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Mueller-Matrix Tomography of Biological Tissues and Fluids

Digital Image Processing and Analysis Techniques

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Introduction—Main Aims and Objectives of Laser Polarimetry for Prostate Tumors

Prostate cancer is the second most common cancer in the male population globally, and in some countries is now the most diagnosed form of cancer [1, 2]. Facile and rapid differentiation of prostate tissues is a critical medical challenge [3], with faster and more accurate tumor diagnoses allowing accelerated intervention and management, leading to significant improvements in patient outcomes [4, 5]. The first step in diagnosis is to identify the presence of a tumor [4] by discriminating between benign (adenoma) and malignant (carcinoma) prostate tissues [5]. Optical diagnosis of tumors offers distinct advantages—it's non-destructive, requires limited sample preparation, and is cheap and fast [6–11]. One of the most promising diagnostic opportunities is to look at the optical anisotropy. Optical anisotropy arises when a material interacts differently with different polarizations of incident light, such that different polarizations are absorbed, transmitted, reflected, and refracted with different intensities [12]. That is, there is a polarization dependence of the speed of light within the material (and hence of the refractive index also). Different biological structures present in different tissue types have different optical anisotropy parameters. Hence, mapping and analysis of the optical anisotropy parameters of a biological tissue can be used to identify and characterize the morphology and tissue type [13–15].

An optical material is characterized by its eigenvectors, which represent light for which the polarization is not altered through interaction with the material. In an optically anisotropic material, the eigenvectors depend on the direction of the light propagation. Where the eigenvectors differ in the absorption term, the resulting physical effect is called dichroism. Where they differ in the refraction term, the resulting effect is called birefringence. Each of these effects can then be further divided into linear and circular variants. For linear variants, one considers the difference in interactions between linearly polarized light with orthogonal polarization planes. For circular variants, one considers the difference in interactions between left and right circularly polarized light where the field vectors rotate (anticlockwise and clockwise, respectively) in the plane perpendicular to the direction of propagation. Thus, there are four optical anisotropy properties to consider for a material: linear birefringence, linear dichroism, circular birefringence, and circular dichroism. The birefringence

and dichroism of a material can be determined by measuring changes in the polarization of light passing through the material by so-called polarimetry measurements [12, 15–17]. Polarimetry is a relatively easy technique to implement. At its most simple, all that is required are: a light source (laser), polarizing filters (and quarter-wave plate for circular birefringence and dichroism measurements), and a detector [18, 19]. More sensitive measurements require interferometric techniques.

It is desirable to correlate the experimental data for the anisotropy properties with the physical sample of soft matter under investigation. Many distinct directions are being considered for this purpose including: the investigation of scattering matrices [6, 20–23]; Mueller-matrix polarimetry [11, 24–27]; polar decomposition of Mueller matrices [28, 29]; and two-dimensional Mueller matrix mapping [16, 17, 30, 31]. The 2D Mueller-matrix reconstruction of the distributions of the optical anisotropy parameters of biological layers has been described previously [32–58].

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