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Evaluate error sources and uncertainty in large scale measurement systems

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ABSTRACT

Modern manufacturing technologies place increasingly higher demands on industrial measurement systems. Over the last decade there have been rapid developments in 3D measurement systems, with the primary requirement coming from industries such as automotives, aerospace, shipbuilding and power plant equipments for accuracy and efficiency. This paper focusses on the analysis of large scale scanning techniques using a laser scanner; investigating the errors which arise during the measurement process and the uncertainty calculations for the measurements. Both point measurement and surface measurement has been performed and the result shows that the consistency of distance measurements between two points was 65 μm and between two surfaces was 9 μm. The laser scanner requires scans from different positions which have to be aligned. The result shows that reference frame alignment is the best method when compared to the tooling ball best fit method, fitting to 17 μm when using the laser scanner.

1. Introduction

Humans have used measurement in some form since the beginning of existence. Metrology was first analysed in metal machining and cutting workshops where reducing scrap metal had cost benefits [1]. It was however technology such as active feedback control, artificial intelligence and rapid data storage which was the driving force for advances in metrology [2]. Modern metrology have not only restricted its use on finished component inspection, control of manufacturing and assembly process, jigs and fixture verification, it has also opened up new application areas for metrology assisted production, for example for end-inspection process of long, heavy parts such as airframe structures and spars. Large components with tight manufacturing tolerances are often measured by large scale measurement systems include the laser radar, laser scanner, laser tracker, coordinate measurement machine (CMM), theodolite and photogrammetry [3]. The development of these measurement systems and the evaluation of the instrument measurability over the last forty years have been well defined [3–9]. However the most portable large volume measurement systems have complex structures and do not have simple characteristics. For instance: laser trackers have angle errors and larger than the interferometric distance errors; accuracy of the photogrammetric systems vary and depends on the range, the number of images used and the location of the images [10]. For controlling the measurement quality, an accepted procedure to verify the system and evaluation of error sources and uncertainty is required. There are different recognised methods for determining the uncertainty of measurement made with CMMs [11]. These methods are covered in the ISO 15530 series of standards [12]. Despite the increasing application of the laser scanner [13–16], common laser scanners are less accurate when compared to touch–trigger probes. Therefore identifying measurement uncertainty and improving digitising accuracy are the most challenging tasks.

Much of the research efforts on laser scanning have been focussed on the development of applicable laser scanning systems and the path planning of commercial laser scanners, only limited research has been carried out to analyse the error sources and uncertainty of the laser scanning systems [17]. The research work presented in this paper attempts to analyse and characterise the measurement uncertainty of a laser scanner. Experimental work has been performed. The objective is to first identify the build up errors within the laser scanner systems. This has been achieved by comparing with the laser tracker on performance measures to see the contributing factors of the uncertainties in laser scanner systems. The second objective is to identify the systemic errors and random errors within the scanner systems. The final objective is to establish the best-fit methods and frame to frame methods to reduce uncertainty for a typical laser scanning operation.

2. Understanding uncertainty

The uncertainty of a measurement, also called accuracy [18], can be described as the doubt or query which exists around a measurement result. Error was the original way of quantifying a

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measurement result; it was used to give an indication of the range in which the measured was located.

As the technology has progressed, measurement procedures and standards defining the results have been developed along side. These standards allow manufacturers to produce high quality products which can be clearly clarified. Two major standards are ISO 1101 series [18] and ISO 14253 series [19]. ISO 1101 relates to geometrical tolerancing, it defines general principles of form and positions of the material requirements. ISO 14253 relates to uncertainties in geometrical measurement (GUM); providing guidelines on the expression of uncertainty in measurement. It was officially recognised in the guide that measurements should be expressed in terms of their uncertainty instead of their error. Error of measurement is seen as a range in which the true value lies. Uncertainty gives a range and a probability that the result is within this range, generally SD=2 (standard deviations) is used which represents 95% probability. This recognises that measurement is an experimental procedure and hence results cannot be 100% reliable. Uncertainty shows it is as important to know the quality level of the measurement as the measurement result [20].

Fig. 1 shows a graphical representation of how measurements taken under the classical approach relate to the feature being measured [21]. y_{true} is the true value of the measurand and y_i is the individual measured value, then $\bar{y}$ is the average measured value. If a large number of measurement results are taken and plotted, the resultant plot will represent a normal distribution. This distribution can be put down to random errors. Systematic errors have a set of values equal to the difference between $\bar{y}$ and y_{true}. This error represents possible issues such as machine calibration. In a measurement series, systematic error is not observable and does not behave in a random nature, therefore statistical analysis cannot be applied as with the analysis of the random errors.

Modern metrology is moving away from the classical approach towards the uncertainty approach. There are two possible approaches, Uncertainty in Measurement approach and the International Electrotechnical Commission (IEC) approach. GUM states that it is not possible to know the exact value and it accounts for systematic and random errors on equal footing. It recognises in Eq. (1) that error is an idealised concept and uses a Gaussian probability density function (*pdf*) to represent it, where $\bar{x}$ is the mean value and σ^2 is the variance.

$$pdf = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{(x-\bar{x})^2}{2\sigma^2}} \quad (1)$$

A measurement result fully defined using uncertainty, would be x mm $\pm$ y mm $z\sigma$, where x is the measurement result and y is the range in which the result lies with a probability of z standard deviations (2σ being 95% probability).

The IEC approach has a more operational method; it works on the basis of the true value being both unnecessary and unknowable. It is important that measurements are compatible with each other and the averaging of multiple measurements is encouraged [21]. When single measurements are taken, the measurement systems calibration must be taken into account when working out the uncertainties. When decisions need to be made on whether a measured quantity conforms to a particular requirement, a hybrid of the classic and uncertainty methods is normally used. Examples of this include machine tolerances and legal requirements. A two step process is used, first measuring a calibration result using a high accuracy level system then repeating the measurement using the lower accuracy machine in the measurement process and assessing errors with respect to the classic approach.

When comparing the error form to the uncertainty form, it becomes clear that the random error is closely linked to the standard deviation used in uncertainty, in that both can be modelled using a normal distribution curve. Random error can be related to the range in which the result lies. The problem with splitting into two parts in error measurement analysis is that the best way to represent random error is to use statistical analysis. Whereas the systematic part, as it is individual to each measurement type, should not be represented using statistical analysis.

Within uncertainty there are two categories for generating an uncertainty value, Type A & B. Type A estimates the uncertainty using statistics based on measurement results. Type B calculates the uncertainty based on known data such as calibration certificates, manufacturer specifications and common sense. Eqs. (2) and (3) [22]

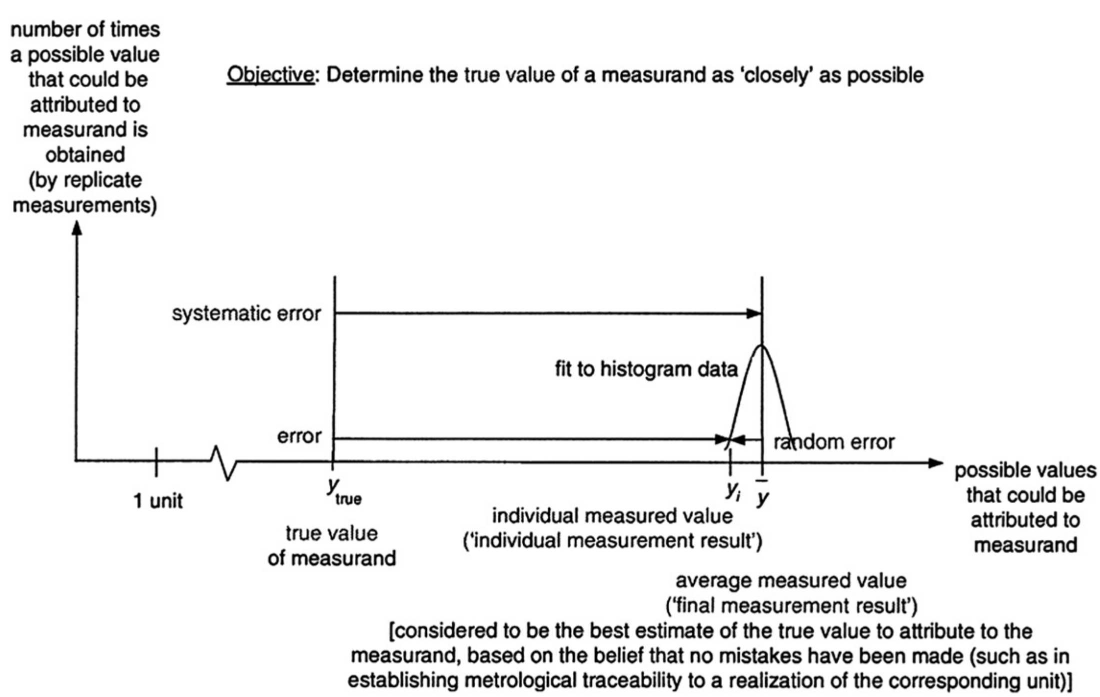

Fig. 1. Representation of errors in the classical approach to measurement.