Analysis on surface texture software measurement standards and their application

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Abstract
For surface texture measuring instruments, the embedded analysing and evaluating software is as important as its hardware for accurate and integral performance. To evaluate the precision and correctness of the software, software measurement standards have been proposed in ISO 5436-2 (2001). As the traditional hardgauge specimens, which are used to calibrate the instrument hardware, the software measurement standards were designed for calibrating the software of the instrument. In this paper, the software measurement standards, including two types of standards Type F1—reference data, Type F2—reference software and data file formats of Type F1, are described. Their recent developments worldwide are reviewed, and differences among software measurement standards for the surface texture developed by different organizations are compared and analyzed in the light of a practical application example of the standards. (PACS, Measurement Science and Technology)

Keywords: surface texture, software measurement standards, algorithm

1. Introduction
Computer-based measuring instruments are widely used for surface texture analysis. Obviously, the analysis precision of the instrument depends on not only the hardware but also the analysis and evaluation software embedded in the instrument. So, as for hardware, software also plays an important role in the measurement result, and influences the whole performance of the instrument. To evaluate the precision and correctness of the software, software measurement standards have been proposed in ISO 5436-2 (2001) [1]. Compared with the relatively developed evaluation standards for the instrument hardware, research on standards for software verification and evaluation is just at its initial stage.

Most measuring instruments of the surface texture are claimed to be manufactured according to ISO 4287(1997)[2], in which surface parameter definitions are all in terms of continuous form, however in practice, sampled surface data is normally used for analyzing and in discrete form. Research shows that converting a continuous definition “directly” to a discrete form for parameter calculation (for instance, replacing integrals to summations) very easily leads to unacceptable evaluation errors [3]. On the other hand, different understandings of parameter definitions in the standard documents and different choices of analysis and evaluation algorithms could also lead to different measurement results even for the same data. It is therefore necessary to verify the accuracy
and precision of an instrument from the prospect of its software, which is the very reason for that the software measurement standards have been proposed in ISO 5436-2(2001).

Unlike the traditional hardgauge specimens which are used to calibrate an instrument hardware, the software measurement standards are designed to evaluate only the software of an instrument. Software measurement standards defined in ISO 5436-2(2001) are the general specification, and a lot of research should and have be conducted for practical applications. Recently, various organizations have developed their own software standard systems to facilitate their use in practice. The Center for Precision Technologies in the University of Huddersfield has collaborated with the Taylor Hobson Ltd and the National Physical Laboratory (NPL) in the UK to develop internet-based software measurement standards for profile parameters. The National Institute of Standards and Technology (NIST) in the US has developed an Internet-based surface metrology algorithm testing system (ISMAT) for parameter evaluation and algorithm verification in the area of surface texture. Physikalisch-Technische Bundesanstalt (PTB) in Germany has also developed reference software for roughness analysis.

In this paper, the contents of software measurement standards defined in ISO 5436-2(2001) are interpreted briefly, the software standard systems developed by the organizations mentioned above are reviewed, the differences among them are compared and analyzed, and an example is given to show the practical application of the software measurement standards.

2. Contents of software measurement standards
Software measurement standards are reference data or reference software to be used for verification of software in measuring instruments. There are two types of software measurement standards, Type F1—reference data and Type F2—reference software.

2.1. Type F1—reference data
The Type F1 measurement standards are reference data files that depict a digital representation of a total surface or profile in a suitable recording medium. A reference data is composed of two parts, one part is the data piece describing the profile and the other part is certified parameter results for the reference data. These measurement standards are used to test software by inputting them as data into the software under test/calibration and comparing the results from the software under test with the calibration certificate of the softgauge.

2.2. File format for Type F1 softgauge
Software packages in commercial instrument have their own data handling formats. Some of them can accept external data files while others can not. In order to provide a uniform interface, a standard file format with the extension of SMD is proposed for Type F1 softgauges.

2.3. Type F2—reference software
Type F2 measurement standards are reference software. Reference software consists of traceable computer software against which the software of a measuring instrument can be compared. Type F2 measurement standards are used to test software by inputting a common data set into both the software under test/calibration and the reference software and comparing the results from the software under test with the certified results from the reference software.

3. Development of software measurement standards

3.1. Introduction to research work in NPL, NIST, and PTB

3.1.1. About Type F1 measurement standards—reference data. As for the reference data at NPL, three types of surface profile data are available in the reference data sets: mathematically defined profiles, such as sine waves, square waves, impulse profiles and etc., simulated profiles for different
processes such as turning and milling, and practical profiles by measurement of master workpiece machined by typical manufacturing processes such as honing and electro-discharge machining [4,6].

The reference database provided by ISMAT contains an electronic catalog of primary surface profiles, filtered profiles, calculated surface parameters and also power spectral density data. Two types of surface profile are included: numerically generated profiles, such as a random profile, sinusoidal profile, square wave and impulse, and three traces from type-D roughness specimens, which were measured, preprocessed, and scaled to 40-50\(\mu\)m \(R_a\) range [5,7]. They are available on the internet website hosted at NIST.

3.1.2. About Type F2 measurement standards—reference software. Reference software package developed by NPL constitutes Type F2—reference software for the calculation of surface texture parameters. The reference software can be downloaded freely from the internet as a zip file. It is standalone and written in Java programming language, and comes with a simple graphical user interface (GUI) to facilitate its use. The reference software can accept data file in the format of SMD defined in ISO 5436-2 (2001). However, since other data file formats have been encountered in surface texture measurements, a file conversion function is provided online to ensure that other format of data files such as PRF, SDF can be accepted. During the conversion, relevant information such as filtering or not, cutoff \(\lambda_c\) and \(\lambda_y\) should be provided, so that they can be recorded in the SMD file. Reference values of all surface texture parameters will be calculated and listed in the SMD file.

NIST provides users with the internet based ISMAT, which is developed using Java Servlet technology. Both reference algorithm analysis tools and reference data sets are distributed freely online. To use the type F2 measurement standards, users submit profiles and topographic images to the system. According to the information about form removal and filtering method selected by the user, the waviness, roughness, or primary profile along with calculated surface texture parameters can be downloaded in formats of SMD, SDF and XML.

PTB has developed reference software of type F2 defined in ISO 5436-2(2001). The goal is to have traceable computer software based on international standards for roughness parameter evaluations. Also, the reference software is internet-based and can process data in SMD format defined in ISO 5436-2(2001)[8].

3.2. Comparison of reference algorithms
In this section, a comparison between the two Type F2 software measurement standards developed by NPL and NIST is conducted. A surface profile shown in Figure 1 is input into the two reference software. To be comparable, analysis has been carried out in the two reference software by the same Gaussian filter defined in ISO 11562 (1996) [9] with \(\lambda_c = 0.8\)mm. The obtained results are displayed in table 1.

![Figure 1 Primary surface profile.](image)

It is shown in table 1 that obtained results are different even under the same evaluation conditions. The reasons for those differences are mainly due to different interpretations of surface parameters definition and different algorithms might be used in the two reference softwares.
Table 1 Obtained values of NPL and NIST

| Parameter | NPL       | NIST       |
|-----------|-----------|------------|
|           | Nominal   | Uncertainty| Nominal | Mean | Uncertainty |
| Ra        | 1.2909um  | -          | 1.2908um | 1.2962um | 6.18nm     |
| Rq        | 1.5870um  | -          | 1.6150um | 1.6150um | 7.46nm     |
| Rku       | 2.6772    | -          | 2.9276   | 2.9140   | 0.015      |
| Rsk       | 0.0752    | -          | 0.1328   | 0.1403   | 0.011      |
| Rp        | 3.9498um  | -          | 5.2540um | 5.2521um | 31.86nm    |
| Rv        | 3.6760um  | -          | 4.3821um | 4.3865um | 36.25nm    |
| Rz        | 7.6258um  | -          | 7.6171um | 7.8082um | 182.09nm   |
| Rt        | 9.6369um  | -          | 9.6361um | 9.6362um | 44.17nm    |
| Rc        | 4.6419um  | -          | NULL     | NULL     | NULL       |
| Rsm       | 102.0672um| -          | 106.2588um| 108.2334um| 5.23um     |
| Rdq       | NULL      | -          | 0.1688um/um | 0.1694um/um | 6.15um/um |

Take the algorithm for Ra as an example.

Ra in ISO 4287(2000) is defined as arithmetic mean of the absolute ordinate values $Z(x)$ within a sampling length $l_r$.

$$Ra = \frac{1}{l_r} \int_{0}^{l_r} |Z(x)| \, dx$$  \hspace{1cm} (1)

For digital implementation by NPL, a natural cubic spline is used to interpolate through the discrete data values [6]. For each sampling length $l_r (i = 1, 2, \ldots, CN)$,

$$Ra_i = \frac{1}{l_{r_i}} \int_{0}^{l_{r_i}} |Z(x)| \, dx ,$$  \hspace{1cm} (2)

$$Ra = \frac{1}{CN} \sum_{i=1}^{CN} Ra_i$$  \hspace{1cm} (3)

For digital implementation by NIST, Ra is calculated within a sampling length with the sampled data value $z_j$,

$$Ra = \frac{1}{N} \sum_{j=1}^{N} |z_j|$$  \hspace{1cm} (4)

NIST adopted algorithms in the discrete form rather than the continuous definition form. As it can be found that this approach could lead to unacceptable errors [3].

Since surface parameters should be unambiguous and have stable and robust definitions so as to reflect genuine properties of a surface [10,11], reference software is needed for verification of analysis and evaluation software of instruments, and reference software themselves should be consistent with each other and traceable to the standards.

4. An example for application of Type F1 — reference software

Flowcharts about how to use the two types of measurement standards F1 and F2 are shown in figure 2. The application of Type F1 measurement standards will be presented in this section.

The profile shown in figure 1 is adopted as the primary profile, which is downloaded from the reference data sets on the NPL website. With $\lambda_c = 0.8 \text{ mm}$ is adopted for the Gaussian filter, putting the reference data into the software under test, we can get the evaluation results in column “Test”.

Compared with the reference results provided with the reference data, it’s shown that the test software needs to be improved. Since some of the parameter results are considerably different, especially for
This may result from the unstable algorithm for this parameter, or maybe different height and spacing discrimination are adopted due to the ambiguous definition in ISO 4287(2000)[4,11]. During the process of the algorithms improvement, the reference results will serve as guidance for the metrology software developer.

Table 2 Application of Type F1—reference software.

| Label | NPL | Test |
|-------|-----|------|
| Ra    | 1.2909 | 1.2797 |
| Rq    | 1.5870 | 1.6050 |
| Rku   | 2.6772 | 2.9286 |
| Rsk   | 0.0752 | 0.1697 |
| Rp    | 3.9498 | 5.3415 |
| Rv    | 3.6760 | 4.3169 |
| Rz    | 7.6258 | 7.4751 |
| Rt    | 9.6369 | 9.6583 |
| Rc    | 4.6419 | 3.1545 |
| Rsm   | 102.0672 | 65.4 |

Figure 2 Flowchart for evaluation.

5. Conclusions
The paper introduces the concept of software measurement standards and their developments. The software measurement standards are of great help for reliable and effective achievement of quality and function information of an engineering surface. They will serve as an indispensable and effective means to regulate the manufacture, measurement and evaluation of engineering surfaces. Two types of measurement standards as Type F1 and Type F2 are described. The present status and development of software measurement standards, especially those developed by NPL and NIST, are reviewed. An example for practical application of the surface measurement standards is given to show how they play important role in assuring the traceability of surface texture measurement software. It is also shown by the example that, reference software is needed for verification of analysis and evaluation software of surface measurement instruments, and reference software themselves should be consistent with each other and traceable to the same international standards.

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