Fast method to measure optical cooperativity

Omar Abo-Namous*, Jörg Seewig**, Markus Kästner*, Eduard Reithmeier*
**Institute of Measurement and Automatic Control, Leibniz University Hannover*
***Institute for Measurement and Sensor-Technology, Technical University Kaiserslautern*
mailto:omar.abo-namous@imr.uni-hannover.de

The term 'optical cooperativity' describes the fact that surfaces can differ in their ability to being measured using optical instruments (Prof. Dr. Wolfgang Osten). There are many possible causes for optical incooperability depending on which optical measurement equipment is used.
This paper describes different causes for optical incooperativity ranging from discontinuities in the object surface over surface gradient up to material properties that impede optical measurement.
The main focus points of this paper are the causes for surface material unsuitability for optical measurement using fringe projection, which are the gloss and volume reflectance. In this paper we describe a way to characterize gloss and its impact on optical measurement. A quick and easy method is proposed to measure material gloss qualitatively without utilizing complex gonioreflectometric instruments.

1 Introduction

Optical measurement systems supply a state of the art geometry measurement with regard to speed and flexibility. They are non-intrusive and can measure whole areas in one sweep rather than distinct lines and their precision is approaching that of tactile measurement systems. They are therefore in most cases very well suited for measurements in industrial framework conditions, but they tend to have special needs for the geometry surface.

The measurement principles vary between the methods of triangulation, interferometry and edge detection as well as image processing. Each one has its own requirements of surface reflectivity and permeability plus geometry slopes and discontinuities. These requirements are especially important, when construing or simulating a measurement sequence.

2 Parameters of optical cooperativity

Optical measuring circuits typically consist of a light source, the device under test and the light sensor. All three have distinct parameters that have to be chosen with care, such that the measurement is effective. Figure 1 represents the general layout of an optical measuring circuit.

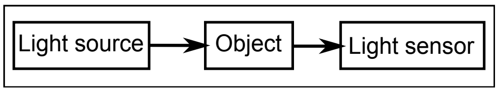

Fig. 1 *General layout of optical measurement systems*

The light source sends light of a specific wave length band and intensity onto the surface of the test object. Both can be structured homogeneously or otherwise. The light may be coherent or polarized and its many attributes may vary in time. The attributes of the light sensors are nearly equivalent to those of the light source.

3 Test object attributes

Special care should be taken with characterizing the test object attributes. Two major fields that can be identified are the object material and the surface topology.

For most optical measurements, one assumes that only the object surface interacts with the incoming light. Some methods require a continuous surface with a topology which does not jump in depth (e.g. white light interferometer). Other methods cannot measure concave elements (e.g. shadow projection), others again cannot measure surfaces with a steep slope. However, most methods assume, that the light is being directly reflected off of the surface of the object.

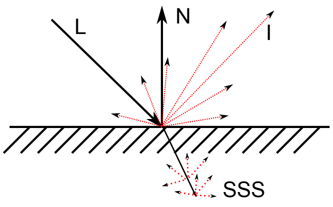

Fig. 2 *Surface and subsurface scattering*

But if the immediate surface is translucent to the specific wavelength, the measured light at the sensor might come from beneath the surface. This effect is called sub-surface-scattering (SSS, see Figure 2). For example measuring organic surfaces like human skin or leafs requires special precaution like narrowing the focus region. Another solution using polarized light has been suggested in [1].

The amount of light that arrives at the sensor lens depends mainly on the scattering attributes of the object surface and the relationship between geometry normal (N), incident light (L) and camera vector (I). If the material structure scatters the incoming light too much, the intensity of the incident light might not be sufficient to measure the surface.

4 Fringe projection with gloss

Fringe projection relies on measuring contrasts between dark and light fringes reflected on a test surface. Gloss effects on the surface can interfere with this contrast and by over- and underexposing the light sensor the system fails to produce an effective result [2]. Fringe projection measurements of glossy and round objects exhibit angle dependent bad spots mainly because the sensor only works properly in the region of modest light intensity around the light peak cone.

To evaluate the qualification of any given surface for being measured using fringe projection we quantify the surface's bidirectional reflectance distribution function (brdf).

5 Gloss measurement

Measuring the complete brdf of a surface requires a gonioreflectometer, which is able to measure incident light intensity at various incidences and incoming light angles in space. The brdf can have many more variables, but mostly it depends only on the four light angles:

$$brdf = f(\delta, \epsilon, \varphi, \gamma)$$

δ, ϵ: space angles of the incoming light (L)
φ, γ: space angles of the outgoing light (I).

Examples of working gonioreflectometers can be found in [3], [4] and [5].

For gloss measuring, only a limited angle band of the brdf is needed and except for anisotropic effects only a two dimensional brdf around the main light cone is required. The function is therefore simplified to

$$brdf = f(\delta, \varphi)$$

We chose a cylindrical object, which is positioned beneath a camera and is illuminated by a light source from a distinct position. This way the principal layout of a triangulation based system as in Figure 3a is reconstructed. Figure 4a shows a typical camera image of that setup. The light intensities over the cylinder can be used to identify the 2d-brdf and thereby estimate the gloss effect of the surface.

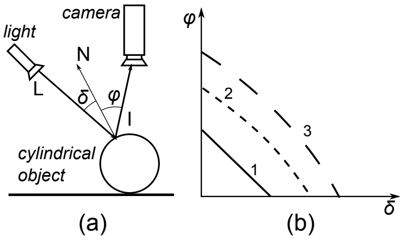

Fig. 3 *(a) Measurement layout, (b) Measurement profiles*

Each camera pixel corresponds to a point on the cylinder, which has a surface normal (N) and a corresponding incidence angle (δ) and an angle for the outgoing light (φ). Curve (1) in Figure 3b displays the resulting angles for one measurement. To measure along other δ,φ-curves ((2),(3)..), the geometry of the setup has to be changed (e.g. camera position, light position).

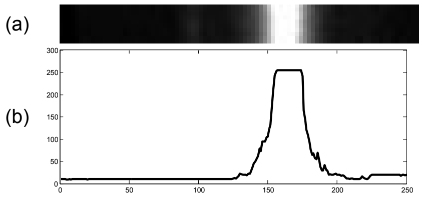

Fig. 4 *(a) Camera image, (b) Intensity profile*

6 Conclusion

Different aspects of optical cooperativity have been shown with a focus on fringe projection. Using a simple measurement layout, it was possible to quickly measure the gloss aspect of cylindrical objects and relate the results to common brdf results.

References

[1] T. Chen, H. Lensch, C. Fuchs, and H.-P. Seidel, "Polarization and Phase-Shifting for 3D Scanning of Translucent Objects," Computer Vision and Pattern Recognition. CVPR '07. IEEE Conference on pp. 1–8 (2007).

[2] D. Hüser, "Entwicklung von Methoden zur Bestimmung der Messunsicherheit von Triangulationssensoren in der KoordinatenmeSStechnik," Dissertation, Physikalisch Technische Bundesanstalt (1995).

[3] H. Li, S. C. Foo, K. E. Torrance, and S. H. Westin, "Automated three-axis gonioreflectometer for computer graphics," Optical Engineering **45**(4) (2006).

[4] D. Hünerhoff, U. Grusemann, and A. Höpe, "New robot-based gonioreflectometer for measuring spectral diffuse reflection," Metrologia **43**(2), S11–S16 (2006).

[5] H. Li, S. C. Foo, K. E. Torrance, and S. H. Westin, "A Gonioreflectometer For Measuring The Bidirectional Reflectance Of Material For Use In Illumination Computation," (1997).