

Extraction of Effective Parameters of Anisotropic and Turbid Media Using Mueller Matrix Method

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Methods for accurately determining the optical properties of opto-electric materials or bio-samples are essential in facilitating the development of advanced inspection and/or diagnostic applications [1]. For example, linear birefringence (LB) measurements provide a useful insight into the characteristics of LCD compensator films or the photo-elasticity of human tissue, while circular birefringence (CB) measurements of human blood provide a reliable indication of diabetes [2-6]. Similarly, linear dichroism (LD) measurements of human tissue can facilitate tumor diagnosis, while circular dichroism (CD) measurements are an effective means of characterizing and classifying protein structures [7-10]. Moreover, linear depolarization (L-Dep) and circular depolarization (C-Dep) measurements provide a valuable experience of the characteristics of tumors or surface measurements, etc. [11-12].

Cameron et al. [5,6] proposed a method based on a Mueller matrix imaging approach for estimating the scattering coefficient of turbid media such as rat tissue and melanoma-based tissue culture. Luo et al. [13] used an effective Mueller matrix approach to characterize the spatially-resolved diffuse backscattering patterns of highly scattering media based on the assumption that the photon trajectories include only three scattering events. A good agreement was observed between the backscattering patterns obtained using the proposed method for a polystyrene sphere suspension and those obtained via Monte Carlo simulations. Wang et al. [14] compared the backscattering patterns of birefringent anisotropic turbid media obtained using a single-scattering model and a double-scattering model, respectively, with those obtained from Monte Carlo simulations. Ghosh et al. [4,11,12] proposed an approach based on the Mueller matrix polar decomposition method [15] for extracting the Linear Birefringence (LB), Circular Birefringence (CB), Linear Dichroism (LD), and depolarization coefficient of complex turbid media such as polyacrylamide phantoms, polystyrene microsphere suspensions, and sucrose. The validity of the proposed approach was demonstrated by means of Monte Carlo simulations. Although the methods presented in [2-14] provide a useful insight into the scattering behavior of turbid media, they have several important drawbacks. For example, the methods proposed in [2,3,5-10,13,14] are unable to measure enough properties of scattering media. Similarly, the methods presented in [4,11,12] fail when the Mueller matrix of linear dichroism is singular.

In a recent study, Pham and Lo [16] proposed a decoupled analytical technique for extracting the six effective Linear Birefringence (LB), Linear Dichroism (LD), Circular Birefringence (CB) and Circular Dichroism (CD) parameters of anisotropic optical materials. By decoupling the extraction process, the "multiple solutions" problem inherent in previous models [17,18] was avoided. However, the method was unable to extract the Linear Depolarization (L-Dep) and Circular Depolarization (C-Dep) properties of turbid samples. Accordingly, an enhanced analytical model is proposed by Lo et al. [19] for extracting all the effective LB, CB, LD, CD, L-Dep and C-Dep parameters of a turbid medium in a decoupled manner. The validity of the proposed method is demonstrated by extracting the parameters of various optical

samples. In contrast to existing analytical models, the model proposed extracts the effective parameters in a decoupled manner and considers not only the circular dichroism properties of the sample, but also the depolarization properties. The results show that the proposed method enables all of the effective parameters to be measured over the full range. Moreover, it is shown that the extracted value of the depolarization index is unaffected by the order in which the depolarizing Mueller matrix is decomposed during the extraction procedure. In addition, a method is proposed for calibrating the optical rotation angle of a polystyrene microsphere suspension containing dissolved D-glucose powder in accordance with the distance between the sample and the detector. The experimental results show that the sensitivity of the resulting D-glucose measurement is equal to approximately 1.73 mol/l. The experimental results have shown that the decoupled nature of the analytical model localizes the effects of measurement errors and enables the properties of pure LB, LD, CB, CD, L-Dep or C-Dep samples to be extracted without the need for any form of compensation process or pretreatment. In general, the results presented show that the proposed method has the potential for such applications as collagen and muscle structure characterization (based on LB/Depolarization measurements), protein structure characterization (based on CB/CD/Depolarization measurements) or diabetes detection (based on CB/Depolarization measurements).

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