A METHOD FOR FAST GAUSSIAN FILTERING FOR 3D ROUGHNESS EVALUATION

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Introduction

In the assessment of engineering surfaces, it is fundamental to decide correctly a datum line or plane. The precision of datum line or plane directly influences the precision of the assessment of surface parameter.

In the assessment of parameters of surface roughness, the method of mean line assessment datum and the one of filtering are often to be used. The mean line assessment datum mainly includes the least square mean line and the arithmetic mean line. The mean line methods have two inherent disadvantages. Firstly, along the overall evaluation length, the assessment datum is not continuous. A step may appear at the crossover region of two adjacent sampling lengths. Naturally, the datum should be a smooth curve. Secondly, the datum greatly relies on the sampling length to extract surface roughness. Distortions in surface roughness assessment may occur if the sampling length is too long or too short.

The traditional filtering method mainly relied on 2RC filter. Many instruments of surface roughness in the earlier period use the 2RC filter in the electronic filtering. Due to the inherent nonlinear phase characteristics, the 2RC filter may lead to distortions in a reference datum plane. The 2RC filter has gradually been phased out in recent years.

The wavelet method has been widely applied in the areas of signal processing. In surface feature processing, the wavelet datum to be used as an assessment datum for surface feature assessment has produced some interesting results [1]. The option to use the wavelet datum also has a disadvantage such as the level of wavelet decomposition is uncertain.

The datum line of surface roughness assessment is required to be a Gaussian datum line in the current international standard ISO 11562. The sampling signal is to pass through a Gaussian low pass filter in order to obtain a datum line for roughness assessment. The main advantage of the Gaussian filter is the linear phase characteristics [2-3]. Currently, surface measurement and assessment is moving from 2D to 3D. The Gaussian filter has been accepted for both 2D and 3D surface roughness assessment.

However, in the post measurement data treatment, the filter is computationally intensive. A new algorithm is presented to provide a solution to the problem. The algorithm is based on the approach of direct and fast convolution. The essential technique in the algorithm is to utilize the iterative characteristics and the separable characteristics of the 2D Gaussian function to significantly reduce the number exponential computations. Numerical example shows that the proposed algorithm is faster than the Fourier transform approach.

Filters and Datum Surface for 3D Surface Roughness Evaluation

A 3D surface f may be defined as

$$f(x, y) = s_1(x, y) + s_2(x, y)\,, \tag{1}$$

where the Fourier transformation of s_1 and s_2, , noted as S_1 and S_2, respectively, satisfy

$$S_1(w_x, w_y) = \begin{matrix} F(w_x, w_y), & |w_x| \le w_{cx}\ |w_y| \le w_{cy} \\ 0, & |w_x| > w_{cx}\ |w_y| > w_{cy} \end{matrix} \tag{2}$$

and

$$S_2(w_x, w_y) = \begin{matrix} F(w_x, w_y), & |w_x| > w_{cx}\ |w_y| > w_{cy} \\ 0, & |w_x| \le w_{cx}\ |w_y| \le w_{cy} \end{matrix}\,, \tag{3}$$

where F is the Fourier transformation of $f(x,y)$, w_{cx} and w_{cy} are the cut-off frequencies in the x and y directions, respectively. Choosing suitable cut-off frequencies, s_1 includes the form and waviness errors of the 3D surface. It can be the datum surface. s_2 is the 3D roughness surface for the 3D roughness evaluation. It is clear that $s_2 = f - s_1$. In addition, s_2 can be obtained by using a low-pass filter $h(x, y)$ [4-5] as

$$\begin{gathered} s_1(x, y) = f(x, y) * h(x, y) \\ S_1(w_x, w_y) = F(w_x, w_y)\, H(w_x, w_y) \end{gathered}\,, \tag{4}$$

where H is the Fourier transformation of the function h. H may have either a square shape or a circle shape in the frequency domain (Fig. 1). For convenience in the digital implementation, the Gaussian low pass filter (Fig. 2), noted as g and its Fourier transformation as G, may be used to replace the idealized filter h (Eq. (2) and Eq. (4)). In this case, s_1 is noted w (Eq. 4).

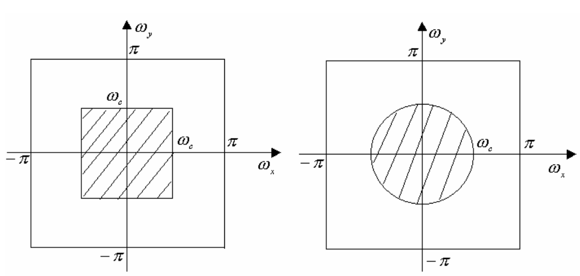

Fig. 1 Datum filter characteristics

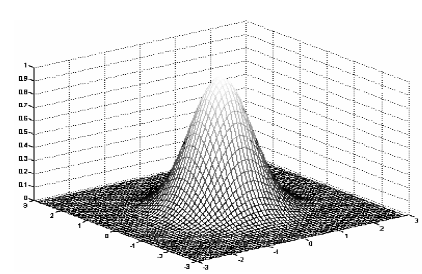

Fig. 2 Gaussian filter characteristics

Fast Estimation of Gaussian Filter and Datum Surface

The actually measured 3D surface *f* is typically discrete. *w* must be discrete as $w_{i,j}$. The sampled data of a 3D surface is noted as $z_{i,j}$. The datum surface $w_{i,j}$ can be obtained as

$$w_{i,j} = \sum_{k=-M}^{M} \sum_{l=-N}^{N} z_{i-k,j-l} g_{k,l} \Delta x \Delta y , \tag{5}$$

where $i=M,\ldots,LX-M$, $j=N,\ldots,LY-N$, LX and LY represent number of samples, and

$$g_{k,l} = \frac{1}{\alpha^2 \lambda_{cx} \lambda_{cy}} \exp\left[-\pi \left(\frac{k\Delta x}{\alpha \lambda_{cx}} \right)^2 - \pi \left(\frac{l \Delta y}{\alpha \lambda_{cy}} \right)^2 \right]. \tag{6}$$

Equation (5) may be done using two methods, FFT or direct convolution. The FFT method involves the Fourier transformation and the inverse transformation. The direct convolution method does not require the two complex computational operations. For both methods, extensive computations of the exponential function are involved. To reduce the computation time for high efficiency, this problem must be solved.

In the proposed method, the convolution method is utilized and the fast algorithm is based on the use of the symmetrical feature of the exponential function, noted as $g(-k)=g(k)$. The datum surface can be obtained as

$$w_{i-k} = z_{i-k,j-l}\ g(l=0) + \sum_{l=1}^{N} (z_{i-k,j-l} + z_{i-k,j+l})\ g(l)\, \Delta y , \tag{7}$$

and

$$w_{i,j} = w_{i-k}\ g(k=0) + \sum_{k=1}^{M} (w_{i-k} + w_{i+k})\ g(k)\, \Delta x . \tag{8}$$

The above equations have a similar structure, for which a reduction of 50% in the multiplication computations can be achieved for each of the cases. Therefore, a total reduction of 75% in the multiplication computations can be achieved.

In addition, a reduction in the number of computations of the exponential function can be realized to further improve the datum surface algorithm. This is illustrated as

$$g_0 = \frac{1}{\alpha \lambda_c},\ g_k = p_{k-1} g_{k-1},\ k=1,\ldots, M \text{ or } N, \tag{9}$$

where

$$p_0 = q\,,\ p_k = q^2 p_{k-1}\,,\ p_k = q^{2k+1}\,,\ q = \exp\left(-\pi\left(\frac{k\Delta}{\alpha\lambda_c}\right)^2\right), k=1,\ldots, M \text{ or } N. \qquad (10)$$

The above algorithm indicates that the (2M+1)(2N+1) multiplications have been used to replace the (M+1)(N+1) exponential calculations. Thus the calculation has significantly been reduced and the proposed method is very fast.

Experimental Testing, Discussion, and Conclusion

The proposed algorithm has been realized using VC6 and Matlab5. The code has been tested experimentally (Fig. 3). In the example, the number of the 3D surface data points was 250x250. The calculation time on a Pentium III 450MHz PC was only 2s. The calculation time using the FFT method was 3s. The direct convolution took 6s approximately on the same PC. This shows that the proposed method is effective. In terms of computational efficiency, the proposed method is more advantageous than the other two methods.

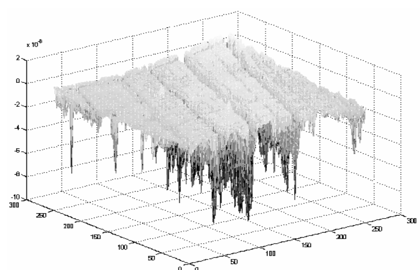
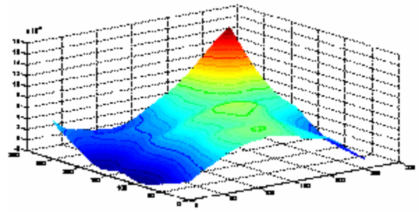
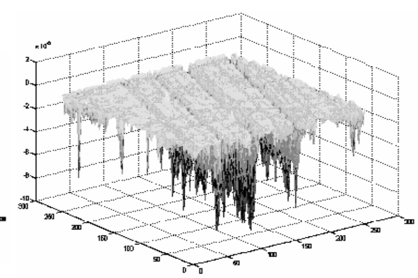

Fig. 3 Measured 3D surface f **Fig. 4** 3D datum surface w **Fig. 5** 3D roughness surface s_2

Acknowledgement

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