Thickness Measurement of Transparent Coatings Based on Polarization Effects at Dielectric Surfaces

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Summary

By utilizing the polarization effect of reflection at the brewster angle the presented setup can eliminate troublesome reflections from transparent surface layers, or measure the layers thickness. For this a polarization sensitive camera is built and incorporated into a laser triangulation setup.

Introduction

When unpolarized light hits an optical interface between two media with different refractive indices at an angle, the reflected light can change its polarization. This effect is most prominent at the brewster angle, where only perfectly polarized light is reflected. In this publication the change in polarization is used to visually separate optical interfaces from one another and measure the thickness of transparent layers using triangulation methods.

Theoretical Considerations

Triangulation based measurement systems utilize an assembly of light source and detector, fixed at a certain angle to one another to reconstruct 3D points from observation of light reflections. By projecting a laser line onto an object and recording the reflected light from that line with a camera, two light rays can be calculated to reconstruct 3D shapes. If the object (or substrate) is coated with a protective film, multi reflection on the surface may occur. This makes the 3D reconstruction more difficult since it is no longer clear how the light ray from the camera should be reconstructed.

By using unpolarized light (e.g. a line laser) and setting the angle of incidence on the object ε_0 to the brewster angle, the reflected ray from the coating material is linearly polarized [1]. This allows the use of polarizing filters to block the reflection from the top of the transparent coating material and leaves only the diffuse reflection from the substrate material, allowing easy ray reconstruction for the substrate. A schematic view of the beam path for a coated sample is shown in Fig. 1.

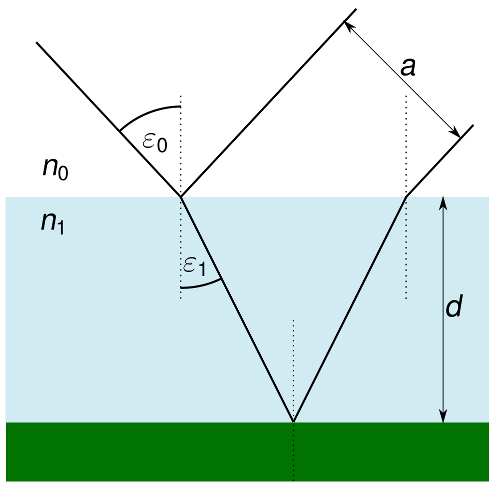

Fig 1. Schematic view of the beam path during reflection and refraction at the interface

Additionally the surface of the coating material can be reconstructed with the same experimental setup. By recording two images, one with a filter position allowing the polarized light ray from the coating material to pass onto the camera sensor, and one blocking said ray, both surfaces can be determined. Since the reflected ray from the substrate is unpolarized, it is visible in both images.

First the surface of the substrate is determined from the image where the polarized ray is blocked. Here a single laser line is visible, making the 3D reconstruction easy. Since this same line is also visible in the other image where the polarized ray is not blocked, it can be eliminated with simple computer vision procedures. This leaves only the polarized ray from the top of the coating material, again allowing for easy triangulation.

With both laser lines reconstructed the line distance a (see Fig. 1) can be measured. From this and the known angle of incidence ε_0 it is possible to calculate the thickness d of the coating as

$$d = \frac{a}{2 \cdot \tan(\varepsilon_1) \cdot \cos(\varepsilon_0)}. \tag{1}$$

The internal angle ε_1 can be calculated from snell's law.

Experimental Setup

To allow easy filtering of the polarized ray a camera system with controllable polarizing filter is build (see Fig. 2). For this the polarizing filter is mounted inside a bearing and attached to stepper motor via toothed belt. This gives fine control over the angle of the polarizing filter, and therefore the polarization direction that is being filtered.

With this camera system a laser triangulation setup is implemented. Since the angle of incidence of the laser line on the measurement object has to be close to the brewster angle (in this experiment $\approx 43^\circ$) the resulting setup has a very large triangulation angle of approximately twice the brewster angle.

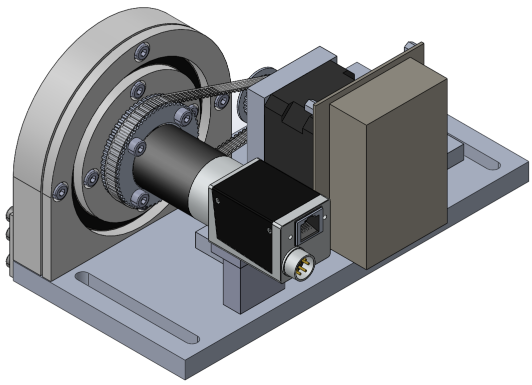

Fig 2. Render of the used camera system with controllable polarizing filter

Results

As test objects for the described measurement procedure acrylic glass plates of varying thickness from 1.7 mm to 2.9 mm, and a soda lime glass plate of 1 mm were used to simulate the coating material. These plates were clamped onto a diffuse reflecting substrate plate, keeping the air gap between the two to a minimum. The refractive index of the acrylic plates and the glass plate were taken from literature values and their corresponding thicknesses measured with the help of calipers to get a rough estimate of the expected values.

The reconstructed thickness values from the presented experimental setup were within 6 % of the expected values.

Conclusions

This publications shows a simple way to utilize the effect of polarization of reflected light in laser triangulation. With the help of a controllable polarization filter it is possible to either eliminate troublesome reflections from transparent materials or utilize it to measure the thickness of transparent layers.

References

[1] F. A. Jenkins, and H. E. White, *Fundamentals of Optics, 4th Edition*, (McGraw-Hill, 1976)