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Ding, Hao, Scott, Paul J. and Jiang, Xiang

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Inverse problems of measurement
with application on specification of surface profile

Hao Ding, X. Jang, and Paul J. Scott*
Computing and Engineering, EPSRC Centre, The University of Huddersfield, UK

Introduction:
A contradiction of the specification of free-form surface profile is pointed out. The inverse
problem of measurement (IPM) is defined based on the representational measurement theory.
By correcting the contradiction, a new approach is proposed.

Specification and measurement of surface profile
The upper and lower specification limits (LSL and USL) of a free-form surface profile
defined in ISO 1101 are two curves enclosing circles of certain diameter r, the centres of
which are located on the nominal surface profile (see figure 2a). For an actual surface
profile $l_1$, if all the points on it are within the tolerance zone, i.e. $L_S L < l_1 < U_S L$, $l_1$ is within
the space.
The canonical method of measuring surface profile is contact measurement by moving a
tactile stylus along the surface to be measured to obtain the locus of the centre point of the
stylus tip.

Figure 1. working principle of measuring surface profile with a tactile stylus

A Conduction of the Specification of Free-form Surface

The contradiction
Due to the extensive property of closing filter, the estimated profile is always above the
actual profile (see figure 1). Hence when an actual surface profile coincides with the LSL
(depth within space), the measurement result (without error) would, however, be out of
space, which contradicts with the real situation.

Figure 2. Accuracy of the tolerance zone of surface profile

Representational model of measurement
The representational measurement theory allows measurement to be defined as the
assignment of numbers to attributes of objects in such a way as to describe them
(Steinhaus, 1990). Hence measurement can be considered as a mapping from the
measured objects to the measured values.

For the measurement of a attribute, one or more empirical relations would be
defined between the measured objects. E.g. consider $x$ is a very general empirical
relation.
The set of the measured objects with the empirical relations, $R_1, R_2, ..., R_n$, can be
taken as a mathematical object MRS $M_s = \{R_1, R_2, ..., R_n\}$, called an empirical relational
system (ERS). E.g. the ERS of length (or mean, mean) is $(M_s, \leq)$, where $\leq$ is a
proportion, is a commutation operation.

Measurability: a measurement is possible only if there exist a structure-preserving
mapping from the ERS to a specified numerical relational system (NRS). E.g. the
NRS representing the length is $(R_s, \leq s)$. The numbers in the NRS are the values of
the measured (quantity to be measured).

A desired property of spec. limits should be satisfied. Let $l_0$ be a spec. limit, $x_0$ then $\delta = l_0 - x_0$.

Principle of correcting the contradiction

To estimate the surface profile according to the observed locus is an
inverse problem: $D_0$ is the forward mapping and its inverse
one is $E_0$, i.e. $D_0 E_0 = I$.

Essential reasons of the contradiction:

- The forward mapping $D_0$ is not one-to-one;
- The inverse solution $l_1$ is a maximal point of the possible input,
i.e. $l_1 \geq D_0 (l_0) = l_0$.

The spec. limits should reflect the required manufacturing variation, e.g. $3.000 \pm 0.10$mm. So the spec. limits given in ISO 1101 should be amended.

We expect that the true value of a measured object is within spec.,
its measured value is also within spec. Hence the following desired property of spec.
limits should be satisfied.

A correction of the specification