Improved optical light scattering measurements by BSDF

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Light scattering can be exploited for in-vehicle displays and interior lighting with special visual effects. By knowledge of the light scattering behavior, software tools can optimize these effects. Besides surface scattering also volume scattering exists. Light scattering measurement results of surface and volume scattering of different surfaces and additive manufactures (AM) material is shown.

1 Introduction

Automotive interior design becomes increasingly important as cars head for the third living space: Light emitting (e.g. displays, light guides) and reflecting (e.g. structured materials) enable stunning effects. Optical design tools are used for efficient engineering, also for future special effects. The software requires the scattering characteristics of materials as input. Additionally, transparent additive manufactured material (AM, 3D printed) show surface and volume light scattering.

This work will present results of various vehicle interior materials in terms of surface light scattering and AM material with additional volume scattering. Therefore, it is necessary to characterize the optical properties of these materials with appropriate measurement methods. We measured successfully the light scattering as BSDF in reflection and in transmission using a goniophotometer. Furthermore, we are able to acquire precisely the BSDF of different surface materials and for transparent AM material.

2 BSDF fundamentals

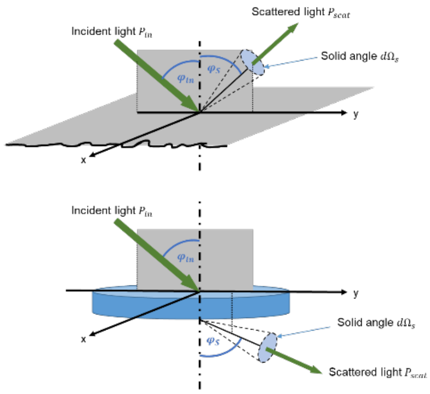
Light scattering is commonly described by the bi-directional scattering distribution function ($BSDF$) [1]. The $BSDF$ is the ratio of "scattered surface radiance L_{scat}" to "incident surface irradiance E_{in}":

$$BSDF(\alpha_{in}, \varphi_{in}, \alpha_s, \varphi_s) = \frac{L_{scat}}{E_{in}} = \frac{d^2 P_{scat}}{dP_{in} \cdot \cos\varphi_s \cdot d\Omega_s} \quad (1)$$

where $d^2 P_{scat}$ is the amount of scattered light power in the scattering solid angle $d\Omega_s$, A_S the size of the detector for the scattering power, and dP_{in} the amount of incident light power. This area A_S depends on the "detecting scattering angle" φ_s, since only the cosine part can be "seen" by the detector. The unit of the $BSDF$ is 1/steradian $(1/sr)$. In order to avoid singularities at around $\pm 90°$ the cosine corrected BSDF (also called angle-resolved scattering, ARS) is plotted:

$$ARS(\varphi_S) = BSDF \cdot \cos\varphi_s = \frac{d^2 P_{scat}}{dP_{in} \cdot d\Omega_s} \quad (2)$$

If scattered light is measured in reflection, it is called BRDF (bi-directional reflection distribution function), whereas in transmission it is called BTDF (T for transmission) - Fig. 1 illustrates both cases.



We measured BRDF and BTDF with our goniophotometer, details see [2]: A photodiode detects the scattered light and the electrical current is converted by a transimpedance amplifier. We further optimized this amplifier for high signal-to-noise ratio (SNR) as this device was the main contributor to noise.

3 Examined materials

We measured different materials in terms of ARS. The first three materials under test (white leather, wood, and blue cloths) show surface scattering and we measured them in reflection, results see Fig. 2.

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As these materials are not transparent, they exhibit (nearly) only surface scattering. In contrast the light scattering of the transparent AM material in transmission consist of twice surface scattering and multiple volume scattering due to boundaries inside the AM material resulting from its manufacturing process. Fig. 3 shows all three different light scattering sources.

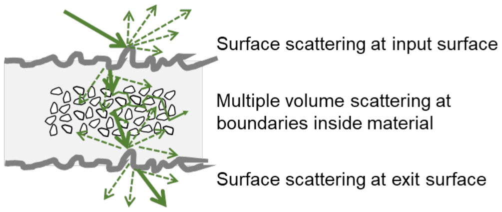

Fig. 3 *Scattering sources of AM material in transmission*

4 Surface (BRDF) light scattering measurement results

We measured the light scattering of the three materials of Fig. 2 in reflection. The results in terms of ARS shows Fig. 4. A green laser diode serves as a source (wavelength: 529 nm, optical power: 4.5 mW CW) positioned it at –20°.

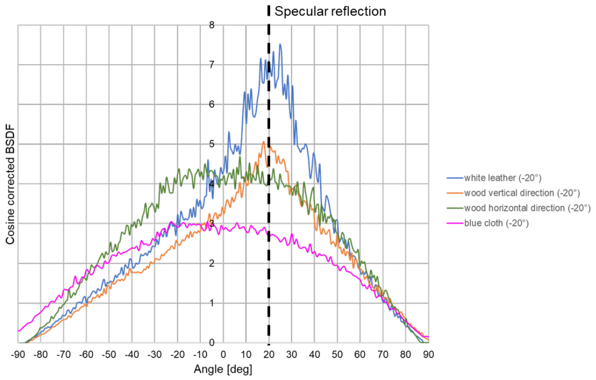

Fig. 4 *BRDF of the materials in Fig. 2.*

Fig. 4 shows the peak-like characteristic of white leather with peak scattered light at +20° - at the specular angle. The light scattering of wood depends on its orientation. For orientation in horizontal direction the light scattering shows nearly no peak and shows nearly a Lambertian characteristic. In the other direction, wood has a peak at the specular angle. The lowest light scattering exhibits blue cloth (red line) with a nearly cosine shaped (i.e. Lambertian) scattering characteristic.

5 Multiple scattering measurement results of AM material

Next, we measured AM material in reflection and in transmission (in terms ARS). We positioned the laser at -15°. Fig. 5 shows the BRDF and a picture of the AM material. Note the layered structure of the AM material due to its manufacturing process.

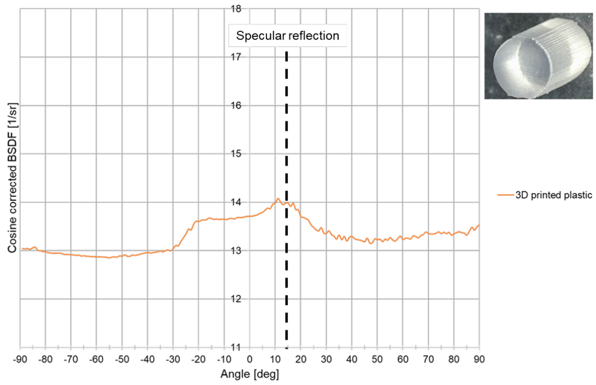

Fig. 5 *BRDF of our AM material. The inset shows the layered structure of the material.*

Fig. 6 shows the BTDF of the AM material. Note, that this measurement includes all scattering mechanism shown in Fig. 3.

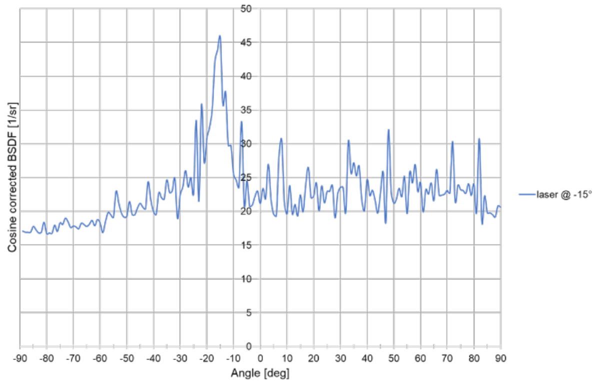

Fig. 6 *BTDF of our transparent AM material.*

The BRDT of our transparent AM material is even higher than white leather most probably due additional volume scattering. Furthermore, the BTDF is even higher than the BSDT due to three different scattering mechanism and peaks at the incident angle of -15° which is the incident light direction.

6 Summary

We successfully measured the surface light scattering (as cosine corrected BRDF = ARS) of different vehicle interior materials. In addition, the light scattering of transparent AM material was measured in reflection and in transmission as BRDF and BTDF including different scattering mechanisms.

References

[1] John Stover, *Optical Scattering Measurement and Analysis*, (SPIE Press, Bellingham 2012)

[2] S. Reichel et al: „Optical Characterization of Automotive Interior Materials by BSDF“, DGaO-Proceedings 2020, ISSN: 1614-8436 (2020).

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