

H-minima transform for segmentation of structured surface

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Abstract. The watershed segmentation method has been used in surface metrology to determine the feature parameter and the segment of areal surfaces. However, during segmentation, over-segmentation always happens, which may overshadow the significant features. Thus, a new method is required to reduce this over-segmentation, as well as to retain the necessary information for further improvement in the signal processing data. Hence, this paper proposed a new method to overcome over-segmentation for segmentation of structured surface. Over-segmentation happens when the surface area is over-segmented into a large number of insignificant, tiny, and shallow hills and dales features rather than a few significant dales/hills features. H-minima transform was proposed to overcome this issue. From the results, the data pertaining to simulated and measured surface topographies, as well as height threshold value of H-minima transform had depended on the irregularities of the surface to obtain the required features. As a result, it had been concluded that H-minima transform is possible to reduce over-segmentation.

1 Introduction

Structured surface is purposely designed to meet a specific functional requirement [1]. It contains a topography of generally high aspect-ratio and deterministic feature pattern [2]. This surface is critically important because its influence on the functionality of that surface, such as in tribological application for improving lubrication, reduction of friction and wear [3], as well as in manufactured items like micro and nanometer scale transistor, micro-electro mechanical systems (MEMS), nano-electro mechanical systems (NEMS), and optics.

Thus, in order to improve the functional performance of this structured surface, it is a must to characterize and analyze the surface. Recently, several researchers have proposed characterizing structured surfaces based on geometrical properties of individual features on the surface [4]. Hence, for surface characterization, it is necessary to identify the relevant features by segmenting the surface into regions of interest. Surface features consist of areal features (hills and dales), line features (course and ridge lines) and point features (peak, pit and saddle points). The stable extraction of significant surface features can be carried via Watershed Segmentation method [2]. According to Maxwell, a landscape surface is divided into regions of hills and dales. Hill is an area

from which maximum uphill paths lead to one particular peak, while dale is an area from which maximum downhill paths lead to one particular pit. The boundaries between hills are course lines (watercourses), while the boundaries between dales are ridge lines (watershed lines). Besides, the ridge and the course lines are maximum uphill and downhill paths that originate from saddle points and end at peaks and pits.

Meanwhile, segmentation is used to determine regions of the scale-limited surface that defines the scale-limited features [5]. In this study, the features involved included hills and dales. In order to segment this surface, both features cannot exist at the same time during the segmentation is carried out. However, the existence of a large number of insignificant or irrelevant features during segmentation often occurred over-segments the surface, as shown in figure 1.

Over-segmentation may affect the extraction of the significant relevant features from the structured surface. It could distort the required structured surface data during the surface data analysis and characterization. Hence, a method is required to reduce this over-segmentation. The most common method used to reduce over-segmentation in surface metrology is Wolf Pruning [6]. This method determines the significance of regions based on height and depth. The insignificant regions are merged together until all remaining regions become significant. Even

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though the Pruning method is usually used to overcome over-segmentation, this method is not fully explored [7]. Then, in this context, the objective of this study was to propose a new mechanism to reduce over-segmentation on structured surface in the segmentation method. In this paper, an alternative method is introduced to reduce over-segmentation by applying H-minima transform [8][9][10][11].

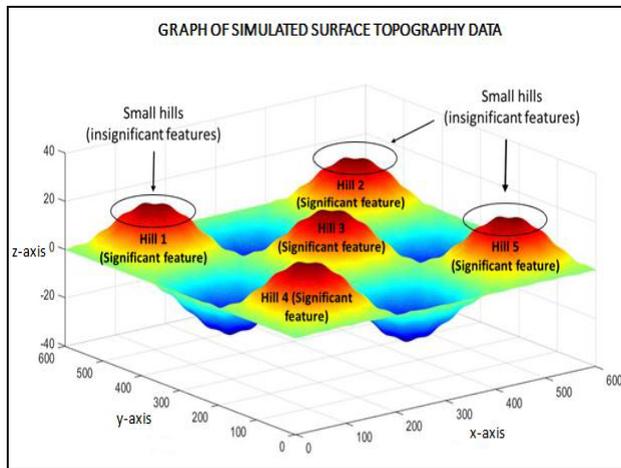


Figure 1. Over-segmentation that occurs on the simulated structured surface.

1.1. The Proposed Segmentation Procedure for Structured Surface

A few steps are involved in determining the significant features. Figure 2 shows proposed segmentation procedure for structured surface.

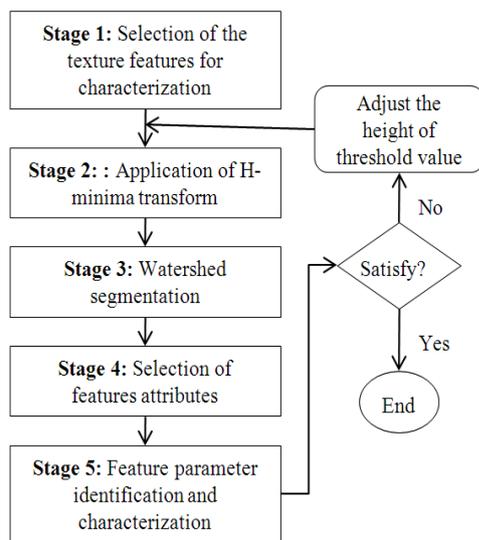


Figure 2. The proposed segmentation procedure.

From figure 2, stage 1 involves the selection of the types of structured data. Then, application of H-minima transform is introduced in stage 2. This method should be applied before the watershed segmentation to eliminate insignificant features on the surface. The existence of small and tiny dales within the large dales may overshadow relevant surface features wanted. Once the

significant features are determined, watershed segmentation will segment the surface into region of interest. Meanwhile, stages 4 and 5 are the future works for feature parameter characterization to determine the functional performance of the structured surface. The process is repeated until the featured parameters of the required structured surface are satisfied.

1.2. H-Minima Transform Method

This paper proposed the H-minima transform to reduce over-segmentation. This method is applied before the watershed segmentation is carried out. H-minima transform is the method proposed to replace the Wolf pruning[6]. H-minima transform suppresses all regional minima in I, whose depth is less than or equivalent to H. I is the areal surface topography dataset, while H is the height threshold value (non-negative scalar) [12]. Besides, regional minima are connected components of pixels with the same dataset value, t, whose external boundary pixels all have a value greater than t [13].

To eliminate all regional minima, except the significant minima, H-minima transforms can be applied to specify a height threshold value by using the following equation:

$$H = N * Z \tag{1}$$

Where: H = height threshold value
 Z = maximum height from mean plane
 N = percentage from maximum height (%)

From the equation, it is observed that height threshold value is dependent on the percentage from maximum height. Value of N is depending on the irregularities of the measured surface topography data respectively (~5%-20%). For this method, H-minima transform only affects the regional minima; as none of the other pixel values is changed. The significant minima remain, although their heights are increased. Moreover, the size of the significant minima tends to increase and the number of regional minima decreases. Figure 3 shows the overview of H-minima transform function applied on the structured surface.

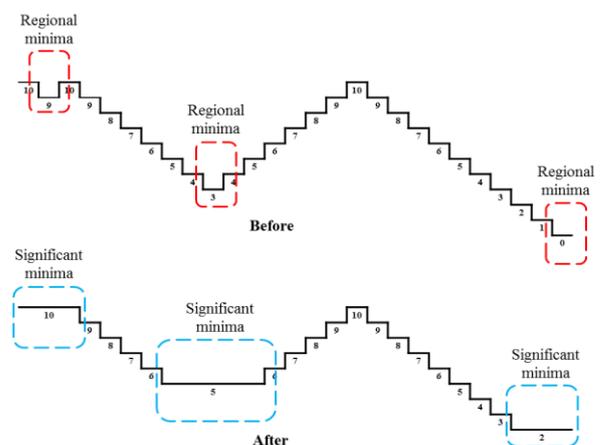


Figure 3. Overview of H-minima transform algorithm for 1-dimensional diagram.

Before application of H-minima transform, numbers 9, 3, and 0 (inside the dotted red box) were the regional minima. For number 9, its depth was 1 (from 9 to 10), while for number 3, its depth was 7 (from 3 to 10), and for 0, its depth was 10 (from 1 to 10). For example, by taking 20% of the maximum height, the height threshold value becomes 2 (also called as depth). After the application of the H-minima, the result showed that H-minima transform removed all the regional minima, which were insignificant with depth smaller or equal to 2, and increased the height of the regional minima by 2. As per figure display, before and after application of H-minima transform, the regional minima (9, 3, and 0) are merged with the adjacent minima to become significant minima. Hence, all regional minima that had been less significant were transformed by ‘flattening out’ any insignificant regional minima into the required significant minima. Thus, H-minima transform is defined as the reconstruction by erosion of f , and increased by a height, H as in the equation 2 [14][8]:

$$Hmin_H(f) = R_{\epsilon}(f+H) \quad (2)$$

Where: $Hmin_H(f)$ = H-minima transform
 $R_{\epsilon}(f+H)$ = reconstruction by erosion of f increases by height threshold H

2 COMPUTATIONAL SETUP

2.1 Computational procedure

Structured surface from simulated and measured data were taken for the computational setup in order to demonstrate the function of H-minima transform on the surface. The types of structured surface involved were areal surface features, which consisted of hill and dales. The simulated structured data were generated by combining the sine and cost values, whereas the measured structured data were obtained from the electroplated diamond tool specimen measured with Confocal Laser Scanning Microscope (CLSM). Furthermore, the topography data had been stated in pixel size with (data interval) dx and dy . The grid number of the topography data was #120, while the average grain size of the topography data was about $150 \mu m$. The diamond grain distribution and the orientation were in random arrangement. Both surfaces were analyzed and evaluated by Matlab software[12].

Apart from that, both structured data focused on hills segmentation alone. The percentage of maximum height was taken as the control parameter. Both surfaces were divided into two simulations. First, both structured surfaces must undergo watershed segmentation only, while the other employed the simulation watershed segmentation plus H-minima transform methods. The reason was to demonstrate the effect of H-minima transform on the structured surface. H-minima transform specified the height threshold as per stated before. Moreover, this research started with the simulated surface topography data. As for simulated surface topography

data, the number of percentage taken began with 1% and it was added up to 0.5% till 5.5%. The simulation was run for ten times in order to obtain the most stable number of segments for the structured surface. Nonetheless, the simulation was stopped when the significant features matched within the region segment.

Then, for measured surface topography data, the procedure applied was the same. Before the simulation begins, the grains on the real data are manually counted (figure 4). The reason is to validate the results before and after simulation. However, due to the large number of the dataset, the number of percentage that had been taken began with 5% and was added up to 5% till 55%. The simulation was run for 15 times in order to obtain the most stable number of segments for the structured surface. The results of the application H-minima transform for both simulation is discussed in Results and Discussion section.

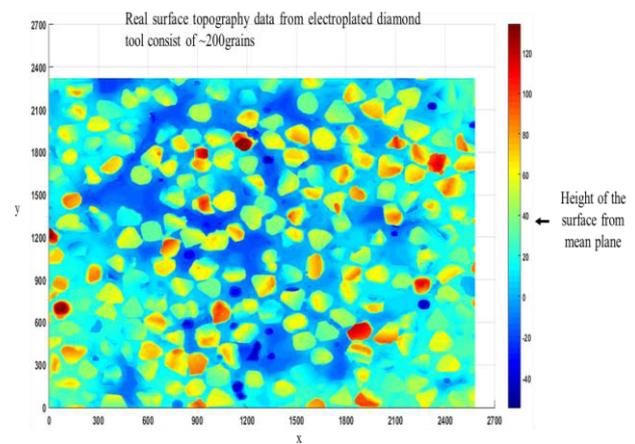


Figure 4. Real surface data from electroplated diamond tool consist of ~200 grains.

2.2. Data Structure

The dataset that contained areal surface topography information of height values (z values) arranged along the rows and the columns of a regular x, y grid with constant Δx and Δy was plotted on a three dimensional Cartesian coordinate system with an origin at 0, as portrayed in figure 5. The colors indicate the height of the surface features in the surface topographical map.

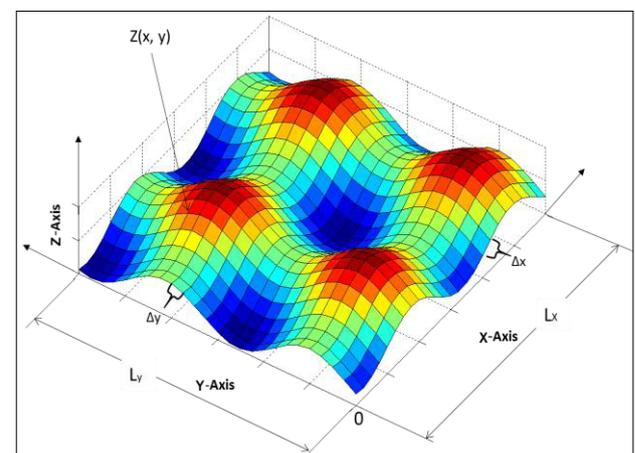


Figure 5. Data structure plotted in 3-dimensional graph.

$Z(x, y)$ = surface height matrix consists of x and y pixel values

Δx = constant x data interval

Δy = constant y data interval

L_x = length of x values

L_y = length of y values

0 = origin value on Cartesian coordinate system

3 RESULTS AND DISCUSSIONS

In this section, results of the H-minima transform applied on the simulated and the measured surface topography data are demonstrated. Graph number of segments versus percentage of N from maximum height for simulated and measured data had been plotted.

Figure 6 to figure 9 shows the structured surfaces without and with application of the H-minima transform for both simulated and structured surfaces. Figure 6 represents the results obtained without application of H-minima transform, whereby the simulated structured surface had been over-segmented, as well as the mixing of insignificant and significant features. The line segments on the surface also are not well segmented on the simulated surface. Total hills which are over segmented are 37 hills. Figure 7 shows the results retrieved with application of H-minima transform, where significant features were determined on the simulated structured surface at 2.5% from maximum height. Number of hills segments after application of H-minima transform is 5 hills. Each hill represents grains as shown in the previous figure (figure 1).

Figure 8 depicts results for without application of H-minima transform, where measured structured surface were over-segmented, significant and insignificant features were mixed-up together, and significant features could not be identified. Total hills over segmented are 30651 hills. Figure 9 shows with application of H-minima transform, significant features were determined on the measured structured surface at 10% from maximum height of the measured structured surface. There are 191 significant features are detected within the segmented regions. Each region contains one significant feature which has its own attributes towards those surfaces. In this research, it was found that at 10% from maximum height, the significant features detected are nearly similar with the manual calculation which is ~200 grains. For this types of surface, 10% may suit and possible to determine the relevant features.

Otherwise, from each figures (figure 6-figure 9), the color bar represents the height of the measured surface (z value) from a mean plane. The unit for z value is in μm . While for x and y , both unit are in pixels. Thus, both values need to be converted to the μm in order for feature parameter characterization. The line between the colors of the region is the line segments, which separate one feature to the adjacent feature. Each feature was evaluated and quantified in order to determine the feature parameter for future works.

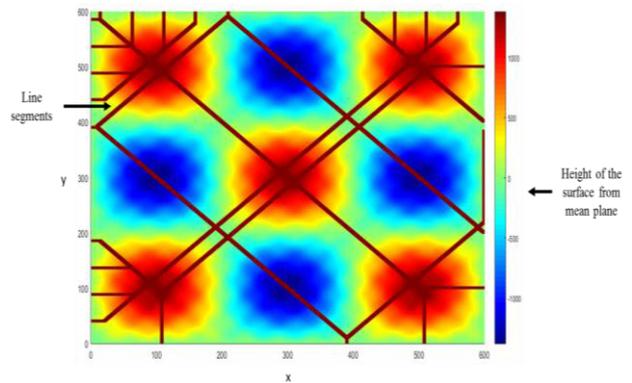


Figure 6. Over-segmentation occurred on the simulated surface topography data. Total segment is 37 hills (without H-minima transform algorithm).

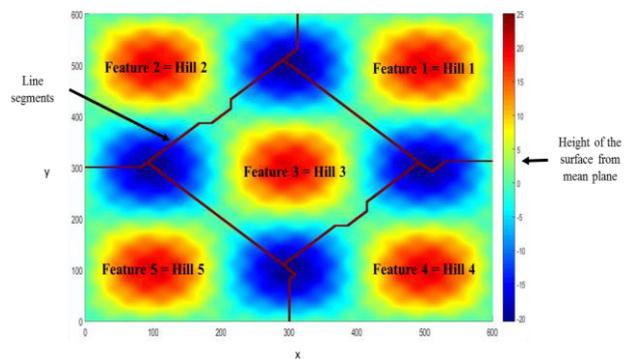


Figure 7. Significant features were determined on simulated structured surface at 2.5% H-minima transform, number of hills =5.

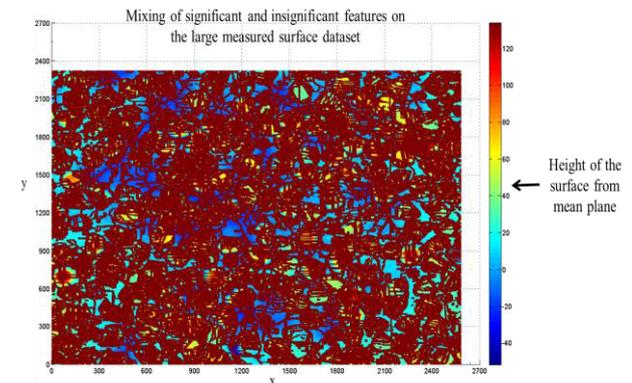


Figure 8. Over-segmentation occurred on the measured surface topography data. Total segment is 30651 hills (without H-minima transform algorithm).

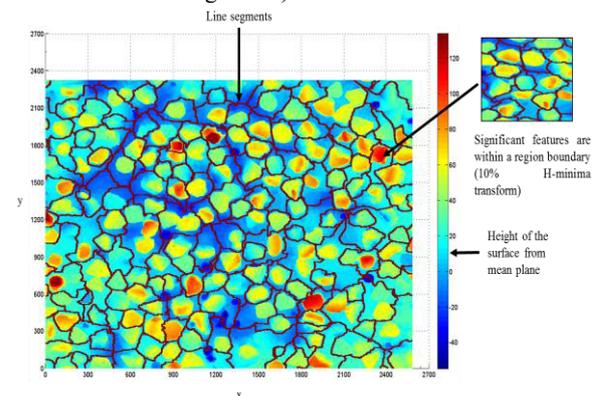


Figure 9. Significant features were determined on measured structured surface at 10% H-minima transform, number of hills =191.

The data collected from the experiment on simulated structured surface had been plotted in the graph number of segments versus percentage of N from maximum height as shown in figure 10. The number of segments had been varied when the percentages were changed. The results showed that at 2.5% to 5.5% the number of segments had become stable. The significant features are obtained at 2.5% H-minima transform. Figure 10 shows the data collected from the experiment on measured structured surface, which were plotted in the graph number of segments versus percentage of N from maximum height.

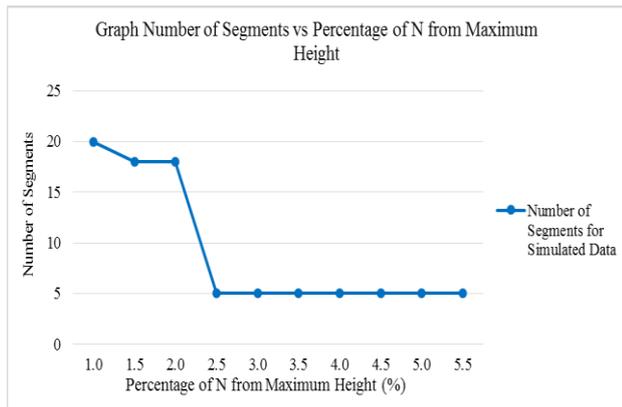


Figure 10. Graph number of segments versus percentage of N from maximum height for simulated data.

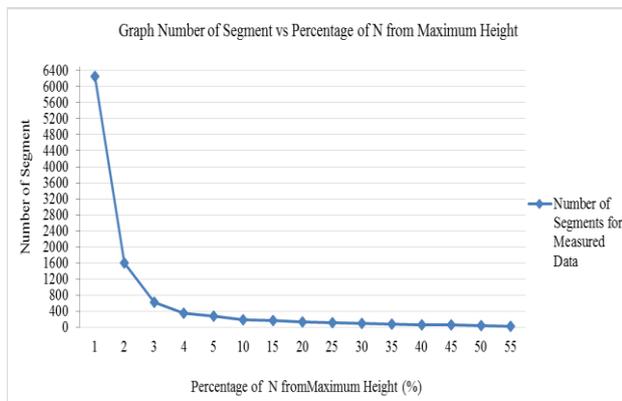


Figure 11. Graph number of segments versus percentage of N from maximum height for measured data.

Graph in figure 11 shows the number of segments is decrease as the percentage of H-minima transform is increases respectively. The number of segment is decreased sharply at 1% to 5% and become stable at 10% towards the end of the experiment. 10% is the most suitable percentage to determine significant features because the number of hills segmented is nearly similar with the manual calculation which is ~200 grains.

3.1. Limitations

The H-minima transform applied parallel with Wolf Pruning method depended on height threshold value. The height threshold value of the H-minima transform was determined by the percentage of the maximum height. Nevertheless, the percentage might not always lead to the desired segmentation result, as per discussed before.

Thus, several combinations of areal data pre-processing and H-minima transform solutions are needed in order to obtain the best percentage for determination of significant features. Additionally, trial and error method is still needed for the user side to apply this application until they satisfied. Otherwise, prior knowledge about the surface also important for the surface texture characterization. However, the solution proposed in this study could help in minimizing time consumption for the segmentation method to solve the over-segmentation issue.

4 CONCLUSION

In this paper, a new method for segmentation had been proposed. The proposed method successfully segmented the surface feature into the features of interest by applying H-minima transform. The height threshold value of H-minima transform is depended on percentage from the maximum height. The results showed that H-minima transform could be used to overcome over-segmentation during watershed segmentation process on the structured surface.

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