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MUELLER MATRIX POLAR DECOMPOSITION OF BREAST TISSUE

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ABSTRACT

We report the potential of Mueller decomposition images to discriminate the Breast tissue to generate scattering intensities images with different optical states of seven and four independent variables. Polarimetric imaging is an emerging technique that uses polarized light to probe the acceptance of the tissue with the different independent variable states. A polar decomposition technique reveals the polarization parameters of the breast tissue effectively. It is observed there is a change in the Mueller matrix that which is obtained from the Breast tissue with the states of seven and four independent variables.

Keywords: mueller decomposition, scattering polarization, imaging through tissue.

INTRODUCTION

Tissue are generally estimated by noting changes in the epithelium and stromal region The grade of Breast tissues decided by the thickness up to which structural changes occur in the epithelium component cells and stromal component. Stromal component also consists of the fibrous, blood vessels and lymphatic vessel. Normal tissue will be consisting of the stromal component and the epithelium component cells in the ratio of 2:1. [1]. However, it has been reported in the literature that there is a distortion in the collagen fibers during the development of dysplastic stage in stroma [2].Optical Light generation is used to reveal subtle structural changes in cells [3]. Polarized light scattering in the form of Mueller matrix describes completely optical properties of any scattering medium like tissue, polystyrene micro-spheres etc..

The 16 elements of Mueller matrix generated by recording images of any scattering medium for various combinations of polarizer and analyzer can provide information such as the size and refractive index of the scattering medium [4]. In addition to these Mueller matrix elements, diattenuation, retardance and depolarization values can also reveal more information about the structure and morphology of highly scattering media such as biological tissues. These parameters (diattenuation, retardance and depolarization value) for any scattering medium can be extracted by polar decomposition of Mueller matrix given by Lu *et al.* [3].

Experimentally it is easier to measure scattered intensities in terms of Stoke's parameters using an Open state (O), Horizontal (H), Vertical (V), Linear+45°(+45°),Linear-45°(-45°),Right circular(R) and Left circular (L) states as the seven independent states than to directly measure the phase and magnitude of scattered electric fields. [5-7] The Stoke's vector is a description of the polarization state of light based on these measurable intensities. The Mueller matrix is a description of how polarized light propagation through a sample changes this Stoke's vector.

A Mueller Matrix must satisfy two constraints to be experimentally perfect i.e., physically realizable. First the Polarization Constraint i.e. the matrix must not over-polarize and secondly the Gain Constraint i.e. the gain of the matrix must be less than unity [8-9].

The 16 elements of the Mueller matrix generated by using the Mueller matrix decomposition approach enables one to extract quantify and interpret the individual intrinsic polari metric characteristics of tissue in terms of Diattenuation, Depolarization and Retardance [10].

THEORY

Let M be a 4x4 Mueller matrix as given below

$$\boldsymbol{M} = \begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{pmatrix} \tag{1}$$

The Mueller matrix M can be decomposed into three elementary matrices represented as

$$\mathrm{M} = \mathrm{M}_\Delta\, \mathrm{M}_\mathrm{R}\, \mathrm{M}_\mathrm{D} \tag{2}$$

Where M_Δ is the Depolarizing matrix which indicates the depolarizing effects of the sample. M_R represents the effects of linear birefringence and optical activity and is called as Retardance matrix and finally M_D describes the effects of linear and circular dichorism called as Diattenuation Matrix.

All these values can be directly obtained from the Mueller matrix and are elaborately discussed by many researchers [8]. A program is written in Mat Lab platform to decompose the Mueller matrix in terms of the intensity values obtained for each pixel of the illuminated region

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and considering the mean intensity values. The mean values of Diattenuation, Retardance and Depolarization are obtained

We can calculate directly diattenuation D from the Mueller matrix M as

$$D= \frac{(m_{01}^2+m_{02}^2+m_{03}^2)^{\frac{1}{2}}}{m_{00}} \tag{3}$$

From the Mueller matrix M**,** first we can construct a diattenuator Mueller matrix by taking diattenuation vector D

$$\text{As } \bar{D} = \frac{1}{m_{00}}\begin{pmatrix} m_{01} \\ m_{02} \\ m_{03} \end{pmatrix} \tag{4}$$

Thus the first row of M gives the diattenuation vector. Then from this diattenuation vector the diattenuator Mueller matrix can be constructed as

$$M_D = \begin{bmatrix} 1 & \overline{D^T} \\ \bar{D} & m_D \end{bmatrix} \tag{5}$$

EXPERIMENTAL DESIGN AND PROCEDURE

The samples used in this study were pathologically characterized, stained vertical sections of breast tissue (containing both epithelial and stromal regions) for normal states on glass slides. The lateral dimensions of tissue sample were 4 mm x 6 mm, having thickness of 5 μm. These samples were illuminated with He-Ne laser (Melles Griot, 20mW, λ = 632.8 nm) having spot size of 1.1 mm. Mueller images of these tissue slides were recorded in the transmission mode on a CCD

The sample considered here is pathologically characterized normal Breast tissues. The Breast tissue is sent in 10% formalin for proper fixation of the tissue. Unfixed and autolyzed tissues cannot be processed. The fixed specimen is grossed accordingly for identifying specific sites of Breast tissue, then using a scalpel blade the concerned part of the specimen is cut into even square shaped bits and taken into capsules, these capsules are then taken through different concentrations of alcohol for dehydration and hardening of the thyroid tissue [5-6]. It is inserted into containers with molten wax for impregnation of the wax into the tissues. This is to harden the tissue to prepare blocks which are later cut. The impregnated Breast tissues are then blocked with molten wax so that the cut surface of the Breast tissue is properly aligned and then allowed to harden. These blocks are mounted onto a micro tome which cuts the Breast tissue in the blocks in to 3-4 microns thick sections. These sections are taken onto slides and stained with Hematoxylin and Eosin stains. The slides are obtained from Gandhi Medical College, Hyderabad, India.

The Breast tissue sample was illuminated with 556nm laser source of 10mW power and through an appropriate PSG system. The collection optics is kept in line from the input beam direction throughout the experiment to acquire the intensity images in transmission mode, and the intensity information is gathered by a charge coupled device, after interacting with the sample and through an appropriate PSA system, the optical elements in the PSG and PSA system are calibrated well before the experiment,

RESULTS AND DISCUSSIONS

Using the seven independent variable states 49 intensity images are recorded and stored in jpeg format. Considering Lu and Chipman expressions these images are processed to obtain the 16 elemental Mueller matrix images [10] and from these the mean intensity values of each image is calculated and 4 × 4 Mueller matrix is generated by a program written in Mat Lab. From the measured Mueller matrix the necessary and sufficient condition for a physically realizable Mueller matrix given in above equations verified, this is observed to be in good agreement. Thus a physically realizable Mueller matrix is obtained and is represented in Table-1.

Table-1. Mueller matrix of seven independent variables.

1.00	0.32	0.08	0.16
0.96	0.64	-0.52	0.20
-0.52	-0.84	-0.04	-0.44
0.88	0.4	0.16	-0.52

The 49 recorded intensity images are processed using polar decomposition technique to obtain the Diattenuation, Depolarization and Retardance images, these are as shown in Figure-1(a), 1(b) and 1(c).

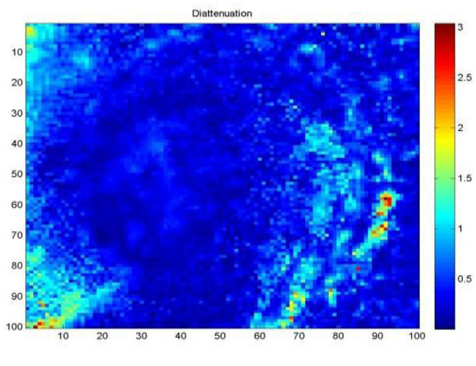

Figure-1(a). Diattenuation.

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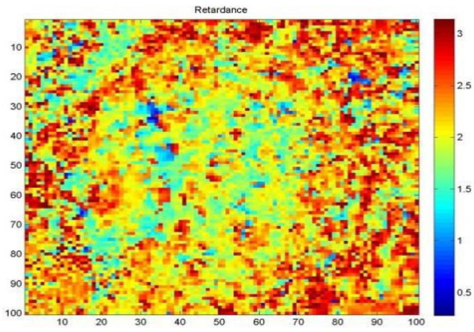

Figure-1(b). Retardance.

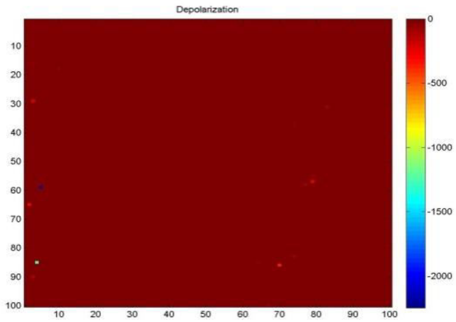

Figure-1(c). Depolarization.

Another method to obtain the intensity images from the experiment is by using 4 independent variable states i.e. H,V, +45° and R that generate only 16 intensity images, these are recorded and stored in JPEG format. Considering Yao and Wang expressions these images are processed to obtain the 16 elemental Mueller matrix images and from these the mean intensity values of each image are calculated and a 4 × 4 Mueller matrix is generated by a program written in Mat Lab. The matrix is verified according to above mentioned equations; here also it is observed that the matrix is in good agreement. The Mueller matrix obtained is given below in Table-2.

Table-2. Mueller matrix of four independent variables.

1.000	0.875	-0.75	-0.50
0.93	0.875	-1.25	-1.125
-0.125	-0.999	0.375	0.005
-0.500	-0.625	0.75	0.125

The 16 recorded intensity images are further processed using polar decomposition technique to obtain the Diattenuation, Depolarization and Retardance images, these are as shown in Figure-2(a), 2(b) and 2(c).

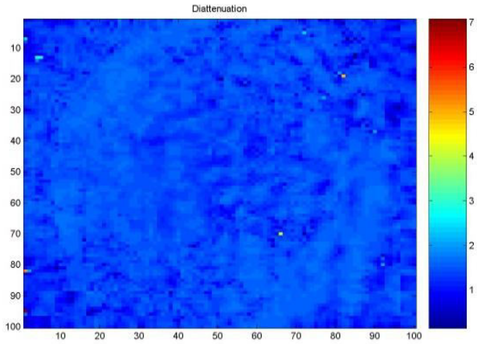

Figure-2 (a). Diattenuation.

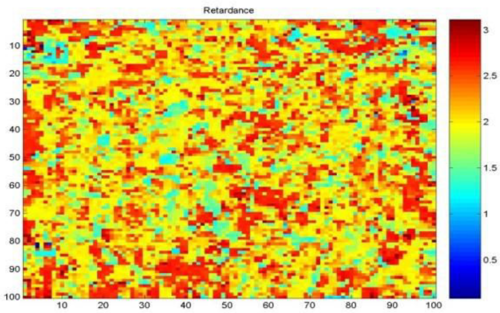

Figure-2(b). Retardance.

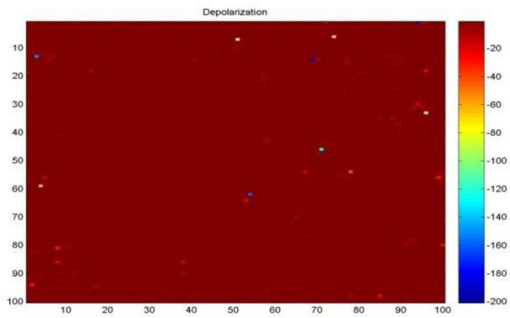

Figure-2(c). Depolarization.

Each of the independent polarization parameters hold a potential biological measurement, Depolarization is the ability to create randomly polarized light i.e.; loss of coherence of the incident field. Retardance is the shift of phase between orthogonal components of the incident field. Diattenuation is the difference in transmittance or reflectance between orthogonal components of the incident fields.

If larger is the Diattenuation value larger is the scattering coefficient which implies that higher density of scattering particles in the sample, Diattenuation is responsive to morphological and structural changes. The sample is a normal Breast tissue in which the epithelial component is less than the stromal component; the cells are columnar in structure. An optical contrary is observed in Diattenuation images that are never expected for the same tissue sample and with the same experimental setup.

This is because all the polarization states are important one cannot consider only positive components of polarization, the significant difference in the Diattenuation images explains this difference that is attributed to utilization of 4 states of polarization when compared to 7 states of polarization.

CONCLUSIONS

Our study shows that a physically realizable Mueller matrix can be obtained by using both 7 and 4 independent variables. Mueller decomposed images using Polar decomposition techniques have a potential to reveal polarization parameters of Breast tissue effectively. However in our observations the decompositions involving 7 independent polarization states is preferred for Breast tissues that contain columnar shaped cells.

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