*ASIATRIB 2002International Conference*
*JEJU ISLAND, KOREA*

# ALGORITHM FOR DETERMINING 3D CHANGES IN MICRO-GEOMETRY USING IMAGE PROCESSING TECHNIQUES

J.W. SLOETJES , Y.C. TAŞAN, M.B. DE ROOIJ and D.J. SCHIPPER

*University of Twente, Faculty of Engineering Technology, P.O. Box 217, 7500 AE Enschede, THE NETHERLANDS*

An algorithm has been developed to determine changes in surface topography on asperity level. The software stitches small but detailed images together to create one large image. If such an image is made before and after an experiment, their difference shows a direct 3D view of the changes in micro-geometry, rather than a change in surface parameters. The algorithm is described in detail and illustrated using artificial as well as real surfaces.

**Keywords** : Rough surfaces, 3D roughness measurements, Image processing

## 1. INTRODUCTION

Tribological experiments often involve the measurement of wear, or in general the change in surface topography. These changes can be determined in many different ways. Most methods are based on volumetric or mass differences or statistical parameters such as Ra and Rq (CLA and RMS respectively). Although these methods proved to be very useful they have some disadvantages. Due to the properties of the parameters local changes in micro geometry are averaged out. In many cases it is this local behaviour that dominates the overall behaviour of the tribological contact. In addition, significant changes in parameter value requires a substantial amount of change in surface geometry. In case of wear resistant materials this can lead to extensive measuring times.

Another way of measuring changes in surface topography is proposed by [1]. Using interference microscopy they were able to measure the *real* wear on asperity level. Although the method gave very good results, it was limited by the disadvantages of interference microscopy, i.e. only a large measurement domain combined with a large sampling interval *or* a small sampling interval together with a small domain can be obtained, whereas in many cases a large domain as well as a small sampling interval is preferred. In [2] a method to stitch several separate images together is proposed. As a result, the obtained image can have any combination of measurement domain and sampling interval. Obviously the next step is comparing two stitched images, which gives the opportunity to see the changes in surface topography on a *global* as well as on a *local* scale. The results shown in [2] clearly illustrate the power of this method.

## 2. MATCHING

### 2.1 Basic concept

The process of matching two images can be described as aligning the overlapping part of two successive images. To obtain the ``best fit", many approaches can be followed. What most of them have in common is that they are based on identification of *matching primitives*, certain distinctive features (edges, contours, etc.) in one image and the location in the other. However, many of these methods are not appropriate, since it is very difficult to determine such kind of primitives due to the stochastic properties of the surfaces.

The template method used by [1] however gave very good results when applied to roughness images. In this method a certain neighbourhood (template) is extracted from one image and the position with maximum correlation to the other is determined. For sufficient accuracy of the complete match, a number of templates have to be used. Although it results in relatively large computing times, this method is used in the present algorithm since it proved to be very appropriate. To obtain maximum accuracy, instead of several small templates the complete region of overlap is used. Again, this slows down the matching process.

Two types of matching can be distinguished. For the determination of wear, the overlap is generally large (about the size of the images), whereas the amount of overlap containing substantial differences between the two images can also be considerable. On the other hand, for stitching both the overlap and the differences in the area of overlap are small. At first sight it seems that two algorithms have to be developed, each optimized for its application. However, the two procedures are very similar. For instance, the way worn areas are excluded from the calculational domain in case of wear determination is very similar to the exclusion of outliers and other kinds of measurement errors, which is important with respect to the stitching part. Therefore, for both 'matching for wear' and 'matching for stitching' the same procedure is used.

### 2.2 Correlation and cost function

In the 3D space, the mutual shift and rotation consists of three translations and three rotations, which yields a correlation function depending on 6 degrees of freedom (DoF). Among the functions tested are the least squares cost function, the exponential cost function based on weighted difference proposed in [2] and the maximizing area function used in [1]. To find the global extremum of the cost function a number of optimizers are tested, including the solver discussed in [2], a simple downhill simplex solver [3] and the solver developed by [4].

For the comparison it is necessary to define a measure which decides if the extremum of the cost function found has a sufficient accuracy. Two options are available. First, the relative accuracy of the cost function is less than ε. Secondly, the absolute accuracy of every DoF is less than ε. At this point the second option is chosen, since this is the goal of the algorithm (an accurate estimation of all DoF's). Moreover, it is independent of the properties of the cost function and accompanying solver.

### 2.3 Amount of overlap for stitching

The efficiency and accuracy of the stitching process depends largely on the amount of overlap used. To see what the minimum amount of overlap should be in order to get a sufficient accurate result, a comparison is made for the artificial surfaces.

### 2.4 Optimization

**2.4.1 6 DoF vs. 3X2 DoF** Since all DoF's are coupled, the most straightforward way to find the extremum of the cost function is to take into account all 6 DoF's simultaneously. In [2] an iterative way is proposed consisting of a 2D search for translations and rotations in the (x,y)-plane and a fast estimation of the tilt parameters and vertical shift by means of fitting a plane through the difference image. The main advantage was that for the solver used in [2] the computing times decreased enormously. If possible, this approach is applied to other solvers in order to study if an increase in efficiency can be obtained as well.

**2.4.1 Coarse grids** In [2] coarse grids were used to limit the search window and accordingly speed up the matching process. For local solvers like the downhill simplex solver coarse grids can be used for the same reason: limit the search window. The purpose however is not to speed up the process but primary to avoid getting stuck in local extrema.

### 3. EXAMPLE

The optimal algorithm derived above is used to determine the difference in surface geometry for an isotropic finished steel surface as a result of a ball-on-disc experiment under pure sliding. Experimental conditions are listed in Table 1.

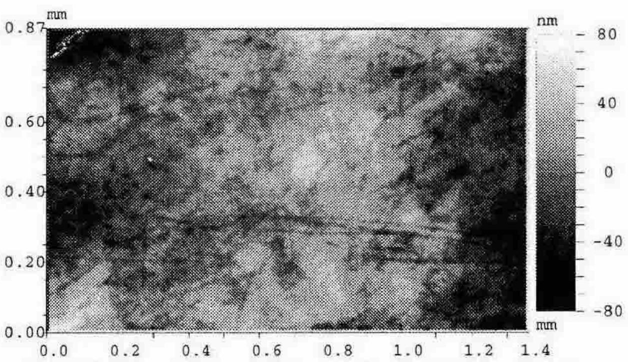


**Fig. 1** Surface before experiment. Rq=0.023 μm, sampling 1.49×1.45 μm, 565552 data points.

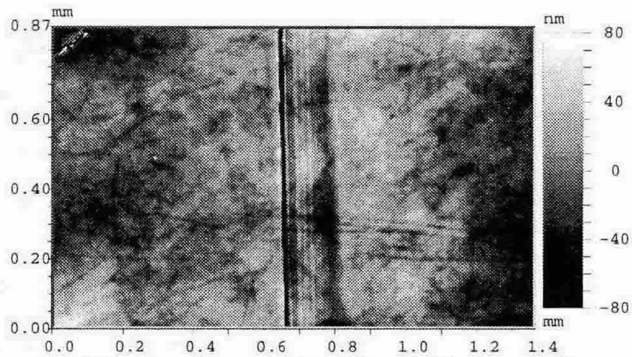


**Fig. 2** Surface after experiment. Rq=0.024 μm, sampling 1.49×1.45 μm, 563684 data points.

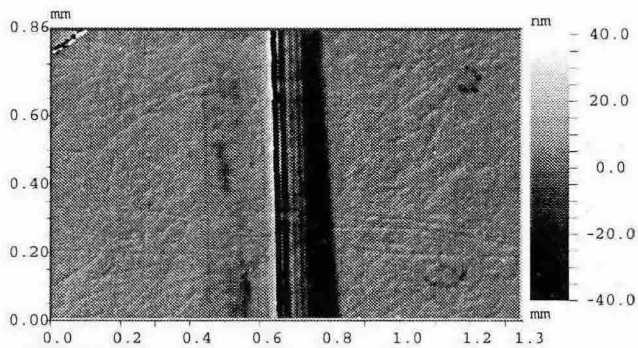


**Fig. 3** Difference image. Sampling 1.49×1.45 μm, 555044 data points.

**Table 1.** Experimental conditions

| | | |
|---|---|---|
| $R^* = 5$ mm | $\eta_0 = 30$ mPas | $\alpha = 23$ GPa$^{-1}$ |
| $F = 130$ N | $E^* = 230$ GPa | $u_s = 0.1$ m/s |
| $a = 0.2$ mm | $h_c = 0.028$ μm | $p_h = 1.5$ GPa |

### 4. CONCLUSIONS

An improved way of determining changes in surface topography has been developed. The method is capable of giving the changes on both local and global scale simultaneously.

### 5. REFERENCES

[1] De Rooij, M.B. and Schipper, D.J., "A wear measurement method based on the comparison of local surface heights," Wear, 217, pp.182-189, 1998.

[2] Sloetjes, J.W., Schipper, D.J., Lugt, P.M., and Tripp, J.H., The determination of changes in surface topography using image processing techniques, "Proceedings of the International Tribology Conference Nagasaki, 2000," Japanese Society of Tribologists, pp.241-246, 2000.

[3] Press, W.H., Teukolsky, S.A., Vetterling, W.T., and Flannery, B.P., "Numerical Recipes in C: The Art of Scientific Computing," Cambridge University Press, 1993.

[4] Huyer, W. and Neumaier, A., "Global optimization by multilevel coordinate search," Journal of Global Optimization, 14, pp. 331-355, 1999.