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ABSTRACT

In the approximation of weak phase fluctuations, a polarization-correlation method for diagnosing the optical anisotropy of small-scale optically anisotropic fibrillar structures of myocardial tissues is proposed. The algorithms of analytical description and experimental determination of the coordinate distributions of the value of the modulus and phase of "two-point" Stokes vector parameters are defined. Within the statistic, correlation and fractal analysis the possibility of differential diagnostics of slight changes in optical anisotropy of myocardial tissues of different pathological states. The comparative analysis of objective statistical, correlation and fractal analysis of distributions of "single-point" polarization azimuth and ellipticity and "two-point" Stokes vector parameters of polarization-inhomogeneous images of the studied histological sections demonstrated excellent accuracy ($Ac > 90\%$) of differential diagnostics of changes in the optical anisotropy myocardium tissues.

Keywords: optics, photonics, light, lasers, templates, journals.

1. INTRODUCTION

In the series of research works the possibility of polarimetry diagnostic¹⁻¹⁹ of optically anisotropic layers of biological tissues²⁰⁻²² and fluids²³⁻²⁹ is demonstrated.

This research aims to study fundamental potentiality of the new Stokes-polarimetry approach to polarization-correlation mapping of microscopic images of ischemic heart disease and acute coronary insufficiency died patients myocardial tissue.

2. THEORY OF THE METHOD

T.Setola, Ya.Tervo and A.T.Friberg^{30,31} proposed to describe the correlation structure of the stationary distributions of the fields of complex amplitudes of laser light converted by optically anisotropic biological layers, one can use the following mutual spectral density matrix

$$W_{i,j}(r_1, r_2) = E_i^*(r_1) \cdot E_j(r_2), i, j = x, y \quad (1)$$

Here r_1 and r_2 - the coordinates of the neighboring points in the field of laser radiation.

In the approximation of weak phase fluctuations using relations (1) we obtained the following expressions for to calculate the polarization parameters that characterize the birefringence of small-scale structures of the myocardium

$$\left\{ \begin{array}{l} |S_1| = [1 + tg\rho_1 tg\rho_2] \\ ArgS_1 = arctg \left[\frac{(\delta_2 - \delta_1)}{1 + ctg\rho_1 ctg\rho_2} \right] \end{array} \right. \quad (2)$$

$$\begin{cases} |S_2| = [1 - tg\rho_1 tg\rho_2]; \\ ArgS_2 = arctg\left[\frac{(\delta_2 - \delta_1)}{ctg\rho_1 ctg\rho_2}\right]. \end{cases} \quad (3)$$

$$\begin{cases} |S_3| = 1 - ctg\rho_2 tg\rho_1; \\ ArgS_3 = arctg\left(\frac{\delta_2 - \delta_1 ctg\rho_2 tg\rho_1}{1 + ctg\rho_2 tg\rho_1}\right); \end{cases} \quad (4)$$

$$\begin{cases} |S_4| = 1 + ctg\rho_2 tg\rho_1; \\ ArgS_4 = arctg\left(\frac{1 + ctg\rho_2 tg\rho_1}{\delta_1 + \delta_2 ctg\rho_2 tg\rho_1}\right). \end{cases} \quad (5)$$

It follows from the analysis of the obtained relations (2) - (4) that the SCP modulus $|S_{i=1,2,3,4}(\Delta x, \Delta y)|$ carries information about the orientation structure $\rho(x, y)$ of polycrystalline networks and structures. The SCP phase $Arg(S_{i=1,2,3,4}(\Delta x, \Delta y))$ carries information about their birefringence ($\delta(x, y)$).

3. MATERIALS AND METHODS

Measurement of the coordinate distributions of the values of $|S_{i=3}(\Delta x, \Delta y)|$; $Arg(S_{i=3}(\Delta x, \Delta y))$ and $|S_{i=4}(\Delta x, \Delta y)|$; $Arg(S_{i=4}(\Delta x, \Delta y))$ was carried out in the experimental arrangement of Stokes-polarimeter^{9,13,17}.

4. BRIEF DESCRIPTION OF THE RESEARCH OBJECTS

Optically thin (attenuation coefficient $\tau < 0.01$) samples of histological sections (geometrical thickness $l = 25 \mu m \div 30 \mu m$ $0.0093 \leq \tau \leq 0.0099$) of myocardium biological tissues of internals of two statistically significant (37 samples each) groups.

Histological sections of biological tissues of rat's internal were produced by the standard technique in freezing microtome.

5. EXPERIMENTAL RESULTS AND DISCUSSION

In the series of Fig. 1 - Fig. 4 is shown the cross-correlation functions of the coordinate distributions of the modulus (Fig.1, Fig.2) and the phases (Fig.3, Fig.4) of the polarization-correlation parameters of the Stokes vector images of the histological sections of the myocardium with IHD (Figure 1, Figure 3) and ACI (Figure 2, Figure 4).

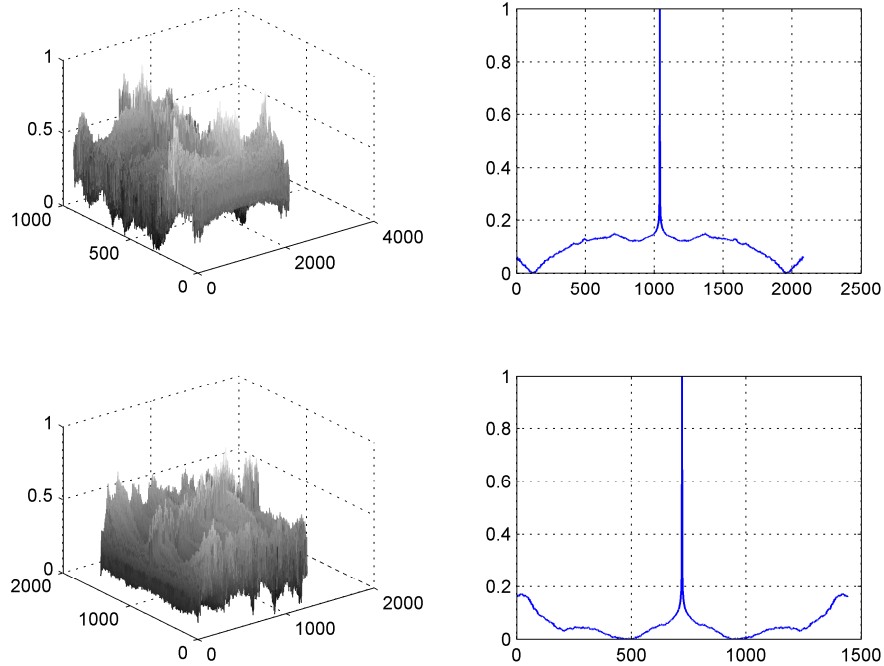


Figure. 1. Cross-correlation functions of polarization parameters modulus of the myocardium with IHD histological section image

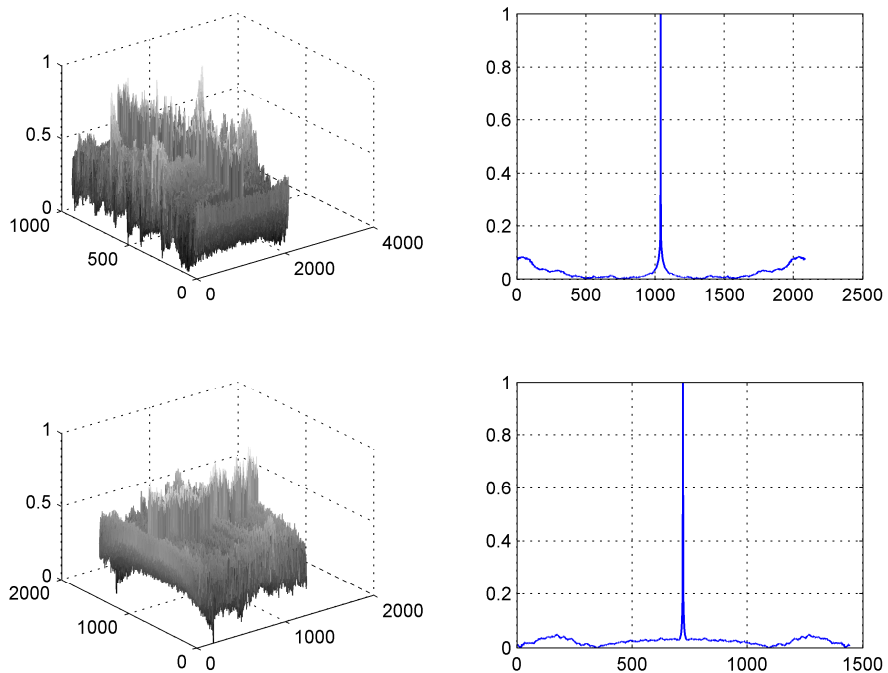


Figure. 2. Cross-correlation functions of polarization parameters modulus of the myocardium with ACI histological section image

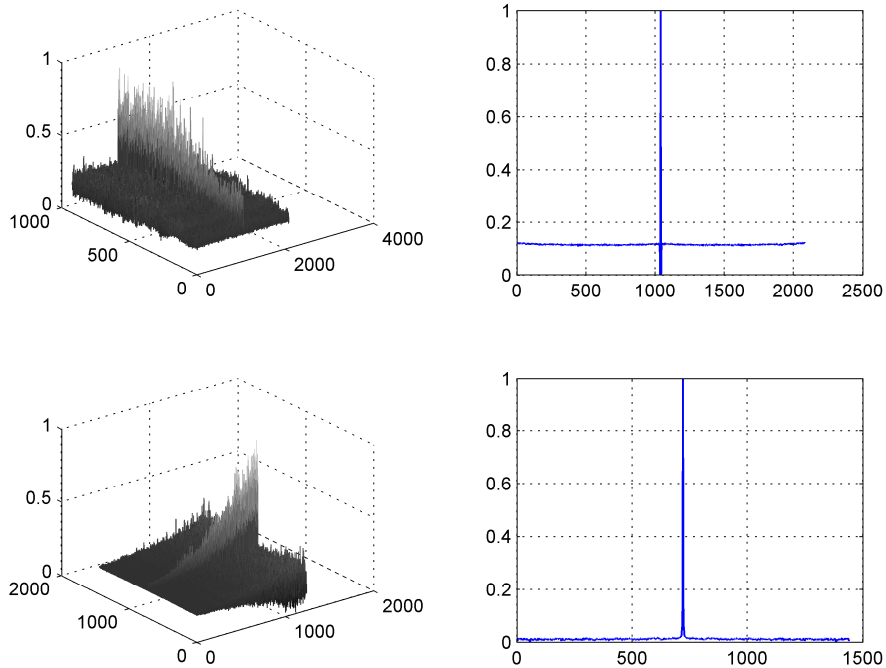


Figure. 3. Cross-correlation functions of polarization parameters phase of the myocardium with IHD histological section image

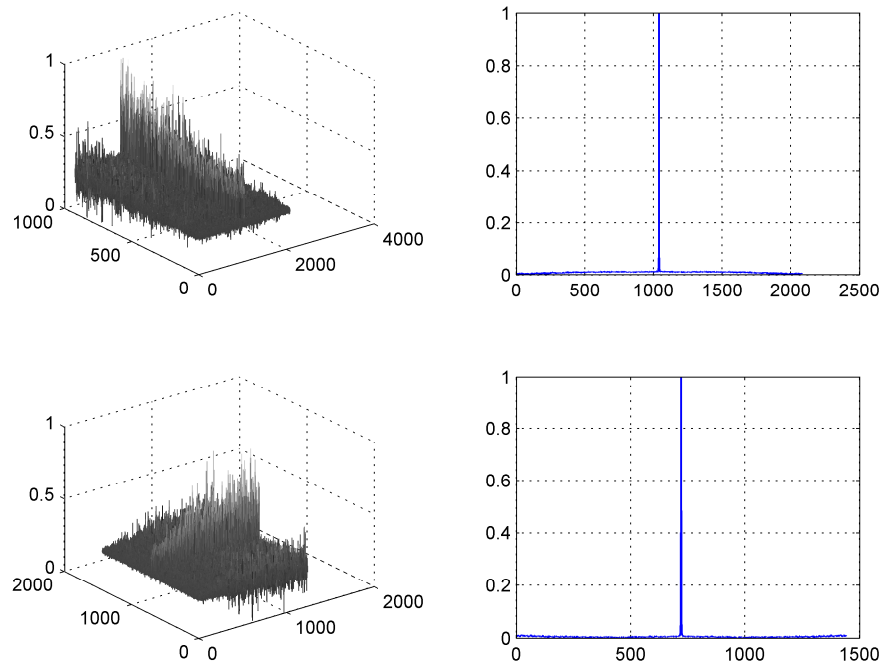


Figure. 4. Cross-correlation functions of polarization parameters phase of the myocardium with ACI histological section image

The potentiality of Stokes-correlometry differentiation of the two groups of myocardium samples is quantitatively illustrated by the data presented in Table 1 and Table 2.

Table 1. Correlation parameters of SCP modulus maps of polarization-inhomogeneous images of histological sections of myocardium

Parameters	$ S_{i=3}(\Delta x, \Delta y) $		$ S_{i=4}(\Delta x, \Delta y) $	
	IHD ($n = 39$)	ACI ($n = 39$)	IHD ($n = 39$)	ACI ($n = 39$)
Z_2^k	$0,077 \pm 0,0052$	$0,13 \pm 0,0092$	$0,065 \pm 0,0053$	$0,093 \pm 0,0072$
Z_4^k	$2,34 \pm 0,19$	$0,92 \pm 0,073$	$1,68 \pm 0,15$	$0,89 \pm 0,063$

Table 2. Correlation parameters of SCP phase maps of polarization-inhomogeneous images of histological sections of myocardium

Parameters	$Arg(S_{i=3}(\Delta x; \Delta y))$		$Arg(S_{i=4}(\Delta x; \Delta y))$	
	IHD ($n = 39$)	ACI ($n = 39$)	IHD ($n = 39$)	ACI ($n = 39$)
Z_2^k	$0,065 \pm 0,0053$	$0,12 \pm 0,009$	$0,045 \pm 0,0035$	$0,067 \pm 0,0054$
Z_4^k	$3,24 \pm 0,19$	$1,38 \pm 0,073$	$4,41 \pm 0,42$	$2,43 \pm 0,038$

The data analysis revealed the following differences between the set of objective parameters that characterize the maps of SCP-modulus of polarization-inhomogeneous images of both types myocardium histological sections:

- $\Delta Z_2^k = 1.45 - 1.52$ times; $\Delta Z_4^k = 1.82 - 2.43$ times;

These data were obtained for the SCP phase distributions:

- $\Delta Z_2^k = 1.34 - 1.61$ times; $\Delta Z_4^k = 1.89 - 2.37$ times;

6. COMPARATIVE EFFICIENCY OF THE TECHNIQUES OF LASER POLARIMETRY AND STOKES-CORRELOMETRY OF POLARIZATION-INHOMOGENEOUS IMAGES OF HISTOLOGICAL SECTIONS

The Stokes-correlometry method of SCP modulus $|S_{i=3,4}(\Delta x; \Delta y)|$ and phase $Arg(S_{i=3,4}(\Delta x; \Delta y))$ distributions of polarization-inhomogeneous images was compared with the that of polarization mapping of distributions of the values of azimuth and ellipticity of the corresponding microscopic images of histological sections of myocardium (Table 3).

For the possible clinical application of both methods the following was determined for each group of samples ³²⁻³⁸ traditional for probative medicine operational characteristics - sensitivity ($Se = \frac{a}{a+b} 100\%$), specificity

($Sp = \frac{c}{c+d} 100\%$) and balanced accuracy ($Ac = \frac{Se + Sp}{2}$), where a and b are the number of correct and wrong diagnoses within group 2; c and d - the same within group 1 - Table 5.

Table 3. Accuracy of the methods of Stokes-correlometry and laser polarimetry of myocardium tissue in the differential diagnostics of pathologies

Parameters	<i>Ac, %</i>					
	$ S_3 $	$ S_4 $	$ArgS_3$	$ArgS_4$	$\alpha(x, y)$	$\beta(x, y)$
Z_2^k	84	81	86	87	69	74
Z_4^k	92	94	95	96	84	81

CONCLUSION

A new method of polarization - correlometry – determination of the coordinate distributions of the modulus and phase of "two-point" Stokes-vector parameters of polarization-inhomogeneous images of histological sections of biological tissues of myocardium is suggested and analytically substantiated.

Within the correlation analysis the objective criteria characterizing the SCP-maps of polarization- inhomogeneous microscopic images of two groups (IHD-ACI) of samples of biological tissues of myocardium with the structured collagen birefringent fibrillar networks are determined.

The comparative analysis of the objective correlation analysis of distributions of polarization "single-point" azimuth and ellipticity and "two-point" Stokes-vector parameters of polarization-inhomogeneous images of histological sections under study demonstrated the excellent accuracy ($Ac > 90\%$) of differential diagnostics of changes in optical anisotropy of myocardium by the polarization - correlometry method.

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