Anisotropic Artifacts Introduced by Horizontal Scanning Instruments in Surface Metrology

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Introduction

The objective of this work is to study the extent and nature of artifacts that appear as differences in the tracing and scanning directions of surfaces measured by horizontal scanning instruments. These differences can impart, masque, or distort anisotropic characteristics in measured surface textures, which can confuse the assessment of anisotropy. A better understanding of these measurement artifacts can improve the quality of metrology systems for assessing anisotropy in surface textures.

Horizontal scanning instruments include atomic probe (e.g., AFM, STM), scanning laser and scanning stylus microscopes. These kinds of instruments repeatedly trace a sequence of profiles and scan a surface to build a data set of surface heights as a function of position in the tracing and scanning directions. Because of the similarity of the horizontal scanning we should suspect that these instruments might be subject to the same sorts of artifacts influencing the assessment of anisotropy.

Methods

In this work we use length-scale fractal analysis (Brown and Savary 1991) to analyze several measurements, made by a scanning laser microscope (SLM). The SLM was built in the Surface Metrology Laboratory at WPI for measuring runway surface textures in a project with NASA Langley Research center. In this work the SLM was used to measure a roughly finished sample of a concrete based pavement surface. A region 10mm x 10mm was measured with a sampling interval of 25μm in each direction.

Length-scale analysis is a type of fractal analysis based on the Richardson, coastline or compass method. The method analyzes the changes in the relative length (ratio of the measured length to the straight-line length) of a profile, which increases as the scale of measurement decreases (Fig. 1). Two parameters are derived from the analysis. The length-scale fractal complexity, Lsfc, is negative 1000 times the slope of a regression line fit to a portion of the log-log, length-scale plot (Fig. 2). The Lsfc is related to the fractal dimension (Fd = 1 + (Lsfc/1000)). The smooth-rough crossover, SRC, is the scale that delineates the coarse scale regions where the profile appears smooth, or Euclidean, from the fine scale regions where it appears rough, or fractal. At scales below the SRC the relative lengths are significantly greater than one. These parameters, unlike average roughness, depend on the order of the measured heights in the profiles. The complexity and crossover are orthogonal measurements, in that one can change without influencing the other.

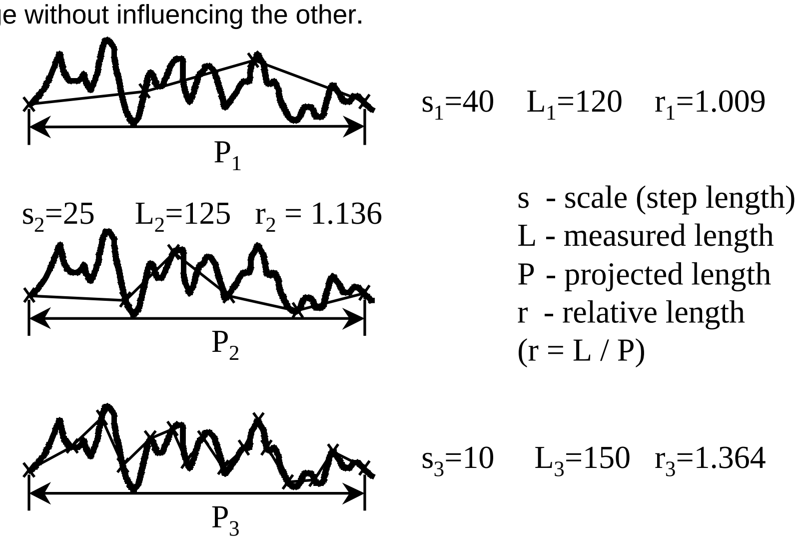

Fig. 1. Length-scale analysis

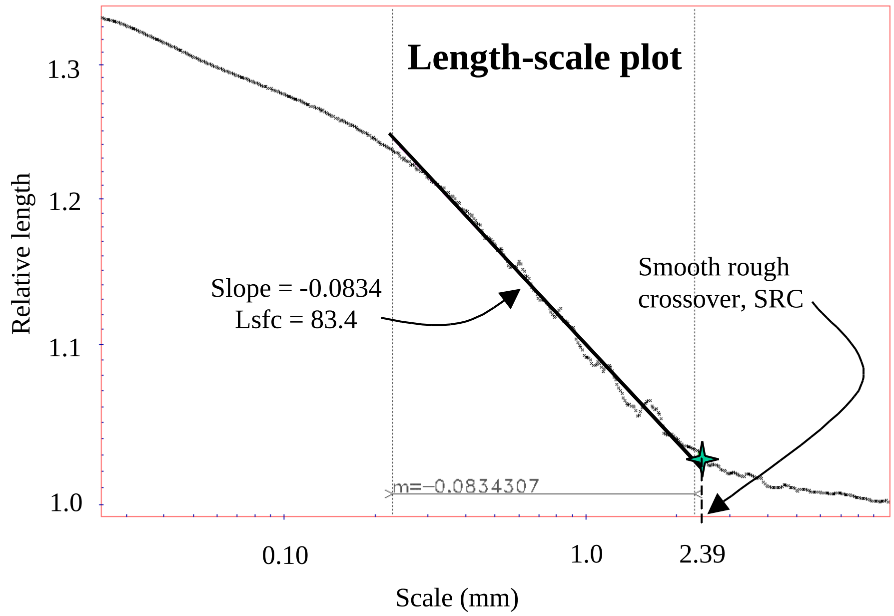

Fig. 2. Annotated length-scale plot.

More common profile characterization parameters, such as Ra, are not capable of detecting anisotropy without careful individual filtering of each profile from the data set. No filtering is used prior to the length-scale analysis.

There are two sources of potential artifacts to consider. First, the height sensors on the scanning instruments can have some directionality inherent in their design. The SLM uses a triangulation laser to measure the heights. Surface features with slopes approaching or exceeding the triangulation angle on the triangulation cannot be measured from at least one direction by conventional triangulation laser devices. Other kinds of sensors are also subject to directionality, e.g., the shape and stiffness of cantilevers on AFMs may not have the symmetry required for measuring features in the same way parallel and perpendicular to the axis of the cantilever. Second, non-random noise can be imparted on the measurements differently parallel and perpendicular to the tracing direction. One manifestation of this is the streaks frequently found on images of measured surfaces that indicate the tracing direction.

To be able to address both of these potential sources of artifacts, and assuming that the surface is anisotropic, 8 different cases are examined, perpendicular analyses each on 4 different measurement configuration at the same location. Twelve repetitions of each measurement are used so that it will be possible to separate systematic artifacts and random noise. One region on the surface was measured 12 times, after which the tracing and scanning directions were exchanged. The same region then was measured 12 more times. Following these measurements the surface was rotated 90° and the operation was repeated producing a total of 48 measurements. On each measured surface, the length-scale analysis was performed in both the tracing and scanning directions, for a total of 96 analyses.

Results and Discussion

The plot of complexity (Lsfc) versus smooth-rough crossover (SRC) shows seven distinct different groups of results (Fig. 3). There are only two cases where the scatter from the 12 measurements overlaps. This overlapping of the two cases is supposed to be a random event and is not considered to be consequential. The measurements within one case appear to be highly reproducible, yet when viewed in the complexity-SRC plane it appears that the results are sensitive to all the measurement variables, sensor orientation, tracing direction, and analysis direction. If the surface is isotropic and there is no influence of the orientation of the measurement then all the parameters for all eight cases would have the same values, which is not observed. If the surface is anisotropic and the complexity-SRC combination is not sensitive to the measurement variables, there would be two groups of four cases each, according to the direction of the analysis relative to the surface. This was not observed either.

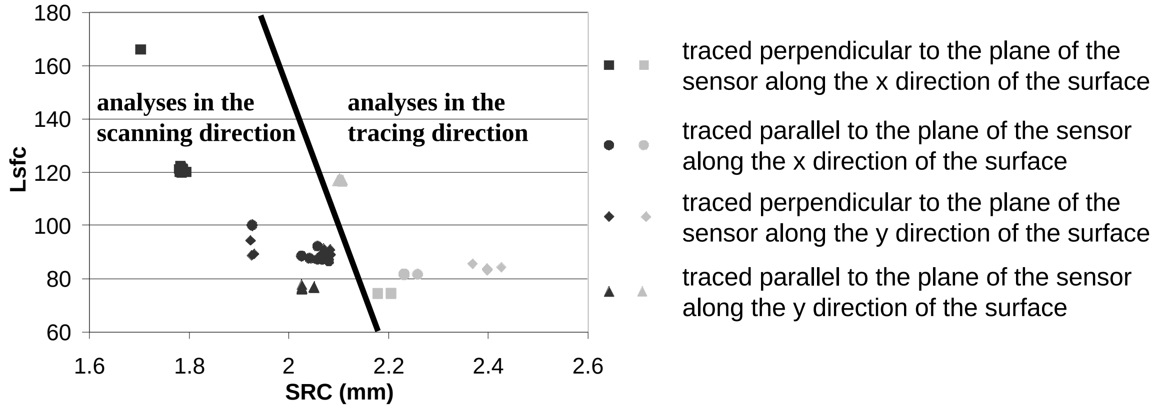

Fig. 3 Complexity (Lsfc) versus smooth-rough crossover (SRC) for all measurements and analyses. The gray symbols indicate analysis in the tracing direction.

If we consider the rotation of the surface relative to the SLM, to be essentially changing the orientation of the sensor relative to the surface then the anisotropic nature of the surface is apparent. For analyses made in the same direction on the surface, regardless of the measurement direction, the complexity is consistently greater when the analysis is made in the plane of the sensor triangulation, as shown in Fig. 4. This indicates that the surface is anisotropic, with respect to complexity. In other words, when the orientation of the sensor is controlled for then the anisotropy of the surface with respect to complexity is evident. The sensor orientation is able to masque the anisotropy.

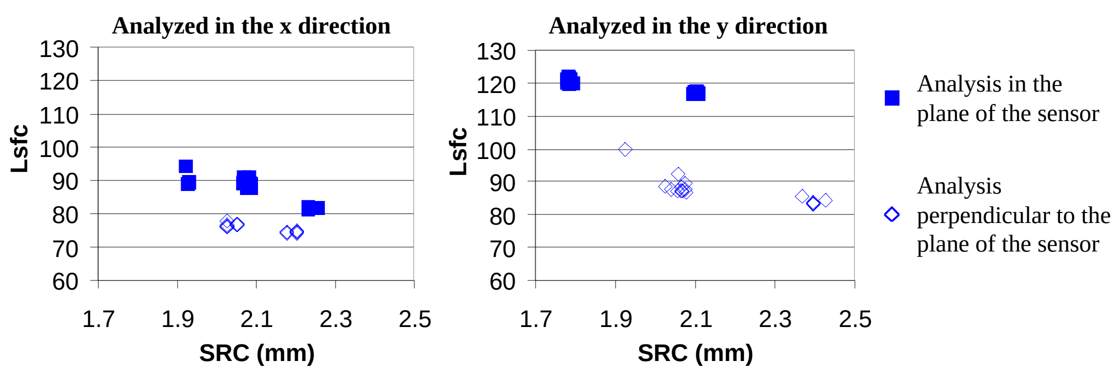

Fig. 4 Complexity (Lsfc) versus smooth-rough crossover (SRC), controlling for the analysis direction relative to the surface.

The influence of the tracing and scanning directions is apparent as the complexity of the analyses made in perpendicular to the tracing direction has greater scatter than parallel to the tracing direction. The standard deviation of each measurement analyzed in the scanning direction is greater than the standard deviation for the same measurement analyzed in the tracing direction. The influence of the tracing and scanning directions is also evident, as shown in Fig. 1, as the analyses in the tracing directions tend to have higher SRCs that those in the scanning direction. It may be that the noise is registered in the measured surface in the scanning direction in a way that tends to blur the features that contribute to the SRC, smoothing of the surface with respect to SRC.

Conclusions

- The complexity - SRC space can be used to differentiate sensor orientation, tracing direction and analysis direction on the same surface.
- Anisotropic characteristics with respect to complexity are apparent, only when the orientation of the sensor is controlled.
- Analyses perpendicular to the tracing direction results in a greater scatter in the complexity of the measurements.
- Analysis in the tracing direction results in a greater smooth-rough crossover.
- Artifacts are imparted both by the orientation of the triangulation laser sensor and by the scanning and tracing tables or some noise which varies with time.

Acknowledgements

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References

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