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Inverse problems of measurement
with application on specification of surface profile

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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 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 LSL) of a free-form surface profile defined in ISO 1101 are two curves enveloping circles of certain diameter \( r \), the centres of which are situated on the nominal surface profile (see figure 3a). For an actual surface profile \( f \), if all the points on \( f \) are within the tolerance zone, i.e., \( \text{LSL} \leq f \leq l \text{SL} \), \( f \) is within the spec.

The empirical 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.

The essential reasons of the contraction:
- To estimate the surface profile according to the observed locus is an inverse problem, \( D_{i} \) is the forward mapping and its pseudo-inverse is \( E_{i} \), in the sense that \( D_{i} E_{i} = D_{i} \).
- Essential reasons of the contraction:
  - The forward mapping \( D_{i} \) is not one-to-one;
  - The inverse solution \( l_{i}^{*} \) is a maximal point of the possible input, i.e., \( l \leq E_{i} D_{i} (l_{i}^{*}) \).
  - The spec. limits should reflect the required measurement resolution, e.g., 3.00 \( +\) 0.10 mm. So the spec. limits given in ISO 1101 should be amended.
  - We expect that if the true value of a measured object is within the spec., its measured value is also within spec. Here the following desired property of spec. limits should be satisfied.
  - Let \( a \) be a spec. limit, \( b \) be then \( a + b \).

The contradiction of the specification of free-form surface profile

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 (flats within spec.), the measurement result (without error) would, however, be out of spec., which contradicts with the real situation.

A proposed solution

1. Correcting the curve of LSL from \( l_{i} \) to \( l_{i}^{*} = C_{E} l_{i} \) (see figure 2b), where \( C_{E} \) is the closing filter with the structure element \( S \).
2. The diameter of the stylus \( S \) is assumed to be smaller than the dimension \( e \). It can be proved with the invariance property of closing filter that the desired property is satisfied after the correction.

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