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Mathematical softgauges: a new method for validating metrology algorithms

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Abstract

Surface texture parameters, filters and association methods are defined by ISO standards in the continuous world (ISO 21920-2 [1], ISO 25178-2 [2]…). However, their implementations in software packages are always done in the discrete world and applied on digital data. Metrology software editors need to be able to check their implementations against references, the same way instrument manufacturers use material measures to calibrate their instruments and calculate uncertainties. For several years, NMIs have issued so-called *reference software* or algorithms, in an effort to standardize implementations, but these reference software packages have never been close to a reference, with even different reference software giving different results! [3]. This is why, in the recent years, a new concept was introduced, based on mathematics, and with a framework allowing editors to check any implementation and assess the deviation from true values. This method is currently described in a draft standard within the ISO 25178 series (part 74). This paper provides a short overview of the benefits of this method and its applications.

Keywords: material measure, mathematical softgauge, ISO 5436-2, reference software

1. Introduction

The purpose of the proposed method is to provide an absolute reference that is independent from any implementation, based on mathematics. The input data (profile or surface) is defined by an equation (called a *mathematical softgauge*), then is inserted in the definition equation of a surface texture parameter and the combined equation is then solved formally to obtain the parameter result value as an equation (called *mathematical true value*).

The pair [*mathematical softgauge*, *mathematical true value]* can be considered as a software material measure, with a similar use as a hardware material measure and its calibrated value. This method is quite new to surface texture as the concept of reference software (type F2 software measurement standard) was previously preferred. A few authors have applied similar methods but without explaining clearly the global framework [3, 4].

2. Methodology

In order to test an implementation, it is necessary to create a discrete version of the *mathematical softgauge*, called the *realised softgauge*. On the other hand, a *realised true value* is calculated with any number of decimal places.

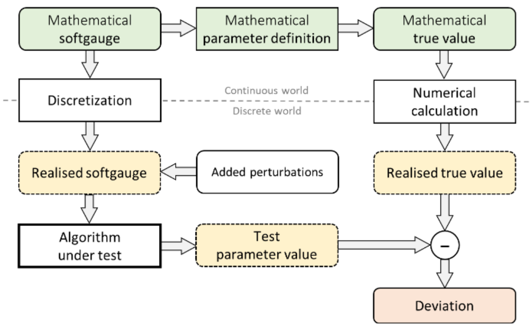

Figure 1: *workflow for testing a parameter algorithm*

ISO/WD 25178-74, under development, defines new terms:

- Mathematical softgauge: input data described by an equation $z = f(x)$ for a profile or $z = f(x, y)$ for a surface. These equations may depend on design parameters (amplitude, wavelength, …)
- Mathematical true value: equation obtained by combining the equation of the mathematical softgauge and the equation of the parameter (or filter).
- Realised softgauge: data file obtained by sampling the mathematical softgauge with a given lateral resolution and with a given discretization step in Z. This file is used as an input to the algorithm under test.
- Realised true value: numerical value obtained by assigning values to the design parameters of the mathematical true value, and calculated to a given number of decimal places.

The method for testing an algorithm consists in loading the *realised softgauge* into the software, calculate the *test parameter value*, and compare it to the *realised true value*. The deviation allows the editor to identify potential causes of inaccuracies.

This method also makes it possible to assess the stability of a parameter definition by adding perturbations in the realised softgauge, such as noise, outliers, slope, etc. Unstable algorithms (or parameter definitions) can be identified when the output value shows large deviations for a small input perturbation.

The method is also compatible with the test of filters (Gaussian, Spline…) [5] and association methods (levelling, form removal…) [6].

Finally, the mathematical softgauge can represent other types of curves such as the Abbott or autocorrelation curve, in order to test material ratio or volume parameters [7].

An example can be given with a sinusoidal profile defined by:

$$z(x) = A \sin\left(\frac{2\pi x}{\lambda}\right)$$

By combining this equation with parameter equations, we can deduce their respective *mathematical true values*, and by assigning values to the amplitude *A*, we can calculate the numerical approximation (*realised true value*).

Mathematical true value	Realised true value
$P_a = \frac{2A}{\pi}$	$P_a = 3{,}183\ 098\ 861\ 838\ \mu m$
$P_q = \frac{A}{\sqrt{2}}$	$P_q = 3{,}535\ 533\ 905\ 933\ \mu m$
$P_{sk} = 0$	$P_{sk} = 0{,}000\ 000\ 000\ 000\ \mu m$
$P_{ku} = \frac{3}{2}$	$P_{ku} = 1{,}500\ 000\ 000\ 000\ \mu m$

3. Towards a new standard

The working group WG16 of ISO TC 213 has started in 2024 the drafting a new standard describing this method with the intention to complement existing standards related to material measures and softgauge file format. This standard will replace ISO 5436-2 [9] that defines reference data (type F1) and reference software (type F2). Together with the replacement of ISO 5436-1 [8] by ISO 25178-70 [10], it will be possible to withdraw both parts of ISO 5436 that are more than 25 years old.

Mathematical softgauges are introduced as a type F3 software measurement standard, and the two other ones are renamed:

- *reference data* is now called *traceable softgauge*
- *reference software* is now called *traceable software*

The three software measurement standards are organized in a hierarchical way, similar to the chain of traceable references used in accreditation tasks.

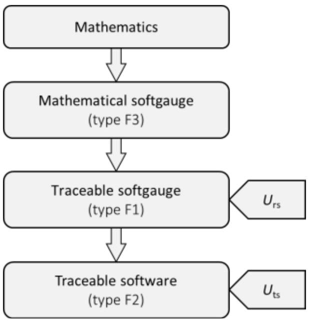

Figure 2: *hierarchy chain for software measurement standards*

The type F3 standard remains in the mathematical domain but the *traceable softgauge* is a discrete data file that is affected by an uncertainty U_{rs} that represents errors due to the sampling and discretisation.

The *traceable software* is an algorithm that implements a parameter calculation or a filter. It is affected by an uncertainty U_{ts} that represents errors due to implementation choices such as the type of integration (simple summation, linear interpolation, spline interpolation…) or the type of gradient (simple difference, 3-term approximation, 5-term approximation…) A traceable software needs to be validated for a set of parameters using mathematical softgauges. Once it is validated, it can verify real data files that are measured by instruments or generated by an algorithm.

4. Conclusion

Mathematical softgauges allow software developers to implement their algorithms as they wish but provide them a mean of calibrating the results produced by their implementations.

This new concept is independent from any implementation and is based upon mathematics. It can therefore be considered as a genuine reference, contrary to the old concept of reference software that could not be considered as references despite their name [3].

Unfortunately, not all parameters can be validated that way because either the calculation of the mathematical true value is too complex, or because the parameter is not defined using an equation but rather by an algorithm, such as the R&W parameters of ISO 12085 [11].

The majority of profile and areal parameters implemented in the Mountains® analysis software [12] have been successfully tested with this method. This method has revealed its potential for detecting small numerical inaccuracies in algorithm implementations [6], which are normally undetectable on real data and are often indicative of sub-optimal implementation.

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