Measurement Uncertainty in Scanning Instruments Due to Data Acquisition Methods

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Introduction

The objective of this study is to advance the understanding of measurement uncertainty in horizontal scanning measurement instruments. Such instruments are widely used in a variety of industries to measure form, fit, and surface texture on scales ranging from nanometers to meters. They are currently available from several manufacturers, and use sensors and motion control elements having different characteristics to implement their measurements. The measurement modes used in these instruments inherently affect the uncertainty in measurements. As the speed, accuracy, and repeatability of measurements become increasingly critical, identifying, quantifying and minimizing such measurement uncertainty take on increased industrial relevance.

Approach

Research on measurement uncertainty typically focuses on instrument calibration (Garnaes, et. al., 2003; Qian, et. al., 2000; Bienias, et. al., 1997; Mainsah, et. al., 1995) or on instrument comparison (Ohlsson, et. al., 2001). Yan and coworkers have decomposed the sources of geometric error, studied the effect of measurement uncertainty and suggested methods of reducing variation in a three-part paper (Yan, et. al., 1999). Literature searches revealed little information on the effect of software design and instrument configuration on measurement uncertainty. Therefore, this study focuses on the effect of the design of the software used to control the instrument and the design of the data acquisition function.

Equipment

A 3-axis scanning laser microscope (SLM) was used to identify and quantify sources of measurement uncertainty. The SLM was originally built with support from NASA to measure the fine scale texture on runway surfaces and was designed to be easily reconfigurable. It uses three CompuMotor™ stages (Parker-Hannafin, CA) coupled to quadrature encoders and has a horizontal range of 150 x 150 mm and a vertical range of 66 mm. A Keyence™ LC-2210 triangulation height sensor (Keyence Corporation, NJ) is used to measure the topography and has an experimentally determined lateral resolution of 25µm and vertical resolution of 12 µm (Johnson, 1997). A Sensoray 421™ (Sensoray Inc., OR) data acquisition card was used to acquire laser height readings. The stages were configured to move at a near-constant velocity while the triangulation sensor records the height at predetermined locations for this study. The SLM was controlled by a PC running Microsoft™ Windows™ 2000. These hardware and software configurations were chosen as they allowed relatively easy changes in the implementation of data acquisition and instrument control.

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Results and Discussion

Figure 1 shows the effect of software thread priority on the interval between successive data points. The charts represent a single trace at a velocity of 10 mm/s, with a desired measurement interval of 25.4 µm. The chart on the left shows the achieved measurement interval under normal thread priority for the data acquisition loop. Large spikes appear, as other running threads scavenge processor cycles from the data acquisition thread. When the thread priority is changed to real-time, (Figure 1, right), all other threads are preempted by the data acquisition thread. Under these conditions, the data acquisition thread is able to acquire data at consistent intervals.

![Effect of thread priority of the data acquisition loop](image)

*Figure 1: Effect of thread priority of the data acquisition loop.*

Left: The operating system may unilaterally preempt the data acquisition thread in normal priority mode, leading to large (~1800 µm) intervals between data points. Right: No such preemption was noticed under real-time priority.

There may be conditions under which the number of operations being executed in the data acquisition loop changes. This temporarily affects the data acquisition rate, increasing the uncertainty in the measurement. Figure 2 shows the effect of varying the effective length of the data acquisition loop by requiring the software to dynamically allocate memory. Two memory buffers were compared: one, with a size of 0.2 MB and another with a size of 20 MB. The data being written to the buffer was 16 bytes long, so the smaller buffer was guaranteed to fill up before the measurement ended. In both cases, the desired measurement interval was set at 10.16 µm.

![Effect of varying the effective length of the data acquisition loop](image)

*Figure 2: Effect of varying the effective length of the data acquisition loop.*

In both cases, the average measurement interval is equal to the desired measurement interval of 10.16 µm. However, in the case of the smaller buffer, (Figure 2, left), the operating system was forced to dynamically allocate memory every time the memory buffer filled up. This periodically increased the number of instructions in the loop, increasing the measurement uncertainty. The measurement uncertainty was seen to decrease as the scan velocity was increased because fewer data points were collected at higher velocities, requiring fewer memory allocations. For the larger buffer, (Figure 2, right), the instruction length of the data acquisition loop effectively remained constant, as the buffer never needed to be replenished. Thus, the instrument was able to consistently meet the required measurement interval and the standard deviation was zero across the velocities tested.
The operating system allocates memory for the acquired data. Left: memory must be allocated frequently at slower speeds. Right: The buffer is pre-allocated, so the data acquisition proceeds unhindered.

A measurement mode often used is to have the vertical axis “follow” the surface. In this mode, the axis moves vertically whenever it crosses a predefined threshold, attempting to keep the surface within the range of the measuring laser. Surface following may be achieved using either software or hardware control. In the former case surface following functional requirement competes with data acquisition functional requirement, while in the latter case, it is independent or decoupled (Suh, 1990; Suh, 2000).

The instrument was designed to “follow” the surface being measured. Left: surface following is dependent on data acquisition loop to initiate vertical axis movement, increasing measurement uncertainty. Right: surface following is decoupled from data acquisition loop and implemented by hardware, decreasing measurement uncertainty.

Figure 3 shows the effect of decoupling axes-related functional requirements from data acquisition. Each figure consists of two lines – one for the forward trace and one for the reverse.

When the vertical axis movement is triggered by software, (Figure 3, left), the number of instructions to be processed in the loop temporarily increases every time the threshold is reached. The height reading
reported, therefore, does not exactly correspond to the horizontal location. As a result, a peak appears when the vertical axis is moving away from the surface while a trough appears when the vertical axis is moving towards the surface (Figure 3, inset).

When the vertical axis movement is triggered by hardware, (Figure 3, right), vertical axis motion is triggered using “near” and “far” hardware triggers. The motor controller moves the vertical axis independently upon sensing either of these events. Since this does not affect the data acquisition, which is implemented using software, the measurements mirror surface features well.

**Conclusions**

This study has demonstrated how the control software design affects the measurement uncertainty of scanning instruments. It has also demonstrated that the data acquisition loop in the code must be decoupled from the other functions of the equipment to reduce the measurement uncertainty.

**References**


