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Automatic measurement of spectral bidirectional transmittance distribution function on translucent optical materials

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ABSTRACT

A measurement platform of spectral bidirectional transmittance distribution function (BTDF) with a full three dimensional spatial coverage is developed based on a fiber spectrometer, a tungsten–halogen lamp and a 3D mechanical rotation angle system. The measurement software and the control software are integrated to realize the automatic measurement. The measurement equipment has a broad spectral coverage, a large angle range, a wide dynamic response and a short acquisition time. The measured spectral range is 380–760 nm with 0.04 nm spectral resolution. The measured angle range is 0–80° in zenith angle and 0–360° in azimuth angle with 0.01° angle resolution. The dynamic range is 10^7 and the minimal integration time is 1 ms. The measurement of spectral BTDF on translucent frosted glass is performed and a large amount of measured data is obtained with the measurement error no more than 3.28%. It provides a reliable description facility for spectral and spatial transmission characteristics of the translucent materials.

1. Introduction

With the rapid development of new material processing technology, transparent and translucent material has been widely used in the industrial production, daily life, architectural design, computer graphics and many other fields [1–5]. With regard to aerospace camera design, for example, the coating technology is usually used to improve transmission characteristics of the optical system [6]; in daily life, the transmission characteristics of the materials, such as frosted glass doors and windows, are also universally used to achieve the effect of light homogenization or fuzzy imaging; in respect to building design, transmission calculation or measurement of numerous translucent material is also involved, such as glass curtain wall; in the field of computer graphics, transparent and translucent of 3D modeling can be achieved through the analysis of transmission characteristics.

As the only determined function that can effectively describe the transmission properties of optical material, the bidirectional transmittance distribution function (BTDF) was studied in the past thirty years. In 1982, Eustace l. Dereniak developed a working equation for BTDF based on the practical limitations of the instrumentation, but a more general wavelength scaling law for BTDF data is not proposed in the article [7]. In 2001, Andersen devised a novel bi-directional photogoniometer based on digital imaging techniques to assess an almost continuous BTDF function, however, the procedure of calibration is kind of troublesome [8]. Since then, Andersen did a lot of effective work, for example, in 2003, Andersen compared measurements and calculations for the specific case of prismatic daylight-redirecting panels, but it lacked of an absolute measurement standard

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[9]. In 2005, Andersen compared the measured data with ray-tracing results achieved with a virtual copy of the device, while the spectrum was not considered [10]. In the same year, Andersen designed a time-efficient video-goniophotometer to assess bidirectional transmission and reflection characteristics, the performance of the instrument is remarkable, only the construction is relative complex [11]. In 2007, Nicholas Gayeski measured the bidirectional scattering distribution function (BSDF) of building materials for different angle and wavelength values by digital camera, whereas the complex data processing decreased the precision of the obtained measured data [12]. Combes developed a new spectro-goniophotometer, while the sample holder is rotated by steps of 20°, which limits the measurement angle range [13]. Jonsson presented a method to determine the bidirectional transmittance distribution function (BTDF) using an integrating sphere, while the measurement uncertainty was not analyzed systematically [14]. In 2008, Leloup developed a measuring instrument that allows for an absolute determination of the spectral BSDF with a full three dimensional spatial coverage in both reflectance and transmittance mode, but the data processing involving matrix transformation is a heavy workload [15]. In 2009 to 2011, Finck, Lequime and Zerra designed a serial of light scattering measurement facilities for a comprehensive research of optical coatings, which reveal perfect measurement abilities, only the operation is a bit complicated [16–18]. In 2013, Jan Audenaert applied the Bayesian deconvolution technique to experimental BTDF data of holographic diffusers, which exhibit a symmetrical angular broadening under normal incident irradiation, but this study was limited to symmetrical BTDF and normal incident light [19]. In 2014, Leloup designed an alternative goniometric measurement system for measuring the photometric BSDF in full 3D space, while the measurement error was not given [20].

In summary, the measuring equipment and data processing method mentioned above limits the measuring angle range and affects the measurement accuracy to a certain extent. It is necessary to improve measurement platform for extending the BTDF measuring angle and acquiring more optical transmission information of the material for different lighting and viewing direction. In the meantime, it is very important to make an in-depth study on the data acquisition and processing method for increasing the BTDF measuring precision further.

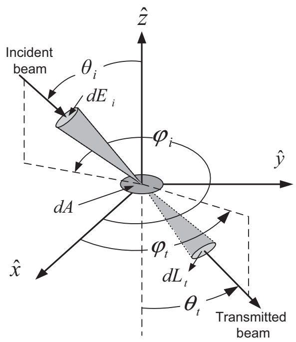

Fig. 1. Light transmission geometry.

2. BTDF measurement method

2.1. Spectral BTDF definition

Spectral BTDF is a physical quantity to describe spectral transmission characteristics of various materials based on radiometry and geometrical optics. And it is the only determined parameter to represent transmission characteristics of a material in different incident zenith angle, incident azimuth angle, observed zenith angle, observed azimuth angle and wavelength. The zenith and azimuth angle are described in a spherical coordinate system (see Fig. 1). Where, dA is a micro area of the sample, and the zenith angle is defined as the angle between the normal direction of dA and the lighting or viewing directions. If the lighting or viewing vector to a point of interest is projected perpendicularly onto the sample plane, the azimuth angle is defined as the angle between the projected vector and a reference vector on the sample plane, usually the reference vector is positive direction of x-axis.

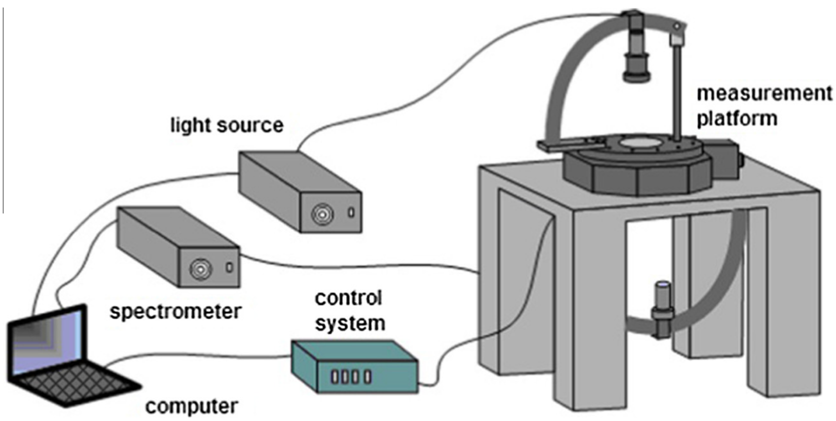

Fig. 2. Measurement scheme of BTDF.