Non-invasive research of biological objects by the method of laser polarimetry

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Abstract. Recent studies have displayed that the biological tissue, especially skin, alters the polarization state of the incident light. Using this property will enable the study of abnormalities and diseases that change not only the light intensity but also its polarization state. This paper briefly considers spatial speckle-correlometry and polarimetry method for measuring changes of polarization state of the light scattered from a biological tissue. This technique provides the possibility to have the most comprehensive information on the optical and polarization properties of the skin sector containing scar structures and other abnormalities and diseases. Practical application of the developed approach is shown in the research.

1. Introduction
Recently there have been increased rather disputable questions related to the optical methods for diagnosing diseases caused by alterations in morphological characteristics in biological tissues including the epidermis. The evolution of proper diagnostic techniques for monitoring skin abnormalities is currently one of the most challenging areas of research. Nearly all examination and diagnostic methods for measuring the progress of skin disease are based on visualisation [1]. Abnormal changes in the skin layers structure cause optical properties alteration of healthy and diseased tissue. In general skin shows absorption and scattering properties when it is exposed to light. The majority of the existing methods are based on measuring intensity of backscattered and transmitted light. Studies have shown that tissue affects the polarization state of the incident light. The main polarization-altering agents are scattering particles such as cell nuclei, mitochondria and collagen fibers which demonstrate birefringent effect [2]. Thus, the progress of diseases could be determined and monitored by measuring the polarization state changes. That particular property is the basis for proposed method. Non-invasive and highly sensitive three dimensional speckle-correlometry and polarimetry technique has certain perspectives. Such approach helps to get the information on properties of large scatterers in human epithelium, provide histological data about human tissues without causing damagers of the cutaneous structure [3,4]. Apart from that this method can be performed in-vivo. Moreover, our optical spatial speckle-correlometry technique may be efficiently applied in various areas, for example in experimental mechanics for obtaining the information about macro displacements, anelastic deformations, rotations, velocity of moving objects, vibration characteristics, surface finish quality, structural defects, etc. [5].

2. Theory
Correlation and statistical analysis of the speckle intensity fluctuations of scattered fields provide the additional information about the inner and morphological structure of the scattering object. The possible approach for speckle modulated scattered fields is the usage of cross-correlation functions of
the speckle intensity fluctuations with different polarization states. This provides demonstration of the developed fine polarization structure [6]. The speckle size can be determined from calculations of the normalized autocovariance function of the speckle intensity pattern obtained in the observation plane, \( R_I(\Delta x, \Delta y) \) corresponds to the normalized autocorrelation function of the intensity. It has a zero base and its width provides the “average width” of a speckle. Obviously, \( R_I(\Delta x, \Delta y) \) is calculated from the intensity distribution of the measured speckle, \( I \), as described in [7]

\[
R_I = \frac{\text{FT}^{-1}\left[\left.\text{FT}[I(x,y)]^2\right]-\langle I(x,y) \rangle^2\right]}{\left\langle I(x,y)^2 \right\rangle-\langle I(x,y) \rangle^2},
\]

where \( \text{FT} \) is the Fourier Transform, \(< > \) is a spatial average, \( R_I(\Delta x,0) \) and \( R_I(0, \Delta y) \) are the horizontal and the vertical profiles of \( R_I(\Delta x, \Delta y) \), respectively.

3. Experimental setup

The experimental setup for studying the diffuse back-reflectance of polarized light is depicted in Fig. 1.

![Figure 1](https://example.com/figure1.png)

**Figure 1.** Scheme of the experimental setup. 1 — laser diode, 2 — polariser, 3 — lens, 4 — tissue under study, 5, 6 — polarizer, 7, 8 — photomultiplier with a pinhole, 9 — oscilloscope, 10 — computer.

In this research model experiments were performed on the leaves of trees which are at various stages of withering. In some places, there were damages on the samples under study — a small area of the leaf. During scanning with polarized light of the examined objects alterations in the recorded signals when the beam passed through the affected regions were observed. To each polarimetric state of the incident field corresponds a unique variation of intensity during the scan [8]. During this scan, the projection state that is the closest to the polarimetric state of the incident field will give rise to maximum intensity at the output of the analyser. On the contrary, there will be the minimum output when the incident state of illumination is projected on the more diametrically opposed state [9, 10]. The experiment was carried out in a darken room. A laser diode emitted a beam with \( \lambda = 650 \) nm through a linear polarizer oriented parallel to the sample scattering plane. After, went through a lens, it gets on the sample under study. Further the backscattered light passes through a second linear polarizers 5 and 6 oriented parallel and perpendicular to the scattering plane. The data recorder
consisted of photodetectors 7, 8 and also an oscilloscope 9 and the personal computer for further processing 10.

4. Results of the research and their discussion
Our experimental study was performed in vivo and as a result the time series of speckle intensity fluctuation induced by the sample scanning were obtained. The intensity fluctuations are caused by the sample scanning across the light beam. Figure 2 shows the typical forms of the intensity cross-correlation function for different stages of the leaves withering.

![Figure 2](image)

**Figure 2.** Normalized autocorrelation function of registered speckle intensity fluctuations of the studied leaves samples which are at various stages of withering.

Here $g_1$ is a correlation function for the green leaf, $g_2$ – yellow, $g_3$ – red one. Different correlation characteristics of speckle intensity fluctuations of samples that were investigated showed a high sensitivity to discussed changes in tissue structure [11]. This approach has a number of assets over the other diagnostic methods, by reason of rather high speed-of-response, accuracy and multifunctionality [12]. Thus, it can be applied to an internal and external research of structure of the human tissue in vivo. We are currently working on the analysis of the area of the skin that contains scar structures and other abnormalities and diseases. Eventually, charts of the polarization characteristics distribution of the skin will be received.

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