A new method to reduce the measuring uncertainty and the number of outliers in white-light interferometry

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We present a new method to reduce the measuring uncertainty and the number of outliers in white-light interferometry. We generate two or more statistically independent speckle patterns and evaluate these speckle patterns by assigning to brighter speckles more weight.

1 Introduction

In white-light interferometry on rough surfaces ("Coherence Radar") [1] the physically limited measuring uncertainty is determined by the random phase of the individual speckle interferograms. The statistical error in each measuring point depends on the brightness of the corresponding speckle; a dark speckle yields a more uncertain measurement than a bright one. If the brightness is below the noise threshold of the camera, the measurement fails completely and an outlier occurs. We present a new method to reduce the measuring uncertainty and the number of outliers.

2 Rough surfaces in white-light interferometry

Generally, we speak of a rough surface if height variations greater than $\lambda/4$ appear within the diffraction spot of the imaging system. Then, the interference fringes disappear and instead, a speckle pattern appears. Since the phase varies statistically from speckle to speckle it does not carry any useful information and one can only evaluate the envelope of the interference signal ("correlogram"). Since this resembles a time-of-flight measurement we called the method "coherence radar" [1]. Comparing the correlograms of different camera pixels, one can see two main features of the interference signal different from smooth surfaces:

- statistical displacement of the signal envelope ("physical measurement error")
- varying interference contrast

If we explore the reliability of one measured height value, we find [2,3] that the standard deviation of the height values $\sigma_z(I)$ depends on the surface roughness σ_h, the average intensity $<I>$ and the individual speckle intensity I:

$$\sigma_z(I) = \frac{1}{\sqrt{2}}\sqrt{\frac{<I>}{I}}\sigma_h \qquad (1)$$

The consequence of Eq. 1 is far reaching, because it reveals that every measured height value is associated with a physical measurement error. The darker the speckles are the bigger is this error. Hence, we are eager to create and select bright speckles.

If only the camera noise is reduced, for example by cooling the CCD-chip or by applying higher integration time, the repeatability would be increasd but according to Eq. 1, the measured height in a camera pixel is still unreliable. The consequences can be summarized as

- bright speckles generate more reliable measurements
- bright speckles avoid outliers

Therefore, in order to improve the quality of a measurement one has to look for bright speckles. A posteriori solutions such as filtering the measured image are not an appropriate approach.

3 Offering different speckle patterns to the system

Our new approach is to offer not only one but two (or more) decorrelated speckle patterns to the system. The combination displays a better statistics: For one speckle pattern the darkest speckles have the highest probability. However, if we may select the brightest speckle in each pixel, out of two (or more) independent speckle patterns, the most likely speckle intensity of the combined images is shifted to higher values and the probability to end up with a very dark speckle is small.

Decorrelated speckle patterns can be generated either by the use of different wavelengths [4] or by moving the light source. In this case the camera sees different speckle patterns. In our setup we synchronized the camera with the two laterally separated light sources: For odd frame numbers only light source "one" was radiating, whereas for the even frames only light source "two" was on. A separated signal evaluation for the correlograms recorded in odd and even camera frames is carried out. Subsequently, the SNR for both signals is estimated and that height value which displayed the better SNR is selected. The cost of this method is of course a reduction of the actual frame rate but according to Eq. 1 there is a significantly higher reliability of the measured profile.

4 Results

In an experimental verification two LEDs with a central wavelength of 840 nm are used as light sources. They are placed in front of a beam splitter. One of the LEDs is mounted on a micrometer slide to shift the sources against each other. The rough object under test is a diffuse surface and the signals are recorded by a standard 50 Hz camera. The LEDs are alternately switched on and off as described above. Subsequently, in 10.000 camera pixels the higher SNR value is estimated. For comparison with the standard setup, a second measurement is performed using only one LED. Again, in ten thousand camera pixels the SNR value is estimated. Figure 1 displays the SNR histogram of the two measurements. The improvement by the "choice of the brighter speckle" is significant: The maximum of the histogram is shifted towards higher SNR values (indicated in Fig. 1 by the arrow) and the amount of pixels with low SNR is significantly reduced. To quantify this, a series of measurements with different scanning speeds was performed and the share of pixels with a SNR not exceeding 4 was determined. A SNR value of at least 4 ensures a safe distinction from noise. The result is displayed in Figure 2. For all scanning speeds the share of low SNR camera pixels is smaller for two speckle patterns than for one.

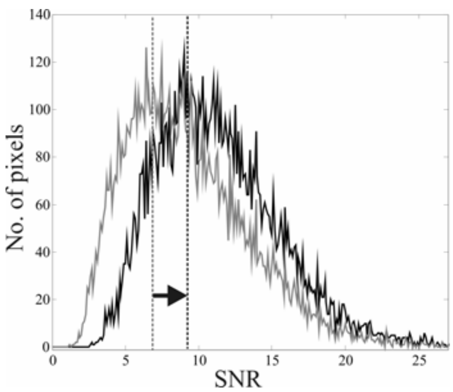

Fig. 1 *Histogram of ten thousand SNR values measured with both, one (grey) and two speckle patterns (black). The arrow shows the improvement of the SNR by the "choice of the brighter speckle"*

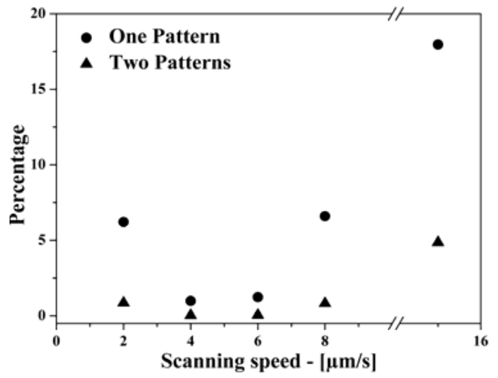

Fig. 2 *Percentage of camera pixels with a SNR < 4 for one and two speckle patterns.*

References

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