Liquid crystal retarders for fully automated fast measurement of the Mueller matrix of the skin without moving parts

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The optical properties of different biological tissues vary significantly. While often spectral information is used for tissue characterization, in our approach, we use information about its polarization changing properties. Collagen is one important substance in the skin that is also connected with skin diseases and specifically changes the polarization of the light upon reflection. Thus, measuring the Mueller matrix is one method to fully determine the polarization properties such samples.

1 Introduction

The Mueller matrix (MM) of a sample contains all information about its polarization changing properties. Here, we present an experimental setup to measure the MM of biological tissue. Several different images have to be taken to measure the location dependent MM. In order to avoid variations in the images due to the movement of patients, fast measurement is required. We designed an experimental setup to quickly measure the MM of samples in reflection. Measurement in transmission is also possible upon a few simple modifications. We describe our prototype system and the first results acquired.

2 The Mueller matrix (MM)

With the MM (M_{MM}), it is possible to calculate the Stokes vector of the outgoing light ($\vec{S}_o$) after interaction with a medium for every incoming Stokes vector ($\vec{S}_i$):

$$\vec{S}_o = M_{MM} \cdot \vec{S}_i \qquad (1)$$

As can be seen from this equation, the MM contains all information about polarization changing properties (see Fig.1).

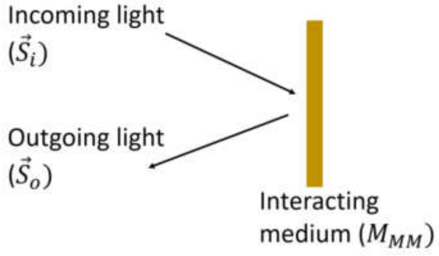

***Fig. 1** Visualization of the basic interaction. The MM (M_{MM}) contains all information about the light interaction in the medium including polarization changing properties.*

3 Calculating the MM from different images

To calculate the MM, different polarization states with respect to light-source and imaging must be realized. It is possible to calculate the MM from different amounts of images, e.g., 16, 36 or 49 images [1]. At least 16 images are needed because the MM has 16 independent elements and can be calculated from 4 Stokes vectors with 4 independent elements each [2]. With 36 and 49 images, the matrix is over determined which reduces calibration and measurement errors and therefore leads to more accurate results [3]. For the 36-image matrix, it is necessary to realize the following polarization states:

$$\begin{aligned} H &= horizontal \\ V &= vertical \\ P &= +45° \\ M &= -45° \\ L &= left\ circular \\ R &= right\ circular \end{aligned}$$

Our prototype measures the 16- and 36-image MM. The 36-image MM is for example given by the following image calculation:

$M_m =$

$HH+HV$ $+VH+VV$	$HH+HV$ $-VH-VV$	$PH+PV$ $-MH-MV$	$RH+RV$ $-LH-LV$
$HH-HV$ $+VH-VV$	$HH-HV$ $-VH+VV$	$PH-PV$ $-MH+MV$	$RH-RV$ $-LH+LV$
$HP-HM$ $+VP-VM$	$HP-HM$ $-VP+VM$	$PP-PM$ $-MP+MM$	$RP-RM$ $-LP+LM$
$HR-HL$ $+VR-VL$	$HR-HL$ $-VR+VL$	$PR-PL$ $-MR+ML$	$RR-RL$ $-LR+LL$

(2)

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In this equation, the first character of each summand stands for the polarization state of the illumination and the second character for the polarization state of the signal. The outcome consists of 16 images. Each pixel in these images shows the value of the associated MM element. That means, now the MM for every pixel and consequently every location on the image can be read out.

4 The experimental setup

The setup is designed for fast measurement of the MM in reflection. Therefore, no moving parts are used. A helium-neon laser is used as light source. The light is coupled into a multimode fiber which is combined with a vibrating motor to realize an effective low-cost speckle reducer. The combination of a polarizer and two liquid crystal retarders (LCR) realizes the required polarization states. To achieve this, the fast axis of the second LCR has to be in a specific angle relative to the first LCR. Switching time of the LCR at room temperature is below 15 ms which enables measurement of the 36-image MM within 1 s. A set of two fixed polarizers and four LCRs is used to realize all polarization states necessary for the 36-image MM.

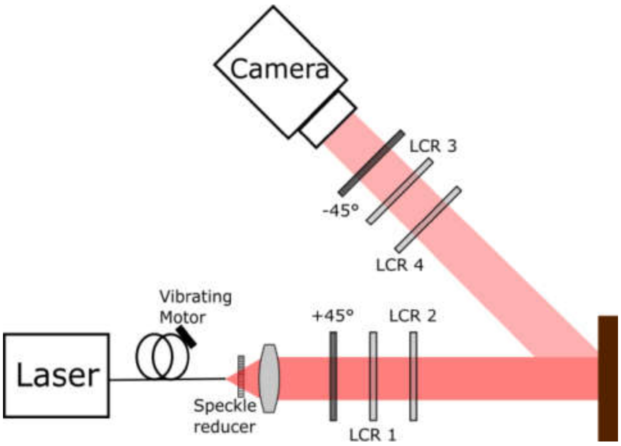

Fig. 2 *Experimental setup for MM measuments. A 633 nm laser source is used. It is coupled into a fiber with an attached vibrating motor to reduce speckle. In addition, a commercial speckle reducer is also employed. The light is modulated by a linear polarizer and two LCRs. The same configuration in reverse order is mounted in front of a digital camera.*

5 First results

Fig. 3 shows a MM measurement of the human skin. All elements are normalized to the first element of the MM. The MM can be read out for every pixel and provides location dependent polarization properties of the sample. To read out this information, a decomposition is needed [4–6] where the resulting MM of the tissue will be expressed by MM of known physical components, e.g. an diattenuator, a retarder or a depolarizer. Thus, the physical properties can be separated and quantified.

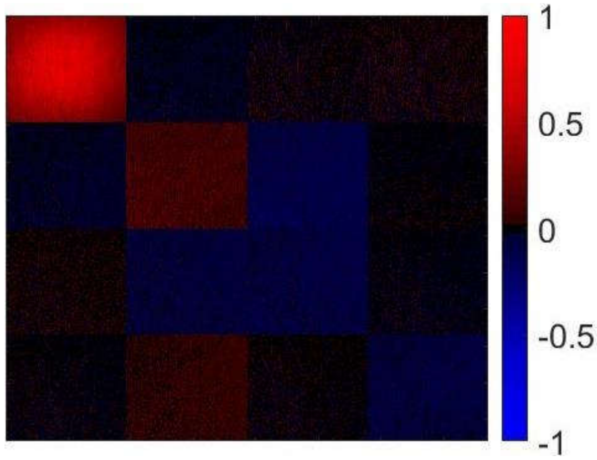

Fig. 3 *Visualization of the MM of the skin of a human hand. All elements are normalized to the first entry of the MM. The MM is now determined for each pixel, i.e. each location in the image.*

6 Conclusion and Outlook

With the prototype of a Mueller matrix measurement system, a location dependent fast analysis of the polarization properties of a sample is possible. Using this method, the distribution of structures such as collagen fibers which have depolarizing properties can be investigated. In the next step, the system will be tested on various skin-like targets. Furthermore, preclinical and clinical studies will be carried out.

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