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Research Article

Surface Roughness Measurement by Analysis of 3D Scan Data According to ISO 25178-2

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ABSTRACT

Surface roughness measurement can be performed using devices equipped with contact probes or optical probes, such as roughness meters, profilometers, CMMs, measuring arms, as well as all kinds of electron microscopes and others. The objective of this paper is to analyze the data from 3D scanning by a laser scanning measuring arm according to ISO 25178-2 in order to determine the 3D surface roughness parameters. To the best of our knowledge, the development of a 3D scanning procedure and the analysis of an acquired point cloud have been applied for the first time in surface roughness measurement. In this work, the analysis of the acquired data allowed the determination and comparison of the 3D roughness parameters of a flat S335 steel surface before and after a Ti-W-N coating.

Keywords: Surface roughness, 3D scan data, measuring arm, ISO 25178-2, 3D roughness parameters.

INTRODUCTION

The rapid evolution of manufacturing techniques such as numerically controlled machines has made it possible to obtain relatively complex surfaces that require control in real form (three dimensions) by using three-dimensional control instruments (three-dimensional measuring machines, optical measuring instruments...). The three-dimensional measurement is currently the most reliable way to characterize a surface. It allows the observation, identification and quantification of irregularities. The three-dimensional measurement has taken an important place in the production systems. Indeed, the economic profitability of the automation of the means of production requires a rigorous and automatic control of the geometrical specifications of the produced parts. These techniques may seem more interesting because they are contactless. They offer greater speed and efficiency, but their accuracy is less and it often happens that we do not have direct access to the object, which makes their use impossible [1]. For several years, research work on the analysis, segmentation and orientation of textures has been carried out in the vision group. Intuitively, the notion of texture seems familiar to us, but in fact giving a precise definition is rather complex. A texture is a piece of information that gives an account of the surface state of an object. It is characterized by the more or less regular arrangement of elementary patterns. We distinguish two major classes of textures: - Macro-textures which are constituted by the spatial distribution of one or more elementary patterns called Texel - Micro textures which have a random aspect, but for which the visual impression remains globally homogeneous. Textures provide information inside a region. In fuzzy or disturbed environments, where edge information is not a reliable data, having a description inside a region is an important asset. Classical texture analysis methods are very much related to the texture category. For macro textures, preferably structural methods will be used, while the analysis of micro textures is often done by statistical type methods. When a profile is measured in 2D, the sensor records the relief only along its path. The measurement can therefore be representative of the surface itself only under certain conditions that depend on the isotropy of the surface. A surface is said to be isotropic when it has identical characteristics, regardless of the direction of measurement. This is the case, for example, of surfaces whose surface state is random and does not have any marked texture. This type of surface is unfortunately quite rare and most surfaces encountered in industry have an oriented texture (turned surfaces, honed, brushed, etc..) or periodic structure. In this case, we say that the surface is anisotropic (figure 1).

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a) isotropic texture b) anisotropic texture

Fig. 1: Texture representation

The first 3D parameters to appear were based on existing 2D parameters, extrapolating their equation in two dimensions. Various works towards standardization have been done, such as the work done by the team of Prof. K. Stout at the University of Birmingham in the 90s [2], which allowed to define a first set of parameters (the 14 Birmingham parameters). In 2001, the European SURFSTAND project extended and improved the Birmingham parameters and laid the foundation for the future ISO standard. The ISO parameters sometimes differ a little from the definition given during the European programs, and some parameters have not been included or have been replaced by others. The first rule adopted was that which defines the naming of the new surface parameters. These will begin with the capital letter S (or V for certain functional parameters). Contrary to what exists in 2D, the prefixes of the 3D parameters will no longer reflect the distinctions between roughness, waviness or structure components. Given the multiplicity of treatments and filtering that are now available to metrologists to extract information from a surface, the separation into three components seems indeed obsolete. Where the surface condition in 2D makes the difference between Pa, Ra and Wa, the 3D domain will use only Sa, the latter will be a surface parameter of roughness, waviness or calculated on the primary surface, depending on the pre-filtering that will have been done before calculating the parameter. Most mathematical formulas for calculating the amplitude parameters in 2D according to ISO 4287, the amplitude parameters can be easily applicable to the surface measurement. This is the case, for example, for the root means square roughness of the profile Rq, whose formula contains a simple integral. By switching to the double integral (on a surface), it is natural to define the parameter Sq (root means square roughness of the surface). The same rule also applies to the parameters Sa (arithmetic mean roughness), Ssk (asymmetry factor), Sku (flattening factor), Sp (maximum height of peaks) and Sv (maximum depth of troughs). Only the famous Rz (maximum profile height) is problematic, since there is a so-called "ten-point" Rz parameter (defined in the 1984 ISO 4287 standard) and a variant, defined (in 1997) as the average of the maximum profile heights Rti calculated on each base length. For simplification, Sz will be defined in the future standard as "the maximum height from the highest point to the deepest valley", as it is until now where it defines St. The latter, now unnecessary, disappears from the standard [3]. The measurement of roughness is not easy to define (figure2). For more than sixty years, standards have followed one another, trying to define roughness by using multiple parameters and all sorts of mathematical formulas. Thus, some parameters used to define roughness are still very controversial or seem to be reserved for specific applications. Others, finally, remain poorly known and are a source of confusion [4]. The roughness of a surface explains its sensitivity to corrosion and wear, as well as its adhesion, sliding and rolling properties. However, when one wishes to measure this roughness, the operation is otherwise more complicated. In the last twenty years that topography system has appeared. Their operating principle is to measure parallel profiles regularly spaced to cover a rectangular surface. We obtain an altitude reading z as a function of the position x in the profile, and the position y of the profile at the surface. This is called a 3D survey, and is referred to as 3D topography or sometimes surfometry.

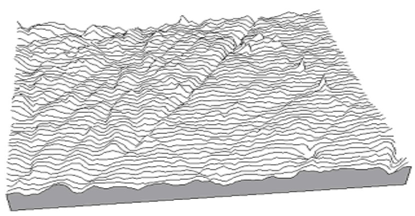

Fig. 2: 3D surface roughness representation

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Digitizing systems allow the discretized representation of the skin of the part to be measured. Indeed, the data from scanning are generally noisy, inhomogeneous and incomplete. Therefore, the problem of measuring the 3D topography of left-handed parts is linked to the choice of the acquisition system, as well as to the definition of the scanning strategy leading to a sufficient quality of geometric information. We recall first, what is a 3D scanning system and what are the characteristics associated with the digitized data. The exploitation of the acquired data is often facilitated thanks to treatments on these data such as noise filtering or structuring in order to recreate a continuity [5] [6]. Note, however, that the majority of applications are : surface reconstruction, rapid prototyping, visualization, or even inspection (Dimensional Metrology). It is on this last one that our work is located, which we started with a work presented in [7].

OBJECTIVES

The objective of this paper is to analyze the data from 3D scanning by a laser scanning measuring arm according to ISO 25178-2 in order to determine the 3D surface roughness parameters.

METHODS

The resolution approach adopted can be summarized as follows:

- Digitizing by a measuring arm.
  - ➢ Positioning of the part in the measurement machine;
  - ➢ Acquisition of the noisy point cloud;
  - ➢ Cleaning of the point cloud by the geomagic studio software;
  - ➢ Saving the data in a specified format that can be used by Matlab.
- Processing of the exported data:
  - ➢ Determination of the optimal surface;
  - ➢ Calculation of the deviations according to the normal between the optimal surface and the point cloud;
- Calculation of 3D roughness parameters of surfaces :
  - ➢ Selection of the areas to be measured
  - ➢ 3D roughness representation of partial surface and global surface;
  - ➢ Determination of the surface state parameters.

A. *Experimental part*

In order to develop and validate the results of the development carried out; experiments were carried out using the necessary hardware and software.

The equipment used to carry out this study is :

- ➢ A measuring arm (ROMER Absolute Arm) (figure 3): is a metrology instrument whose measurement is carried out using a contact probing system or with a laser sheet scanner. The flexibility of the arm allows an easier measurement of parts with complex shapes. The structure of the measuring arm is inspired by the human one. It allows up to seven (7) degrees of freedom. The uncertainty of the measuring arm is relatively more compared to the classical 3D measuring machines; the manipulator and the environment contribute to this uncertainty.
- ➢ Flat S335 steel surface before and after a Ti-W-N coating (figure 4).
- ➢ Computer: (Lenovo Core i7, 16 GB SDRAM)
- ➢ Matlab was been used for the development of the software application that allows the measurement by analysis of the 3D surface condition.

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Fig. 3: ROMER Absolute Arm

a) Flat S335 steel surface before a Ti-W-N coating

b) Flat S335 steel surface after a Ti-W-N coating

Fig. 4: Measured surfaces

The purpose of the manipulation is the acquisition of a point cloud by the 3D scanning of surface, for this, the steps of the manipulation are :

- The part is placed in such a way as to allow the operator to take the measurements correctly and that the surface to be measured is accessible to the scanner.

- A laser beam is projected along the part according to the orientation desired by the operator.

- The information collected is processed as 3D coordinates of points in space.

- Using the Geomagic Studio software, the point cloud obtained is processed and cleaned, then exported as a file in the form of a table with three (3) columns and a number of lines corresponding to the number of points.

B. Theoretical part

In this part, we present the theory necessarily for the developed software application. The mathematical development of this part related to all the cases of studied forms.

➢ Surface optimization

This task deals with the association of a theoretical surface with a cloud of points from a 3D measuring machine. On the latter, the function to obtain the associated surface is based on the minimization of the distance between the Mi point probed and the ideal surface according to one of the optimization criteria. In this part of surface optimization, the method of least squares is used for curve fitting, which is an application associated with Matlab. It provides functions for curves and surface fitting from the data. The toolbox allows to perform exploratory data analysis, to pre-process and post-process data, to compare models and to remove outliers. It also allows performing regression analysis using the library of available linear and non-linear models or by specifying custom equations. The library provides optimized starting conditions and solver parameters to improve the quality of the fits. The toolbox also supports non-parametric modeling techniques such as splines, interpolation and smoothing. After creating a fit, the curve fitting function allows their use in various post-processing methods for plotting, interpolation and extrapolation, for evaluating confidence intervals, and for computing integrals and derivatives.

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- Calculation of surface roughness parameters

There are a large number of three-dimensional parameters that characterize the surface condition, only the elevation parameters of the 2012 ISO 25178-2 standard that will be considered namely: Sa, Sq, Sz, Sv, Sp.

- Determine the optimal or average surface (using the curve fitting function),
- Calculate the deviations between the measured points and the optimal surface (using the Optimization function)
- Inject the calculated deviations into the formulas describing each parameter.

$$Sa = \frac{1}{mn}\sum_{i=1}^{n}\sum_{j=1}^{m}|z(xi, yi)| \qquad (1)$$

$$Sq = \frac{1}{mn}\sum_{i=1}^{n}\sum_{j=1}^{m}\sqrt{|\mathrm{Z}^2(\mathrm{xi,yj})|} \qquad (2)$$

$$Sz = \frac{\sum_{i=s1}^{5} zpi + \sum_{i=1}^{5}|zvi|}{5} \qquad (3)$$

$$Sp = \max(Z(x, y)) \qquad (4)$$

$$Sv = \min(Z(x, y)) \qquad (5)$$

C. *Algorithm*

The programming steps are illustrated in the flowchart shown in Table 1.

Each step is described as follows:

- The file to be read has a form of a data table consisting of three (3) columns and a number of lines equivalent to the number of points.
- Presentation of the data for the visualization of the part.
- The choice of the calculation area is made by the user.

The equation of the surface is determined by the development of least squares method.

Table. 1 SOLVING ALGORITHM

Steps	DESCRIPTION
1	Read data from a file
2	Graphical representation of the data
3	Selection of a calculation area
4	Generate the optimal surface by the least squares method for the calculation area
5	Calculation of the heights of the points with respect to the optimal surface
6	Calculation of the roughness parameters
7	Results presentation
8	Graphic roughness presentation of the selected area

RESULTS

Figure 5 illustrates the optimised surface and the topography of the surface measured in a restricted area.

A. *Validation tests*

Validation tests were performed on uncoated and coated (2 µm Ti-W-N) S335 steel surfaces. Table 2 and Figure 6 illustrate the 3D roughness parameters of both surfaces, demonstrating the reduced roughness of the coated surface

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due to the applied smooth layer. The coated surface's roughness curve in Figure 6 is lower than that of the uncoated surface, confirming its smoother texture.

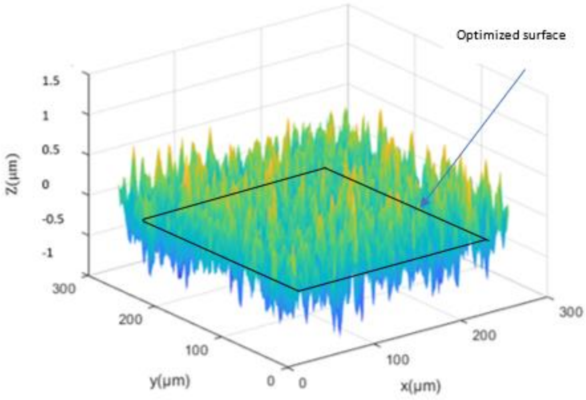

Fig. 5: Optimized surface

TABLE. 2 3D SURFACE ROUGHNESS PARAMETERS

PARAMETERS (µM)	SA	SP	SZ	SQ	SV
SURFACE WITH COATING	0,630	0,948	1,017	0,634	-0,126
SURFACE WITHOUT COATING	0,891	1,070	1,437	0,895	-0,332

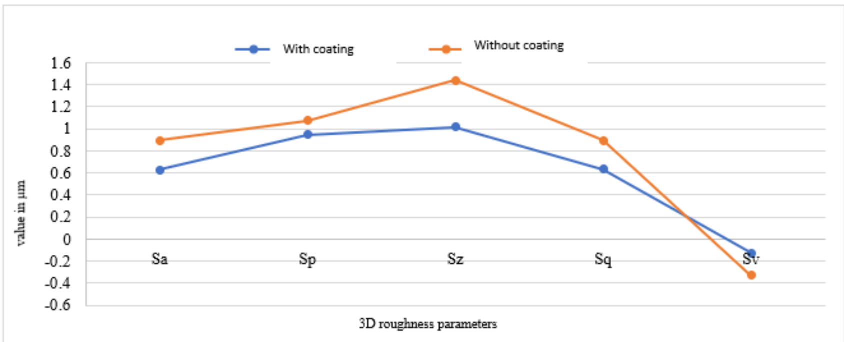

Fig. 6: 3D roughness parameters of surfaces with and without coating

B. Method limits

Some disadvantages appear and affect the credibility of the results they are cited as follows: - The mirror effect of the smooth surfaces reflecting the light generates measurement errors.

- Measurement accuracy is not entirely satisfactory. Although the measuring arm used is fairly accurate, the accuracy is better with the CMM, as greater precision is desirable for calculating roughness.

- A dense point cloud is required, but in this case there is a problem of execution time. The performance of the programs should be improved to obtain better results in less time. This problem is quite significant for non-planar surfaces.

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DISCUSSION

In this paper, we have introduced the problem related to the 3D roughness characterization and digitization. Then, we presented the work-developed process, starting from the geometric digitization data of the surface (points cloud) until the determination of the 3D roughness parameters. Indeed, we have developed a software application for the 3D roughness measurement of surfaces according to the standard "ISO 25178-2:2012, Geometrical Product Specification (GPS) - Surface texture: Surface - Part 2: Terms, definitions and parameters of surface texture". The validation was done by analyzing representative graphs of the variation of roughness as a function of the coating of a surface made of S335 Steel coated with a hard layer (Ti-W-N) of 2 µm thickness. According to our knowledge, we can say that the developed application has allowed for the first time the surface roughness measurement by analysis of 3D scan data by a laser scanning measuring arm according to ISO 25178-2. Finally, we can say that the results are satisfactory and this work can be extended to applications on more complex surfaces (cylinder, sphere, free surface…).

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