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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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# Contents

<b>1 Analytical Review of the Methods of Multifunctional Digital Mueller-Matrix Laser Polarimetry</b> .....	1
1.1 Physical Bases, Methods, and Means of Mueller-Matrix Laser Polarimetry of Biological Layers .....	1
1.2 “Single-Point” Polarization Mapping of Microscopic Images of Histological Sections of Biological Tissues .....	2
1.3 “Single-Point” Polarization Mapping of Microscopic Images of Polycrystalline Films of Biological Fluids .....	3
1.4 Wavelet Analysis of Polarization Maps of Polycrystalline Networks of Blood Plasma Films .....	7
1.5 Structural and Logical Diagrams of Multifunctional Polarization Microscopy .....	8
1.6 Conclusions .....	9
References .....	9
<b>2 Materials and Methods of Computer-Assisted Digital Mueller-Matrix Tomography of Biological Tissues and Fluids</b> .....	13
2.1 Structural-Logical Scheme and Design of the Study .....	13
2.2 Structural-Logical and Model Scheme of Optical Anisotropy of Biological Layers .....	13
2.3 Structural-Logical and Optical Scheme of Singular Polarimetry of Microscopic Images of Biological Layers .....	15
2.4 Structural-Logical and Optical Scheme of Polarization Interferometry of Microscopic Images of Biological Layers .....	15
2.5 Structural-Logical and Optical Scheme of 3D Layer-By-Layer Stokes Polarimetry of Microscopic Images of Biological Samples .....	18
2.6 Objective Methods for Estimating Experimental Databases of Polarization Correlometry Methods .....	22
2.7 Principles of Information Analysis of Databases of Experimental Data X .....	25

2.8 Characteristics of the Investigated Objects ..... 26

2.9 Conclusions ..... 28

References ..... 30

**3 Differential Diagnosis of Tumors of the Prostate.**

**Polarization-Singular Approach ..... 33**

3.1 Optical-Geometric Parameters of Biological Samples  
of Prostate Tumors and Polycrystalline Blood Films of Sick  
Patients ..... 33

3.2 Mueller-Matrix Singular Polarimetry of Histological  
Sections of Biopsy of Benign and Malignant Tumors  
of the Prostate with Different Degrees of Differentiation ..... 34

3.2.1 Experimental Technique for Measuring Distributions  
of the Number of Singular States ..... 34

3.2.2 Topographic and Statistical Structure  
of Polarization-Singular Maps of Histological  
Sections of Biopsy of Prostate Tumors with Different  
Degrees of Differentiation ..... 35

3.2.3 Statistical Analysis of Polarization-Singular Maps  
of Histological Sections of Biopsy of Prostate  
Tumors with Different Degrees of Differentiation ..... 38

3.2.4 Information Analysis of the Diagnostic  
Power of the Method of Mueller-Matrix  
Polarization-Singular Mapping of Histological  
Sections of Biopsy of Prostate Tumors with Different  
Degrees of Differentiation ..... 40

3.3 Mueller-Matrix Singular Polarimetry of Polycrystalline  
Blood Films of Patients with Benign and Malignant Prostate  
Tumors with Different Degrees of Differentiation ..... 42

3.3.1 An Experimental Technique for Measuring  
the Distributions of the Number of Singular States  
in Mueller-Matrix Images of Polycrystalline Blood  
Films ..... 42

3.3.2 Topographic and Statistical Structure  
of Polarization-Singular Maps of Polycrystalline  
Blood Films of Patients with Prostate Tumors  
of Different Degrees of Differentiation ..... 43

3.3.3 Statistical Analysis of Polarization-Singularity  
Maps of Polycrystalline Blood Films of Patients  
with Prostate Tumors with Different Degrees  
of Differentiation ..... 48

3.3.4	Informational Analysis of the Diagnostic Power of the Method of Mueller-Matrix Polarization-Singular Mapping of Polycrystalline Blood Samples of Prostate Swellings with a Different Degree of Differentiation .....	49
3.4	Conclusions .....	50
	References .....	51
<b>4</b>	<b>Polarization-Interference Mapping of Microscopic Images of Biological Layers and Polycrystalline Blood Films in the Differential Diagnosis of Benign and Malignant Tumors of the Prostate .....</b>	<b>55</b>
4.1	The Technique of Polarization-Interference Mapping of the Field of Complex Amplitudes in the Plane of the Microscopic Image of Samples of Prostate Tumors and Polycrystalline Blood Films .....	55
4.2	Polarization-Phase Maps of Microscopic Images of Histological Sections of Biopsy of Prostate Tumors with Different Degrees of Differentiation .....	56
4.3	Polarization-Interference Maps of Samples of Prostate Tumors .....	59
4.4	Coordinate and Statistical Structure of Maps of Local Contrast of Microscopic Images of Histological Sections of Biopsy of Prostate Tumors with Different Degrees of Differentiation .....	61
4.5	Statistical Analysis of Local Contrast Maps of Digital Microscopic Images of Histological Sections of Biopsy of Prostate Tumors with Different Degrees of Differentiation .....	63
4.6	Information Analysis of the Diagnostic Power of the Polarization-Interference Mapping Method of Microscopic Images of Histological Biopsy Sections of Prostate Tumors with Different Degrees of Differentiation .....	66
4.7	Polarization-Phase Maps of Microscopic Images of Polycrystalline Blood Films of Patients with Prostate Tumors of Different Degrees of Differentiation .....	67
4.8	Polarization-Interference Maps of Polycrystalline Blood Films .....	69
4.9	Structure of Maps of Local Contrast of Microscopic Images of Prostate Tumors with Different Degrees of Differentiation .....	71
4.10	Statistical Analysis of Local Contrast Maps of Digital Microscopic Images of Polycrystalline Blood Films of Patients with Prostate Tumors of Different Differentiation .....	74