Investigation of stylus tip-size effects in surface contact profilometry

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Abstract

This paper presents refinements to 3D simulations of stylus effects in microtopography measurements. It briefly reviews how statistically richer data can be obtained by extending basic kinematic models, perhaps providing steps towards more sophisticated modelling of the contact process. After a few notes about the new simulation scheme, some illustrative results concentrate on idealized styli operating beyond the limit of their expected resolving power.

1 Introduction: stylus simulation

It is almost impossible to determine directly the complex interactions that occur between a profilometer stylus and a surface during a measurement of surface micro-topography. There is, however, a long history (dating back to the obsolete E-system of reference lines) of simulating the loci of circles, and latterly spheres, rolling on rough topography both as an evaluation tool and in attempts at ‘stylus deconvolution’. Comparison between real results and such simulations can reveal indirect evidence about the behaviour in the contact region, although current models are hardly sophisticated enough to make much impact. They are purely kinematic models, assuming perfect guides and rigid objects and are actually a class of morphological filter (specifically, the centre locus is dilation operation) [1]. Published work concentrates heavily on the effect of the ‘measured surface’, extended in one case to report some statistics on the contact to the stylus [2]. The current research takes this further, motivated by its potential to cast light onto the in-plane uncertainty of stylus measurements, suggest ways to improve comparisons between instruments or lead eventually to methods for self-diagnosis of stylus wear.

A new simulation gathers full data about stylus contact related to its location upon the surface. It introduces a threshold process [3] by which the kinematic condition is violated in small increments and the growth of resulting 'contact areas' recorded. This is intended to give insight, into sensitivity to instrument noise, repeatability, *etc*. It also has potential for modelling the contact process, by approximating stiff but non-rigid contact using relaxation techniques. The contact modelling is implemented in MATLAB® which is interfaced with the commercial topographic analysis software SPIP in order to provide a standard for parameter evaluation and comparison, and to translate between different instrument data formats and MATLAB arrays [4]. The surface could be any set of data representing a real or an arbitrary surface. Also, the stylus could be any set of data representing a real or an arbitrary stylus shape. Both data sets are dealt with as arrays.

2 Styli and fine surface structure

This report concentrates on study of the sensitivity to stylus shape and condition when detecting features of real surfaces at the very limits of conventional profilometer capabilities. It therefore uses relatively small arrays with a grid sampling interval of 0.1 µm. Three ideal computer generated stylus tips with different shapes have been used: conical, pyramid and spherical (Figure 1). The tip radius and heights (for the conical and pyramid shape) are 3 µm and 5 µm. The tip angles of the conical and pyramid shapes are 90^0. Each tip has been used in its perfect shape and with a quite severe truncation at 2µm below the original tip. The spherical tip offers a full hemisphere, not the more usual blend into a cone, allowing estimation of flank contact for different cone angles. Many trials were run of the basic stylus shapes over simple computer generated surfaces, such as single or clustered delta functions. These can rapidly identify major bugs and increase confidence that no subtle errors remain in the simulation routines.

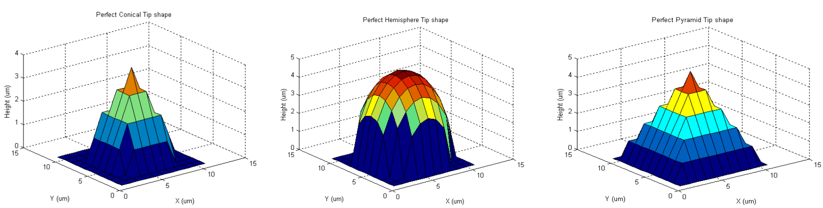

Figure 1: Conical, spherical and pyramid (5µm) Stylus tip shapes

3 Results

Surface maps of the fine structure of ground steel surfaces were measured by Atomic Force Microscopy (AFM) to ensure high lateral resolution. The data collected by the AFM were checked for missing data and interpolated by the SPIP software. Figure 2 shows a typical example.

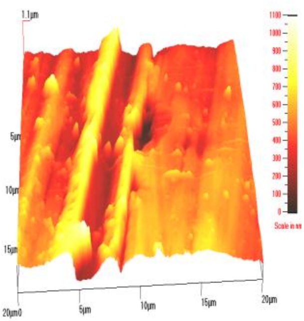

Figure 2: 20x20μm ground surface on 0.2μm sample grid taken by AFM

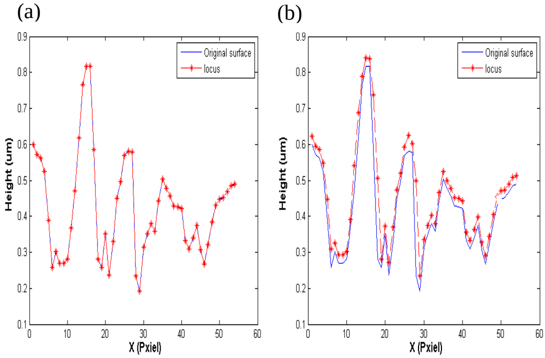

Figure 3: Pprofiles taken from scans across the data in figure2 using (a) 90° Pyramid stylus (b) 5 μm Hemisphere stylus.

Table 1: Error of the roughness parameters of different tips on the ground surface

		Roughness Parameter	Sa	Sq	Sy	Ssk	Sku
			458 nm	481.5 nm	920 nm	1.135	1.37
Stylus Tip	Size	Shape	%Error=100x(Measured Value - Actual Value)/ Actual Value				
Pyramid	3μm	Perfect	0.00	0.00	0.00	0.00	0.00
		2μ Worn	-2.1	-1.5	-7	-1.8	-3.7
	5μm	Perfect	0.00	0.00	-0.02	0.00	0.00
		2μ Worn	-3.62	-3.44	-6.88	-0.877	-1.43
Sphere	3μm	Perfect	-1.09	-1.4	-17.2	-0.88	-0.72
		2μ Worn	-34	-29	-11	-7.96	-16.7
	5μm	Perfect	-6.76	-6.76	-1.6	-18.4	-0.877
		2μ Worn	-65.34	-56.34	-29.9	-10.57	-20
Cone	3μm	Perfect	0.00	0.00	0.00	0.00	0.00
		2μ Worn	-2	-1.4	-7.39	-1.7	-3.64
	5μm	Perfect	0.00	0.00	0.00	0.00	0.00
		2μ Worn	-3.38	-3.34	-7.45	-0.877	-1.4

Surface maps were scanned in simulation by the set of 3 μm and 5 μm styli (which would normally be considered too large for the task). Figure 3a and 3b shows two illustrative profiles taken from scans on the data in figure 2. The 3 μm hemisphere does remarkably well on local detail. Table 1 shows the percentage error of selected roughness parameters of different outputs when scanning the same ground shape with the different tips.

As expected, the maximum deviation occurs when using the 5 µm spherical tip with 2 µm truncation, but many cases show only small errors. The simulations show that in most cases contact do not occur at the central point of the stylus, even with idealized shapes other than perfectly shape ones. With the spherical tip, the mean position of the contact is close to the centerline, while its slandered deviation is about 0.5 µm on 3 µm radiuses. It tends to the radius of the flat on truncated ones.

Initial evidence shows that examination of the contact patterns as threshold increases can identify the intensity with which different asperity regions interact with the stylus. For example, a 5 nm threshold caused little change in contact sizes from the kinematic point, but 50 nm caused them to grow asymmetrically, eventually picking out the major structures of the surface.

4 Conclusion

A new simulation program has been developed and used to examine the measuring fine structure of real surfaces by the stylus method. Although able to scan any arbitrary surface with any arbitrary stylus shape, the results given here use idealized styli and ‘real’ ground steel surfaces.

The simulations have naturally confirmed that the stylus geometry and size can have a significant effect on most roughness parameters of the measured surface in 3D. The surprising feature of them, worthy of greater investigation, is how insensitive to major changes in stylus condition, some of the popular parameters are, even when dealing with very fine structure within localized areas of a ground surface.

References

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