Face and Eye Polarimetry in Near-Infrared

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INTRODUCTION

Every person's polarimetric pattern is unique, like fingerprints. Mueller imaging techniques provide complete polarimetric characterization, allowing these patterns to be measured and modeled. Such measurements are used in fields like biometrics and medicine.

The Mueller matrix is a 4 by 4 matrix that implies polarimetric information about the object, including: (i) retardance, the polarization-dependent phase change; (ii) diattenuation, the polarization-dependent reflectance [1].

The cornea of the human eye is known to be birefringent, meaning it has a polarization-dependent refractive index. This birefringence results in retardance in the Mueller matrices.

Changes in incident angle due to the shape of the face lead to varying diattenuation [2].

BACKGROUND

Fig. 1 is a simulation of azimuth and phase distributions that show axisymmetric patterns as presented by Sobczak et al., assuming the cornea is a non-dichroic linear birefringent medium [4]. According to these assumptions, any measured circular retardance should be negligible.

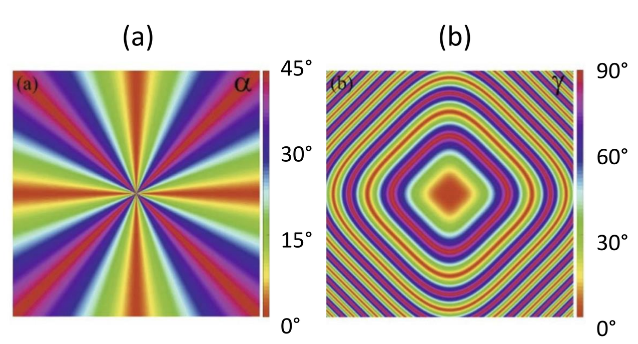

Fig. 1. Simulated distributions of azimuth angle (a) and phase retardance (b) by Sobczak et al.

METHODS

The RGB950, a wide-field imaging Mueller-matrix polarimeter, is designed to measure medium-sized objects [3]. Here, the light source is set at 947 nm with a narrow near-infrared bandpass filter, providing ≥90% transmission for 928-955 nm. The camera has a quantum efficiency of 25% in this waveband.

A minimum of 16 measurements are required to reconstruct a complete Mueller matrix. Here, the number of measurements (K) for face and eye measurements are 40 and 25, respectively. Generally, the greater the value of K, the more robust the results are against noise. However, when the object is constantly moving, such as the face and eyes, a larger K might induce more motion artifacts due to the extended acquisition time. It is essential to adjust the value of K, exposure time, and experimental setup for different objects. For eye measurements, an image registration code is applied to 25 intermediate images to correct motion.

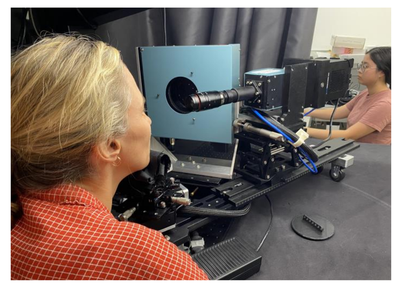

Fig 2. Experimental setup for eye measurements.

The acquisition time is approximately 15 seconds for the eye and 40 seconds for the face.

REFERENCES

[1] Chipman, R. A., et al. (2018). Polarized Light and Optical Systems.
[2] Kupinski, M., et al. (2019). Opt. Eng 58(8).
[3] López-Téllez, J. M., et al. (2019). Opt. Lett. 44(7).
[4] Sobczak, M., et al. (2021). Opt. Exp. 29(10).

RETARDANCE IMAGES OF 20 EYES

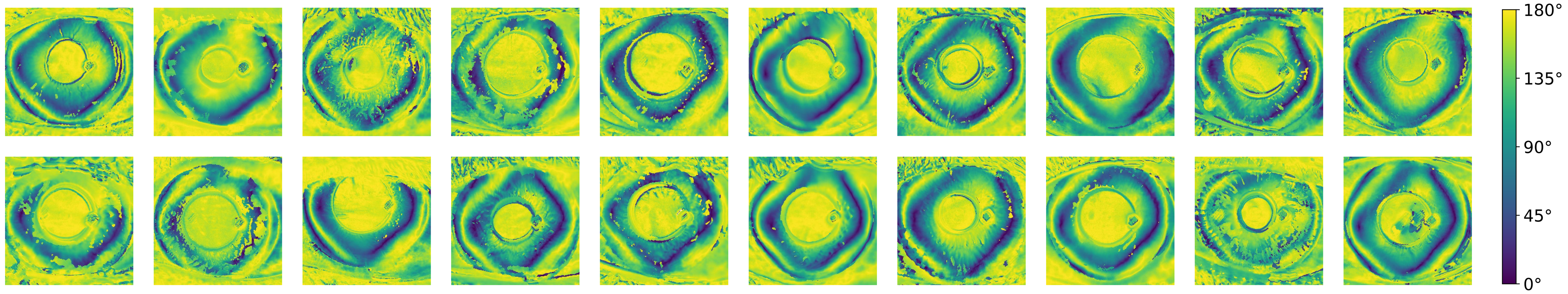

Fig. 3. Linear retardance magnitude. The shape of the linear retardance distribution is qualitatively similar to the model presented by Sobczak et al. in Fig. 1b.

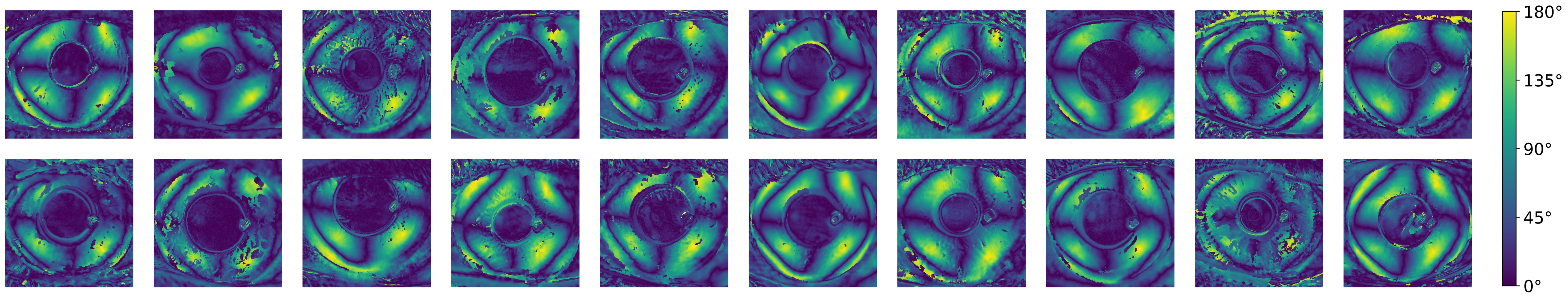

Fig. 4. Circular retardance magnitude. Circular retardance has magnitudes comparable to linear retardance.

DIATTENUATION IMAGES OF 9 FACES

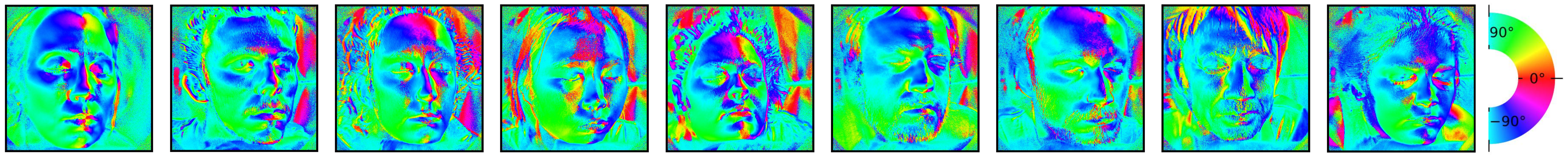

Fig. 5. Linear diattenuation orientation. The patterns follow the shapes and textures of the faces.

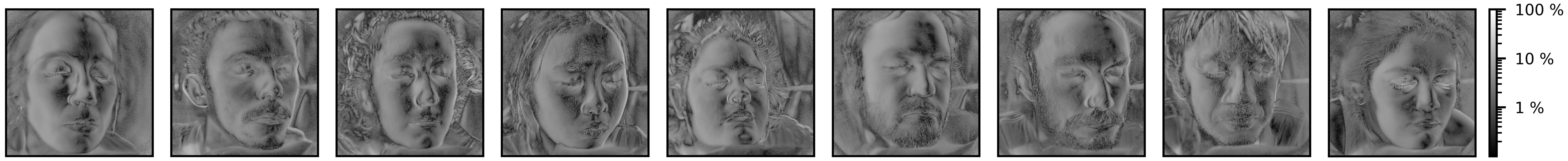

Fig. 6. Linear diattenuation magnitude.

CONCLUSION

The measured linear retardance distributions are similar to the predictions from theoretical models. However, complete Mueller polarimetry revealed significant circular retardance, which is not predicted in the literature. Measurements of diattenuation agree with the expectation that the orientation and magnitude vary with the angle of incidence based on the shape of the face. Complete Mueller polarimetry requires a relatively long measurement duration, making measurements of human subjects highly susceptible to motion artifacts. A partial polarimetric capture strategy, designed based on insights gained from these complete Mueller measurements, is suggested as a way to reduce measurement duration while still obtaining valuable data. Instrument concepts that maintain or increase sensitivity and accuracy while reducing form factor and measurement time would be more conducive to measuring human subjects.

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