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Characterization of engineered surfaces

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Abstract. In the recent years there has been an increasing interest in designing surfaces to meet a particular functional requirement. Examples include surfaces generated using micro-replication and micro-structure technology. The surface analysis techniques currently available only deals with the two-dimensional characterization of the three-dimensional surfaces. There is a growing need to develop an intelligent surface analysis and inspection system that deals with the dimensional aspect of the three-dimensional features. This paper describes the methodology for numerical characterization of surfaces that have repeated or non-repeated features at different scales using image processing techniques. This includes development of an intelligent surface-scanning algorithm and methods for three-dimensional surfaces to identify shape geometries and for stable extraction of significant surface features. Geometric fitting algorithms have been used to calculate the dimensions of the feature.

1. Introduction

Three dimensional surface analysis is used increasingly in industries and has been a focus of intense research in the last few years [1]. The reason being two-dimensional analysis is not sufficient to describe a surface topography completely. The parametric characterization of three-dimensional topography was done by Stout et al [2]. Surface parameters only give information about surface texture and do not address the shape, size and orientation of the micro-features. Due to the increasing nature of complexity of the surface features and the functional role they play in the performance it is required to be able to numerically characterize features on the surface. The other significant work done in 3D characterization area is shown in the references [1-5]. The surface analysis software currently available has limited capability for analyzing engineered surfaces in terms of determining the dimensions and the planar heights of the micro-features on engineered surfaces. There is a growing need for a software system that is automatic and intelligent enough to locate the features on the surface and dimensionally characterize them.

This paper discusses techniques to detect the micro-features on the surface and characterize them using image processing methods in which the input is surface height or intensity data and the outputs are attributes extracted from those datasets. The objective is to develop the necessary tools for characterization and integrate them all in an intelligent surface analysis toolbox.

For characterizing purpose the vast variety of surfaces were categorized into three classes. Class I is the conventional mechanical surfaces like turned, milled, polished, honed etc. Class II consists of surfaces with deterministic pattern geometric features designed to give a specific function. Examples include surface generated by micro-replication technique. Class III is the surfaces with repeated or

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non-repeated features at different planer heights. A MATLAB ^{TM} based intelligent analysis software is being developed to characterize the above mentioned three classes of surfaces.

2. Methodology

The process of characterizing three dimensional surfaces consists of isolating the features on the surface using image processing techniques and then using coordinates to arrive at shape, size and orientation information. A brief description of the methodology is as follows.

2.1 Pre-Processing of Raw Data

Pre-Processing allows you to remove terms, apply filtering, and otherwise enhance raw data. There are several pre-processing options that could be applied to the dataset based on the requirement e.g. form removal, filtering, masking, data restore, data centering.

2.2 Segmentation

Once the data is pre-processed it becomes ready to be processed further. The next step is performing the segmentation operation on the surface. Segmentation subdivides an image into its constituent regions or objects. The level to which the subdivision is carried depends on the problem being solved. That is, the segmentation should stop when the objects of interest in an application have been isolated. Segmentation is a very important part of the characterization. Segmentation accuracy determines the eventual success or failure of computerized analysis procedures.

2.3 Object recognition (Region to boundary conversion)

After an image has been segmented into regions the next step usually is to represent and describe the aggregate of segmented raw pixels in a form suitable for further computer processing. Representing a region involves two basic choices: (1) we can represent the region in terms of external characteristic (its boundary), or (2) we can represent it in terms of its internal characteristics (the pixels comprising the region) [6]. In our experiments we have used the algorithm that traces the exterior boundaries of the objects. The output of boundary tracing is the set of coordinates of the boundary of the object.

2.4 Region Description

The next task is to describe the region based on the chosen representation. For example, a region may be represented by its boundary, and the boundary may be described by features such as length and the number of concavities it contains.

An external representation is selected when interest is on shape characteristics. An internal representation is selected when the principal focus is on regional properties, such as color and texture. Both types of representations sometimes are used in the same application to solve a problem. In either case, the features selected as descriptors should be as insensitive as possible to variations in region size, translation, and rotation.

2.5 Fitting Geometric Element

Once the shape of the features is known fitting algorithms can be used to determine the size and orientation of the features [7]. Each algorithm requires a minimum number of data points. For the best results, the algorithm requires that the data is fully representative of the corresponding geometric element. In general, the more data points there are, the more reliable are the results of the fitting.

2.6 Parameter Finding

Once the geometric shape is fitted the process of calculating the dimensions can be carried out. Euclidean distance formulae can be used to calculate distance between two lines, a line and a point, between two points etc.

3. Results and Discussion

The series of steps described above has been performed on artificially created datasets. For class II the surface created have rectangle shaped repeated features with a deterministic pattern. Some deformation is added to the features so that the boundaries are not perfect straight lines. All the features are at the same height level. There are a total of 84 objects (features) found after performing the segmentation operation. The next step performed is the conversion of the object region to boundary region. Once the boundary and the corners of the rectangular regions are determined then a line is fitted to all the points on each side of the boundary. Figure 1 shows the synthetic surface. Figure 2 shows the surface after performing segmentation and converting object regions to boundary. Figure 3 shows the results after performing the line fitting to each of the four sides of the rectangle. Figure 4 and 5 shows the length and width histogram of all the objects determined. Instead of presenting the actual distance between the line segments here the length and width of the rectangular box that fully contains the object is determined. The actual length and width of each object can be determined by calculating the distance between the fitted lines. Other parameters like slope of the lines, angles between lines, co-planarity of features etc. can also be calculated. Table 1 shows the statistics for the surface in consideration.

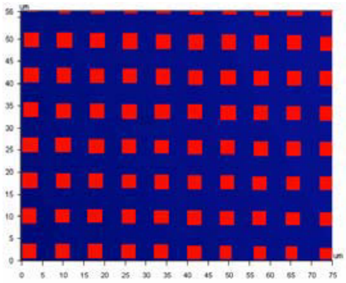

Figure 1. Raw data

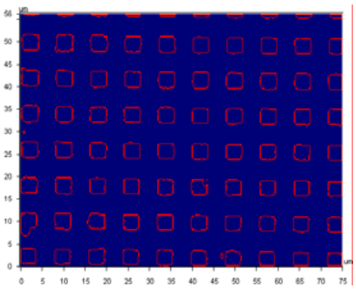

Figure 2. Objects

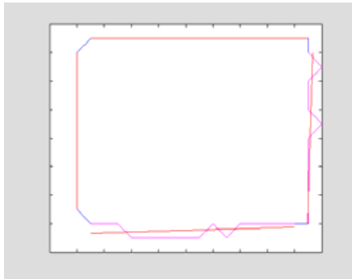

Figure 3. Line fit

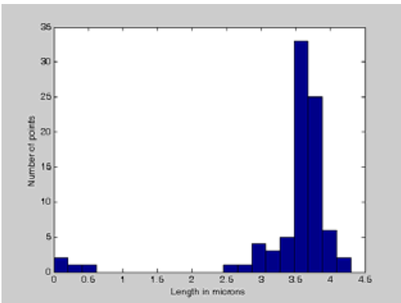

Figure 4. Length histogram

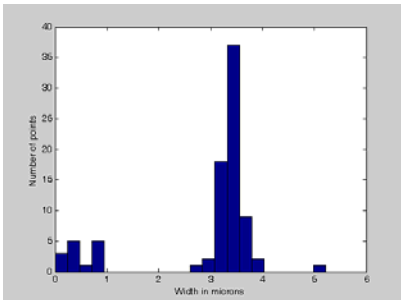

Figure 5. Width histogram

Table1. Statistics of the length and width of all the objects on the surface.

	Length of the Bounding Box (µm)	Width of the Bounding Box (µm)
Min	0	0
Max	4.2930	5.2171
Mean	3.5428	3.0472
Median	3.6797	3.5571
Standard deviation	0.7942	1.1496
Range	4.2930	5.2171

Class III surface is also artificially created and has four different levels as seen in the histogram and bearing ratio curve in figure 12 and 13 respectively. Both histogram and bearing ratio curve can be used to separate the levels in multilevel surfaces. The four different levels and the bearing area at each level are shown in figure 8, 9, 10 and 11. Once the levels have been determined the methodology for characterization can be applied here also.

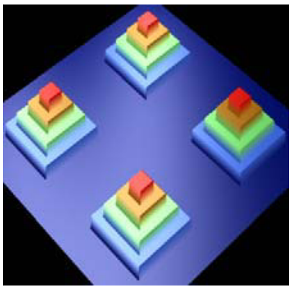

Figure 6. 3D view

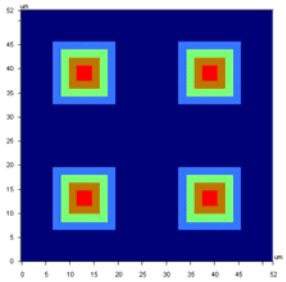

Figure 7. 2D view

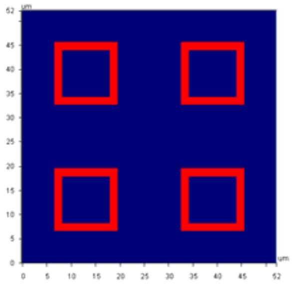

Figure 8. Level 1

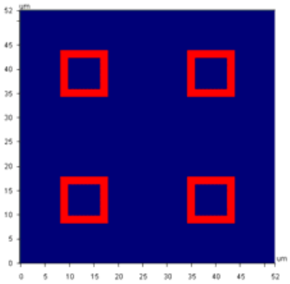

Figure 9. Level 2

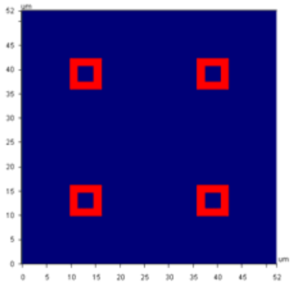

Figure 10. Level 3

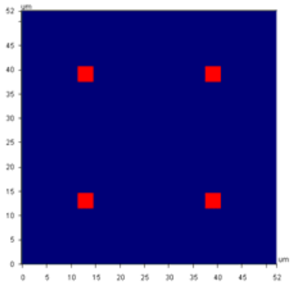

Figure 11. Level 4

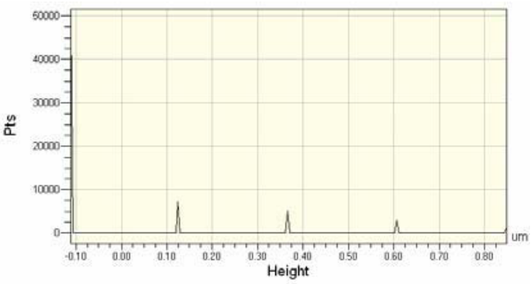

Figure 12. Height histogram

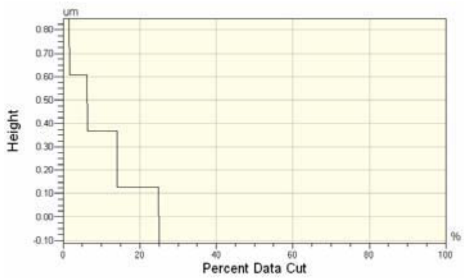

Figure 13. Bearing ratio curve

The above results indicate that the characterization methodology is robust and can be used effectively for characterizing engineered surfaces. A wide variety of real and synthetic surfaces are being used to develop a comprehensive system to analyze class II and class III surfaces.

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