Concerted spatial-frequency and polarization-phase filtering of laser images of polycrystalline networks of blood plasma smears

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Abstract. The complex technique of concerted polarization-phase and spatial-frequency filtering of blood plasma laser images is suggested. The possibility of obtaining the coordinate distributions of phases of linearly and circularly birefringent protein networks of blood plasma separately is presented. The statistical (moments of the first to fourth orders) and scale self-similar (logarithmic dependences of power spectra) structure of phase maps of different types of birefringence of blood plasma of two groups of patients—healthy people (donors) and those suffering from rectal cancer—is investigated. The diagnostically sensitive parameters of a pathological change of the birefringence of blood plasma polycrystalline networks are determined. The effectiveness of this technique for detecting change in birefringence in the smears of other biological fluids in diagnosing the appearance of cholelithiasis (bile), operative differentiation of the acute and gangrenous appendicitis (exudate), and differentiation of inflammatory diseases of joints (synovial fluid) is shown.

Keywords: polarization; birefringence; Fourier plane; spatial-frequency filtering; diagnostics.

1 Introduction
Among the numerous systems for diagnosing the optical properties of biological objects,1–4 a new technique has separated itself—laser polarimetry of microscopic images of biological tissues.5–8 The analysis of the data obtained is based on the approximation of linear birefringence of polycrystalline protein networks.8–11 Based on this approach, a connection has been found between the statistical moments of the first to fourth orders, characterizing the distributions of polarization azimuths and the ellipticity of laser images, and the parameters of anisotropy for biological tissue layers.12,13 As a result, the technique of polarization mapping was developed14–16 and has led to the successful diagnosis of oncological (malignant) changes in human biological tissues.16,17 On the other hand, there is a wide range of phase-modulating biological fluids, due to circular and linear birefringence. Such fluids (blood, bile, urine, etc.) are easily accessible and do not require any traumatic operation—biopsy. Any pathological physiological changes in the human organism are accompanied by the transformation of the biological composition of these fluids. For instance, the appearance of cancer leads to changes of various types of optical anisotropy of blood plasma proteins.18,19 Thus, for further development of laser polarimetry techniques, optical separation of polarization-phase manifestations of such mechanisms is very topical. Polarization mapping does not solve this problem currently. Concerted spatial-frequency filtering can become one of the possible solutions. This technique has been applied successfully to the separation of components with different frequency of intensity distributions in phase-inhomogeneous object images.20–23 The idea of using this approach for biomedical applications, which is quite new, is based on filtering the spatial-frequency spectra of polarization images of biological crystals networks with various anisotropy mechanisms. Optical realization of this technique determines the following stages: direct Fourier transform, spatial-frequency and polarization-phase filtering, and inverse Fourier transform of laser images of the biological fluid layer.

This research is focused on the efficiency of concerted spatial-frequency and polarization-phase filtering of birefringence of blood proteins in diagnosing rectal cancer.

2 Theory of the Method
Conventional samples for medical practice were used as objects of investigation. Blood plasma smears placed on homogeneous glass (birefringence index n = 1.47) were dried at room temperature. As a result, the single scattering (attenuation coefficient τ ≈ 0.083 ± 0.089; geometrical thickness 15 to 20 μm) optically anisotropic layers were formed. In the process of drying such a layer, a planar polycrystalline network is formed by the proteins of albumin (~60%) and globulin (~40%). The molecules of such proteins possess one common primary property—optical activity or circular birefringence.24–26 At the same time, as the blood plasma smear crystallizes, the acicular crystals of albumin and the clumpy crystals of globulin are formed. Such conformation peculiarities show up in the prevalence of various mechanisms of optical anisotropy in the corresponding partial polycrystalline networks:

- Large-scale (100 μm/150 μm) acicular crystals of albumin with predominant linear birefringence are caused by the secondary effect of spatially determinate formation of optical axes directions. Optical anisotropy of such linearly birefringent crystals is characterized by the Jones matrix.
where \( \rho \) is the direction of the optical axes of an acicular crystal in the plane of the smear, and \( \delta = (2\pi/\lambda)\Delta n l \) is the value of a phase shift between the orthogonal components of the amplitude of a laser wave with length \( l \) that has passed the geometric path \( l \) through the crystal with a linear birefringence \( \Delta n \).

- Small-scale (10 \( \mu \mathrm{m} \)/30 \( \mu \mathrm{m} \)), clumpy (without any certain spatially determinate direction of the optical axis) globulin crystals are formed with predominantly circular birefringence or optical activity characterized by the matrix \(^{27-29}\)

\[
\{Q\} = \begin{bmatrix} \sin^2 \rho + \cos^2 \rho \exp(-i\delta) \\ \sin \rho \cos \rho (1 - \exp(-i\delta)) \\ \cos^2 \rho + \sin^2 \rho \exp(-i\delta) \end{bmatrix}.
\]

where \( \theta \) is the rotation angle of the polarization plane of the laser wave.

The amplitude-phase modulation of laser radiation occurs due to different mechanisms of anisotropy of polycrystalline networks of blood plasma. This process is analytically characterized by the matrix equation

\[
\begin{bmatrix} E_x(\rho, \delta, \theta) \\ E_y(\rho, \delta, \theta) \end{bmatrix} = \{Q\} \{A\} \begin{bmatrix} E_{0x} \\ E_{0y} \end{bmatrix},
\]

where \( \{E_{0x}\} \) and \( \{E_{0y}\} \) are Jones vectors of the probing and object waves.

Traditionally, the coordinate distribution of phases \( \varphi(x, y) \) in the plane of a laser image was determined by polarimetry \(^{1,18,30}\) using the algorithm

\[
\varphi(x, y) = \arctan \frac{\tan 2\beta(x, y)}{\tan \alpha(x, y)},
\]

where \( \alpha \) is the azimuth, and \( \beta \) is the polarization ellipticity, measured in the points \( x, y \) of a laser image of an optically anisotropic biological layer.

In this case, the values of polarization \( (\alpha, \beta) \) and amplitude-phase \( [E_x(\rho, \delta, \theta), E_y(\rho, \delta, \theta)] \) parameters of the object field are connected \(^{30}\) by

\[
\begin{align*}
\alpha(\rho, \delta, \theta) &= 0.5 \arctan \frac{[E_x(\rho, \delta, \theta)E_y^*(\rho, \delta, \theta) - E_y(\rho, \delta, \theta)E_x^*(\rho, \delta, \theta)]}{[E_x(\rho, \delta, \theta)E_y^*(\rho, \delta, \theta) - E_y(\rho, \delta, \theta)E_x^*(\rho, \delta, \theta)]}, \\
\beta(\rho, \delta, \theta) &= 0.5 \arcsin \frac{[i(E_x(\rho, \delta, \theta)E_y^*(\rho, \delta, \theta) - E_y(\rho, \delta, \theta)E_x^*(\rho, \delta, \theta))]}{[E_x(\rho, \delta, \theta)E_y^*(\rho, \delta, \theta) + E_y(\rho, \delta, \theta)E_x^*(\rho, \delta, \theta)]},
\end{align*}
\]

where \( * \) designates a complex conjugate. It can be seen from those two equations that the phase map \( \varphi(x, y) \) of a blood plasma polycrystalline network is formed by superposition of different mechanisms of transformation (linear and circular birefringence) of the amplitude and phase of the probing laser beam. Medically, the task of “optical separation” of amplitude-phase manifestations of linear and circular birefringence of albumin and globulin crystals is topical. Pathological changes in the human organism are accompanied by increasing concentration of optically active globulin protein in the blood plasma.\(^{19}\) Statistical and fractal analysis of the phase structure of images of such a polycrystalline component can prove effective in determining diagnostic quantitative criteria. To realize this task, we applied the method of spatial-frequency filtration of laser radiation in the Fourier plane.\(^{20-25}\) The main idea of such an approach lies in the fact that the spatial-frequency structure of the Fourier transform of the laser image of a blood plasma polycrystalline network is different for its large-scale albumin and small-scale globulin structures. Therefore, through space-frequency filtering, one can mainly select either low-frequency (with predominant linear birefringence) or high-frequency (mainly optically active) components, which can be converted into corresponding “separated” laser images by means of reverse Fourier transform.

To measure the phase shift distribution \( \delta \) of linear birefringence, the sample was located between the two crossed quarter-phase filtered plates \( \{\Phi_1\} \) and \( \{\Phi_2\} \). Transmission planes of polarizers \( \{P_1\} \) and \( \{P_2\} \) make up angles with the axes of the highest rate +45 deg and −45 deg. The amplitude \( \hat{E} \) in each point \( (x, y) \) of the laser image is defined by the network equation

\[
\hat{E}(x, y) = 0.5 \{P_2\} \{\Phi_2\} \{Q\} \{\Phi_1\} \{P_1\} E_0,
\]

where

\[
\begin{align*}
\{E_{00}\} &= \begin{bmatrix} 1 \\ 1 \end{bmatrix}; \\
\{P_1\} &= \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}; \\
\{P_2\} &= \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}; \\
\{\Phi_1\} &= \begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}; \\
\{\Phi_2\} &= \begin{bmatrix} i & 0 \\ 0 & 1 \end{bmatrix}.
\end{align*}
\]

The solutions of Eq. (5) are

\[
\hat{E}(x, y) \times \hat{E}^*(x, y) = I_0 \sin^2 \frac{0.5 \delta(x, y)}{I_0} = I_\delta(x, y),
\]

where \( * \) is a complex conjugate value, \( I_0 \) is the intensity of the probing beam, and

\[
I(\delta) \rightarrow \begin{cases} 0 & \leftrightarrow \delta = 0; \\
1 & \leftrightarrow \delta = \pi,
\end{cases}
\]

is the intensity of the points of a polarization-frequency filtered laser image.

Thus, to solve Eq. (8) and determine the distribution of phase shifts \( \delta(x, y) \) in a “low-frequency” image of a polycrystalline
network, it is necessary to record the array of normalized values of intensity \( I_\delta(x, y)/I_0 \) in Eq. (7) by means of charge coupled device (CCD)-camera.

To determine the coordinate distribution \( \theta(x, y) \) in the points of a “high-frequency” image of a polycrystalline network, the smear of blood plasma was placed between two crossed polarizers \( \{ P_1 \} \) and \( \{ P_2 \} \), where

\[
\hat{E}(x, y) = 0, 5\{ P_2 \} \{ A \} \{ P_1 \} E_0.
\]

The solutions of Eq. (6) are

\[
\hat{E}(x, y) \times \hat{E}^*(x, y) = I_0 \sin^2 2\theta(x, y) = I_0 \theta(x, y),
\]

\[
\theta(x, y) = \arcsin 0.5 \sqrt{\frac{I_0(x, y)}{I_0}}.
\]

For an objective estimation of distributions

\[
q = \begin{cases} 
\delta(x, y) \\
\theta(x, y),
\end{cases}
\]

we used the statistical and fractal approaches. There are two reasons for this choice. The first is that all biological objects are phase-inhomogeneous and are traditionally studied using statistical methods of scattering media optics.\(^1\)\(^-\)\(^3\) The second is that the morphological structure of the main types of biological tissues (connective, muscle, and epithelial) is self-similar in scale, and the structure of their polarizationally inhomogeneous images is fractal.\(^27\)\(^,\)\(^29\) On the other hand, within such a complex approach, optical anisotropy of biological fluids has not yet been studied.

### 2.1 Statistical Approach

A total sum of statistical moments of the first to four orders \( Z_{j=1,2,3,4} \) was calculated with the algorithms\(^12\)

\[
Z_1 = \frac{1}{N} \sum_{i=1}^{N} |(q_i)|, \quad Z_2 = \frac{1}{N} \sum_{i=1}^{N} (q_i)^2,
\]

\[
Z_3 = \frac{1}{(Z_2)^2} \frac{1}{N} \sum_{i=1}^{N} (q_i)^3, \quad Z_4 = \frac{1}{(Z_2)^2} \frac{1}{N} \sum_{i=1}^{N} (q_i)^4.
\]

### 2.2 Fractal Approach

A fractal analysis of \( q(x, y) \) distributions was performed using the calculation of logarithmic dependences \( \log J(q) - \log d^{-1} \) for the power spectra \( J(q) \)\(^13\)\(^,\)\(^14\) with an evaluation of \( D \) dispersion.

Dependences \( \log J(q) - \log d^{-1} \) are approximated into curves \( V(\eta) \) using the least squares method and are classified in such a way that:

- \( q(x, y) \) are fractal on condition that the value of the slope is constant \( \eta = \text{const} \) for two to three decades of a change of sizes \( d \);
- \( q(x, y) \) are multifractal, on condition of the presence of several slopes in \( V(\eta) \);
- \( q(x, y) \) are random, in case of the absence of stable slopes over the whole range of a change of sizes \( d \).

### 3 Optical Realization of Fourier Phase Polarimetry

Figure 1 presents a diagram of a laser Fourier polarimeter with spatial-frequency filtration.\(^18\)\(^,\)\(^23\)

Illumination of a sample under study was performed by a parallel (\( \phi = 10^\circ \)) laser beam of He-Ne (\( \lambda = 0.6328 \) \( \mu \)m, \( W = 5.0 \) mW). The polarization light source consisted of quarter-wave plates and a polarizer and formed a right circularly polarized beam. Blood plasma smears applied on the optically homogeneous glass were placed in the focal plane of polarization microscope objective 7 in the figure (focal distance: 30 mm, aperture: 0.1, magnification: 4\( \times \)). The vignetting diaphragm was located behind the (Fourier) focal plane, and its size changed within the range of 2 to 300 pix. Polarization microscope objective 8 in the figure (focal distance: 30; aperture: 0.1, magnification: 4\( \times \)) was located at the focal length from the frequency plane of lens 7 and thus performed an inverse Fourier transform of a filtered out polarization field of laser radiation. The coordinate distribution of intensity of such fields, polarizationally filtered by quarter-wave plate 9 and the polarizer, was registered in the plane of the CCD-camera (The Imaging Source DMK 41AU02.AS, monochrome 1/2\" CCD, Sony ICX205AL (progressive scan); resolution: 1,280 \( \times \) 960; light sensitive area size: 7600 \( \times \) 6200 \( \mu \)m; sensitivity: 0.05 lx; dynamic range: 285).
4 Method of Polarization-Phase Mapping of Laser Images of Blood Plasma

Two statistically valid (confidence interval \( p < 0.01 \)) groups of samples were used as objects of investigation:

- blood plasma of healthy (donor) patients—group 1 (20 samples);
- blood plasma of rectal cancer patients (adenocarcinoma)—group 2 (20 samples).

Figure 2 presents phase maps of polycrystalline networks of blood plasma samples of all groups.

Figure 3 illustrates the coordinate, statistical, and scale-self-similar structure of phase maps \( \phi(x, y) \) of blood plasma images determined by polarization mapping.

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**Fig. 2** Phase maps obtained by (1) polarization mapping, (2) concerted low-frequency filtering, and (3) concerted high-frequency filtering of blood plasma from healthy (group 1) patients and by (4) polarization mapping, (5) concerted low-frequency filtering, and (6) concerted high-frequency of blood plasma from rectal cancer (group 2) patients.

**Fig. 3** Structure of phase maps \( \phi(x, y) \) of the images of blood plasma from healthy patients (left column) and rectal cancer patients. From top to bottom: coordinate maps, probability histograms \( H(\phi) \), and scale self-similar maps \( \log J - \log d^{-1} \).
It can be seen from the data obtained that the optical anisotropy of polycrystalline networks of blood plasma smears is manifested in the insufficient phase-shifting capability of samples from both groups. At the same time, a somewhat higher level of local extremes is typical for the blood plasma samples from cancer patients. However, the main extremes of histograms $H(q)$ are rather close, both in value and in localization.

This can be explained by small values for the geometrical thickness ($\sim 15 \mu m/20 \mu m$) of blood plasma smears and indices of circular ($\theta \sim 10^{-1} \text{ rad/cm}^2$) and linear ($\Delta n \sim 10^{-3}$) birefringence of albumin and globulin.

While analyzing the coordinate structure of phase maps of blood plasma smears, we followed the next principles in dividing the contribution of “signals” and “noise.” The “noise” component is most vivid on the “tails” of logarithmic dependencies of power spectra in the range of 1 to 10 $\mu m$ of changing the sizes of structural elements of the phase map. This fact is stipulated by the absence of blood plasma protein crystals of such size. Therefore, the real spatial-frequency signal is formed by the structural elements of polycrystalline networks, the sizes of which are in the range of 10 to 1000 $\mu m$.

The coordinate structure shown in Fig. 3 is multifractal (two slopes of approximating curves $V(\eta)$ of logarithmic dependencies $\log J - \log d^{-1}$). The determined peculiarity is probably caused by the formation of two differently scaled and scale-self-similar components of polycrystalline network—dendrite (albumin crystals) and clumpy (globulin crystals) ones—in the process of blood plasma drying.

Phase distributions $\varphi(x, y)$ of blood plasma smears’ laser images are quantitatively illustrated by the values of statistical ($Z_{i=1;2;3;4}$) and fractal ($D, V(\eta)$) parameters, averaged within the two groups of patients, as shown in Table 1.

The comparative analysis of these parameters, characterizing the dependencies $\varphi(x, y), H(q), \log J - \log d^{-1}$, did not reveal any sufficient difference between them. Maximal differences between them do not exceed 40% ($Z_{i=4}$) to 50% ($Z_{i=3}$).

The intragroup analysis of diagnostic effectiveness of the polarization mapping method showed a low level of sensitivity $Se = \frac{N_{\text{true}}}{N_{\text{true}} + N_{\text{false}}}$ 100% = 60% and specificity $Sp = \frac{N_{\text{true}}}{N_{\text{true}} + N_{\text{false}}}$ 100% = 60%, where $a = 12$ and $b = 8$ are the number of correct and incorrect diagnoses within group 1; $c = 11$ and $d = 9$ are the same within group 2. In other words, the method proved ineffective for the task of differentiation between the blood plasma samples of healthy and rectal cancer patients.

### Table 1: Statistical $Z_{i=1;2;3;4}$ and fractal $D, V(\eta)$ parameters of phase distributions $\varphi(x, y)$.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Norm (21 samples)</th>
<th>Cancer (20 samples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z_{i=1}$</td>
<td>0.17 ± 0.026</td>
<td>0.21 ± 0.032</td>
</tr>
<tr>
<td>$Z_{i=2}$</td>
<td>0.31 ± 0.055</td>
<td>0.37 ± 0.062</td>
</tr>
<tr>
<td>$Z_{i=3}$</td>
<td>1.23 ± 0.18</td>
<td>1.84 ± 0.29</td>
</tr>
<tr>
<td>$Z_{i=4}$</td>
<td>0.78 ± 0.11</td>
<td>0.99 ± 0.13</td>
</tr>
<tr>
<td>$V(\eta)$</td>
<td>Multifractal</td>
<td>Multifractal</td>
</tr>
<tr>
<td>$D$</td>
<td>0.26 ± 0.043</td>
<td>0.22 ± 0.036</td>
</tr>
</tbody>
</table>

5 Spatial-Frequency Fourier Phasometry of the Linear and Circular Birefringence of Polycrystalline Blood Plasma Networks

To find the optimal conditions of spatial-frequency filtration, the range $\Delta r = 2 \text{ pix} \div 50 \text{ pix}$ of possible measurements for the vignetting diaphragm was selected. Within such a range, we determined the scale, with which a set of statistical moments of the first to fourth orders characterizing distributions $q = \{ \delta(x, y), \theta(x, y) \}$ reached extreme values. In our case, the parameters $q = \{ \delta(x, y) \rightarrow R = 30 \text{ pix} \times 30 \text{ pix}; \theta(x, y) \rightarrow R^{-1} = 20 \text{ pix} \times 20 \text{ pix}$ of selecting the polarization of manifestations of the linear and circular birefringence of optically anisotropic blood plasma components were determined.

Figure 4 presents the coordinate $(x, y)$, statistical $(H)$, and spectral $(\log J - \log d^{-1})$ parameters of distributions $\delta(x, y)$ (“albumin polycrystalline network”), obtained by the technique of concerted polarization-phase and spatial-frequency filtration.

Comparative analysis of the data obtained revealed sufficient difference between the coordinate distributions and phase shifts $\delta$ formed by the linear birefringence of albumin crystals. The histogram $H(\delta)$ of a spatial frequency filtered image of the blood plasma layer from a patient in group 2 is more symmetrical and is characterized by localization of the main extreme in the domain of high values of $\delta$. This can be related to “pathological” growth of albumin concentration and the formation of large-scale acicular crystals in the plane of the blood plasma smear.

As shown in Fig. 4, logarithmic dependencies of power spectra of phases distribution in the laser images of blood plasma of healthy and sick patients are similar.

The phase distributions $\delta(x, y)$ of spatial-frequency and polarization-phase filtered images of blood plasma smears are quantitatively illustrated by statistical ($Z_{i=1;2;3;4}$) and fractal ($D, V(\eta)$) parameters, as shown in Table 2.

The comparative analysis of the data obtained revealed sufficient intergroup differences (marked by gray color) between the statistical moments of higher orders characterizing phase distributions $\delta(x, y)$. The values of statistical moments of the third and fourth orders obtained for blood plasma from group 2 include more corresponding parameters of a group of donors by 2.45 and 3.4 times, respectively.

Intergroup analysis of diagnostic effectiveness of the method of polarization-phase low-frequency filtering of blood plasma laser images revealed the increase of sensitivity indices $Se = 75\% (a = 15$ and $b = 5$) and specificity $Sp = 70\% (c = 14$ and $d = 6$) when compared with the polarization mapping technique (Table 1).

Figure 5 presents the coordinate $(x, y)$, statistical $(H)$, and spectral $(\log J - \log d^{-1})$ parameters of distributions $\theta(x, y)$ (“globulin polycrystalline network”) obtained by the method of concerted polarization, described in Eqs. (9)–(11), and spatial-frequency filtration.

Comparative analysis of the data obtained showed the increase of optical activity of blood plasma taken from a rectal cancer patient. The corresponding histogram $H(\theta)$ is characterized by a higher (up to 2.5 times) half-width $\theta$ value distribution in comparison with the similar distribution obtained for blood plasma of a healthy donor. This can be explained by
“pathological” growth of globulin concentration and by the increased effect of circular birefringence. The above-mentioned process is also manifested in the scalar self-similarity breaking of distribution \( \theta(x, y) \) in the domain of small geometrical sizes 10 \( \mu \text{m} \)/40 \( \mu \text{m} \). In the approximating curve \( V(\eta) \) of logarithmic dependencies of the power spectra \( \theta(x, y) \) in laser images of blood plasma of sick patients, there is no stable slope \( \eta \).

For the blood plasma of a healthy man, the dependencies \( \log J - \log d^{-1} \) have two slopes, as shown in Fig. 5. This indicates the multifractality of phase maps of circular birefringence of clumpy polycrystalline networks of globulin of group 1 samples. The distributions \( \theta(x, y) \) are quantitatively illustrated by statistical \( (Z_{i=1;2;3;4}) \) and fractal \( [D, V(\eta)] \) parameters, as shown in Table 3.

The analysis of the obtained data revealed sufficient intergroup differences (marked by gray color) between all statistical moments \( (Z_{i=1;2;3;4}) \) characterizing distributions \( \theta(x, y) \):

- Statistical moment of the first order \( Z_{i=1} \) increases in group 2 by 2.8 times.
- Statistical moment of the second order \( Z_{i=2} \) increases in group 2 by 2.95 times.
- Statistical moment of the third order \( Z_{i=3} \) decreases in group 2 by 3.9 times.
- Statistical moment of the fourth order \( Z_{i=4} \) decreases in group 2 by 2.4 times.

The scalar self-similar distribution \( \theta(x, y) \) of group 1 is transformed into a random one in group 2. This causes the increase of dispersion \( D \) of \( \log J - \log d^{-1} \) dependencies in group 2 by 2.4 times.

The intragroup analysis of diagnostic effectiveness of the method based on the polarization high-frequency filtration of laser images of blood plasma showed a high level of sensitivity \( Se = 85\% \) (\( a = 17 \) and \( b = 3 \)) and specificity \( Sp = 80\% \) (\( c = 16 \) and \( d = 4 \)) indices.

The considered method of concerted polarization-phase and spatial-frequency filtration was tested for other types of biological fluids in:

- diagnostics of cholelithiasis—bile smears (\( Se = 78\%; Sp = 69\% \));
- operational differentiation of acute and gangrenous appendicitis—smears of exudate from a postoperational appendicostomy (\( Se = 81\%; Sp = 73\% \));

<table>
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<th>Cancer [20 samples]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Z_{i=1} )</td>
<td>0.35 ± 0.047</td>
<td>0.56 ± 0.084</td>
</tr>
<tr>
<td>( Z_{i=2} )</td>
<td>0.33 ± 0.042</td>
<td>0.19 ± 0.28</td>
</tr>
<tr>
<td>( Z_{i=3} )</td>
<td>0.62 ± 0.11</td>
<td>1.53 ± 0.21</td>
</tr>
<tr>
<td>( Z_{i=4} )</td>
<td>0.48 ± 0.077</td>
<td>1.65 ± 0.22</td>
</tr>
<tr>
<td>( V(\eta) )</td>
<td>Multifractal</td>
<td>Multifractal</td>
</tr>
<tr>
<td>( D )</td>
<td>0.31 ± 0.043</td>
<td>0.38 ± 0.052</td>
</tr>
</tbody>
</table>
differentiation of inflammatory diseases of joints (osteoarthritis and osteoarthritis)—smears of knee joint synovial fluid (Se = 74%; Sp = 67%).

6 Conclusion
The model of generalized optical anisotropy of blood plasma polycrystalline networks considering the linear birefringence of albumin acicular crystals and circular birefringence of clumpy globulin crystals was suggested. Within the developed model, the process of forming the amplitude-phase structure of a laser radiation field transformed by polycrystalline networks in the plane of a blood plasma smear image and in the Fourier plane was analyzed.

The method of concerted spatial-frequency and polarization-phase filtration of blood plasma images was substantiated and tested for separating the manifestations of linear and circular birefringence of albumin-globulin networks. The interconnections between the values of statistical moments of the first to fourth order and fractal parameters characterizing phase distributions of spatial-frequency filtered laser images and the physical state of a patient were found.

The sensitivity and specificity of the developed method of concerted spatial-frequency and polarization-phase filtration of laser images of various biological fluids (blood plasma, bile, exudate, and synovial fluid) in diagnostics of different pathologies of human organism were determined.

References