Mueller Matrix polarimetry and its application to biological species characterisation

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Background

- Mueller Matrix (MM) polarimetery is a non invasive, label-free and easy to implement technique for tissue characterisation.
- Currently, 132,000 melanoma skin cancer and between 2 and 3 million non-melanoma skin cancer cases occur globally each year.
- Figure of merit related to polarisation, derived from decompostion of MM gives a sophisticated analysis for cancerous lesions with high accuracy
- MM provides huge application potential for other skin disease such organoid nevi and keratosis

Experimental setup

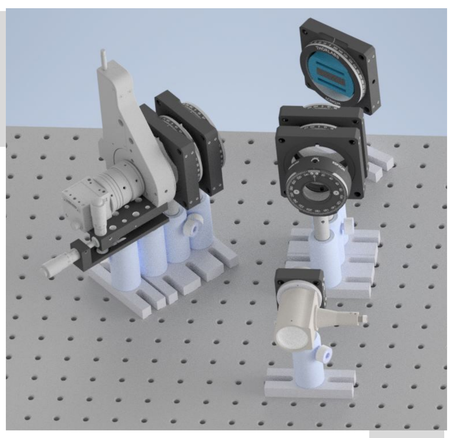


Fig. Dual mode setup with Polarisation State Generator PSG & Analyser PSA.
Liquid Crystal Retarder LCR for pol. state control. Vibration motor ensures speckle reduction.

MM measurement

- If the MM of a sample is known M_m, the outgoing light $\vec{S}_o$ can be calculated for every incoming light state ($\vec{S}_i$) according to:

$$\vec{S}_o = M_m \cdot \vec{S}_i$$

- MM contains the information about any polarisation changing properties of the sample
- Measurement of the intensity of different polarisation states of both the incoming & the outgoing light is required

$$MM_{i,j} = \begin{array}{|c|c|c|c|} \hline I_{HH}+I_{HV}+I_{VH}+I_{VV} & I_{HH}+I_{HV}-I_{VH}-I_{VV} & I_{PH}+I_{PV}-I_{MH}-I_{MV} & I_{RH}+I_{RV}-I_{LH}-I_{LV} \\ \hline I_{HH}-I_{HV}+I_{VH}-I_{VV} & I_{HH}-I_{HV}-I_{VH}+I_{VV} & I_{PH}-I_{PV}-I_{MH}+I_{MV} & I_{RH}-I_{RV}-I_{LH}+I_{LV} \\ \hline I_{HP}-I_{HM}+I_{VP}-I_{VM} & I_{HP}-I_{HM}-I_{VP}+I_{VM} & I_{PP}-I_{PM}-I_{MP}+I_{MM} & I_{RP}-I_{RM}-I_{LP}+I_{LM} \\ \hline I_{HR}-I_{HL}+I_{VR}-I_{VL} & I_{HR}-I_{HL}-I_{VR}+I_{VL} & I_{PR}-I_{PL}-I_{MR}+I_{ML} & I_{RR}-I_{RL}-I_{LR}+I_{LL} \\ \hline \end{array}$$

H = horizontal
V = vertical
P = +45°
M = –45°

R = right circular
L = left circular

XX
Generated Polarisation
Analysed Polarisation

- MM interpretation: Lu-Chipman polar decomposition of non pure matrices

$$M = M_\Delta \, M_R \, M_D$$

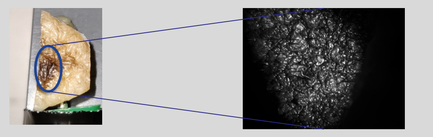
M_D pure diattenuator, M_R pure retarder, M_Δ depolarization & polarizance P:

$$D = \frac{1}{m_{11}}\sqrt{m_{11}^2 + m_{13}^2 + m_{14}^2} \qquad \Delta = 1 - \frac{|m_{22}|+|m_{33}|+|m_{44}|}{3}$$

$$\mathrm{P} = \frac{1}{m_{11}}\sqrt{m_{21}^2 + m_{31}^2 + m_{41}^2}\,.$$

Human skin samples for MM investigation

- 3 ex vivo samples: 1 melanoma & 2 nevi
- MM values, R: clear trend of grouping, malign vs. benign



Skin sample *Measured area for MM*

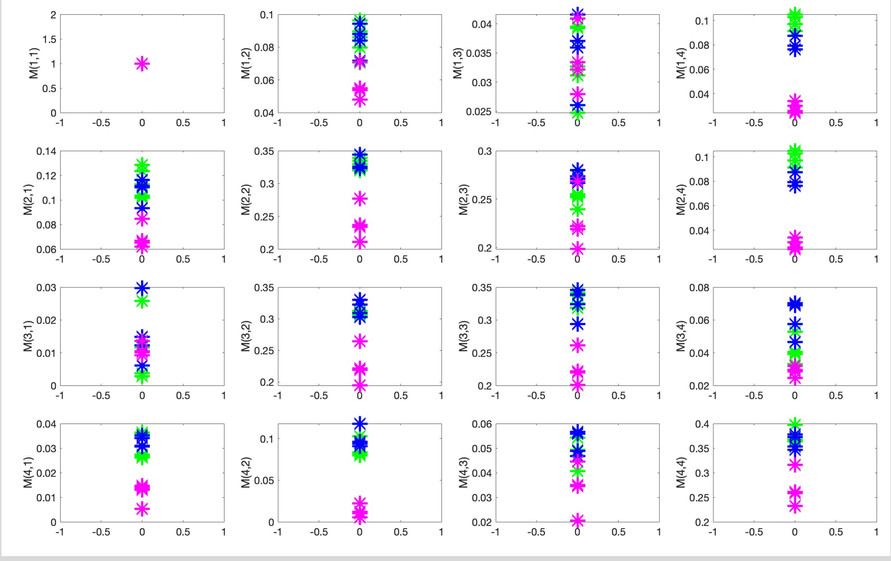


Fig: MM entries comparison of the samples. Laser source 532nm. Similar plots for 632nm & 532nm obtained
* *Nevus 1*
* *Nevus 2*
* *Melanoma*

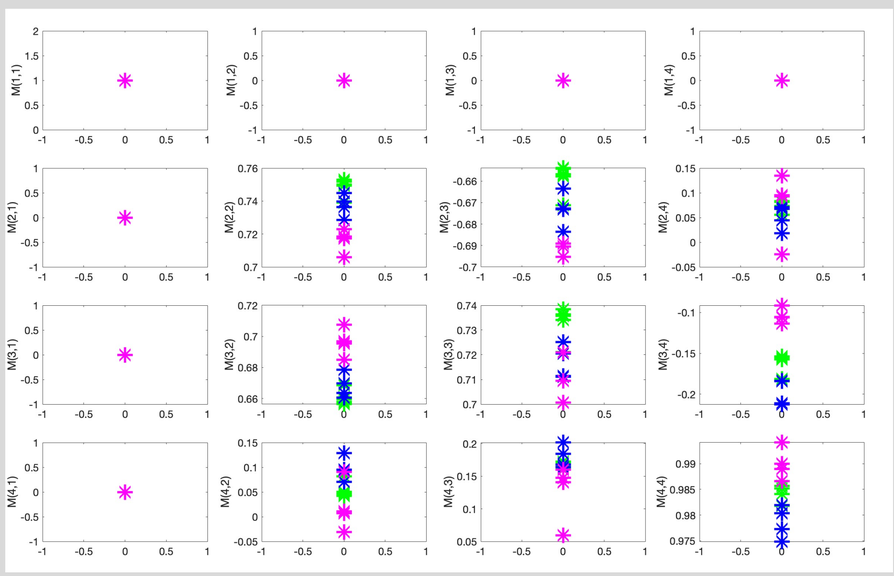


Fig: Retardation R entries comparison of the samples.(at 532nm). Diattnuation & polarizance show similar behaviour (not plotted)
* *Nevus 1*
* *Nevus 2*
* *Melanoma*

Mice skin samples for melanoma detection

- 2 Samples measured with 632nm &532nm

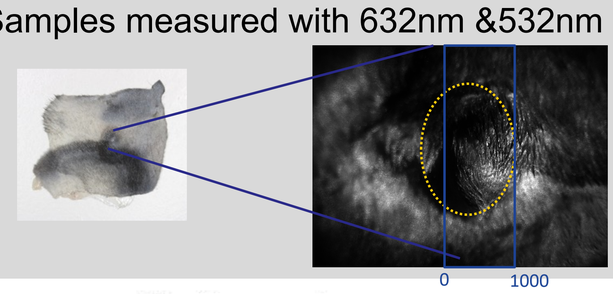
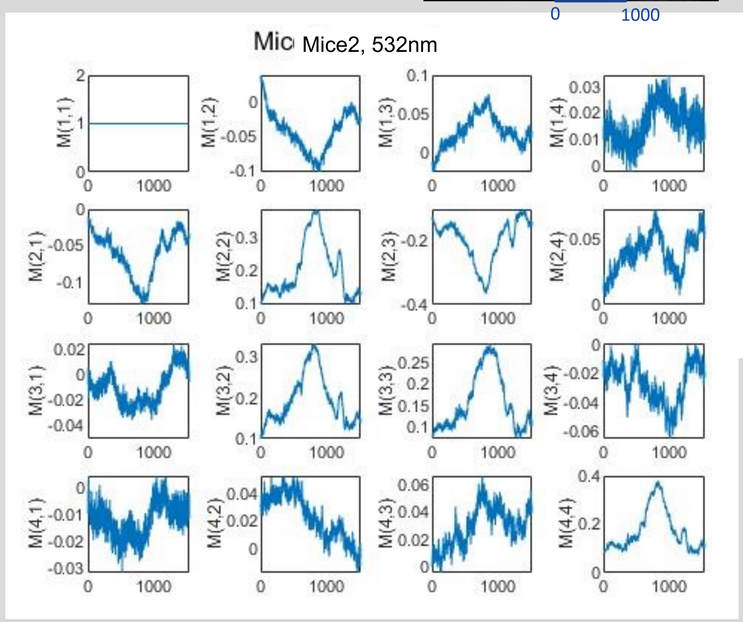


Fig. Measured area by MM.
O Melanoma
MM calculated for the image crop



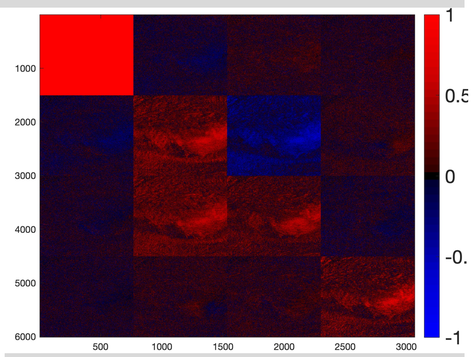


Fig: Mueller Matrix image

Fig: MM entries along the cropped area (shown above)

Conclusion & Outlook

- For human skin and mice skin samples, MM values shown a clear difference between malignant and benign lesions.
- Decomposition metrics support our results with distinct values for each case
- In future, apart from MM values, decomposition metrics maps will provide spatially resolved location of the tissues

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