MATCHING AND STITCHING FOR SURFACE IDENTIFICATION

Jamari[1)]

Abstract

An algorithm to determine changes in surface topography on asperity level has been developed in this paper. The software tool 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 such as RMS or CLA roughness. The algorithm is described in detail and demonstrated by appling to real rough surfaces.

Keywords: rough surfaces, roughness measurements, image processing

INTRODUCTION

The relation between surface micro-geometry and its function is very important. For characterizing the surface micro-geometry the statistical approach is widely used. However, in order to understand the effect of surface micro-geometry on its performance, it is important to evaluate not only the surface micro-geometry itself but also the changes in performance as the surface micro-geometry changes in time. It is thus necessary to compare the changes of surface micro-geometry before and after a period of time or throughout the course of a process.

Omitting the concern of measurement position, it is relatively easy to study the changes in micro-geometry before and after a running process. However, studying the characteristics of the changes in micro-geometry at the same position is more desirable, especially when studying the process of change, thus making it possible exploring the detailed microscopic phenomena. It is necessary to establish special techniques to ensure measuring and observing at the same position the changes of the micro-geometry and its characteristics.

A wear and plastic deformation measurement have been presented by [1, 2] on the comparison of local surface heights. Based on image processing technique they are able to measure and characterize wear of very wear-resistant materials like hard coatings. The information about local height differences at the surfaces caused by wear or material transfer is given by using this method. Basically the method can be described as finding the best correlation and subsequently subtracting two 3D surface measurements before and after the experiment at the same spot. The 3D surface measurements are made by using a non-contacting interference microscope. The method proved to give good results but its capability is limited by hardware, in this case the capability of the optical interference microscope. In most of the practical situations it is not possible to get a detailed image of a complete section across a wear track in one measurement. Since the detailed information along across the wear track is very important, the hardware limits must be overcome by software.

Sloetjes *et al.* [3, 4] proposed a new technique by matching and stitching a number of small but detailed images together from sequence measurements. In this paper, the detailed method is explored and the application example is presented.

BASIC CONCEPT

The matching process of two images can be defined as aligning or repositioning the overlapping part of two successive images. One of the approaches which can be followed to obtain the "best fit" between the matching images is by identifying certain distinctive features such as sharp edges or corners, contours, etc. However, such approach is generally difficult to be applied for roughness surface images due to its stochastic properties. De Rooij and Schipper [2] used the template method and gave very good results for matching the roughness images. This method extracts a certain neighborhood (template) from one image and determines the position which gives the best fit to the other image. Instead of using several small templates [2] the complete region of overlap is used by [3, 4].

In order to get a detailed image of a complete section across a wear track, the stitching process has to be performed. Several measurements are taken in the stitching process and each one having a certain overlap area with the previous one. For every stitching of the subsequence two images the mutual translation and rotation has to be determined based on the overlapping area. This process is referred to as matching. Once all images are matched, one large image is created as a complete of the stitching process (Fig.1).

---

1) *Staf Pengajar Jurusan Teknik Mesin FT-UNDIP*

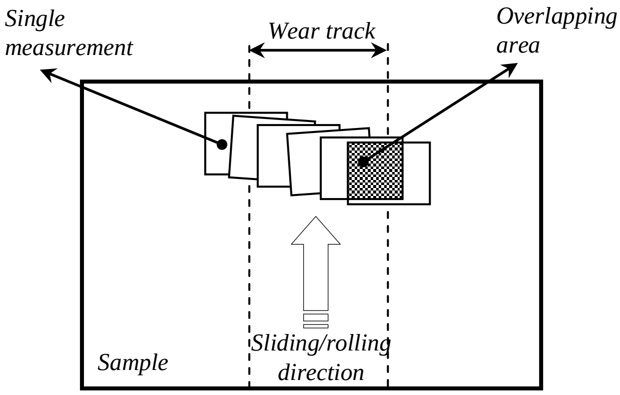


Figure 1. Matching and stitching process.

Data obtained by the optical interferometry generally suffers some errors such as noise, outliers and bad/missing points. Before performing the matching and stitching process, the errors should be reduced as much as possible. Reduction of noise can be realized by simply applying a low pass filter. The height data for missing points are determined by using an interpolation procedure which uses measured neighboring points.

To maintain exactly at the same position of subsequence measurements is very difficult therefore the correlation between the images is needed. In a 3D coordinate system, the mutual fit consists of three translations and three rotations (Fig. 2) which yields a 6 degrees of freedom (DoF) correlation function.

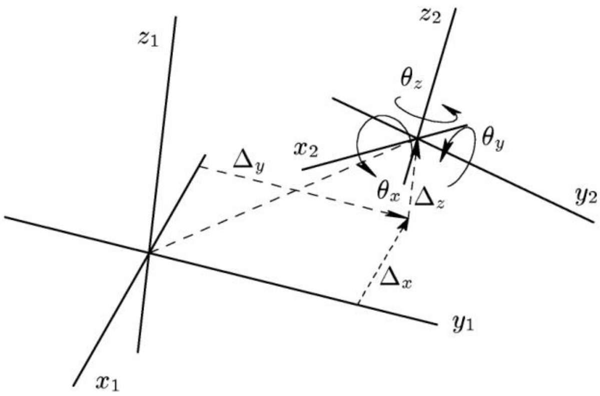


Figure 2. Coordinate systems and DoF's.

A correlation function in general can be written as:

$$cor_i(\Delta_x,\Delta_y,\Delta_z,\theta_x,\theta_y,\theta_z) = \frac{1}{N}\sum F_i(d) \quad (1)$$

where the subscript i is the correlation function type, N is the number of data points and

$$d = z_2^t(x_2^t, y_2^t) - z_1(x_1, y_1) \quad (2)$$

The superscript t indicates a transformation of the second image for the specific values of the DoF's into the first image coordinate system. The difference or distance d is the subtraction between the first and the subsequence image. There are many types of the correlation functions; the one which is presented here is as an example.

The least square correlation function minimizing the sum of the square of the distance:

$$F_{lsq}(d) = d^2 \quad (3)$$

while the weighted distances correlation function summing the weighted distance of the two overlapping images:

$$F_{wgt}(d) = \exp\left[-\frac{1}{2}\left(\frac{d}{R_{q,diff}}\right)^2\right] \quad (4)$$

where $R_{q,diff}$ is the Rq (RMS roughness) of the difference image. It was shown in [3] that the weighted distances correlation function gives better results compared to the least square correlation function.

SOLVERS

There are many types of solvers to find the global extreme of the cost or correlation function. The robust solver of [3] for instance, works with a search window, i.e. for every DoF only for the so-called master DoF's an interval is defined, centered around the main initial guess. Initial guess on the shifted in x and y-direction and rotated in xy-plane images at first is done by just looking the roughness itself. The initial guess of the remaining DoF's and its intervals are determined by the software.

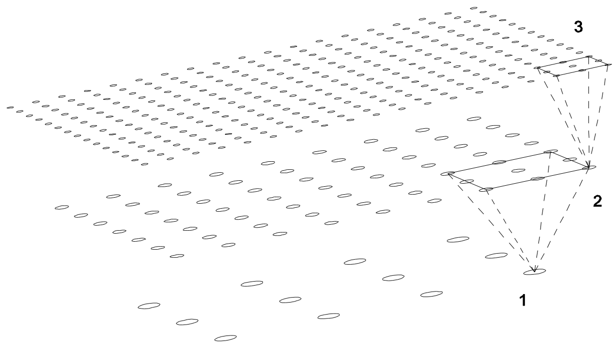


Figure 3. Coarse grids.

A coarse grid (Fig. 3) were used in the robust solver to limit the search window and accordingly speed up the calculation process. While for the other solver, downhill simplex for example, this coarse grid allows larger search intervals and avoids getting stuck in local extreme on the finer grids. The optimal fit on the coarse grid is a proper estimation of the best fit on the next finer grid and the search interval can be reduced to the finer grid. This because of the difference between the high resolution (fine grid) image and the low resolution (coarse grid) image is high frequency related therefore localized information.

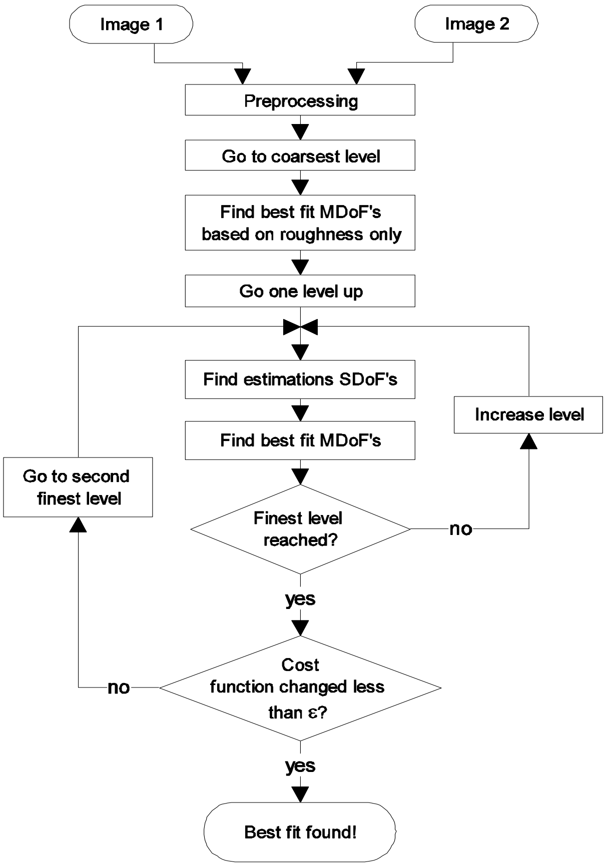
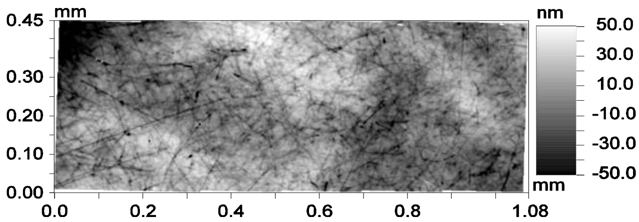


Figure 4. Flow chart of the matching process.

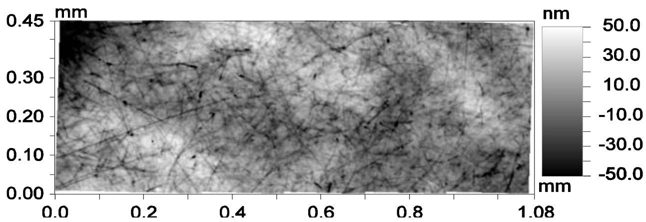
The matching procedure of the matching of two surfaces is shown in Fig. 4. After preprocessing the search for a first approximation of the master DoF's is started on the coarsest level. The macro-geometry is removed only in this level. Next, the level is increased by one and followed by entering the level loop. This loop is repeated until the fit on the finest level is achieved. The difference stop criterion, ε, to the cost function must be applied after the last loop in order to get convergence. The complete cycle from the second coarsest level up to the value of the cost function on the finest level must be repeated at least once to be able to calculate the stop criterion. If this is not satisfied the cycle begins again at the second finest level. There is no need to start at a coarser level since the changes of the DoF's take place mostly on the scale of the finest level therefore for 'safety' reasons the loop is started at the second finest level.

APPLICATION EXAMPLE

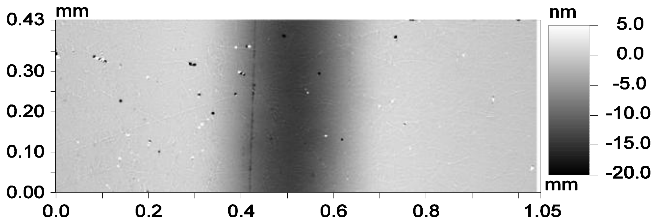
The matching and stitching have been applied to determine the change of a steel surface topography on a ball-on-disc sliding experiment. By the naked eyes it is very difficult to distinguish the image between before and after an experiment (Fig. C.5(a) and (b)). From the difference image (Fig. C.5(c)) it is clear that deformation/wear occurred. A 15 nm deep groove is already visible. This concludes the robustness of the method for determining the changes in micro-geometry of surfaces.



(a)



(b)



(c)

Figure 5. Matching and stitching of 6 images and its difference (c) before (a) and after (b) experiment.

CONCLUSION

An algorithm to determine changes in surface topography on asperity level has been developed. In practice, it is difficult to get a single large but detail image. The proposed software tool stitches small but detailed images together to create one large image. By using this tool for before and after an experiment, the difference between them shows a direct 3D view of the changes in micro-geometry, rather than a change in statistical surface parameters such as RMS or CLA roughness. The concept, correlation and solver of the method demonstrated the robust of the software.

REFERENCES

1. M.B. De Rooij, A wear measuement method based on the comparison of local surface heights, PhD thesis, University of Twente, Enschede, The Netherlands, 1998.
2. M.B. De Rooij and D.J. Schipper, A wear measurement method based on the comparison of local surface heights, Wear 217 (1998) 182 – 189.
3. J.W. Sloetjes, D.J. Schipper, P.M. Lugt and J.H. Tripp, The determination of changes in surface topography using image processing techniques, in Proceeding of the International Tribology Conference, Nagasaki, Japan, 2000.
4. J.W. Sloetjes, Y.C. Tasan, M.B. De Rooij and D.J. Schipper, , Algorithm for determining changes in micro-geometry using image processing techniques, in Proceeding of the 2nd Asia International Conference on Tribology, Asiatrib, Cheju Island, Korea. 2002.