Statistical modeling of local polarization states of laser light multiple scattered: fundamentals of the speckle-polarization correlometry

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Intro: The work is devoted to modeling the states of local polarization of partial waves during multiple scattering of laser radiation in random media, depending on its parameters.

Method: Modeling of the local polarization states of the multiply scattered laser radiation is based on the Monte Carlo method using the Stokes formalism and further visualization of the distribution on the Poincaré sphere.

Incident wave:
\[ \mathbf{E}_0 = E_0 e_1 + E_0 e_2 + E_0 e_3 \]
\[ \mathbf{E}_\varphi = E_{\varphi 1} e_1 + E_{\varphi 2} e_2 + E_{\varphi 3} e_3 \]

Scattered wave:
\[ \mathbf{E}_s = E_{s 1} e_1 + E_{s 2} e_2 + E_{s 3} e_3 \]

\[ \mathbf{E}_s = e^{i(\alpha - \varphi)} \times \begin{pmatrix} S_2 \ 0 \ S_1 \end{pmatrix} \times \begin{pmatrix} E_{\varphi 1} \ E_{\varphi 2} \ E_{\varphi 3} \end{pmatrix} \]

\[ S = \begin{pmatrix} S_0 \ S_1 \ S_2 \end{pmatrix} \]

\[ S_0 = E_x x \times E_y y = I_{x y} \]
\[ S_1 = E_z z \times E_y y = I_{y z} \]
\[ S_2 = E_z z \times E_x x = I_{x z} \]
\[ S_3 = (E_x x \times E_y y) - (E_y y \times E_x x) = I_{x y} - I_{y x} \]

S is the Stokes matrix. The scattering angles are random for each scattering event and \( \varphi \in [0,2\pi) \):

\[ \cos \theta = \frac{1}{2g} \left( 1 + g^2 - \frac{(1 - g^2)^2}{(1 + 2g^2)^2} \right) \]

The degree of polarization is evaluated as:
\[ P = \frac{I_0 - I_0}{I_0 + I_0} \]

*Modeling parameters:
\( \lambda_0 = 633 \text{ nm} \)
\( n = 1.46 \)
\( n_p = 1.44 \)
\( a = 50, 100, 250, 500, 750 \text{ nm} \)

Results of modeling:

Fig. 1. Evolution of the local polarization states depending on the particle size \( ka = 10.72 \) and the number of scattering acts \( N : (a) \cdot N = 3, (b) \cdot N = 6, (c) \cdot N = 12 \). The probing radiation is linearly polarized, as shown by the arrow.

Fig. 2. Evolution of the local polarization states depending on the particle size \( ka = 1.42 \) and the number of scattering acts \( N : (d) \cdot N = 3, (e) \cdot N = 6, (f) \cdot N = 12 \). The probing radiation is linearly polarized, as shown by the arrow.

Fig. 3. The plot showing the interrelation of the residual linear polarization of the multiply scattered radiation and the particle size with increasing number of scattering acts \( 1 \cdot ka = 0.69, 2 \cdot ka = 1.38, 3 \cdot ka = 3.47, 4 \cdot ka = 6.95, 5 \cdot ka = 10.72 \).

Conclusions: In local polarization structures of speckle pictures formed by multiple scattering acts in random media, a certain regularity of polarization states of individual components depending on the particle size, medium parameters, probed radiation and number of scattering acts is traced. In this way, two modes of behavior of local polarization states can be identified:

1. Rayleigh scattering mode;
2. Mie scattering mode.

In the case of Rayleigh scattering, linear polarization states of individual components dominate as the number of scattering acts increases, while in the Mie scattering regime, there is a tendency for elliptical polarization states to predominate, changing randomly from speckle to speckle.