THREE DIMENSIONAL (3D) SURFACE MEASUREMENT BASED ON (2D) STYLUS INSTRUMENT

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Abstract: *Three dimensional measurements (3D) of surface topography are increasingly being recognized as the most adequate method for obtaining a better understanding of surfaces. The dimensional and surface metrology department at the National Institute for Standards in Egypt (NIS) developed a computer-controlled system for 3D surface measurements. The developed system is based on a 2D surface measuring instrument using a stylus contact method. A positioning table is used to displace the specimen underneath the stylus in a cross direction to the traverse stroke .The system can scan small areas on the measured surface (5.6mm × 0.56mm) by traversing the stylus of the measuring instrument over the surface in parallel traces. The system consists of a "Talysurf 10" stylus surface measuring instrument interfaced to an "IBM" compatible PC computer with a data acquisition device (DAQ). The (DAQ) is used to control the movement of the measuring stroke of the pick up in the X – axis, to control the movement of the positioning table in a cross direction to the stroke as Y- axis, and to take the data of each profile from the stylus vertical movements during the measurement stroke as Z-axis.*

The software for the mentioned controls is made using "Labview" programming language. All data of the 3D surface are taken using unfiltered skid less mode of operation. A "Matlab" software is developed and used to take out the trend of the surface using a least square surface plane, then an approximation of a Gaussian filter (moving average) is used to filter the data. A software to analyze the data to get the 3D surface parameters and functions is also developed.

Key words*: Surface, measurements, stylus, instrument, three dimensions, topography*

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1. INTRODUCTION

Although 2D profile measurements and their analysis are still playing an important role in the assessment of surfaces, but to avail yourself of true surface engineering, there is no doubt that 3D measuring of surface roughness is most useful. The most common method of surface assessment is through the use of a stylus-based measurement system. In 2D stylus instrument, a stylus which has a very small tip is traversed (in X-axis) across the surface to be measured, and a pick-up physically connected to the tip, converts the vertical movement (Z-axis) of the stylus, into an electrical signal. The electrical signal is amplified and digitized using data acquisition to be able to analyze the profile data. In order to obtain 3D measurement, one more dimension is needed in the measurement (Y-axis) (Scott 1988). One of the first computer-controlled system based on a rebuilt 2D device that could automatically perform 3D was by Sayles (Sayles & Thomas 1976) . A surface can be represented as a function z(x, y) with two independent variables, x and y. Quantitative 3D surface measurement involves the use of digital computers in the measurement process due to the large amount of information involved. Computers are involved in various stages in the measurement process: control of data collection, data storage, movement of stepper motors, analysis and output of result (Teague et al., 1982); (Koura et al 1997). A surface roughness measuring system has been developed, at the National Institute for Standards NIS-Egypt for 2D-measurement and named NIS-SURF or simply NISURF and was upgraded and named NISURF-II (Zahwi et al 2001). It has been decide to realize 3D measurement based on this system.

2. HARDWARE

The upgraded NISURF-II consists of a stylus instrument, Talysurf-10, interfaced to a personal computer by using DAQ (Data Acquisition System) . In 2D stylus measuring instrument the forward movement of the pickup and starting / ending trace are manual. To obtain 3D measurement of a plane surface, it is required to record N parallel profiles; in an orthogonal direction to that of the profiles (X-axis), in direction (Y-axis), at regular spacing, Δy. Each profile is sampled with an acquisition step, Δx and a number of points M. A surface is therefore characterized by a matrix of N lines and M points per profile. Each point of the co-ordinates matrix (x_i,y_i) has a height z which is recorded in the orthogonal -normal landmark X-Y-Z. A dynamic acquisition type has acquired a matrix of M points and N lines in the form of parallel lines. This type of acquisition is preformed when using the DAQ to control the positioning table in Y-axis, control the movement of the pickup by the stepper motor in X-axis and collect the data of the profiles Z-axis while the stylus traces the surface. The main advantage of this system is that the

DAQ is synchronized with collecting data from the surface. Fig. 1 shows the diagrammatic sketch and a photo of the 3D measuring system proposed for NIS. A precision linear positioning table (no-1-see photo) with a 100mm travel length assembly with 2.5 mm/rev precision ground ball screw (JIS class 3), bellows coupling, stepper motor (2)wired in parallel with a 120 VAC drive(3) and 1 μm incremental optical encoder(4). The table controls the movement of Y-axis with its stepper motor through a micro-stepping drive.

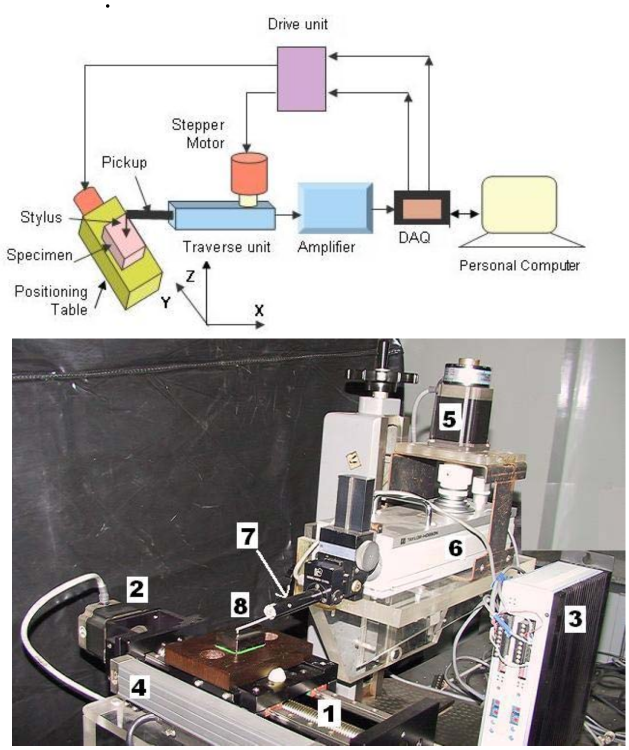


Fig. 1 A diagrammatic sketch and a photo for NIS- 3D surface measuring system

The system uses another stepper motor (5) wired in parallel to the same drive unit. The second stepper motor is mounted on the knob of the traverse unit (6) to move the pick-up (7) forward to the starting position. When the pick-up moves backward the trace is taken in the X-axis. An automatic relay is used to control the starting and ending the tracing of the profile. The stylus (8) movement upwards and downwards during the tracing gives the Z-axis. The data acquisition system (DAQ) used has a resolution of 16 bits, 1 part in 65,536, and 16 single-ended or 8 differential input channels. The personal computer with a 486/33MHz processor and 64 MB RAM is used. In order to minimize the effect of vibration of the floor on measurements, the measuring instrument has been mounted on a vibration isolation table. All data of the 3D surface are taken using unfiltered skidless mode of operation. With this arrangement, the system can scan small areas on the measured surface (5.4mm x 0.64mm) by traversing stylus over the surface on parallel traces.

3. SOFTWARE

Special software is developed to obtain 3D surface measurement. The surface is analyzed to get the surfaces parameters and functions. The software is writing with the LabVIEW G-programming Language version 5.1. All the surface parameters and functions are calculated using MATLAB programming language version 4.2c.1. The software is able to handle all the surface data to be analyzed, through a connection between LabVIEW and MATLAB programs. The sampling conditions for 2D analogue profile i.e. cut-off or sampling length are standardized in ISO 4287. However, 3D surface characterization is based on digital real topographic data and, therefore the sampling conditions are represented by the sampling interval, Δx, Δy, the size of sampling matrix M*N, and the sampling area, A=lx*ly, where lx and ly are the lengths of x and y traces respectively. The sampling area, A, can be calculated from the sampling interval and the size of sampling matrix as shown in equation (1)

$$lx=(M-1)\Delta x \;,\; ly=(N-1)\Delta y \text{ and } A=lx*ly \qquad (1)$$

Where M is the number of sampling point in one trace and N is the number of sampling traces in the area measured.

According to the type of surface measured (isotropic or anisotropic), the sampling interval and size of sampling matrix are recommended (Stout 1993). A function, z(x, y) is used to represent the point-by-point deviations between the measured topography and the mean surface. The software has a module that is used for calibrating the system, in Z direction, either with a two-sided reference step or with a one-sided step consisting of a pair of gauge blocks wrung to an optical flat as given in ISO 5436. This module is named the "Step Kcal" program and used for calibrating NISURF-II in 2D. After calibrating the system in Z-axis the software has three tasks: i) controlling and collecting surface data, ii) pre-processing for leveling and filtering, and iii) analyzing the 3D surface parameters and functions.

3. 1 Controlling and collecting surface data

First the specimen is adjusted to the starting position manually. The number of sampling points, M, in the trace chosen to be 5600 point/trace. The sampling interval in X-axis, Δx, is equal to 1 μm giving a trace length of 5.6 mm, in order to apply the digital filter (seven cut-off lengths). The sampling traces, N, in the Y-axis selected to be 112 trace with the sampling interval, Δy, is equal to 5 μm giving a width of 0.56mm. When the program start, the first trace is taken then the stylus movement is stopped; after that the precision positioning table gives a movement of 5 μm (the sampling interval Δy) and stops, waiting for 2 seconds and the second stepper motor, mounted on the pick-up, moves backward to start another trace. This loop is repeated N times to cover the measuring area. A matrix of array M*N points representing the surface data as height function z(x,y). The collected surface data is stored on a file to be analyzed.

3. 2. Pre-processing

Following the storage of the collected surface data, some processing operations must be carried out before analysis. The pre-processing includes leveling of surface data and filtering. Leveling refers to removal of the linear trend from the recorded surface data due to the misalignment of nominal surface plane and the data collection datum. Filtering concerns the separation of different frequency components in the surface data. A simulating data for a shaped surface to test the program Matlab for the pre-processing has been used.

3.2.1 Linear least squares mean plane

The reference datum used is the least squares mean plane which has the form of the geometrical surface and divides the surface such that, within the sampling area, the sum of the squares of the topography deviations from this plane is minimized (Dong 1994). For a surface data z(x, y), its linear or first order least squares mean plane may be defined by equation (2),

$$f(x, y)= a + b*x + c*y \tag{2}$$

where a, b and c are the coefficients of the surface data. These coefficients of the least squares mean plan are found in (Stout 1993)

$$\left.\begin{aligned} a &= \frac{(7MN+M+N-5)w-6(N+1)u-6(M+1)v}{MN(M+1)(N+1)} \\ b &= \frac{12}{\Delta x}\frac{u-\frac{M-1}{2}w}{MN(M-1)(M+1)} \\ c &= \frac{12}{\Delta y}\frac{u-\frac{N-1}{2}w}{MN(N-1)(N+1)} \end{aligned}\right\} \tag{3}$$

where

$$\left.\begin{aligned} u &= \sum_{l=1}^{N}\sum_{k=1}^{M}(k-1)z(x_k, y_l) \\ v &= \sum_{l=1}^{N}\sum_{k=1}^{M}(l-1)z(x_k, y_l) \\ w &= \sum_{l=1}^{N}\sum_{k=1}^{M} z(x_k, y_l) \end{aligned}\right\} \tag{4}$$

Applying the above equations (3,4) using the Matlab language, the least square plane is obtained. Then the residual surface s(x, y), obtained by subtracting the least squares datum plan from the original surface as in equation (5).

$$s(x, y)=z(x, y) – (a+b*x+c*y) \tag{5}$$

Fig. 2 shows the collected surface data z(x, y), the least square mean plane and the residual surface data s(x, y) after removing the trend from the surface data for the simulating data for the shaped surface mentioned above.

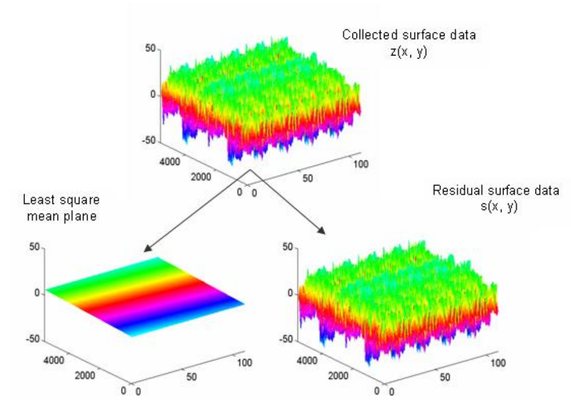


Fig. 2 The 3D surface after removing the trend

3.2.2 Filtering

A digital filter is used to eliminate long wavelength components while retaining short ones, i.e. to remove “unwanted” waviness and form and to retain roughness. The residual surface data is flitted in both direction X-axis and Y-axis. The Gaussian filtered mean line is proposed as the reference line for profiles measured with contact (stylus) instruments ISO 11562. Based on the central limit theorem, approximation methods, and digital signal processing principles, a simplified recursive filter algorithm for determining the Gaussian filtered mean line can be applied.

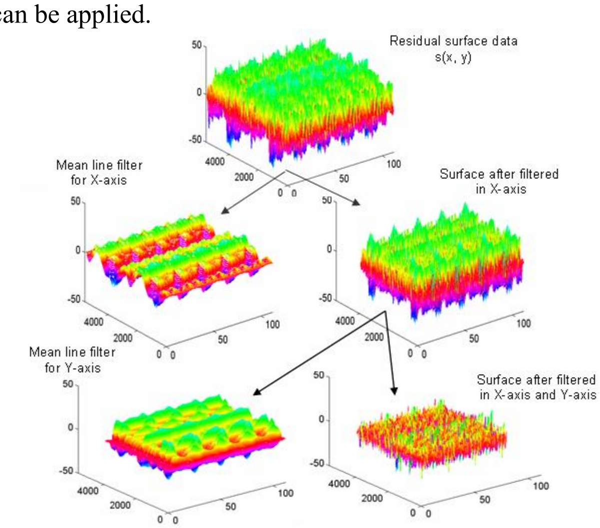


Fig. 3 The roughness surface after filtered by approximation of Gaussian filter.

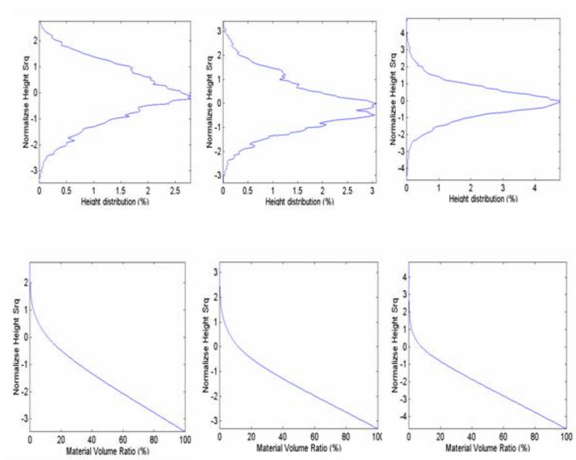
This simplified realization method for the Gaussian filter in surface metrology has been used in this investigation. This approximation filter is installed into the program used for controlling of the system, for measuring roughness and for analysis of the measured surface profile. Using this program for filtering in one direction (x-axis) for the traced profiles one by one but with the use of Matlab language. The traced profile with traversing length 7 cutoffs should be used. Selecting cut-off equal to 0.8 mm, then 5.6 mm needs to be traced in each profile. This is already used in X-axis (5600 point with sampling interval Δx=1µm) but in Y-axis for 112 traces with sampling interval, Δy=5 µm, gives 0.56 mm, a selecting cut-off equal to 0.08mm is used in this direction. Fig. 3 shows the residual surface data, the approximation Gaussian mean line and the roughness surface data after being filtered for a surface having a sinusoidal roughness pattern.

3.3 Analyzing surface data

The software is capable to compute the 3D parameters and 3D functions. The 3D parameters computed are : i) amplitude property; arithmetic mean deviation Sa, root mean square deviation Sq, ten point height Sz, skewness of topography height distribution Ssk, and kurtosis of topography height distribution Sku, ii) hybrid property; root mean square slope SDq, arithmetic mean summit curvature Ssc and developed interfacial area ratio Sdr and, iii) spatial property; density of summits Sds. Table 1, shows these parameter after applied approximation Gaussian filter in X-axis and after filtered in both axes X and Y.

Table 1 The surface parameters value after filter in X-axis only and filter in both axes

Surface parameters	Before filter (µm)	filter in X-axis (µm)	filter in both axes (µm)
Sa	10.81	8.09	4.05
Sq	13.55	10.27	5.36
Sz	45.80	34.03	24.90
Ssk	-0.143	0.23	0.01
Sku	2.80	3.04	4.23
SDq	3.242	2.80	2.56
Ssc	0.42	0.43	0.39
Sdr	86.55(%)	79.27(%)	69.91(%)
Sds	0.003	0.003	0.007



(a) (b)

Fig. 4 3D functions of surface data

(a) Filtered in x-axis

(b) Filtered in both axes

The 3D functions are Bearing area Ratio, Height distribution, Material volume ratio and Void volume ratio. Fig. 4 shows these 3D functions for examples of a surface data after filtered in both axes X and Y.

4. CONCLUSION

A system for the measurement of surface roughness in three dimensions (3D surface roughness measuring system) based on an existing two dimensional stylus measuring instrument is being developed at NIS-Egypt.

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