

A POLARIMETRIC APPROACH TO SHAPE UNDERSTANDING OF GLOSSY OBJECTS

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A polarimetric method is proposed to find surface normals, which will help the 3-D shape understanding of glossy objects. Attention is directed to the fact that glossy objects are characterized by conspicuous specular reflection, which has a certain polarizational property as a function of the incident angle and the refractive index of the material. The relation is formulated between the local normal and the polarizational parameters. The Stokes parameters are used to express the state of polarization. As to several materials preliminary measurements are done to examine for utility of polarizational information to finding local normals. The proposed method will be effective in extracting geometrical parameters from glossy objects whose gloss occurs on dielectric surfaces such as plastics, lacquered items, polished paper and so on.

1. INTRODUCTION

We propose a polarimetric method of obtaining surface normals, which will help the 3-D shape understanding of glossy objects.

Horn[1] has obtained shapes from shading information. Glossy surfaces, however, have little shading information, since they dominantly reflect specular rays.

The specular ray has a certain polarizational characteristic as a function of the incident angle and the refractive index of the surface material.

We examine for utility of polarizational information to finding local normals.

2. POLARIZATIONAL RELATION

In Fig.1, $\mathbf{i}$ and $\mathbf{s}$ are rays of incidence and reflection upon a plane Σ , respectively, and $\mathbf{n}$ is the normal. Ω is the frame to which the Stokes parameters[2] are referred, and ξ' is the reference direction. $\mathbf{g}$ implies the intersection of the frame and the plane of incidence.

The polarization state of the ray $\mathbf{s}$ contains information about the angles ψ and α , which will provide a clue for finding the normal $\mathbf{n}$.

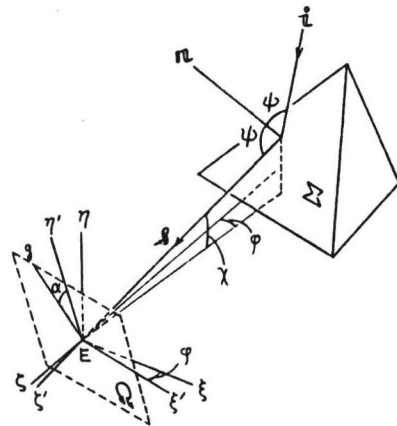


Fig.1 Observation system

We regard the specular plane as a partial polarizer with retardance, and use a right circular ray as an input. Then, the Stokes vector $*$ of the reflected ray will be derived by the Mueller calculus as follows;

* a 4×1 column vector whose elements are the four Stokes parameters

$$\begin{pmatrix} I \\ L \\ X \\ 0 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & C_{2\alpha} & S_{2\alpha} & 0 \\ 0 & S_{2\alpha} & C_{2\alpha} & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} \frac{1}{2}(r_{\perp}^2 + r_{\parallel}^2) & \frac{1}{2}(r_{\perp}^2 - r_{\parallel}^2) & 0 & 0 \\ \frac{1}{2}(r_{\perp}^2 - r_{\parallel}^2) & \frac{1}{2}(r_{\perp}^2 + r_{\parallel}^2) & 0 & 0 \\ 0 & 0 & r_{\perp} r_{\parallel} & 0 \\ 0 & 0 & 0 & r_{\perp} r_{\parallel} \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & C_{\delta} & S_{\delta} \\ 0 & 0 & -S_{\delta} & C_{\delta} \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & C_{2\alpha} & S_{2\alpha} & 0 \\ 0 & S_{2\alpha} & C_{2\alpha} & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} I_c \\ 0 \\ 0 \\ I_c \end{pmatrix} = \frac{1}{2}(r_{\perp}^2 + r_{\parallel}^2) I_c \begin{pmatrix} 1 \\ P C_{2\alpha} - V S_{2\alpha} \\ P S_{2\alpha} + V C_{2\alpha} \\ U \end{pmatrix}$$

↑ output
↑ partial polarizer
↑ retarder
↑ right circular input

rotation from reference direction

where $r_{\perp}, r_{\parallel}$ the amplitude reflection coefficients of components vibrating perpendicular to and parallel to the plane of incidence

δ the phase difference between both components

$C_{\theta}, S_{\theta} \cos \theta, \sin \theta$

I_c the intensity of the light source
 $P = (r_{\perp}^2 - r_{\parallel}^2) / (r_{\perp}^2 + r_{\parallel}^2)$, $U = 2r_{\perp} r_{\parallel} C_{\delta} / (r_{\perp}^2 + r_{\parallel}^2)$, $V = 2r_{\perp} r_{\parallel} S_{\delta} / (r_{\perp}^2 + r_{\parallel}^2)$

On actual surfaces somewhat occurs depolarization. Therefore the next expression will be practical:

$$\begin{pmatrix} I \\ L \\ X \\ 0 \end{pmatrix} = I_d \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix} + I_p \begin{pmatrix} 1 \\ P C_{2\alpha} - V S_{2\alpha} \\ P S_{2\alpha} + V C_{2\alpha} \\ U \end{pmatrix} \quad (1)$$

where I_d and I_p are the intensities of depolarized and polarized components, respectively.

3. MEASUREMENT OF THE STOKES PARAMETERS

We use a simplified "rotating-compensator/fixed-analyzer ellipsometer configuration" [3], which can eliminate the polarization effect of the detector.

The intensity transmitted by this configuration is proportional to

$$I + \cos^2 2\beta L + \cos 2\beta \sin 2\beta X - \sin 2\beta O,$$

where β is an azimuth of the quarter-wave plate, with the analyzer kept at C .

Using its values I_m sampled at $\beta = 22.5^\circ \cdot m$ ($m=0,1,\dots,7$), we find

$$\begin{pmatrix} I \\ L \\ X \\ 0 \end{pmatrix} = \begin{pmatrix} I_0 & I_2 & +I_6 \\ I_0 & -I_2 & +I_6 \\ I_1 & -I_3 & +I_5 \\ I_0 & -I_2 & +I_6 \end{pmatrix} \quad (2)$$

4. SEQUENCE TO FIND THE LOCAL NORMAL

1. Calculate I_p as $\sqrt{L^2 + X^2 + O^2}$.

If I_p is too small, reliable values cannot be obtained at that point. Otherwise,

2. Normalize (1) as

$$\begin{pmatrix} a \\ l \\ x \\ o \end{pmatrix} \equiv \begin{pmatrix} I/I_p \\ L/I_p \\ X/I_p \\ O/I_p \end{pmatrix} = \begin{pmatrix} I_d/I_p + 1 \\ P \cos 2\alpha - V \sin 2\alpha \\ P \sin 2\alpha + V \cos 2\alpha \\ U \end{pmatrix}$$

3. Find ψ to fill $o=U$.

4. Find P and V corresponding to ψ .

5. Find α using l, x, P and V .

6. Determine n using φ, χ, ψ and α .

5. PRELIMINARY EXPERIMENT

In order to examine for utility of P, U and V to finding ψ , we measured l, x and o as to actual materials, changing ψ at $\varphi = \chi = 0^\circ, \alpha = 90^\circ$ (that is, $l = -P, x = -V$ and $o = U$).

Fig.2 shows some results of it. The curves

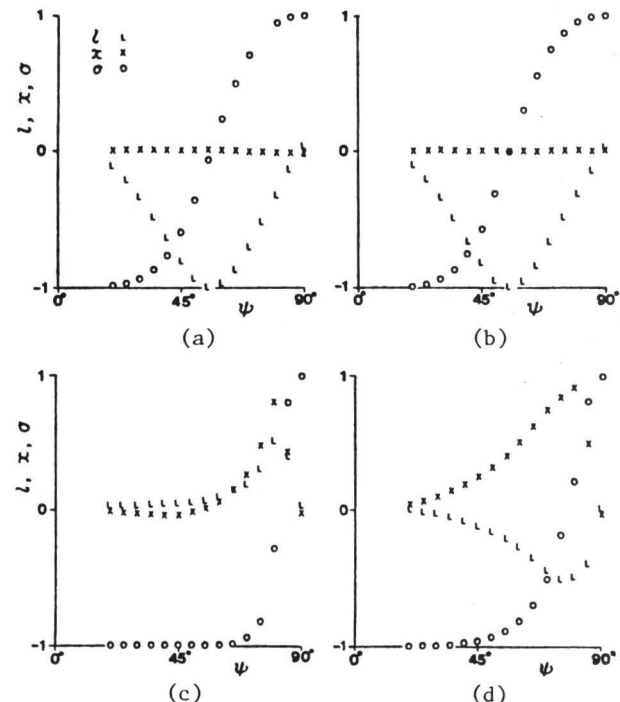


Fig.2 The polarizational characteristics measured from (a)acrylic board (b)polished paper (c)Al-coated mirror (d)chromed plate

feasible for use are obtained from the dielectrics such as the acrylic resin board and the polished paper, while not from the metals.

In this experiment we used Polaroid sheets of quarter-wave plate, linear and circular polarizers, a PIN photodiode detector and a DC-supplied incandescent lamp as a light source.

6. DISCUSSIONS

If ψ is closer to 0° or 90° , both P and V become too small to find a reliable value of α . The normal can be determined for $\psi = 0^\circ$, since it coincides with the observed ray, while, not for $\psi = 90^\circ$ by this method.

P, U and V can be theoretically derived from the refractive index, if known, by Fresnel equation. Otherwise it will be practical to get them by preliminary measurements as we did.

As far as a method of finding normals depends on specularly reflected lights, the light sources must be arranged so as to observe the specular ray from any investigating part of the surface. We, however, need not know their intensities, directions or positions.

The proposed method will be applicable to extracting geometrical parameters from glossy objects such as plastics, polished papers, lacquered items and so on. The objects have no need of uniform coloring, if their surface is coated with a dielectric.

It is under investigation to actually determine the normals from TV camera data.

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