Analysis of the effect of lens components on the optical properties of polarization radiation in experimental studies of biomarkers

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Abstract. This article dwells upon the investigation of the radiation polarization structure in analysing biological tissues. The systematic investigation of the polarization parameters of lens systems with non-planar media boundaries was performed to increase the accuracy parameters of polarization instruments used to analyse biological tissues. A review of existing solutions, developed mathematical model and experimental setup were given, and series of experiments are described.

1. Introduction

Under the authority of anthropogenous impacts, biological systems change their properties. According to these changes it could detect the conversion in entire ecological system. The local plants, the disappearance or appearance of certain living organisms, variance in the composition of the soil or air can serve as markers. However, more significant information can be obtained by studying the morphologic composition of the analytical, physical and chemical methods at the molecular level of such biomarkers. One of the effective method of analysis such biomarkers is using optical polarization devices.

Polarization is a property of a light wave, the vector characteristic of which has a component that is orthogonal to the direction of light wave at a given point in space. However, when radiation passes through a mirror-lens system, the wave structure is changed. These changes lead to errors that are not taken into account when obtaining the results of studies using polarization methods.

The purpose of this article is a systematic investigation of the polarization parameters of lens systems with non-planar media boundaries, the result of which is an experimental setup scheme and a method for obtaining the results. To achieve that it is necessary to describe the optical properties of polarization radiation, which are changed with the passage of lens components, develop a block diagram of the experimental setup for studying the data of optical properties, and formulate a methodology for conducting experiments to study the optical properties of polarization radiation.

Impotent part of the work is an implementing for biomarkers analysis in ecological monitoring. Biomarker is a characteristic or mark which indicated about changing in organism or system. In ecological monitoring, it can be certain plants or bacteria. Worsening or improving the environment can be detected by shift or changing of polarization radiation.
2. Methods and results
During the work, the following methods of describing polarized radiation during the passage of lens systems were identified: if fully polarized radiation is used, then using the method and Jones matrices; if partially polarized, using the method and Muller matrices. The method of three-dimensional tracing was also selected to reduce the calculation error.

The most suitable values for a quantitative assessment of the properties of fluctuating optical radiation are the Stokes parameters introduced in 1852. Through them it was possible to express the various characteristics of the radiation under study and their variations in real time.

This method is based on the analysis of the radiation polarization parameters when calculating the four Stokes parameters:

\[ S_0 = I_0 = I_x + I_y, \]
\[ S_1 = I_x - I_y, \]
\[ S_2 = I_{45^\circ} - I_{-45^\circ}, \]
\[ S_3 = I_r - I_l. \]

All Stokes parameters have intensity dimension. Based on these expressions, the first Stokes parameter is the total wave intensity; the second is the intensity difference of the orthogonally polarized components; the third parameter represents the intensity difference between the linearly polarized components measured in a linear basis, the position of which differs by \( \pi / 4 \) angle from the position of the linear basis determining the first two parameters; the fourth parameter is the intensity difference of the two opposite circularly polarized components [1, 2].

![Figure 1. Method of experimental determination of Stokes parameters.](image)

The method of experimental determination of parameters is based on the idea of four filters F1, F2, F3 and F4 (Figure 1), which transmitted 0.5 frequencies of incident nonpolarized radiation.

In this case:
- The filter F1 has anisotropic properties. Radiation with intensity I1 passes through F1;
- The filter F2 transmits a radiation with intensity I2. Radiation after F2 has principally horizontal direction of vector E oscillation;

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- The filter F3 transmits a radiation with intensity \(I_3\) and vector \(E\) oscillations at an angle of \(\pi/4\) to the horizontal direction;
- The filter F4 transmits a right circulation polarized radiation with intensity \(I_4\).

According to these parameters, the equations of the basic parameters of polarized radiation can be used for detecting the changes in the radiation state: azimuth (5), ellipticity (6) and degree of polarization (7).

\[
P = \frac{\sqrt{(S_1^2 + S_2^2 + S_3^2)}}{S_0},
\]

\[
\alpha = \frac{1}{2} \arctg (S_2 / S_1),
\]

\[
\beta = \frac{1}{2} \arcsin \left( \frac{S_3}{\sqrt{(S_1^2 + S_2^2 + S_3^2)}} \right).
\]

Obviously, Stokes parameters are the most universal tool for analyzing the polarization state of quasi-monochromatic optical radiation in real time. This method is convenient when conducting a real experiment on the installation, since all parameters of polarized radiation can be set on the installation and read through the program.

It is necessary that the developed installation includes the following elements:
- Emission source (ES), with a small angle of divergence of the light beam to create monochromatic collimated radiation;
- Polarizer (P), to create a linearly polarized radiation;
- Analyzer (A), forming polarized radiation, described by the Malu law. Special requirements for the quality and homogeneity of creating polarized radiation are applied to P and A;
- Phase plate (PP), which creates circular radiation at the output of the laboratory setup. The ES should radiate at the working wavelength (or close to it) of the PP, therefore it is more expedient to use the LED as the ES;
- Emission receiver (ER), for accurate reception of the signal from the installation output and for imaging, readable by the Personal Computer (PC). It is necessary that the ER could break the image into small areas and read their intensity. For this purpose, it is recommended to use a receiver with a single matrix field. The matrix receiver also should be taken with a large number of pixels so that it is possible to track small increments of intensities when changing the orientation of the lens.

All elements must lie on the same optical axis. To study the polarization properties of the passage of radiation, it is necessary to enter a prototype - a lens between the P and A. For processing the results, the Stokes method was used.

The following block diagram was developed (Figure 2).

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**Figure 2.** Structural combined experimental installation: ES – emission source, P – polarizer, L – lens, A – analyzer, PP - phase plate, ER – emission receiver, PC – personal computer, PS – power supply.
An LED with a radiation maximum at a wavelength of $\lambda = 523$ nm was used as a source in the scheme, and an EVS VEC-545-USB television camera with a CMOS sensor was used as ER. The television camera used in the installation allows to work both in automatic mode and with adjustable parameters. In particular, one of the features is the disabling of the gamma correction during photometric measurements to ensure the linearity of the light-signal characteristics. In addition, there is the possibility of both automatic adjustments of exposure and amplification, and manual with the aim of matching the desired spot scattering with radiation conditions.

The setup used a quarter-wave PP operating at a wavelength of $\lambda = 532$ nm.

For each of the lenses at different angles of incidence of polarized radiation (0°, 5°, 10° and 15°), it is necessary to determine the Stokes parameters, on the basis of which the ellipticity, azimuth and degree of polarization of the transmitted radiation are calculated.

The method of measuring the polarization parameters of radiation using a laboratory setup consists of the following steps:

1. At the entrance of the P comes the radiation from the LED. With the help of P, the maximum transmission of polarized radiation through it is achieved (linearly polarized radiation is obtained).
2. Set A to 0° and take readings without entering the PP. We also take readings for position A 90°, + 45° and -45°.
3. We enter the PP after A and achieve circular radiation at the output of the experimental installation. We take readings at positions A -45° and + 45°.

A LabView program was formed to analyze the resulting scattering spot by the magnitude of the signal, which makes it possible to investigate test samples in real time. The program evaluates the position of the circle of dispersion and accordingly adjusts the size of the analyzed area of the matrix. This area is generally the size of $m \times n$, where $m$ and $n$ are the number of unit cells horizontally and vertically, respectively. In turn, each unit cell has the dimension $a \times a$, where $a$ is the number of pixels. Thus, the Stokes parameters and, therefore, the polarization parameters of the transmitted radiation are calculated for each of the unit cells [3].

![Single cell](image)

**Figure 3.** Splitting the surface of the lens on a single site.

In case of lens components, there is an unevenness of radiation distribution. The curvature values of the lens in the center and at the edges differ when split into single cells (Figure 3). The consideration of radiation using matrices was proposed.

3. **Conclusion**

Research of the polarization parameters of lens systems in experimental studies of biomarkers is made. In the course of the work the Stokes method was chosen to describe the optical properties of polarized radiation, and polarization parameters such as azimuth, ellipticity and degree of polarization were
selected to record changes in the radiation structure. A block diagram of the experimental setup for studying the data of optical properties was developed and the main blocks were selected. The methodology for conducting experiments on the study of the optical properties of polarization radiation was formed. The installation can be used in environmental monitoring. It can be applied for changes detecting in biomarkers.

References

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