# 3D-Reconstruction of Microstructures on Cylinder Liners

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**Abstract**

Microstructuring of cylinder liners used in internal combustion engines is researched to reduce friction and thereby save fuel and increase engine longevity. To fully describe the effects of microstructuring on roughness and function of the surface, a 3D-acquisition, reconstruction and evaluation of the geometric features of the microstructures is necessary. We developed methods using optical white light sensors to reconstruct the 3D surface using subsequent measurements under varying surface to sensor angles. We improved fourier based image alignment techniques and applied them for the registration of partial images to form larger high resolution measurements which are then aligned with measurements using different surface to sensor angles. These data were used to form a 3D dataset of the microstructured surface including measured undercuts.

## 1 Introduction

Currently the microstructuring of cylinder liners used in internal combustion engines has come to the focus of a number of research groups. The effects of the microstructures need investigation to characterize the caused reduction of friction with the result of increased engine longevity and reduced fuel consumption [1,2]. To fully describe these microstructures a 3D-reconstruction and subsequent analysis is necessary, especially to find undercuts which cannot be detected using light microscope measurements without variation of the measurement angle. Other approaches for 3D reconstruction of microstructures describe methods for serial sectioning, scanning electron microscopy and micro stereo vision respectively [3-5].

## 2 Sensors and Measurement

Methods were developed to measure microstructured surfaces under varying sensor to surface angles using white light interferometry (WLI) for surface samples. Also a confocal chromatic sensor (CCS) which allows for measurements inside of cylinder liners due to application of a specially designed sensor head is used to acquire measurements under varying surface to sensor angles. For each angle either a number of high resolution measurements by WLI are stitched together or a large number of point measurements by CCS using a coordinate measuring machine (CMM) are fused with positioning data obtained from the CMM by interpolation to form a heightmap of the surface. In both cases the resulting measurements are repeated for different surface to sensor angles to acquire the necessary data to form a real 3D data set from 2.5D data.

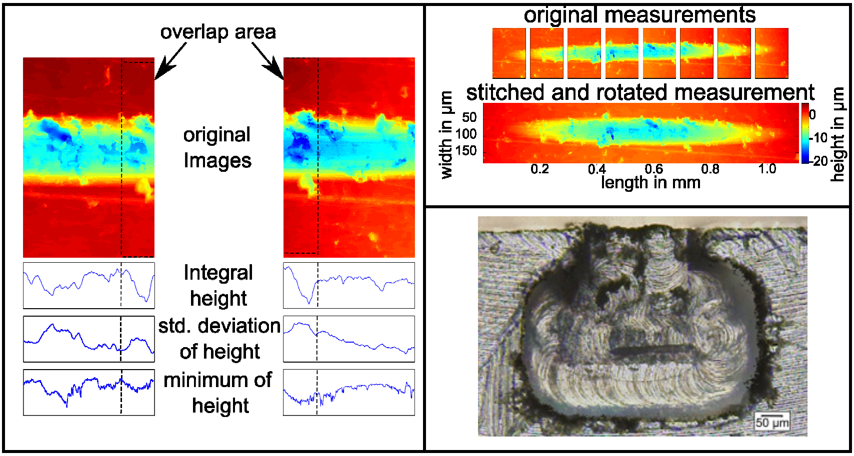


Figure 1: 1D-feature functions for overlap estimation (left), stitched microstructure (top right), profile image of undercut specimen (bottom right)

## 3 Image alignment using 1D feature functions

The measurement by WLI was performed using a numerical aperture of 0.55 and a measurement area of 0.25 by 0.19 mm². The length of the microstructures lies between 1.2 and 1.5 mm along the cross section, which made multiple measurements necessary to fuse them to form a single, high resolution measurement. New methods for image alignment were developed to decrease the needed overlap between the different measurements. Image alignment methods using correlation by fast fourier transform are well known for robustness against noise and for being computationally cheap compared to cross correlation [6], but require large overlap areas. We elaborated on ideas presented in [7] to use 1D functions based on integral height values along pixel columns. To achieve robustness against translational errors we also used other 1D functions based on the height values along the columns. We used the standard deviation, the maximum, the minimum and the median. As these functions are mathematically independent of one another we are able to gain additional accuracy in predicting the overlap area by correlating these five functions. The positional information is then used to restrict the areas of the input measurements for correlation by fast fourier transform (FFT). By this method we are able to decrease the necessary overlap for a successful alignment down to 7%.

## 4 Fusion of 2.5D data to full 3D data

To reconstruct the volumetric information of the microstructures the different measurements are converted to point clouds, which are rotated by a least squares algorithm, aligning the reference planes of the measurements. Because usual plane fits do not compensate for elongation of the measurement grid due to rotation, we use the transformed point clouds, which are interpolated to gain 2.5D data sets. The structures are segmented using histogram based methods to temporarily remove the structure. This is necessary as the data of the microstructures is dependent on the measurement angle while the reference plane is not affected by rotation. The planes with the micro structure edges are registered using the method described in section 3. Each point cloud is used to generate a binary 3D matrix in which '0'-voxels represent the object material. The 3D datasets are fused by application of a logical 'or'.

## 5 Application for undercut detection

Undercuts are detected by three different methods. First, the number of true voxels below the surface height, identified by histogram based methods, is counted for each image and compared to the fused version which gives an indication on the existence of undercuts as well as volume information, second, the true voxels below the segmented surface are counted and third, the positions of specific undercuts are detected by morphological 3D-thinning. This allows for a volumetric analysis of the microstructures, which benefits the characterization for oil retention capacity.

## 6 Conclusion

We developed methods by which steep slopes and undercuts can be detected by use of single optical sensors. To achieve this we developed new methods for image registration based on 1D-functions. We showed how undercuts can be evaluated in volumetric binary data.

## 7 Acknowledgement

This work was partially financed by the "Deutsche Forschungsgemeinschaft" as part of the project "Datenfusion optisch flächenhaft erfasster Mikrotopografien mit Bezugsebene" (Data fusion of optically measured micro topographies with plane of reference).

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