Deflectometry Rivals Interferometry

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Interferometry can measure the distance of atomic layers and the distance of stars. This remarkable dynamic range of more than 24 orders of magnitude contrasts with its weakness to measure strongly aspheric surfaces or deep surface steps.

To overcome the difficulties of aspheric surface measurement is one motivation of the paper. Surprisingly, we found a solution for this problem by asking a completely different question: "how much may an optical 3d-sensor cost?"

To answer the latter question it is appropriate to consider an optical sensor as a communication system [1]. A canonical communication system has an information source, a source encoder, a channel, a decoder and a sink. The identification of the sensor components to the components of the canonic system is crucial. Channel capacity (amount of information that can be transmitted through the channel) is expensive. We can define an "information efficiency" of an optical sensor: the more raw data we have to acquire, for the shape of the object, the lower is the efficiency and the more costs the sensor.

The efficiency is quite different: for stereo vision ~ 1%, for fringe projection ~ 12%, for white light interferometry ~ .1%, for shape-from-shading ~ 50%. The reason is that different sensor principles include more or less source encoding. What is the source encoder in our optical sensors? It is the illumination system!

What should the illumination system do, for efficient sensing? In practice, all objects are highly correlated, their power spectrum drops with 1/f (f=spatial frequency) – they display much redundancy. A proper source encoder should equalize the object power spectrum. A nice approximation to do this is optical differentiation, so we need an optically differentiating optical sensor: For diffusely scattering objects "shape-from-shading" is the proper principle. For smooth objects it is shearing interferometry, Nomarski differential interference contrast, or "deflectometry" [2].

Estimating these systems we find that deflectometry reveals some remarkable features – making it a rival of interferometry: It intrinsically measures the local slope of the surface. So the acquisition of the local refractive power does not require a (noise-prone) second order derivation. The slope may range from -60° to +60° or more. The sensitivity against small slope variations ranges down to less than 1/100 arc sec. The high sensitivity against local “defects” is remarkable. We can resolve a few nanometers depth variation over only 1 mm lateral distance, working at Heisenberg’s limit. The object may have several meters size (car wind shields). The total shape accuracy is limited by the calibration accuracy and by the numerical integration procedure. We could achieve an accuracy of a few micrometers over 100 mm object size.

Eventually, I will mention one last advantage, which makes deflectometry robust against environmental perturbation: it is not based on interferometry.

1. Christoph Wagner and Gerd Häusler, Appl. Opt. 42, 5418-5426 (2003)
2. Markus Knauer, Jürgen Kaminski and Gerd Häusler, Proc. of the SPIE 5457, 366-376, (2004)