter of 1 mm but can be other less intrusive features. The registers are also used for data cropping and rotation control if a precision rotary axis is not present on CNC machine to generate the two orthogonal data sets.

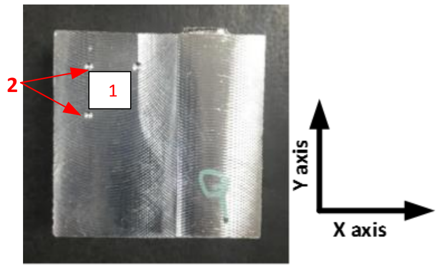


Figure 1 – Specimen Block -1;Sample Area, 2 Register marks

The sample area shown in figure 1 was scanned in two perpendicular directions. During each scan, the spindle of the CNC machine, on which the Keyence instrument was attached; was kept stationary while the worktable was translated in the X-axis with a feed rate of 2.5 mm/min. The sampling frequency of the Keyence was set to 100 Hz, which provides a compromise between good averaging in the Laser scanner and good lateral resolution of scan in the Y-axis which was 416 nm and which was maintained for all further measurements shown in this paper.

$$Resolution\ in\ Y\ axis = \frac{Feedrate}{Sampling\ frequency} \tag{1}$$

$$= \frac{2.5\ mm/mins}{100\ Hz}$$

$$= \mathbf{416\ nm}$$

With the sampling frequency set to 100 Hz, the acquired data can be averaged (the laser sampling cycle is 62 kHz) this will reduce the effect of noise. Also, measuring at a feed rate of 2.5 mm/min, allows sufficient data to be captured for a spatial resolution in the Y-axis better than the resolution in a typical stylus profilometer.

Once the first scan was completed, the sample was rotated by 90 degrees with the aid of the rotary axis of the CNC machine after which the worktable was translated again in the X-axis. Figure 2 shows the Keyence mounted on the CNC machine. The two data sets obtained after the scans were first imported into a Matlab programme for resizing, filtering of noise from each data set, removal of form/slope from the data, and finally rotating and meshing the two data sets together. With the aid of Fast Fourier Transform waveform analysis on a set of 2D sections through the surface, the preliminary cut off frequencies for Gaussian filtering were obtained.

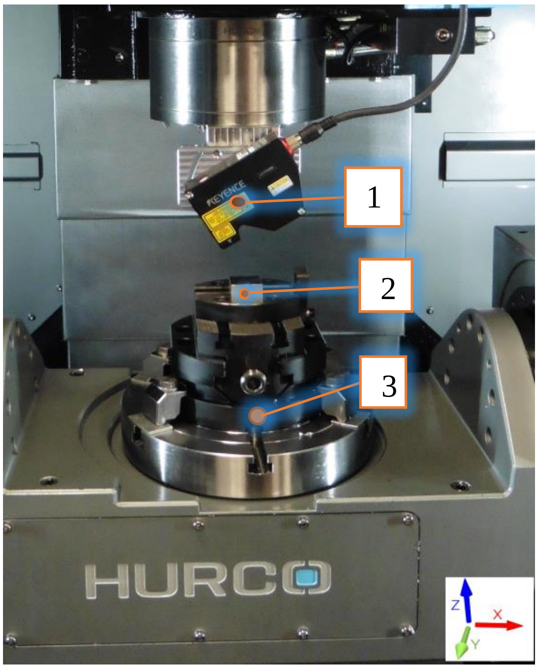


Figure 2. CNC machine with Keyence mounted on for in machine surface measurement. 1;Keyence Scanning Head, 2. Specimen Block 3. Rotary worktable of Hurco

The new data set is saved as a .CVS file which is then imported into the Surfstand software package for parameterization [9]. Figure 3 shows the screenshot of all the stages before the new data is obtained.

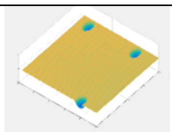
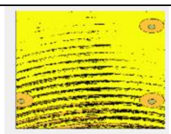
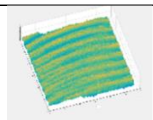
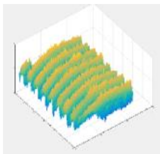
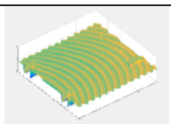
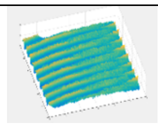
Scan 1				
Scan 2				
	Initial imported data obtained from Keyence	Data Cropping using Contour plots	Slope removal and data rotation for merging	New data

Figure 3 Images of each stage of the data manipulations before obtaining the new data set

The areal parameters used in this experiment were the root mean square deviation of the surface (Sq) and the arithmetical average of the surface (Sa). These are considered to be representative of the quality of the surface and often used in manufacturing industry.

3. Results and Verification of the Technique.

Traceability in measurement is the concept of establishing a valid calibration of a measuring instrument or measurement standard, by a step-by-step comparison with better standards up to an accepted or specified standard. In general, the concept of traceability implies an eventual reference to an appropriate national or international standard.

For the verification and traceability of this new measurement technique; which will be referred to as Multidirectional Scanning (MDS) measurement technique; along with validations of the quality of the data, a standard commercial instrument, the Talysurf CCI 3000, was used as a benchmark. Also, data obtained from a single / normal scan using the Keyence LJ-V7020k was recorded to reveal the improvement in quality by using the MDS technique.

The TalySurf CCI 3000 instrument [10] is a type of Coherence Correlation Interferometer known for its high resolution and repeatability. Using a magnification lens of X20, it provides a measurement area of 0.9 x 0.9 mm^2 with a lateral sampling resolution of 0.88 µm and a vertical resolution of 10 pm. However, due to its high sensitivity, it is not designed to be used for on-machine or co-located measurement.

Five blocks were machined using a variety of spindle speeds, axis feedrates and depths of cut to induce varying surface quality. Three arbitrary areas within the sample surface of each block were measured by the CCI. Table 1 and Table 2 presents the results of the Sa and Sq values respectively obtained from the CCI, the proposed multidirectional scanning technique and the single/normal scanning.

Table 1: Sa values in (µm) obtain from instruments and MDS

	CCI Measurement (0.9x0.9 mm^2)	**Multidirectional Scanning (6x6 mm^2)**	**Normal Scanning (6x6 mm^2)**
Block 1	2.261	2.197	1.95
Block 2	1.392	1.397	1.943
Block 3	2.595	2.18	3.009
Block 4	1.066	1.127	0.856
Block 5	0.777	0.761	1.021

Table 2:Sq values in (µm) obtain from instruments and MDS

	CCI Measurement ($0.9x0.9\ mm^2$)	**Multidirectional Scanning ($6x6\ mm^2$)**	**Normal Scanning ($6x6\ mm^2$)**
Block 1	2.717	2.751	2.458
Block 2	2.494	1.838	1.599
Block 3	3.059	2.743	3.602
Block 4	1.215	1.484	1.071
Block 5	0.898	0.973	1.346

Further investigations allowed the identification of a strong correlation between the results from the CCI and MDS. The percentage correlation for the Sa values presented in Table 1 was 98.36 % and 89.78 %; for MDS and single scan respectively while using the CCI as the reference. Also, from Table 2, the percentage correlation for the Sq values was 93.1 % for MDS technique and 82.92 % for a single scan. The percentage correlation result has proved that the data obtained while using MDS technique has a stronger relation with the data obtained from the CCI. Based on the above results, MDS turns to be a better option for a more accurate data for on-machine surface metrology than a normal scan. The differences between the results obtained from the CCI and MDS is as a consequence of the difference in the size of the area measured.

4. Conclusion

This paper proposes a new solution to obtain on-machine areal measurement for surface finish inspection. The new technique (Multidirectional Scanning) combined with the application of a blue light laser line scanner has improved the accuracy achievable by using such an instrument and provides a much larger coverage area ($6x6\ mm^2$) than most areal instruments without losing quality from changes in magnification. MDS has proven to be very robust for on-machine measurements since all the experiments were carried out on a machine tool in a typical shop floor environment. Also, by comparing the data obtained from MDS and normal single scan, using the CCI as the reference, it was noticed that MDS provides a more reliable data than normal scans when using a laser profilometer. The high accuracy of the MDS is as a result of the merging of the two data sets and the multiple filtering of the measured data.

Further work should be conducted on the effect of the angle of rotation of the surface on the areal parameters. Also since the sampling frequency of the instrument can be increased; further research should be considered on the effect of increasing the sampling rate on the quality of the data. Moreover, this work can be expanded to consider all the areal parameters.

5. Reference

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