Tribology International 103 (2016) 309–315

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Tribological study in microscale using 3D SEM surface reconstruction

Emad Omrani [a,*], Ahmad P. Tafti [b,*], Mojtaba F. Fathi [c], Afsaneh Dorri Moghadam [a], Pradeep Rohatgi [a], Roshan M. D'Souza [c], Zeyun Yu [b]

[a] Department of Materials Science & Engineering, University of Wisconsin-Milwaukee, WI, 53211 USA
[b] Department of Computer Science, University of Wisconsin-Milwaukee, WI, 53211 USA
[c] Department of Mechanical Engineering, University of Wisconsin-Milwaukee, WI, 53211 USA

ARTICLE INFO

Article history:
Received 6 April 2016
Received in revised form
1 July 2016
Accepted 3 July 2016
Available online 5 July 2016

Keywords:
Wear and friction
Tribological analysis
Scanning electron microscope (SEM)
3D SEM surface reconstruction
3D surface modeling
3D Tribological study

ABSTRACT

Tribology as a branch of materials and mechanical engineering sciences incorporates concepts of friction, wear, and lubrication to discover knowledge and facts about different surfaces. The scanning electron microscope (SEM) and the optical microscope (OM) are two common imaging equipment that have been used in tribological research to visualize and characterize worn surfaces. SEMs are more practical than the OMs since: (1) they are able to generate higher resolution and increased magnification, and (2) they can also provide a greater depth of field. While SEM micrographs still remain two-dimensional (2D), tribological studies truly require information about three-dimensional (3D) surface structures. 3D surface reconstruction of SEM images is very useful in the literature since it helps to analyze the surface roughness of worn surfaces which can imply the wear and friction behavior of materials. In this contribution, copper pins were tested by pin-on-disk tribometer on three different counterfaces (aluminum as softer material, copper with the same hardness, and stainless steel as harder material) and worn surfaces further characterized by using an optimized multi-view 3D SEM surface reconstruction framework. The surface roughness of pin is also calculated by using the 3D SEM surface reconstruction algorithm. In addition, wear mechanisms were studied in further details. Results show that the COF and wear of copper pin against stainless steel are less than COF and wear of copper pin against aluminum and copper due to the formation of in situ iron rich layer on the surface.

1. Introduction

Tribology is the study of interacting surfaces in relative motion [1] with a focus on friction, wear, and lubrication. It has been growing in importance as manufacturers gain a better appreciation of its impact on product performance and lifespan. Engineers involved in tribology applications can benefit greatly from a metrology tool that can measure and quantify how a surface is affected at a microscopic level, by abrasion, adhesion, scuffing, galling, fatigue, rolling contact, delamination, spalling, impact, fretting, corrosion, or a combination of these types of wear [2]. The measurement data obtained can be critical to engineers optimizing the design of a component or assembly, a surface finishing process, a coating formulation, or a method of lubrication.

Surface topography and surface roughness play a crucial part in controlling and predicting the response of rubbing two materials against each other [3]. Characterizing and controlling surface topography is paramount for selecting appropriate materials for components where friction and wear are dominant failure modes. In applications such as tribology, refinement of surface finishing processes, and lubrication engineering, optical surface profilometers are used to generate images of the surface. They can examine surface features with high precision and provide reliable quantitative measurement data quickly and reliably. Optical profilometers are valuable tools for wear analysis, regardless of whether the wear is the result of actual use, or wear testing with a tribometer. Common optical profilometers use interference optical microscopes. There are two main types of optical inteferemeters. One is the scanning laser profilometer and the other is the white light interference microscope. While the depth resolution is of the order of nm, the lateral resolution is limited by the wavelength of the light and is limited to the μm range.

Recently, scanning electron microscopes (SEMs) have been used to image the topography of surfaces. SEMs have several advantage over optical microscopes. SEMs have a much high lateral resolution, 250 times more than optical microscopes. SEMs have direct magnification as high as 160,000X and photographic magnification is 1,000,000X compared to optical microscope which have a magnification less than 3000X [4]. SEMs have been widely

* Corresponding authors.
E-mail addresses: eomrani@uwm.edu (E. Omrani), pahlava2@uwm.edu (A.P. Tafti).

http://dx.doi.org/10.1016/j.triboint.2016.07.001
0301-679X/

adopted by researchers to generate detailed images of materials across a range of length scales to characterize the morphology of material samples and to determine the chemical composition, crystallographic orientations, and textures of the constituents [5]. However, the main draw back of SEM images is the fact that they do not provide any depth information.

There have been a few attempts made to convert gray scales from a single SEM image in different research areas. To reconstruct a 3D surface model from SEM images, several SEM images taken at different angles are required [6]. In this study we present a new method for 3D surface reconstruction using multiple view SEM images. This method is then applied to characterize topographical geometry of worn surface of a copper pin in different counterface. Subsequently, the surface roughness of pins is measured. In Section 2, we describe SEM imaging and 3D surface reconstruction, and roughness measurement method. Experimental validation of the method is presented in Section 3. We conclude the paper in Section 4 by summarizing our contribution and results.

2. Materials and methods

In this section, we begin by describing 2D SEM imaging and sample preparation used in this study. Next we describe our multi-view 3D surface reconstruction algorithm. The results of this algorithm are used to compute the surface roughness.

2.1. SEM imaging and sample preparation

The dry pin-on-disk test (ASTM G99) was employed to investigate tribological behavior at room temperature. During the wear test, a stationary pin was forced into a rotating disk. Samples as pins were cut from as-received copper C110, with a contact surface of the rounded, 6 mm diameter shape. The disks were of hardened 440C stainless steel (harder than copper pin), C110 copper and aluminum 2024 (softer than copper pin). The diameter of disks are 55 mm with 10 mm thickness. The surface of disk is polished to have very smooth surface. The applied load is 10 N and the sliding speed was kept 25 mm/s. The sliding distance was fixed to 1 km, allowing the system to reach a steady friction and wear process. For each disk, at least three repetitive tests were performed. Subsequently the worn surfaces were examined by scanning electron microscope in different angle (0, 8, 15, 24 and 35°). These images were used to reconstruct the 3D surface. SEM analysis was carried out on both etched and worn surfaces of specimens using a Hitachi S-4800 Ultra High Resolution Cold Cathode Field Emission Scanning Electron Microscope (FE-SEM) at 10 kV.

2.2. 3D SEM surface reconstruction

Methods: 3D surface reconstruction and visualization from a set of 2D images has been a longstanding research area in computer vision over the past decades and has led to a broad range of

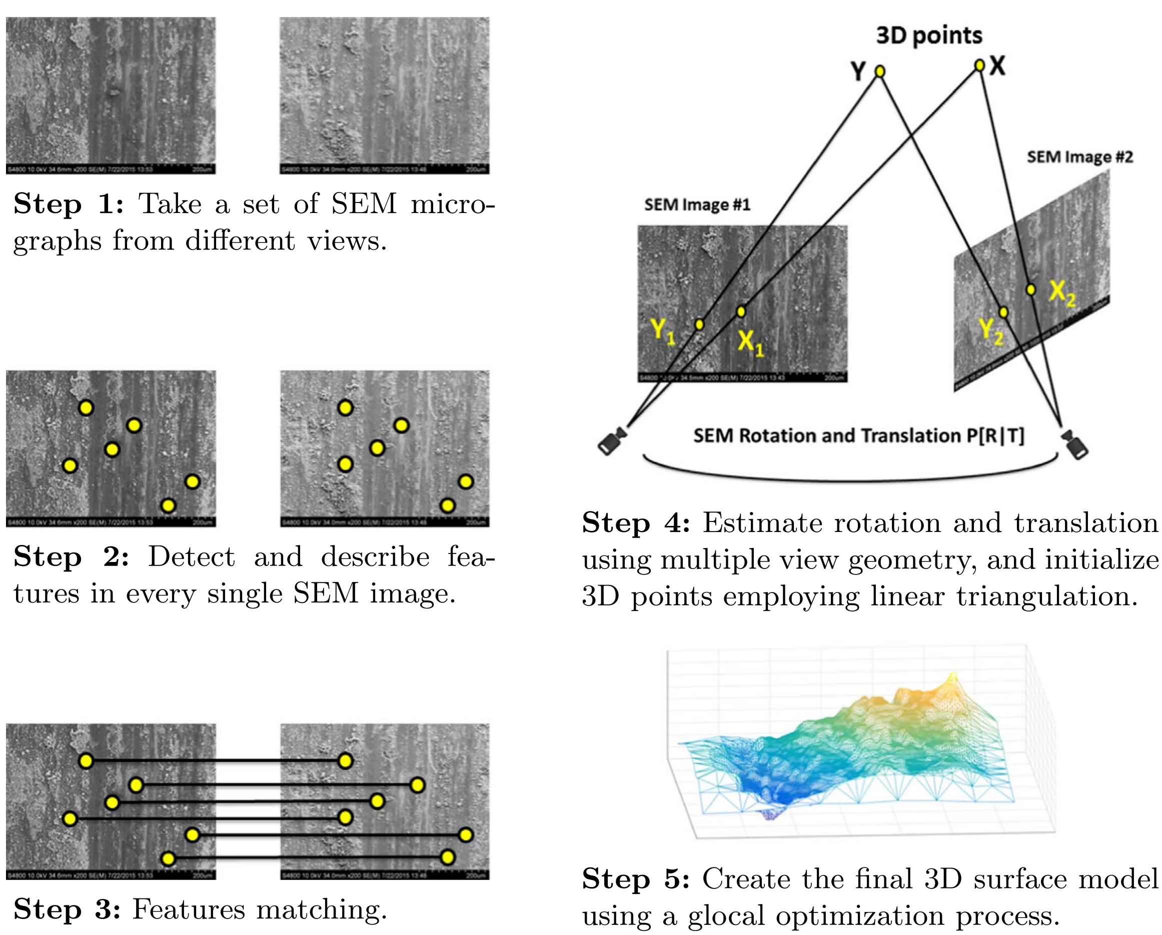

Fig. 1. The multi-view 3D SEM surface reconstruction approach. At first, multiple images of a microsurface are taken from different views. Then, we estimate the relative position including rotation and translation based on the matching points in the image set. After estimating the image motion, the 3D position of all matching points would be reconstructed using linear triangulation. The final step is doing a global optimization process to find the best fitness model for SEM's extrinsic parameters and all of the initial 3D points. (a) *Step* 1: Take a set of SEM micrographs from different views. (b) *Step* 2: Detect and describe features in every single SEM image. (c) *Step* 4: Features matching. (d) *Step* 4: Estimate rotation and translation using multiple view geometry, and initialize 3D points employing linear triangulation. (e) *Step* 5: Create the final 3D surface model using a glocal optimization process.