Centre for Sensors, Instruments and Systems Development

UNIVERSITAT POLITECNICA DE CATALUNYA

Shaping light to your needs

A FULL STOKES IMAGING POLARIMETER BASED ON A CONSUMER CMOS CAMERA

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INTRODUCTION

Polarimetry has emerged over the past four decades as a powerful tool for image classification. Imaging polarimetry consists of the measurement of the polarization state of the light across a scene. However, polarization is not directly obtained with a single measurement. Theoretical parameters have been developed to calculate the light state with a minimum of four independent intensity measurements. Changes of polarization in a scene can give information on surface features like shape, shading and roughness. Applications in imaging polarimetry have been found in remote sensing, sensing through diffusive media like fog or smoke, aerosol characterisation, non-invasive cancer diagnostics, and astrophysics [1,2]. Here a time division imaging polarimeter based on a consumer CMOS camera is presented to validate a calibration procedure.

MEASUREMENT PRINCIPLE

Due to the vectorial nature of light polarization, it is needed to measure the Stokes parameters.

$$\vec{S} = (S_0, S_1, S_2, S_3) \qquad (1)$$

Where S_0, S_1, S_2 and S_3 describe the total intensity, the prevalence of linear state at 0º over 90º, the prevalence of linear state at 45º over 135º and the prevalence of the right circular state over the left circular state, respectively.

These parameters are obtained just by solving the linear system eq. (2), which requires at least 4 intensity measurements at different polarization states:

$$\vec{S} = \boldsymbol{W} \cdot \vec{I} \qquad (2)$$

Where $\vec{S}$ is the Stokes vector, **W** is the measurement matrix and $\vec{I}$ is the intensity vector.

Therefore, the system must be calibrated in order to het the measurement matrix to obtain the polarimetric images by implementing eq.(2) at each pixel of the image. This calibration is performed using the data reduction matrix technique where no a *priori* knowledge is required. The method allows to determine **W** by means of singular value decomposition (SVD) performing N measurements at different polarization states of M input polarization states using a polarization state analyser (PSA) [3].

When the calibration is already done, a map of the four Stokes parameters can be recovered from eq. (2), as well as some maps of advanced parameters related to polarization such as degree of polarization (DOP), degree of linear polarization (DOLP) and degree of circular polarization (DOCP).

$$DOP = \frac{\sqrt{S_1^2 + S_2^2 + S_3^2}}{S_0} \quad (3) \qquad DOLP = \frac{\sqrt{S_1^2 + S_2^2}}{S_0} \quad (4) \qquad DOCP = \frac{S_3}{S_0} \quad (5)$$

EXPERIMENTAL SETUP

The source consists in a pigtailed diode laser of wavelength 632nm attached to an integrating sphere. Next, a Polarization States Generator (PSG) composed by a linear polarizer and two circular polarizers mounted on a manual rotator will generate the reference polarization states for calibration. The imaging optics consists in a PSA, which allows to measure the desired polarization state, followed by a telescope integrated in the set-up to enlarge the beam size to cover almost completely the active area of the sensor, which is a Canon EOS1000 commercial camera with a CMOS RGB sensor. The PSA is composed by a quarter-wave plate and a linear polarizer mounted on a manual rotator selects the preferred polarization configuration.

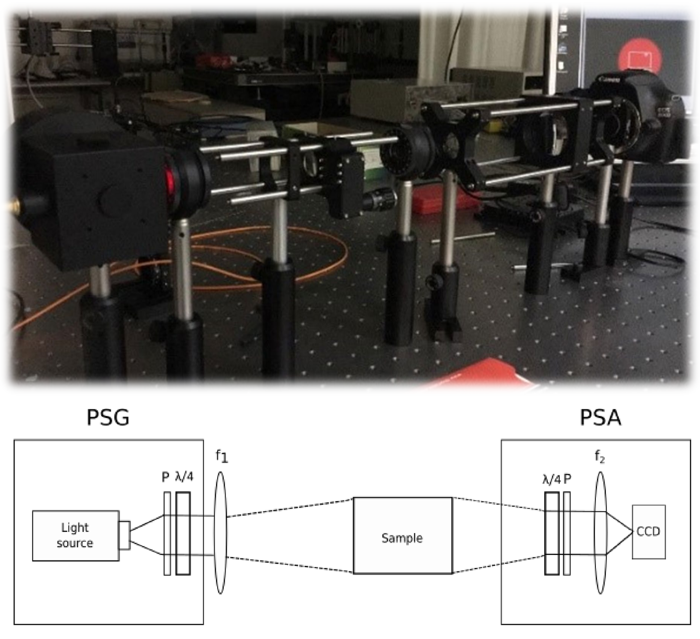

Fig. 1: Calibration setup (top). Scheme of the calibration setup (bottom).

The calibration procedure involves to produce several RPS measured by the PSA at the optimum angles chosen for the recovery. The polarization states selected to comprise the set of measurement for calibration are six: four linear states at angles 0º; 45º; 90º; 135º and two circular states: right (RC) and left circular (LC)

RESULTS

Calibration results

Fig.2 shows the obtained Stokes parameters based on the improved method of DRM for calibration and their errors. The recovered data (solid line) shows small deviations from the theory (asterisks) that could not be described by the simplified description of the polarimeter.

Polarimetric images

The polarization of the reflected light of the scene is measured. Here, a linear sheet polarizer located at an oblique azimuth angle is imaged. The DOP maps can be appreciated in Fig.3 and it is remarkable how clearly the whiter area limits the polarizer location in the scene.

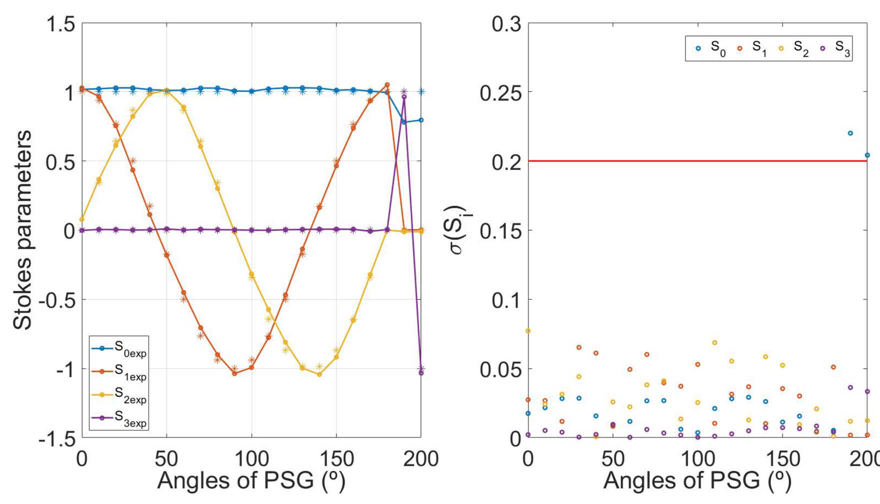

Fig. 2: Recovered Stokes parameters (lines) and theoretical Stokes parameters (asterisks) as a funcitn of PSA angle.

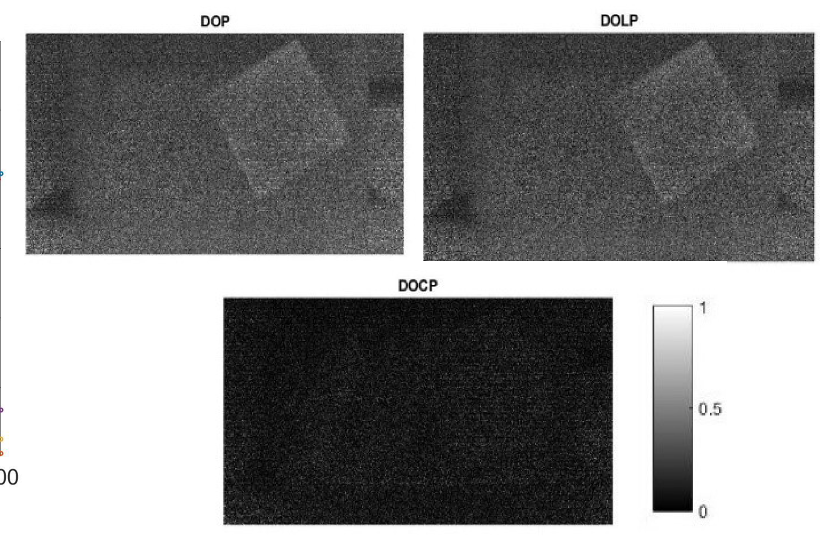

Fig. 3: DOP maps of a linear polarizaer at an oblique angle.

CONCLUSIONS AND FUTURE WORK

The system presented here constitutes a simple imaging polarimeter oriented towards validation and set-up of a calibration procedure. Using very basic optical elements and a consumer CMOS, we have been able to build a polarimetric imaging device whose calibration results are very satisfying. Some misalignment errors may still be present due to the manual rotation of the optical elements due to the application of the improved calibration method for normal polarimeters. Their maximum deviation error, lower than 10% in linear Stokes parameters estimation, makes the calculated measurement matrix **W** a good calibration to perform polarimetric imaging and validates the calibration methodology proposed.

As future work, this explained methodology will be used for the calibration of our self-developed imaging polarimeter based on division of aperture, currently under construction, to apply it in several kind of polarimetric applications.

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