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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. Jiang, and Paul J. Scott
Computing and Engineering, EPSRC Centre, The University of Huddersfield, UK

Introduction:
A contradiction of the specification of free-form surface is pointed out. The inverse problem of measurement (IPM) is defined based on the representational measurement theory. By using the concept of IPM, a desired property of specification limit is derived and a correction for solving the contradiction is proposed.

Specification and measurement of surface profile
The upper and lower specification limits (LSL and ULSL) of a free-form surface profile defined in ISO 1101 are two curves enclosing circles of certain diameter r, the centers of which are situated on the nominal surface profile (see figure 2a). For an actual surface profile i, if all the points i are within the tolerance zone, i.e. LSL ≤ i ≤ ULSL, i is within the spec.

The conventional 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 profiles with a tactile stylus

With S as the structuring element, the locus is the dilation of i, and i can be estimated by the equation of, l2 = E2(i) = E2(i). The combination of D2 followed by E2 is a closing filter, C2 = D2E2.

A Contraction of the Specification of Free-form Surface

Due to the extensive property of closing filter, the estimated profile is always above the actual profile (see figure 1). Here when an actual surface profile coincides with the LSL (i.e. within spec.), the measurement result (without errors) would, however, be out of spec., which contradicts with the equal situation.

Figure 2. Accuracy of the tolerance zone of surface profile

Inverse problems of measurement

Inverse problem in general framework of problems that infer information from observations (Sabater, 2009).

In many cases, the measurements are not directly observable, they can only be inferred from the observed data of some related proxy quantity.

Definition: inferring the values of the measurements from the observed data is the inverse problem of measurement (IPM). Inward mapping is the characteristic function of the measurement process, It is X → D.

The inverse or pseudo-inverse of h, denoted as g, D → X, can be used to find the inverse solution, it is expected to satisfy the following equation:

\[ D = h \rightarrow X = g(D) \]

For any IPM, X and D are always determined by an ensemble ERS.

A correction of the specification

Principle of correcting the contradiction

• To estimate the surface profile according to the observed locus is an inverse problem, D2 is the forward mapping and its pseudo-inverse is E2, i.e. D2E2 = D2.

Reasons for the contradiction:
• the forward mapping D2 is not one-one;
• the inverse solution l1 is a maximal point of the possible input, i.e. l1 ∈ E2(D2(i)) = l1.

The spec. limits should reflect the required measurement resolution, e.g. 3.00 / 0.01mm. So the spec. limits given in ISO1101 should be amended.

We expect that if 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:
Let i be a spec limit, let i be then 3.00 + 0.01.

A proposed solution

• Correcting the curve of LSL from i to l1 = C2(i) (see figure 2b), where C2 is the closing filter with the structuring element S.

The diameter of the stylus S is assumed to be smaller than the dimension r. It can be proved with the invariance property of a closing filter that the desired property is satisfied after the correction.

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*Contact: p.j.scott@hud.ac.uk, +44 1484 471285