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A programmable software framework for the generation of simulated surface topography

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Abstract
A flexible and programmable software framework has been developed that enables the creation of simulated, areal surface topography datasets. The framework allows the creation of surfaces through a layered approach where deterministic topographic structures can be combined with pseudo-random periodic and non-periodic components. The software can be used to generate reference topographies useful for the testing and validation of surface metrology methods and algorithms. The software framework is implemented in Matlab, and features a graphical user interface that enables easy navigation, and allows users to control the topography creation process. In addition to providing a complete analytical description for some classes of generated surfaces, the framework allows the surface datasets to be exported in the Surface Data File format, thus enabling easy transfer to a wide array of commercial surface metrology software applications.

Surface texture, simulated surfaces, surface topography

1. Introduction

Surface texture can have a significant effect on part properties, such as a part's efficiency and lifespan [1,2]. Surface texture parameters are numerical descriptors of the topography of a surface, and are used in the assessment of manufactured parts to identify whether the part exhibits the required characteristics to suit its purpose [3,4]. Surface texture parameters are typically calculated using software, either standalone or incorporated into measurement equipment, into which a discrete dataset representing the measured surface is input. Since many surface texture parameters involve integration, differentiation and other elements of mathematical analysis, numerical analysis is needed to compute these parameters algorithmically.

Reference software and data, provided by national metrology institutes, are currently used to validate software packages developed for the calculation of surface texture parameter values [5-8]. Reference software, however, also uses numerical methods. This paper presents part of ongoing research work dedicated to overcoming the use of approximate numerical methods through the development of a software framework that: a) promotes the generation of simulated surface datasets driven by analytical equations; b) promotes the computation of texture parameters via symbolic manipulation; and c) limits the use of numerical computation to the minimum necessary. In this paper, the part of the framework dedicated to the generation of simulated surface datasets is presented.

2. Analytical surface representation

The proposed software framework utilises a two-dimensional Fourier series approach to produce a two-dimensional analytical expression describing a surface using a series of exponential terms. The software features a graphical user interface in which users can select parameters that build up a simulated surface, such as cosine terms with user-defined frequencies, phase shifts and amplitudes. These terms are then combined to create an analytical surface representation using the form

$$f(x,y) = \sum_{l}\sum_{m} A_{l,m} \exp\left(2\pi i f_s \left(\frac{lx}{N_x} + \frac{my}{N_y}\right)\right) \qquad (1)$$

where f_s is the fundamental frequency, N_x and N_y are the size of the surface in the x and y directions as multiples of $1/f_s$, l and m are integers specifying the distance from the zero-frequency in Fourier space in multiples of the fundamental frequency in the x and y directions, and $A_{l,m}$ is a matrix defining the amplitudes of each frequency term. In addition, the software can sample this expression at a user-defined rate to create a discrete dataset representation of the simulated surface of any density. This dataset is exported in the Surface Data File (SDF) format, a standardised format [9], enabling the discrete representation to be used in a variety of third-party surface texture analysis software packages. An example surface created using this method is shown in figure 1.

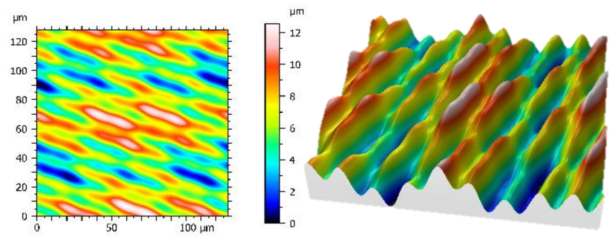

Figure 1. Simulated surface example created using five cosine terms in the surface generation software.

It should be noted that only using a Fourier series representation in terms of x and y limits the shape of the resulting surfaces. To produce surfaces with radial effects and rotational symmetry, other techniques such as Zernike polynomials must be included [10]. These will be considered for inclusion in any future work.

3. Graphical user interface

The software framework is presented to the user in the form of a graphical user interface (GUI), which helps to guide the user through the software in a logical manner with simple inputs.

Upon launching the software, the user is presented with an initial starting dialog. From this dialog, the user can specify the sampling period and size of the desired surface, along with options for adding simulated noise to the surface (section 3.3). The software offers two methods of surface creation to the user: by specifying individual cosine terms, or by using a combination of pre-defined functions. Both approaches are explained below.

3.1. Summation of cosine terms

Upon selecting the cosine term surface creation method, the user is presented with the page shown in figure 2. Simple controls are used to produce a two-dimensional cosine equation defining a surface. Users can define any number of these cosine equations to manually create a simulated surface. The user inputs are stored as Fourier space representations of a surface, and converted to exponential form using Euler's formula,

$$\cos x = \frac{\exp(ix) + \exp(-ix)}{2}. \qquad (2)$$

From here, the user is shown an image of the generated surface and is given the option to save the analytical expression in a .TXT file for use in the analytical computation of surface texture parameters via symbolic manipulation. Also output is a discrete dataset representation of the surface in an .SDF file for numerical computation.

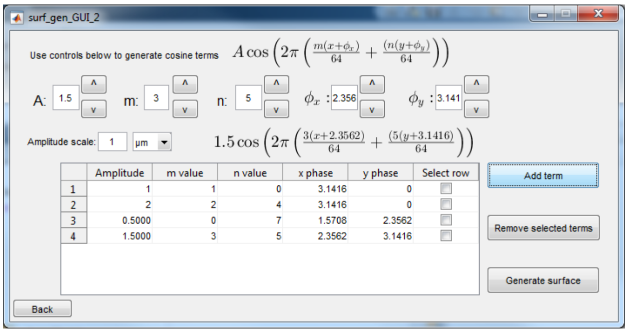

Figure 2. GUI page for the cosine summation surface generation method.

3.2. Pre-set functions

As an alternative to specifying cosine terms, the user can also create a surface using an approximation of a combination of pre-defined adjustable functions, including Gaussians, sinc waves and boxes. After each new function is added, a preview of the resulting surface is generated. Due to the complexity creating the pre-set functions in Fourier space, the functions are created in terms of spatial coordinates x and y. Once the desired functions are combined together, the resulting surface undergoes a Fourier transform, and the resulting Fourier space representation of that surface is used to create the analytical expression. As this process utilises a discrete fast Fourier transform algorithm, which can introduce distortions when attempting to transform a finite size spatial image with discontinuous edges into a continuous Fourier representation, the resulting analytical expression is not an exact copy of the designed surface, but instead is an approximate continuous representation. From this expression, the final preview of the surface and the optional .SDF file are produced.

3.3. Noise generation

Included in the surface generation software is an option for adding pseudo-random noise to the surface, to better simulate the small-scale variations representative of surface texture.

The software utilises a multi-scale Fourier space Gaussian blur method to introduce noise into the simulated surface [11]. This method convolves normalised random Fourier space values with Gaussian functions of varying widths to produce random Fourier space 'surfaces' with increasingly large scales of variation. These Fourier surfaces are then combined, with the surfaces scaled such that the highest frequency noise components have the smallest amplitude. The resulting multi-scale random noise Fourier space surface is then combined with the designed Fourier surface and used in equation (1) to produce an analytical expression that includes the pseudo-random noise. A simple example of multi-scale noise is shown in figure 3.

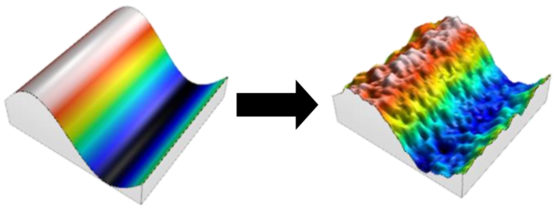

Figure 3. A simple surface of a one-dimensional cosine, before and after the application of multi-scale noise.

4. Conclusion

This paper presents a software framework that enables the generation of analytical simulated surface representations. The GUI acting as front-end to the framework delivers an easy-to-use experience that allows users to design and specify their own analytically-defined surfaces. Manual surface creation can be achieved in two ways: using a combination of pre-defined functions, or built piece-by-piece with an array of cosine terms. In addition, the software enables the addition of multi-scale Fourier space Gaussian blur pseudo-random noise to the surface to better simulate realistic surfaces, whilst still retaining the ability to deliver an analytical expression.

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References

[1] Pettersson U, Jacobson S 2003 *Tribology International* **36** 857-864
[2] Merlo A M 2003 *Surface and Coatings Technology* **174-175** 21-26
[3] Leach R K 2013 *Characterisation of areal surface texture* (Berlin: Springer)
[4] Whitehouse D J 2010 *Handbook of surface metrology, 2nd ed.* (Boca Raton: CRC Press)
[5] Harris P M, Smith I M, Leach R K, Giusca C, Jiang X, Scott P 2012 *Meas. Sci. Technol.* **23** 105008
[6] Harris P M, Smith I M, Wang C, Giusca C, Leach R K 2012 *Meas. Sci. Technol.* **23** 105009
[7] Bui S H, Vorburger T V 2007 *Precis. Eng.* **31** 218–25
[8] Jung L, Krüger-Sehm R, Spranger B, Koenders L 2004 *XI Int. Colloq. Surfaces*, Chemnitz, *Germany, Feb.* 164
[9] ISO 25178-71 2012 *Geometrical product specifications (GPS) - Surface texture: Areal - Part 71: Software measurement standards* (Geneva: International Organisation for Standardisation)
[10] Bezdidko S N 1974 *Sov. J. Opt. Techn.* **41** 425
[11] Perlin K 1985 *ACM Siggraph Computer Graphics* **19** (3) 287-296