Highly improved measurement speed of white light interferometry

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White-light interferometry is a well established optical sensor principle for shape measurements. It provides high accuracy on a great variety of surface materials. However, the scanning time of common systems limits the field of applications. We present a novel solution to reduce the scanning time significantly.

1 Introduction

In this paper we present a novel method to reduce the measuring time of white-light interferometry using a standard setup. White-light interferometry is a well established sensor to measure industrial optically rough and smooth surfaces [1]. With a reduced scanning time this sensor principle will have another advantage over competing principles like mechanical probes.

Trying to increase the scanning speed we are facing two problems. Due to the integration effect of the camera the modulation of the interferogram is decreasing dramatically. In addition to that the Nyquist sampling theorem is violated and we have to deal with sub-sampled signals.

In recent years several developments have been made to overcome these problems. Most of them use a very short exposure time of the camera. However we are interested in measuring optically rough surfaces with often low reflectivity and want to keep the exposure time as high as possible, e.g. 20 ms using a 50 Hz camera. Other setups need a very precise sampling of the signal [2]. Due to the instability of mechanical linear positioning systems this precise sampling cannot be guaranteed and therefore our method must not be sensitive to variations in the sampling frequency.

2 High modulation at high scanning speeds

During the exposure of an image the linear positioning system is continuously moving. Therefore the optical path difference between reference arm and object arm of the interferometer varies. This leads to a decrease of the modulation of the interferogram at high scanning speed [3]. To avoid this averaging effect the optical path difference must be approximately constant during the exposure of an image.

Our basic idea is to introduce a motion to the reference mirror to compensate for the motion of the positioning system during the exposure of one frame. During this time interval the optical path length of both arms is changing in the same way and therefore the optical path difference remains constant. In the inter-frame-gap the reference mirror is switched back to its initial state. A schematic diagram of this movement can be seen in Fig.1. In our experiment we introduced this saw tooth movement by mounting the reference mirror on a piezo.

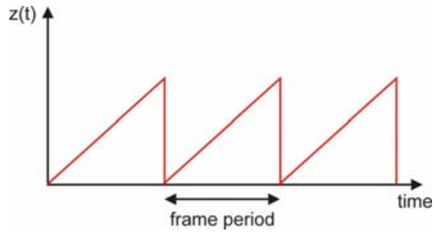

Fig. 1: *Schematic diagram of reference mirror movement*

The movement is synchronized with the frame rate of the camera. To test this setup we recorded the signals of 10.000 interferograms at several sample distances and calculated the mean modulation for each sample distance (see Fig. 2). The sample distance can be calculated by dividing the scanning speed by the frame rate of the camera. The object under test is a mirror.

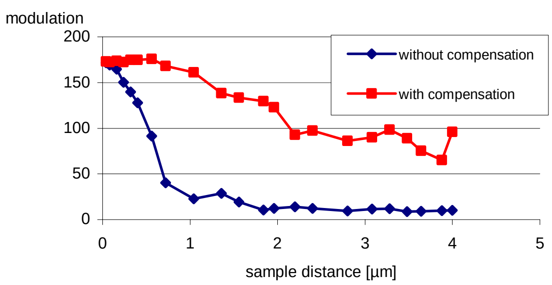

Fig. 2 *Modulation of interferograms at different sampling distances with and without compensating the integration effect*

The lower curve displays the integrating effect of the camera. The modulation is rapidly decreasing down to about 13 digits at high sampling distances, disappearing in the background noise. Using the compensation (upper curve) the modulation at small sample distances is the same compared to the standard setup. Still at higher scan velocities the modulation is just slightly decreasing. With this setup it is possible to increase the scanning speed by a factor of 8 maintaining the same modulation as with the standard setup.

3 Evaluating sub-sampled signals

Carrying out measurements with high sampling distances causes sub-sampling of the interferogram. To fulfill the Nyquist sampling theorem the maximal sampling distance for the light source we used is 160 nm. With the new setup sample distances up to 4 µm are possible. Established algorithms, e.g. Sliding Average or Single-Side-Band, do not provide the required accuracy at such high scan velocities. We present two approaches to evaluate sub-sampled signals in white-light interferometry.

The first approach is a center-of-mass algorithm. This is a very simple algorithm and enables very fast data processing. To improve the evaluation method the mean intensity is subtracted from the signal and the result is rectified.

The second approach uses the a-priori knowledge we have about the interferogram shape. To calculate the height information we apply a cross-correlation between the recorded interferogram and the known ideal interferogram. This method is more complex than the center of mass algorithm and needs more evaluation time.

4 Experimental results

With this combination of hardware add-on and evaluation methods we achieved in first experiments a measurement uncertainty of 230 nm on a mirror. The scanning speed was 100 µm/sec using a 25 Hz frame rate.

On optically rough surfaces we were able to increase the scanning speed up to 78 µm/sec without significant loss of accuracy.

In Fig. 3 we depict the comparison of two crossections of a measured coin. Measurement (**a**) was performed with a standard setup and a scanning speed of 4 µm/sec. Measurement (**b**) was done with the new setup and a scanning speed of 34 µm/sec. Both measurements display each detail on the coin surface. In measurement (**b**) only five outliers occur (i.e. single pixel with invalid evaluation result). The measurement uncertainty which is limited to the object roughness [4] is the same in both measurements.

4 Conclusion

The scanning speed of white-light interferometry can be increased by motion compensation and specialised evaluation methods. Applying a proper movement to the reference mirror yields high signal modulation even at high scanning speed. The signals recorded with this setup are evaluated with algorithms that can deal with sub-sampled signals. With this setup the scanning speed was increased by a factor of 10 for many types of object surfaces.

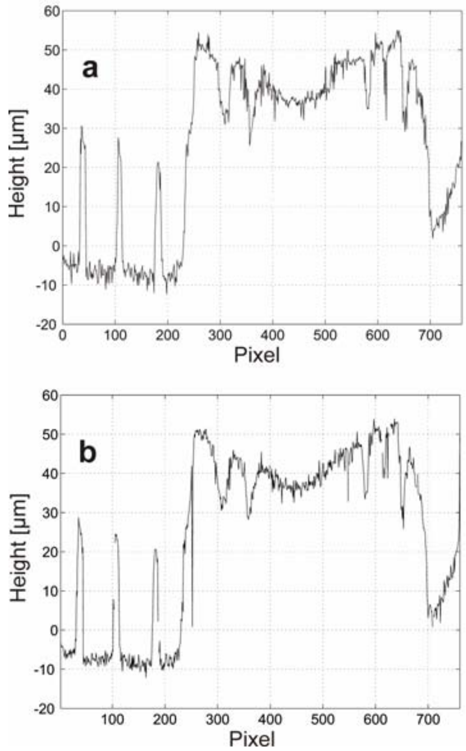

Fig. 3 *Crossection of a measurement (coin);* ***a****: Normal setup, scanning speed 4 µm/sec;* ***b****: New setup, scanning speed 34 µm/sec*

References

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