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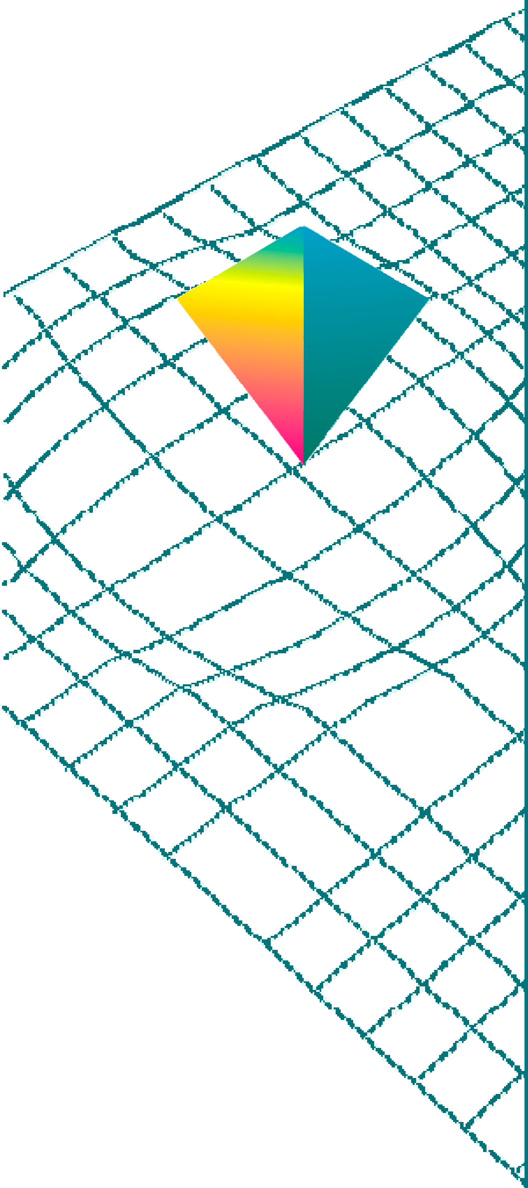

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50. Internationales Wissenschaftliches Kolloquium
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Chromatic confocal sensors for micro-topography measurements

ABSTRACT

Confocal microscopy is a widespread method to measure volume structures or surface topographies. It has a growing impact on the measurement of technical and biological micro-structures. In comparison to confocal laser scanners, a chromatic confocal setup achieves a complete parallelization of the z-scan by using white-light and chromatic effects of the focusing lenses. Therefore, no mechanical depth scan is necessary. We present applications of this principle to different sensors. This includes a miniaturized point-, a line- and an area-sensor.

INTRODUCTION

Specifications and tolerances of microstructures are of growing interest for technical surfaces. Therefore, robust measurement systems are needed, that are optimized for the special application. E.g. components with a complex geometry such as small drilling holes or channels are difficult to access. Such objects can be measured with a miniaturized point sensor. Other applications as the measurement of welding seams around cylindrical objects can be done faster with a line sensor. The lateral movement or rotation of the object can be used to scan a complete surface. The advantage of the chromatic confocal measurement principle is, that the measurement of a complete height section can be done in parallel by using white-light illumination and a spectroscopic detection. The highest degree of parallelization is achieved with an area measuring chromatic confocal microscope. Such a setup is capable of single-shot measurements of complete surfaces.

Confocal and chromatic confocal principle

In confocal distance measurement, a point light source is imaged onto the object while the latter is imaged onto a point detector [1]. Figure 1 illustrates the optical system of a reflection confocal point sensor. If the object lies in the focal distance, the images of both, the point source on the object and that of the object on the point detector are sharp and a high intensity is measured by the point detector. If the object is out of the focal plane, both images are defocused and only a small part of the light is detected.

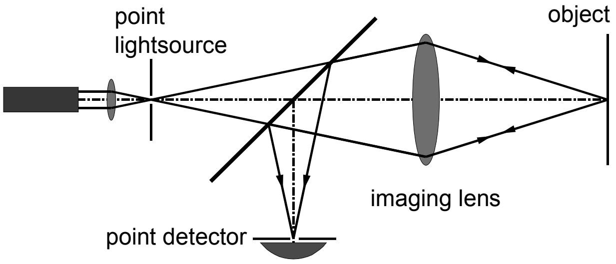

Fig 1: Confocal principle.

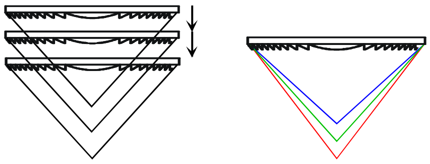

Fig 2: Mechanical and chromatic depth scanning.

Moving the object or the focus in axial direction results in an intensity curve which depends on the wavelength and the numerical aperture of the front lens. It has been shown that this axial response can be expressed as [2][3]:

$$I(z)=\left[\frac{\sin\left(\frac{u}{2}\right)}{\frac{u}{2}}\right]^2 , \quad with \quad u=\frac{2\pi}{\lambda}NA^2 z \qquad . \tag{1}$$

Here λ is the wavelength, NA is the numerical aperture of the focusing lens and z is the defocus. The full width at half maximum (FWHM) of the intensity signal is

$$FWHM=\frac{0.443\lambda}{1-\cos(\alpha)} \quad , \tag{2}$$

where sin(α) is the numerical aperture.

Using chromatic effects of the imaging lens, it is possibility to avoid this depth scan. This is accomplished by a design of the optical system which focuses the light in different focal distances depending on the wavelength. The light is detected with a spectrometer and the measured intensity curve is now spectrally coded [4]. In Figure 3 the intensity signals of a monochromatic confocal system with mechanical depth scan and a polychromatic confocal system with chromatic depth scan is illustrated. With an a priori knowledge of the wavelength dependent focal distances, the spectral intensity distribution can be translated to height information.

Fig. 3: Confocal intensity signal a) with mechanical depth scanning and b) with chromatic depth scanning.

One possibility of such a chromatic confocal configuration is realized utilyzing a varying illumination wavelength, where only a small spectral width is used at a time. Hereby the mechanical depth scan is substituted by a wavelength scan. An alternative configuration is to use a spectrally broad light source and a spectrometer as a detector. The depth scan is then completely parallelized.

Miniaturized chromatic confocal point sensor

A chromatic confocal point sensor has a high miniaturization potential because no mechanical elements are needed to perform the measurement at one point of the object. We realized a chromatic confocal point sensor with an outer diameter under two millimeter [5]. Since a 90°-redirection is included, this sensor is capable to measure the surface of drilling holes of two millimeter diameter. A convenient way of separating the sensor head from the illumination module and the detection module is by use of an optical fiber [6][7]. This allows us to reduce the sensor head to the optical fibre and some micro-optics. We choosed a combination of a half-ball lens and a diffractive lens. The optical setup is illustrated in figure 4. A backsite reflection-coating on flat surface of the half ball lens is used as redirection mirror. The diffractive lens is integrated in the carrier-substrate, which is needed for the mountings of the optical fibre and the half-ball lens.

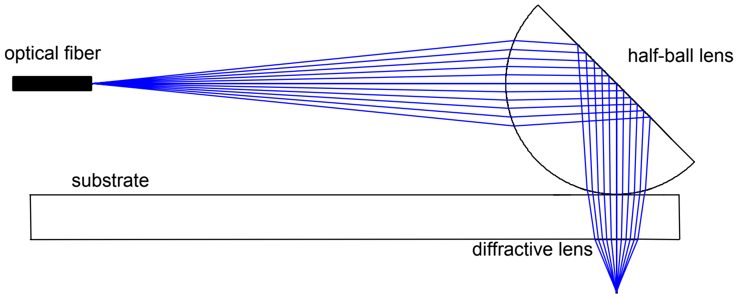

Fig.4: Illustration of the setup of the chromatic confocal point sensor.

A white-light source with wavelength range from 400 nm to 550 nm is used for illumination. Within this spectrum, the sensor has a measurement range of 30 µm, a numerical aperture of 0.4 and sub-µm height-resolution. Examples of the spectrally coded confocal signals are plotted in figure 5.

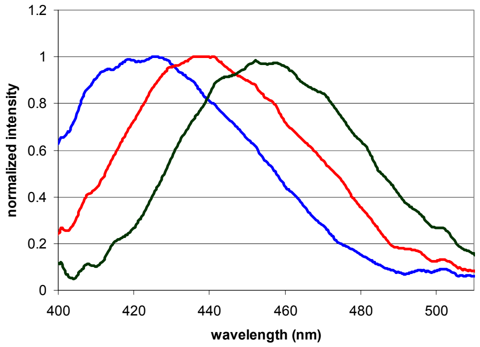

Fig.5: Three spectrally coded confocal signals from the miniaturzed chromatic confocal point sensor.

Chromatic confocal line sensor

The chromatic confocal line sensor enables us to measure the topography along a line in a single shot [8]. The setup is illustrated in figure 6.

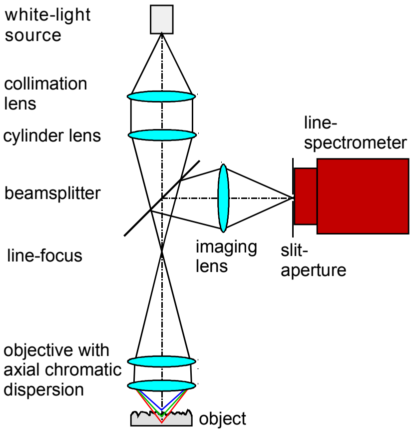

Fig 6: Chromatic confocal line sensor.

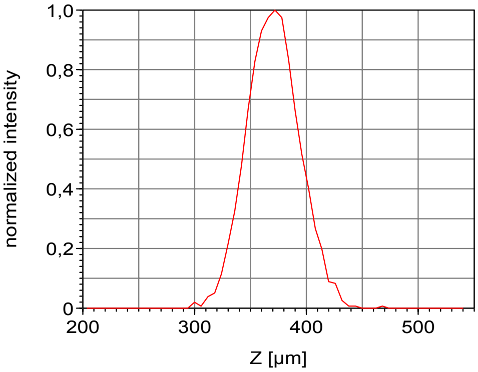

Fig. 7: Confocal depth response.

Polychromatic light from a xenon arc lamp is coupled into a multimode fiber. The light from this fiber is then collimated and focused by a cylinder lens to form a line focus, which is imaged onto the object. The imaging optic consists of refractive achromatic lens systems and a diffractive lens to realize the chromatic focus lenght variaton while maintaining telecentricity. The reflected light is imaged via the beam splitter onto a slit aperture. This slit aperture is the confocal aperture, which blocks the defocused light and stray light. At the same time it is the entrance slit of a spectrometer. In contrast to the point sensor, the lateral information of the object is retained. Therefore, we used a line spectrometer, which is able to maintain the lateral resolution. The achieved chromatic depth measurement range was 0.7 mm for a spectral range from 450 nm to 700 nm and a field-diameter of

2.4 mm. A slit aperture as a depth discriminating element matches the line focus of the cylinder lens but blocks the defocused light only in the direction perpendicular to the slit. The depth discrimination property is therefore less than that of a pinhole. The confocal depth signal is plotted in figure 7 and had a FWHM of 55 µm.

Chromatic confocal area sensor

The highest degree of parallelization is achieved with the area-measuring chromatic confocal microscope. To get the spectral information of each pixel in the image, the illumination wavelength can be varied [10][11] or a color camera can be used as an area-spectrometer while illuminating with white-light [12][8]. This latter setup is capable of single-shot measurements of a complete surface, which enables on-the-fly topography measurements. The setup is illustrated in figure 8.

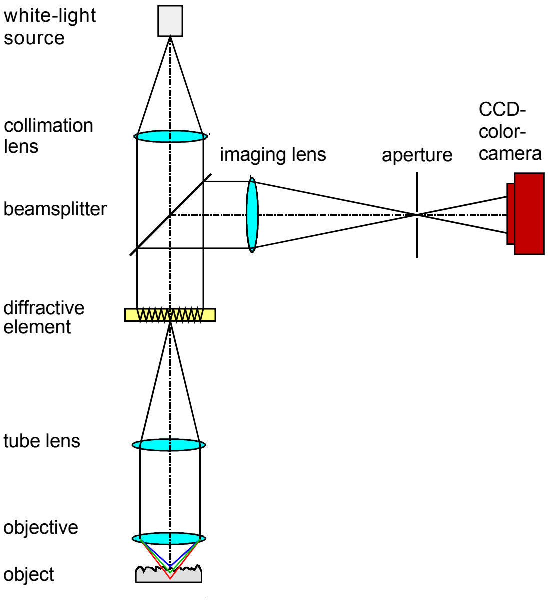

Fig.8: Chromatic confocal area sensor

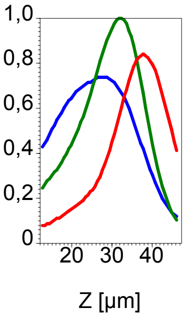

Fig. 9: Normalized reference curves.

The white-light is collimated and illuminates a rotating microlens nipkow-disc [12]. The foci of the microlenses are imaged onto the object. Again the foci are imaged into different distances depending on the wavelength. The microlenses act as laterally distributed point sensors, which work in parallel. With the rotation of the disc, the field of view is scanned with high resolution. Each microlens recollimates the light reflected by the object. The microlenses in the field of view are imaged on a CCD-color camera. The depth discriminating aperture in this setup is a single pinhole, located in the focus of the imaging optics [10][13].

The spectral information in each pixel is represented by the three RGB-values. The reference curves for the three channels are shown in Fig 7. Each color in the image corresponds to a certain height.

Therefore, only a single image is needed to measure the topography of a complete area. In our setup a depth measurement range of app. 20 µm at a field of app. 700 µm times 800 µm was realized.

Summary

The concept of chromatic confocal topography-measurements reduces the number of mechanical elements needed in the measurement setup. This can be used to minaturize the sensor or to parallelize the measurement to shorten the measurement-time. Three different chromatic confocal sensors for different measurment-tasks are presented: A miniaturized point sensor, a line sensor and an area measuring sensor. Setup and specifications of the sensors are presented.

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