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OPTICAL SIGNATURE of WOOD SAMPLE WITH DIFFERENT SCATTERING ANGLES BY USING MUELLER MATRIX

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ABSTRACT

Mueller Matrix Detection Polarimetry is a highly effective imaging technique that provides precise measurements of Mueller matrices in each detected image pixel. The employed technology obtains 16 Mueller Matrix pictures, which are then processed to look at the sample's polarization properties. This discussion describes the optical setup used to capture the Mueller Matrix Images operating in reflection frame, and presents the resulting polarization characteristics for the same wood sample under a selection of scattering angles.

Keywords: Anisotropy, Muller Matrix Polarimetry, Polarization, Imaging Polarimetry, Multiple scattering.

INTRODUCTION

A relationship between the polarisation states of incident and exiting beams for a sample can be obtained through the application of sample measuring polarimetry, which is one of the subfields that make up the science of polarisation measurement. This subfield is one of several that are divided into distinct categories. The measurements are taken with the assistance of a group of polarising elements that are situated between a source and a sample, and the beams that are leaving the apparatus are examined with the assistance of an additional group of polarisation elements that are situated between the sample and the detector. Therefore, a complete polarimeter, also known as a Mueller polarimeter, is obtained.

The Mueller matrix measurement system that is described in this paper is comprised of a polarisation generator, a polarisation analyzer, and a sample to be measured in between them. Both of these devices contain a rotating waveplate, which was described in the works of a number of different researchers. 2-7. The effects of optical polarisation that are simultaneously happening in the sample are investigated in relation to the 16 Mueller matrix elements that were obtained. Altering the angle at which the scattering occurs and studying the properties as a function of the scattering In addition, the results of this investigation are expected to provide information regarding the nature of the composition of the material and the influence that nature has on the state of the input polarisation.

THEORY

The polarisation state of light can be characterised by four objective factors that are collectively referred to as the Stoke parameters. The column vector [8] is the most common representation of this 4-stroke vector. $S = \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix}$ ----------------- (1)

The principle of optical equivalence developed by G.G. Stokes in 1853 demonstrates that the Stokes vector is an exhaustive representation of the polarisation state of a light beam. The Stokes vector (S) of a light beam goes through a linear transformation to become a new Stokes vector (S') whenever the Stokes vector of the light beam is modified (scattered) by an optical element. This transformation is typically referred to as the Mueller or Polarization matrix (M), and its representation is a four-by-four matrix with the common notation.

$$S' = M \times S \qquad \text{------------ (2)}$$

$$\begin{pmatrix} S_0' \\ S_1' \\ S_2' \\ S_3' \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{pmatrix} \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} \text{------ (3)}$$

Since the Mueller matrix stores all polarisation information, the Stokes vector used to describe the light beam's polarisation is sufficient.

The Mueller matrix M, in addition to its standard form, can be represented as

$$M = m_{11} \begin{pmatrix} 1 & \bar{D}^T \\ \bar{P} & m \end{pmatrix} \text{------- (4)}$$

Where $\bar{D}^T = \frac{1}{m_{11}}(m_{12} \quad m_{13} \quad m_{14})$ & $\bar{P} = \frac{1}{m_{11}}(m_{21} \quad m_{31} \quad m_{41})$called as Diattenuation and Polarization vectors correspondingly and 'm' is a 3 X 3 matrix.

Hans Mueller was the first person to use matrices to perform complicated computations in order to solve complicated polarisation problems. In fact, the formalism that bears his name, the Mueller Matrix formalism, was named after him. In order to make significant progress in completing the difficult computations, he computed the matrices for the polarizer, wave plate, and rotator. This was an important step. The Mueller Matrix provides a comprehensive characterization of polarisation elements [11&13-14]. Hans Mueller, the person who formalised polarisation calculations based on intensity, is recognised as the namesake of the

Mueller formalism. It's possible that not all Mueller Matrices can be realised in the physical world. For a Mueller Matrix to be considered physically realisable, the primary requirement is that the incident Stokes vector must be physically realisable from the resultant Stokes vector through the use of the Mueller Matrix. Because of this, it is necessary to have a Degree of Polarization that is either less than or equal to one, also known as.

$$P = \frac{\sqrt{(s_1{}^2+s_2{}^2+s_3{}^2)}}{s0} \leq 1 \qquad (5)$$

The inequality [16] is a well-known restriction on the Mueller Matrix.

$$(MM^T)^T = \sum_{i,j=0}^{3} m_{ij}{}^2 \leq 4m_{11}{}^2 \qquad (6)$$

The diattenuation is defined as,

$$D = \frac{T_{\max} - T_{\min}}{T_{\max} + T_{\min}} \qquad (7)$$

and values varies from 0 - 1.

The diattenuation of the Mueller Matrix is

$$D = \frac{T_{\max} - T_{\min}}{T_{\max} + T_{\min}} = \frac{1}{m_{11}} \sqrt{m_{12}{}^2 + m_{13}{}^2 + m_{14}{}^2} \qquad (8)$$

The individual terms constituting the diattenuation vector are operationally defined by

$$D_H = \frac{T_H - T_V}{T_H + T_V} = \frac{m_{12}}{m_{11}}, D_{45} = \frac{T_{45} - T_{135}}{T_{45} + T_{135}} = \frac{m_{13}}{m_{11}} \; and \; D_C = \frac{T_R - T_L}{T_R + T_L} = \frac{m_{14}}{m_{11}} \qquad (9)$$

here T_H is the horizontally polarized light transmittance, T_V is the vertically polarised light transmittance, T_{45} - linear 45^0 polarised light transmittance, T_{135} - linear 135^0 polarised light transmittance, T_R - right circularly polarised light transmittance, and T_L - left circularly polarised light transmittance.

Polarizance refers to the polarisation that occurs when totally unpolarized light is converted into polarised light.

$$P = \frac{1}{m_{11}} \sqrt{m_{21}{}^2 + m_{31}{}^2 + m_{41}{}^2} \qquad (10)$$

and can take values from 0 to 1.

The fast axis and the retardance vector are denoted by

$$\overline{R} \equiv R\hat{R} = \begin{pmatrix} Ra_1 \\ Ra_2 \\ Ra_3 \end{pmatrix} \equiv \begin{pmatrix} R_H \\ R_{45} \\ R_C \end{pmatrix} \tag{11}$$

where the components define the circular, horizontal, and 45^0 linear retardances. The linear retardance that is still present is

$$R_L = \sqrt{R_H^2 + R_{45}^2} \tag{12}$$

and the total retardance is

$$R = \sqrt{R_H^2 + R_{45}^2 + R_C^2} = \sqrt{R_L^2 + R_C^2} = |\overline{R}| \tag{13}$$

The following is a normalised Mueller Matrix M:

$$M = \begin{pmatrix} 1 & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{pmatrix} = \begin{pmatrix} 1 & \overline{D}^T \\ \overline{P} & m \end{pmatrix} \tag{14}$$

Where the sub Matrix m is

$$m = \begin{pmatrix} m_{22} & m_{23} & m_{24} \\ m_{32} & m_{33} & m_{34} \\ m_{42} & m_{43} & m_{44} \end{pmatrix} \tag{15}$$

And $\overline{D}$, $\overline{P}$: diattenaution , polarization vectors and the diattenuator M_D is considered after the first row of M, and M_D^{-1} be multiplied by M to find retarder Matrix $M_R = MM_D^{-1}$. Then diattenuator of Matrix is specified as

$$M_D = \begin{pmatrix} 1 & \overline{D}^T \\ \overline{P} & m_D \end{pmatrix} \tag{16}$$

where

$$m_D = aI_3 + b\left(\overline{D}.\overline{D}^T\right) \tag{17}$$

and where I3 is the identity matrix for a 3 by 3 grid, and a and b are scalars that are obtained from the norm of the diattenuation vector, i.e., where I3 is the norm of the diattenuation vector.

$$D = |\overline{D}|, \ \ a = \sqrt{1 - D^2} \text{ and } b = \frac{1-\sqrt{1-D^2}}{D^2} \tag{18}$$

The attenuation vector is used to characterise the intensity transmission of the polarization element. The polarization state that is produced as a result of an unpolarized input state may be described using the depolarization vector. This study goes through a few different topics, including attenuation, depolarization, and retardance.

EXPERIMENTAL PROCEDURE

In order to illuminate the sample with distinct polarisation states, a linear polarizer (P) and a quarter wave plate (Q1) set were utilised as the light sources. In order to examine the polarisation state of the light that was reflected from the sample that was collected onto a detector, a different linear analyzer set (A) and a quarter wave plate set (Q2) were utilised. During the measurement, the analyzer and the collecting optics were maintained at three distinct scattering angles, respectively 30^0, 45^0, and 60^0, with respect to the beam direction. In order to collect the images of the 4 x 4 Mueller matrix, we generated 49 photographs by spinning the Polarizer and the Analyzer in the appropriate ways. The Wrightia Tinctoria sample is a piece of wood that was taken from a natural source. The sample number is 3, and its sample name is Passiflora edulis

The material that was obtained was dried for an entire year in order to allow the moisture content to naturally evaporate without altering the chemical composition. After that, it was submitted to a laboratory in Hyderabad, India, for a chemical analysis, and the results of that analysis are shown in Table 1 below.

Table 1: Sample chemical composition

Wood sample (Passiflora edulis)					
C %	H %	N %	O %	H_2O %	Others %
15.95	1.89	1.11	12.56	66.51	1.98

The sample has been finely polished to have an average thickness of 1.15 millimetres, with an average width of 58.25 millimetres and an average length of 136.45 millimetres accordingly. Figure 2 depicts the experimental setup schematic that was used in the experiment.

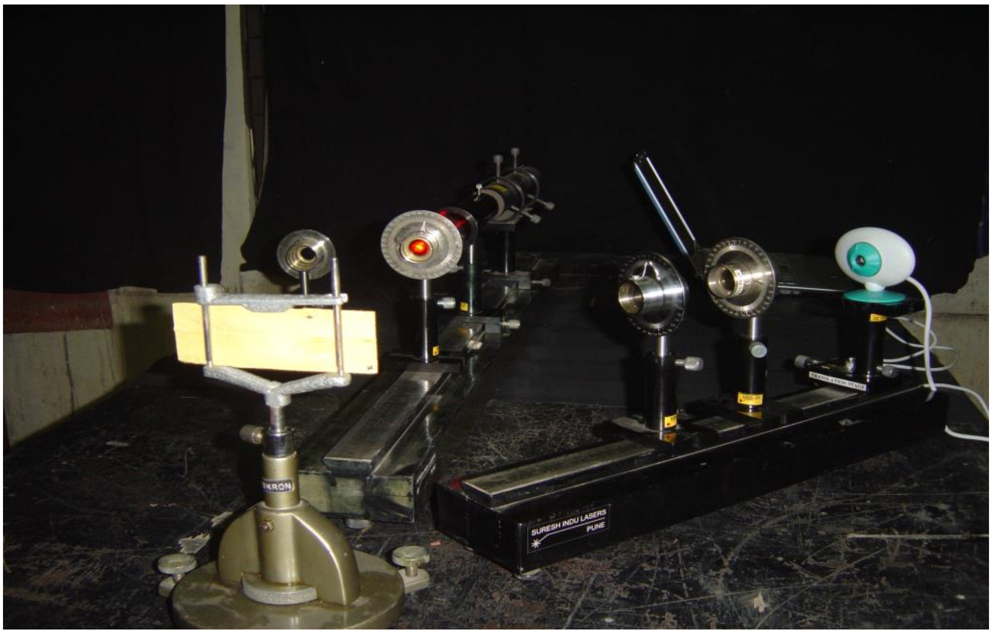

Figure2: Mueller matrix elements: an experimental setup diagram

Figure3: Wood sample (Passiflora edulis)

EXPERIMENTAL RESULTS

The Mueller matrix provides the sample's optical fingerprint. To acquire the 16 Mueller matrix pictures, 49 intensity photos with varied Polarizer and Analyzer orientations are required12. Following the acquisition of 49 intensity photos, the following 16 elemental Muller matrix images are obtained:

where the first subscript in the intensity parameters represents the input state and the second subscript represents the output state, and here, H represents horizontal polarisation, V represents vertical polarisation, P represents $+45^0$, M represents -45^0, R represents right circular polarisation, and L represents left circular polarisation. Figure 4 shows the similar images, which were acquired by using a self-developed MATLAB programme to crop the image for uniform pixel size and extract intensity information for the image pixel by pixel.

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Once all 16 photos have been gathered, they are processed using a MATLAB programme that was written to calculate the intensity component of each pixel in the image before processing the image to obtain its overall intensity information. The resulting Muller matrix is normalised to the m11 component, which separates the intensity-dependent effects from the polarisation effects and makes further analysis more straightforward.

The diattenuation, depolarization, and retardance pictures are derived from the measured Mueller matrix and are displayed in Figures 3, 5, and 6. Finally, the sample's mean values of diattenuation and depolarization are determined using a MATLAB tool created for intensity image analysis, and the findings are displayed in Table3.

Table3: Average values of Diattenuation, Depolarization & Retardance gained from the images from sample -3 (Passiflora edulis)

Scattering angle	Diattenuation	Depolarization	Retardance
30^0	0.6038	0.3692	2.3748
45^0	0.3649	0.9021	2.0962
60^0	0.2947	0.7953	2.3973

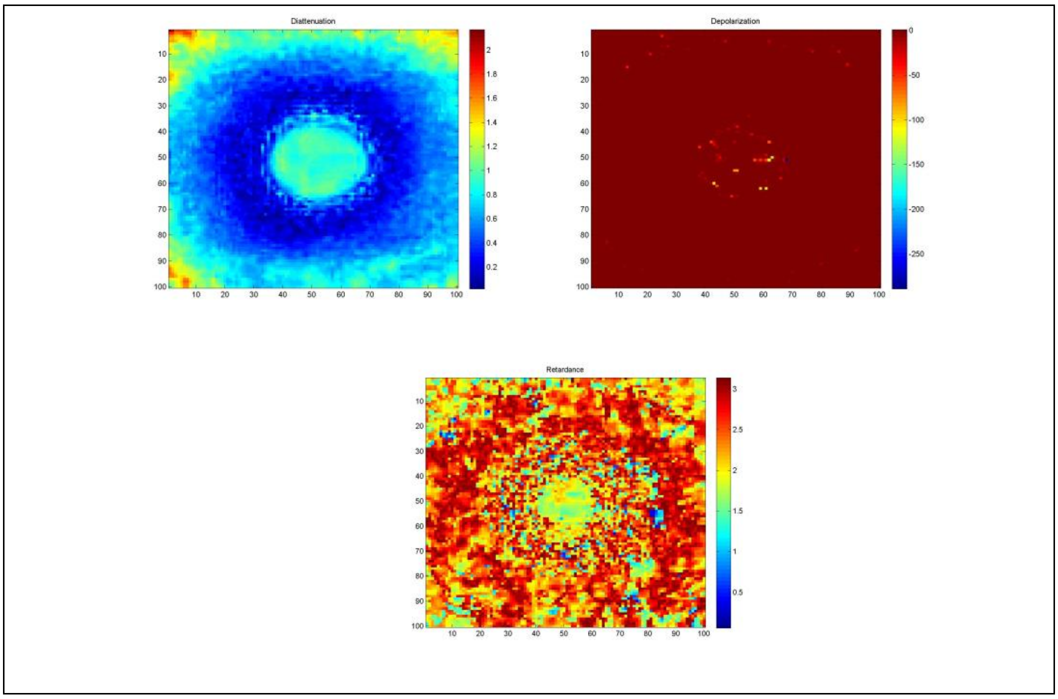

Figure 3: Images of diattenuation, depolarization & retardance sample scattering angle-30^0

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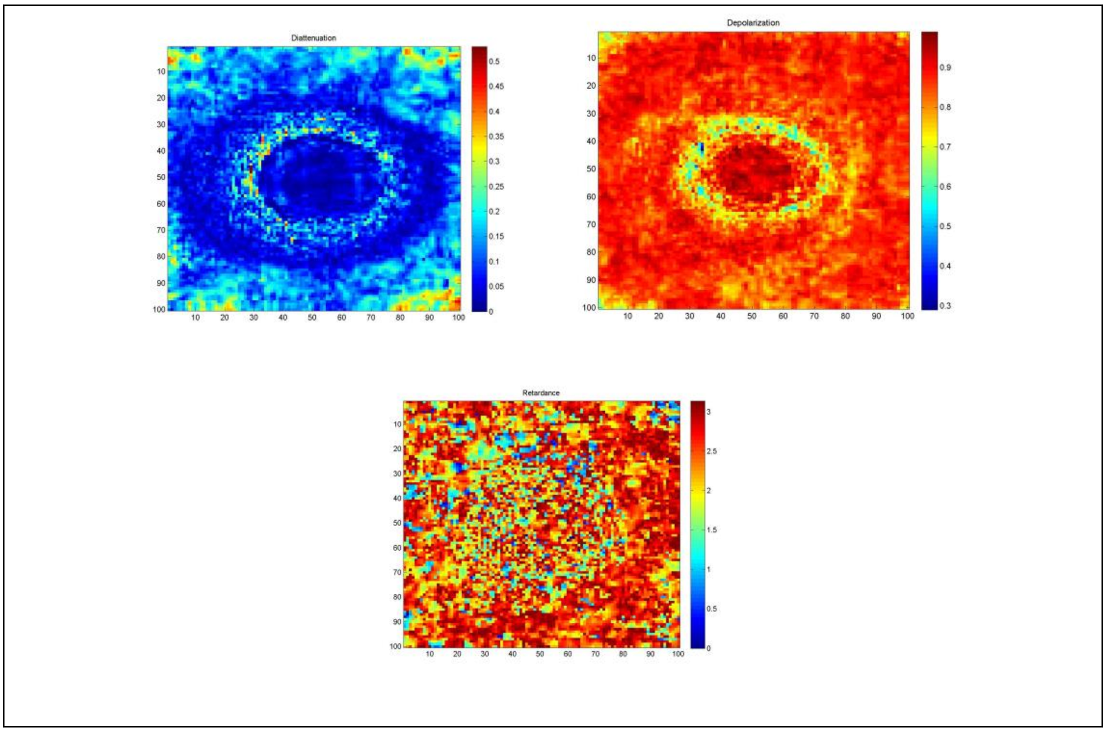

Figure4: Diattenuation, Depolarization & Retardance Image for sample scattering angle-45^0

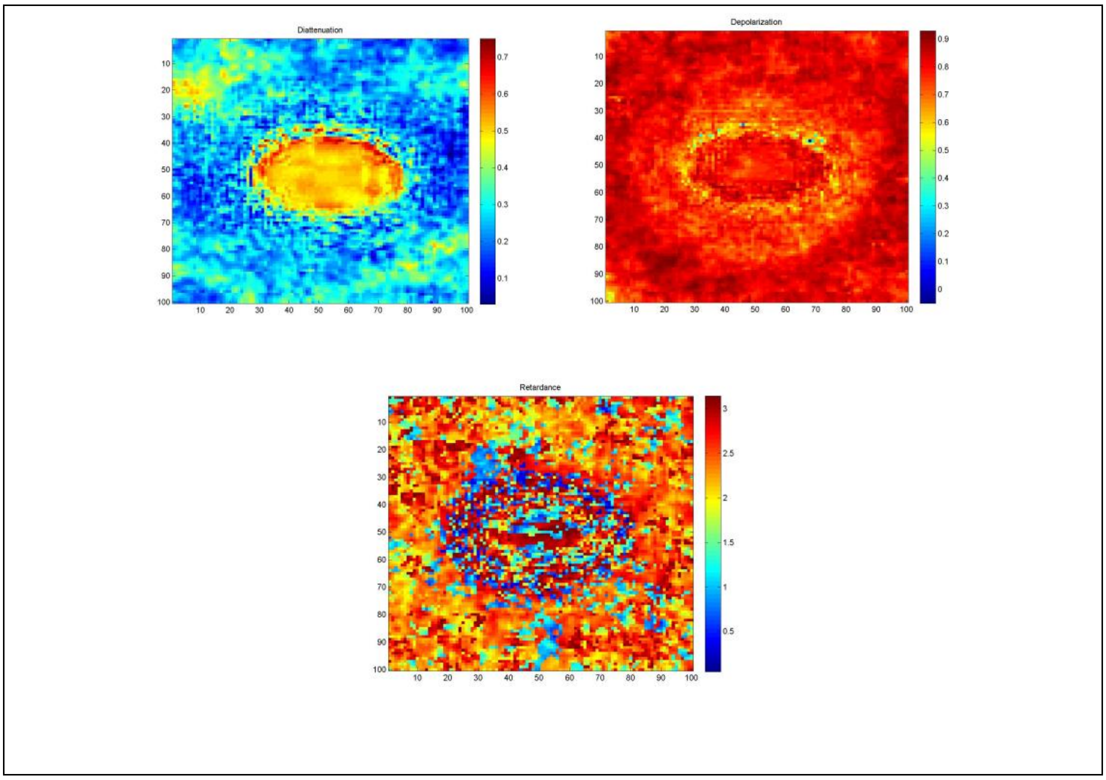

Figure5: Diattenuation, Depolarization & Retardance Images for sample at scattering angle-60^0

RESULTS AND DISCUSSION

The following is an explanation of how the analysis was carried out in these studies, which involved the use of data in the form of photographs. The photos that were taken were then processed and cropped to the dimensions of the bright spot (128 X 128 pixels). After the images were cropped, they were decomposed so that values for diattenuation, depolarization, and retardance could be obtained for each individual pixel. The values of these parameters were then plotted after being averaged out across all of the pixels. In addition, the Mueller images were computed, and the results are compared. These pictures were levelled with regard to the first element of the Mueller matrix before being used (M11). The decomposition plots were averaged column by column, and the associated values were shown so that a comparison could be made between the various scattering angles of the sample (30^0, 45^0, and 60^0). The pictures from the Mueller investigation were likewise subjected to the same procedure.

CONCLUSION

We were able to obtain the wood sample's optical signature in the form of a Mueller matrix through our experimental methods. The results show, as predicted, that at different scattering angles, such as 30^0, 45^0, and 60^0, the wood sample displays a varied polarisation anisotropic character. The full nature of a sample can be gleaned by examining how its Depolarization, Diattenuation, and Retardance change as a function of scattering angle.

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