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Feasibility analysis of Savitzky-Golay Filter implementation in surface texture filtering and measurement

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Abstract

This paper analyzes the feasibility of the Savitzky-Golay filter to be used in the characterization of surface texture measurements. First, the mathematical bases of the filter are presented. The following is the analysis of the filter behaviour against an example profile by modifying the two degrees of freedom considered: number of points of the filtering window and degree of the polynomial approximation. Additional considerations such as the behaviour against end effects and the possibility of application on 3D surfaces are also considered. Finally, an application of the filter on a series of machined probes is performed comparing the obtained results against the Gaussian and Splines filters.

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Keywords: Surface texture; filtering; Savitzky-Golay

1. Introduction

A great variety of functional behaviours of engineering components such as tribology properties, aero and fluid-dynamics phenomena or corrosion or fatigue resistance, among others, depend on the micro-geometric irregularities present on component's surfaces. Hence, the study of surface finish has a great importance in engineering. In most cases, the amplitude of the irregularities and their spatial distribution are the two essential elements of analysis for

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the characterization of the surface finish. Because of that, all those operations that allow to quantify and delimit both elements are of interest in the study of the surface finish. In particular, the split of measurement information according to the different wavelengths is one of the most important operations, since the influence of the surface finish on the part's functionality is closely linked to the range of wavelengths contained in the set of measured values [1]. The ISO standard 16610 series regulate the filtration of both two-dimensional (profile) and three-dimensional (areal) data. This regulation consists of different parts, under the general title 'Geometrical product specifications (GPS) - Filtration'. In both 2D and 3D cases, the ISO standard considers three types of filters: Linear, Robust and Morphological [2]. Although the most common filters are linear ones, robust filters are showing a growing application in the last years, being the morphological filters the ones that have less diffusion. About ASME regulation, it only considers linear filters in its current version [3]. The most standardized filter is the Gaussian filter [4] and all the current measuring instruments have it built-in. Although it is a well-known filter and its behaviour is reasonably satisfactory, its implementation suffers from certain limitations that can be significant. The first limitation is an excessive sensitivity to surfaces with very sharp deviations (usually valleys), as occurs, for example, in EDM-machined surfaces. The second limitation derives from the lack of sufficient measurement information at the ends of the range or the measured surface, since the Gaussian filter requires values on both sides of the point considered, and this condition does not occur at the ends of the intervals. Because of these two limitations, and with the intention of avoiding them, other filters have appeared, such as the Robust Gaussian filters or the Spline filters, collected by ISO [2]. Savitzky-Golay filter falls within the category of linear filters, and was initially proposed by its authors [5] in 1964 in order to smooth the computational processing of data. Although it is a well-known filter, used in spectroscopic applications, in other fields of engineering its use is limited [6]. In the original approach of the filter, as well as in most of its applications in signals treatment [7, 8], two-dimensional signals are used, which would correspond to a profile-based surface finishing treatment. This approach will be considered in the epigraphs of the present work dedicated to the feasibility analysis and the comparative analysis with the Gaussian filter. In addition, the initial bases of application of the filter in the case of surfaces represented by three-dimensional values will also be pointed out. The idea underlying the Savitzky-Golay filter is to eliminate possible noises in the data by smoothing them using least-squares polynomials. For this purpose, and knowing the values of a function f (x) in a series of points f (x_i), the value of the function is approached at each point x_i by p (x_i), where p (x) is the least squares polynomial of N order in a given interval. This interval is defined by the number of points considered on the left (n_L) and on the right (n_R) respectively with respect to the point considered. An example of this can be seen in Fig. 1. The number of points available for the smoothed function is usually considerably greater than the number of points from which the regression polynomial is calculated. This means that the number of polynomials to be determined is equal to the difference between the number total points of the function n_T and the sum of the values n_L and n_R. In the limiting case, in which all the points of the function were used for the construction of the least squares polynomial, a single polynomial would be obtained as a result. Although the number of polynomials to be calculated is theoretically high, once the degree and number of interpolation points are established, the coefficients for all of them are equal. Thus, these coefficients have only to be determined once, allowing consequent computational savings. Once it is done, the resulting profile can be obtained by evaluating the calculated polynomials at each point. Mathematically, the problem of application of the Savitzky-Golay filter is reduced to finding for each point the polynomial p_i (x) of degree N defined by:

$$p_i(x) = \sum_{k=0}^{N} b_k \left(\frac{x - x_i}{\Delta x}\right)^k \tag{1}$$

Where bk are the coefficients of the polynomial that satisfy the relation:

$$\sum_{j=i-n_L}^{i+n_R} \left(p_i(x_j) - f(x_j)\right)^2 = min \tag{2}$$

Which can be obtained from the resolution of the nT + 1 equations system determined by: