Modeling and simulation of a chromatic-confcal sensor to measure rough surfaces

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The measurement of rough surfaces is a still ongoing field of investigation. Here we present the modeling and simulation of a sensor to measure rough surfaces. The proposed new approach for the simulation model is based on a simple ray-trace simulation. With this model of a rough surface we are able to predict how a sensor will interact in a measurement of a technical surface.

1 Introduction

For the production of high precision products an accurate quality control is necessary. In order to avoid rejected products due to an incorrect manufactoring it is desirably to have a production monitoring system as close as possible to the production process. For a reliable monitoring it is necessary to use fast and robust sensor that have a minimal-invasive interaction between object and sensor. A solution for this is the use of optical sensors. With such sensors it is guaranteed that a non-contact measurement of the surface can be obtained. The robustness of the method can be achieved by avoiding a mechanical depth scan during the measurement. A solution for this is the principle of chromatic-confocal microscopy. But a known problem of such sensors is that speckling appears during the measurement of rough surfaces. For that reason we investigate how a chromatic confocal sensor responds to a rough surface. With the theoretical analysis of this phenomenon, it might be possible to decrease the measurement uncertainty due to speckling.

2 Sensor design

The chromatic confocal principle is based on the spectral splitting of a broadband lightsource [1]. That implies for each wavelength another focal point position. With a confocal discrimination of the light beam, the height position of the object can be resolved from the spectral intensity. Therewith we get a depth scan in one single measurement [2].

In the proposed design of a sensor for the investigation of speckling at rough surfaces we use a diffractive optical element (DOE) for the chromatic split of the broadband light source. As a lightsource we use a super luminescence diode (SLD). The specifications of the sensor are summarized in Tab. 1.

Bandwith SLD λ [nm]	800-860
Numerical Apertur	0.1
Depth measurement range [µm]	300
Spot size [µm]	10
Focal length DOE [mm]	24
Focal length lenses [mm]	18.5
Spectrometer resolution [nm]	0.05

Tab. 1 *Specification of the chromatic confocal sensor*

3 Building the simulation model

The simulation of the sensor was obtained in a non-sequential ray-tracer ASAP. The sensor model is shown in Fig 1. The DOE is used in this design for the collimation of the lightsource and in the same step it splits the broadband lightbeam into its spectrum to generate the wavelength depending distance of the focal point.

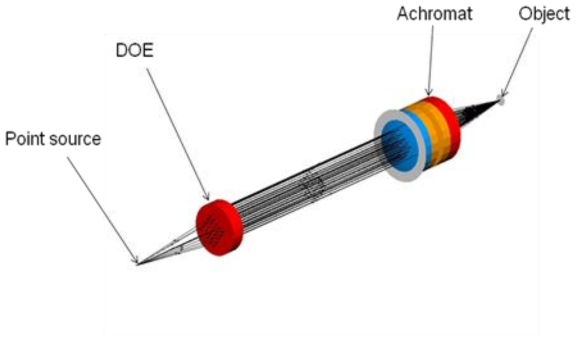

Fig 1 *Simulation Model*

The modeling of the surface is done in two steps. In the first step we generate the height difference between a peak and a valley modeled here by a set of steps or edges. With this modeling we generate the difference into the optical path length of the light that is responsible for the effect of interference on the detector.

The second part of our surface modeling is the implementation of a bidirectional reflectance distribution function (BRDF) to simulate the scattering at the rough surface. The BRDF is originally a set of measurement data that describes the reflectance distribution if a light ray hits the surface under a defined incidence angle. But it is also possible to calculate the BRDF data based on a reflectance model. In formula 1 such a model is stated that applies for rough surfaces. It was introduced by Torrance and Sparrow [4] and it was shown by Shen et. al. [3] that this reflectance model shows a suitable analogy to real measured data as shown in Fig 2.

$$f_r(\theta_i,\varphi_i,\theta_r,\varphi_r) = \frac{A}{\cos(\theta_i)} * \left[\frac{g\rho_{dh,s...}(\theta_d)G}{\cos\theta_r}\exp(-c^2\alpha^2)+\cos\theta_i\right] \qquad (1)$$

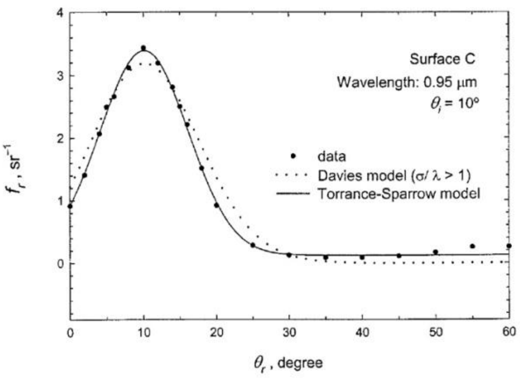

Fig 2 *Comparison of the Torrance-Sparrow reflectance model with measurement data [3]*

4 Simulaton results

First, to verify the model of the sensor we simulated a perfect reflecting surface and compared the result with a measurement of a mirror, obtained with a sensor similar to the design of the simulation model.

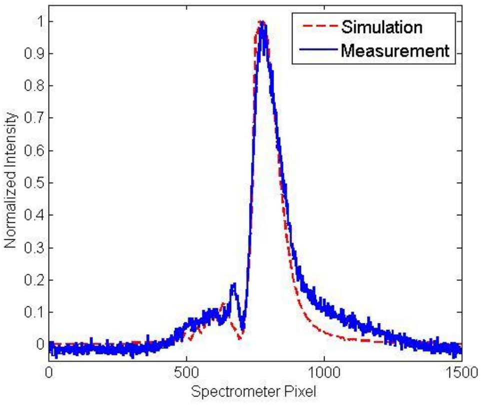

Fig. 3 *Simulation and Measurement of a mirror*

The results are shown in Fig. 3 and one can see a good correlation between the results of the simulation of a perfect reflecting surface and the measurement of a mirror. The remaining variation between the simulation and the measurement can be explained with aberrations that are not considered in the simulation model that are for example errors induced through contamination of the mirror or displacement of lenses in the experimental setup.

In the next step we obtained a measurement of a rough object and compared these results with the simulation of a rough object modeled according to the introduced model of a rough surface. The comparison of the simulation and measurement of the rough object are shown in Fig 4.

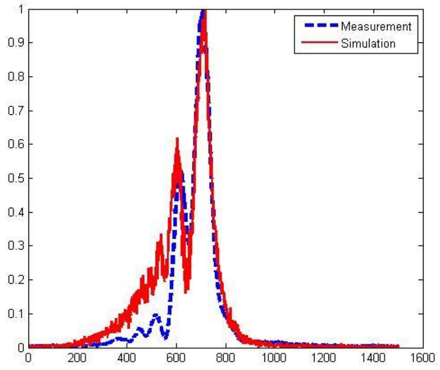

Fig 4 *Simulation and Measurement of a rough surface*

We got a good correlation between the simulation and the measurement data using the simple model of a rough surface presented here. The still remaining difference could be caused through the simplifications introduced through the simulation model. Though, to verify that, future investigations have to be focused on this aspect.

Literature

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