AIJREAS VOLUME 1, ISSUE 9 (2016, SEPT) (ISSN-2455-6300) ONLINE
ANVESHANA'S INTERNATIONAL JOURNAL OF RESEARCH IN ENGINEERING AND APPLIED SCIENCES

POLARIZATION SIGNATURE - COFFEE SAMPLES COMPARISON

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ABSTRACT

Mueller Matrix imaging polarimetric technique was used to understand the polarization property of coffee sample, a complete Mueller polarimeter of coffee sample is obtained using the technique. The potential application of this in optical characterization and discrimination of coffee sample with a reference to the elemental composition of sample is described.

A highly collimated monochromatic and polarized beam with predefined states of polarization from a source was incident on surface of coffee powder sample, from the reflected beam using appropriate optics and states of polarization, the variation of polarization in the sample was recorded as image and translated into a signature matrix. Image processing algorithms are established for obtaining 16 elemental Mueller Matrix images that are verified theoretically to meet the conditions of a complete polarimeter. The obtained images were processed using polar decomposition technique to determine the normalized elemental Mueller Matrix which was further used to understand the Depolarization, Diattenuation and Retardance coefficients in the sample.

Keywords: *Mueller Matrix Imaging, Optical signature, Polarization states, Coffee sample*

I. INTRODUCTION

Mueller Matrix imaging polarimetry is a widely used technique for polarization measurement, in these linear variations between polarization states of incident and excited beams from a sample are obtained [1-7].

The optical polarization effects simultaneously occurring in the sample are studied with respect to the 49 captured images with predefined polarization states and then reduced to 16 element Mueller matrix images as described in the works of some researchers [8-14]. These images are processed pixel by pixel and are then normalized to first element to get a signature matrix. The polarization change in the sample is understood in terms of the values and images obtained from the signature matrix, that are further processed to understand the characteristic change in the image and are attributed to the variation in properties of coffee sample

The basic constraint for a Mueller matrix to be physically realizable is that the incident Stokes vector is physically realizable from the resultant Stokes vector through the Mueller matrix.

THEORY

The polarization state of light is characterized by stokes parameters represented as

$$S=\begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} \tag{1}$$

A light beam represented by this Stokes vector when incident on the sample, undergoes a transformation represented by a 4 X 4 matrix called the Mueller Matrix and the transformed Stokes vector is written as

$$S' = M \times S \tag{2}$$

$$\begin{pmatrix} S'_0 \\ S'_1 \\ S'_2 \\ S'_3 \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{pmatrix} \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} \tag{3}$$

Where $\begin{pmatrix} S'_0 \\ S'_1 \\ S'_2 \\ S'_3 \end{pmatrix}$

is the stoke vector of transmitted/reflected/ scattered light.

$\begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{pmatrix}$ is the Mueller matrix and

$\begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix}$ is the stoke vector of incident light.

This S' matrix gives measurable polarization information of the output light beam.

The Mueller matrix M can be also written as

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

Where $\bar{D} = \frac{1}{m_{11}}\begin{pmatrix} m_{12} & m_{13} & m_{14} \end{pmatrix}^T$ &

$$\bar{P} = \frac{1}{m_{11}}\begin{pmatrix} m_{21} & m_{31} & m_{41} \end{pmatrix}$$

are called as Diattenuation and Polarizance vector respectively and 'm' is a 3 X 3 matrix [4].

Diattenuation characterizes the intensity transmittances of the incident polarization states.

All Mueller matrices may not be physically realizable. The basic constraint for a Mueller matrix[10] to be physically realizable is that,

$$\left(MM^{T}\right)^{T} = \sum_{i,j=0}^{3} m_{ij}^{\;2} \le 4m_{00}^{\;2} \qquad (5)$$

This imposes a condition that the Degree of Polarization is less than or equal to one, i.e.,

$$P = \frac{\sqrt{\left(S1^2 + S2^2 + S3^2\right)}}{S0} \le 1 \qquad (6)$$

In our earlier works [13-14] we have proved that we get a recognizable Mueller matrix for these coffee samples.

Retardance is a property that indicates the phase change and has constant intensity transmittance for any incident polarization state.

II. Experimental Procedure

Coffee samples were illuminated with a beam of light through a Polarization state Generator and with predefined polarization state. The collection optics is kept at 45^0 from the input beam direction throughout the experiment. As shown in Figure 1.

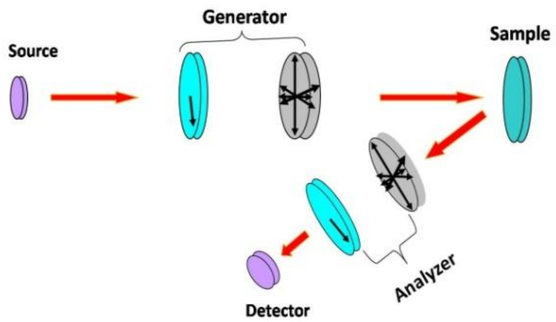

Figure 1: Experimetnal setup.

The coffee samples considered here are collected from different regions of Ethiopia as shown in Figure2.

Grown on the rolling hills of southwestern Ethiopia, the Arabica type Yirgacheffe gourmet coffee is hand-sorted and harvested. Each batch is wet processed to improve the acidity and enhance its clean floral notes. Full bodied with mild earthly flavor, the coffee is roasted medium-light, it produces a unique fragrance and a lingering intensified finish. It boasts a sweet, rich and smooth flavor.

Figure 2: Coffee Sample Collected

The samples is powdered and sewed to obtain a uniform granular size and is ready for experimentation as shown in Figure 3.

Figure 3: Roasted and powdered coffee

49 intensity images with various orientations of Polarizer and Analyzer are necessary to obtain the 16 elements of Mueller matrix images. The 49 intensity images obtained are named as follows

I_{OO}	I_{OH}	I_{OV}	I_{OP}	I_{OM}	I_{OR}	I_{OL}
I_{HO}	I_{HH}	I_{HV}	I_{HP}	I_{HM}	I_{HR}	I_{HL}
I_{VO}	I_{VH}	I_{VV}	I_{VP}	I_{VM}	I_{VR}	I_{VL}
I_{PO}	I_{PH}	I_{PV}	I_{PP}	I_{PM}	I_{PR}	I_{PL}
I_{MO}	I_{MH}	I_{MV}	I_{MP}	I_{MM}	I_{MR}	I_{ML}
I_{RO}	I_{RH}	I_{RV}	I_{RP}	I_{RM}	I_{RR}	I_{RL}
I_{LO}	I_{LH}	I_{LV}	I_{LP}	I_{LM}	I_{LR}	I_{LL}
I_{OO}	I_{OH}	I_{OV}	I_{OP}	I_{OM}	I_{OR}	I_{OL}

where, the first subscript indicates input state, and the second subscript the output state.

After acquiring 49 intensity images the 16 elemental Mueller Matrix is obtained from the following relations

$\mathbf{m_{11}}= I_{OO}$; $\mathbf{m_{12}}= I_{HO}-I_{VO}$

$\mathbf{m_{13}}= I_{PO}-I_{MO}$; $\mathbf{m_{14}}= I_{LO}-I_{RO}$

$\mathbf{m_{21}}=I_{OH}-I_{OV}$; $\mathbf{m_{22}}=(I_{HH}+I_{VV})-(I_{HV}+I_{VH})$

$\mathbf{m_{23}}=(I_{PH}+I_{MV}))-(I_{PV}+I_{MH})$;

$\mathbf{m_{24}}=(I_{RV}+I_{LH})-(I_{RH}+I_{LV})$

$\mathbf{m_{31}}=I_{OP}-I_{OM}$

$\mathbf{m_{32}}=(I_{HP}+I_{VM})-(I_{HM}+I_{VP})$; $\mathbf{m_{33}}=(I_{PP}+I_{MM})-(I_{PM}+I_{MP})$

$\mathbf{m_{34}}=(I_{RM}+I_{LP})-(I_{RP}+I_{LM})$; $\mathbf{m_{41}}= I_{OL}-I_{OR}$

$\mathbf{m_{42}}=(I_{HL}+I_{VR})-(I_{HR}+I_{VL})$; $\mathbf{m_{43}}=(I_{PL}+I_{MR})-(I_{PR}+I_{ML})$

$\mathbf{m_{44}}=(I_{RR}+I_{LL})-(I_{RL}+I_{LR})$

The 16 element Mueller Matrix image obtained for one coffee sample are as shown here in Figure 4. For the other coffee sample the images obtained similarly.

The acquired intensity images are processed using polar decomposition technique using scripts in MATLAB platform to acquire intensity component [13]. This Mueller Matrix obtained is normalized to the first element of the matrix to isolate the intensity dependent effects in the image

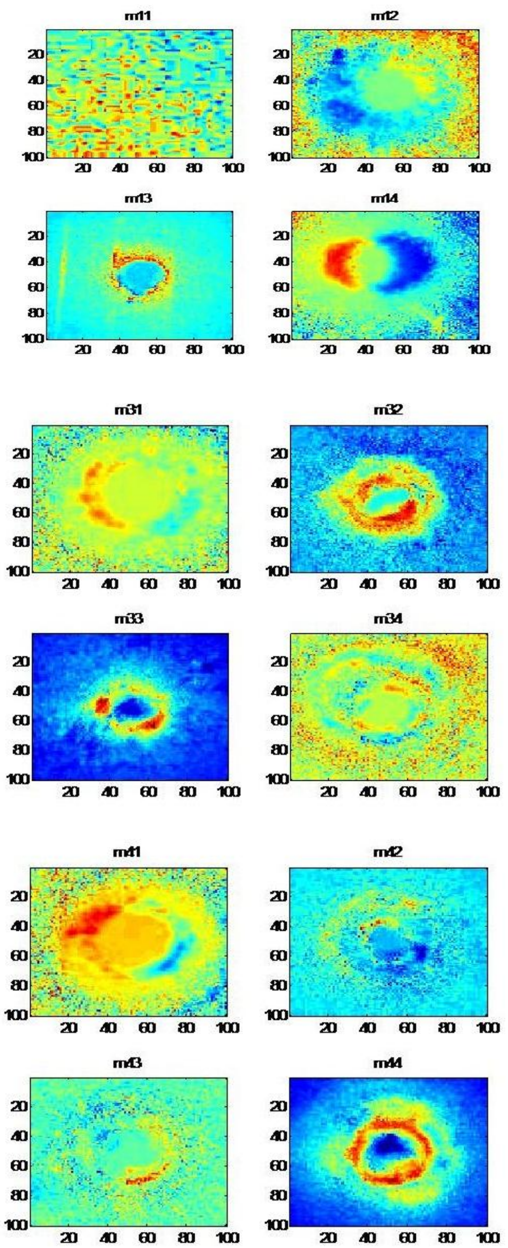

Figure 4: Mueller Matrix images of Yirgacheffe region coffee

and also simplifies the analysis. The measured Mueller Matrix is shown in Table 1 and Table 2 for sample 1 and sample 2 respectively.

Table 1: Mueller matrix values of coffee sample1

(M_{11}) 1	(M_{12}) 0.0697	(M_{13}) -0.0697	(M_{14}) 0.0235
(M_{21}) 0.4186	(M_{22}) 0.0976	(M_{23}) -0.2558	(M_{24}) 0.0325
(M_{31}) 0.7209	(M_{32}) 0.5116	(M_{33}) -0.0932	(M_{34}) -0.3729
(M_{41}) 0.0279	(M_{42}) 0.2760	(M_{43}) 0.0932	(M_{44}) -0.2093

TABLE I.

Table 2: Mueller matrix values of coffee sample2

(M_{11}) 1	(M_{12}) 0.0967	(M_{13}) -0.4418	(M_{14}) 0.0162
(M_{21}) 0.1162	(M_{22}) 0.0697	(M_{23}) 0.2558	(M_{24}) 0.4651
(M_{31}) 0.3488	(M_{32}) 0.4486	(M_{33}) -0.0930	(M_{34}) -0.3534
(M_{41}) 0.0674	(M_{42}) 0.2930	(M_{43}) 0.1395	(M_{44}) 0.2465

III. Results

From the measured Mueller Matrix the Diattenuation, Retardance and Depolarization images are acquired and the mean values of Diattenuation and Depolarization for the samples are obtained and indicated in Table3 and Table4 for sample1 and sample2 respectively.

Table III. Mean polarization values obtained for sample 1

Coffee sample	Mean values
Diattenuation	0.3580
Depolarization	0.4470
Retardance	2.1175

Table IV. Mean polarization values obtained for sample 2

Coffee sample	Mean values
Diattenuation	0.3821
Depolarization	0.3940
Retardance	2.0935

The 49 intensity images with various orientations of polarizer, Analyzer and waveplates are obtained and from them the 16 element Mueller Matrix image are obtained as shown in Figure 4

IV. Discussion

The polarization response of samples were observed and compiled with equation5 to fulfill the constraints. The diattenuation, depolarization, Retardance values are obtained. The depolarization value is attributed to the different scatterings of incident light by coffee sample, the diattenuation variation is because of different surface texture though same granular size is used for investigation. The difference in Retardance value is due to discontinuity present, this value also reflects the variation of composition and moisture present in the sample.

V. Conclusion

Optical signatures of the Coffee samples, collected from Yirgacheffe region and Dara region of Ethiopia, in the form of a Mueller matrix were obtained and as expected they exhibited polarization anisotropic character which is evident from the results tabulated. The experiment results identified various optical polarization changes and scattered intensity distributions for both samples were helpful in distinguishing the samples considered.

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