# Characterisation of Geosynchronous satellites through the Analysis of On-Sky Polarimetric Signatures obtained with a Micropolariser Array Image Sensor

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**Abstract:**
We measured passive polarisation of reflected sunlight with an amateur class telescope, and analysed the polarisation components in unresolved images obtained using a micropolariser array camera to better characterise satellites in the geosynchronous belt. Our results show the presence of polarimetric signatures when observing different objects, which indicates the potential for identification and classification of objects in terms of different attributes, like, aging of materials, attitude and geometry of the spacecraft.


**OCIS codes:** 260.5430, 350.1260.

## 1. Introduction

Polarimetric imaging is a useful technique to infer geometric changes and to classify materials, as object material and geometry show different degrees of polarisation depending on the specular and diffuse characteristics at surface microstructure level and on relative material composition. In the case of observations of Geosynchronous Earth Orbit (GEO) satellites, polarimetric signatures will depend on the type of materials from which they are formed and the angle of incidence of the Sun with respect to the observer. Therefore, these signatures potentially can provide information than can help in the identification of the spacecraft, its attitude and its tumbling period. Also, due to the time-dependant material degradation in Space, these signatures could also provide information about the ageing of materials of a particular spacecraft or piece of debris. Some studies about this topic have been conducted with computer simulations and controlled experiments in laboratory, where different spacecraft materials have been tested [1]. Their result demonstrates different polarimetric signatures can be obtained depending on the type of material and the incident light angle. Polarimetry can be considered an underused technique [2], though it has been used successfully to detect geometry and material characteristics for the purpose of its classification [3]. The measurement of light polarization properties of spacecrafts was initiated by Stead [4], and some authors have continued these studies [5–7].

## 2. Materials and Methods

The four Stokes parameters are used to describe the polarization state of light: $S_0, S_1, S_2$ and the difference between left and right components of circularly polarised radiation. In this work, due to the available polarisation filters in the camera used, we can measure the first three components, and obtain the Degree of Linear Polarisation (DoLP) and the Angle of Linear Polarisation (AoLP) using the formulas:

$$DoLP = \sqrt{(S_1^2 + S_2^2)/S_0}, \quad AoLP = \frac{1}{2}\arctan\frac{S_2}{S_1}, \tag{1}$$

We utlised a a Schmidt-Cassegrain Meade LX200GPS f/10 telescope with a 304mm aperture. A focal reducer/field flattener was included in the optical train which increased the FOV and in turn the chances for finding a particular object.

The science camera is a Lucid Vision Labs camera Phoenix 5.0 MP Polarization model [8]. Fig. 1 shows the internal structure of the camera. Four directional polarising filters at 0°, 90°, 45°and 135°angles are located on every 3.45 µm square pixel, on top of a global shutter imager with a total number of 2048 x 2448 pixels. A micro lens array is situated on top of the polarising filters, to reduce crosstalk from pixels that detect the wrong polarising

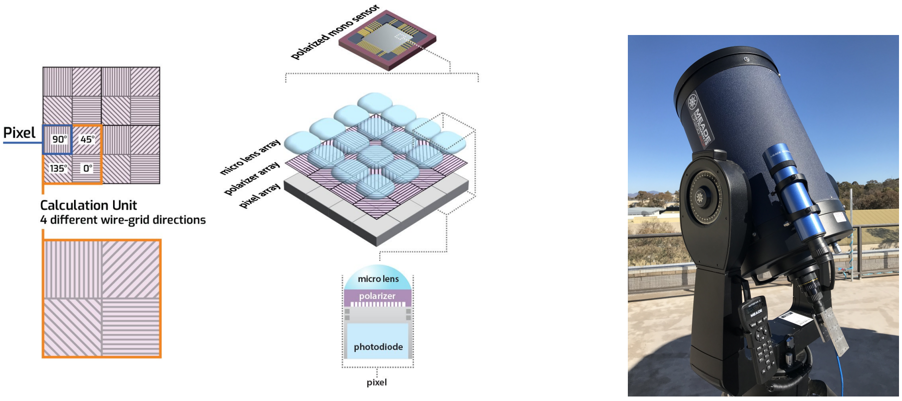


Fig. 1: Internal structure of polarization camera (left, credit: https://thinklucid.com). Optical on-sky setup (right).

Fig. 2: $s_0$ of an Eutelsat 172B image (left) and its DoLP (right). The square indicates the low noise region.

angle. To calculate AoLP and DoLP in each image sensor pixel, light passing through each of the four polarising filters is reconstructed using a Fourier domain technique [9].

The on-sky setup (shown in figure 1 right), was intially calibrated in laboratory with a integrating sphere, that generated an incoherent light source, and in the telescope aperture a diffuse material was used to scatter the light on the primary mirror surface of the telescope. A set of calibration images at different exposure times were obtained, where a strong linearity was observed.

## 3. Results

A set of relatively bright objects from the geosynchronous orbit were selected as the targets to study, which are (NORAD numbers in brackets): Optus 10 (40146), Yamal 300K (38798), Intelsat 19 (38356), Superbird 8 (43271), Beidou G7 (41586) and Eutelsat 172B (42174). We have obtained different polarisation signatures for each, and have compared these values with previous author's observations and analysis, where a set of Low Earth Orbit (LEO) rocket bodies and GEO satellites were selected as targets. Fig. 2 shows the results for Eutelsat 172B, the DoLP of the valid region in the square has a DoLP of about 0.05.

## 4. Conclusions

We have continued with the work initiated by the same authors [7], with a different polarimetric system, and performed a better calibration to reduce the bias observed in the images from the previous work. On-sky results show different polarisation properties depending on the particular object, that could be due to different parameters, such as: forming and aging of materials, specular/diffuse components of the reflective surface, turbulence, slant range, attitude and tumbling status, among others. Association of particular polarisation properties with these parameters is on-going.

## References

1. Stryjewski J. et al., "Real Time Polarisation Light Curves for Space Debris and Satellites," in Proc. AMOS, Hawaii, US (2010).
2. J. Scott Tyo, Goldstein L., Chenaut D.B., Shawn J.A.,"Review of passive imaging polarimetry for remote sensing applications," Appl. Opt. vol. 45, no. 22 (2006).
3. Israel J. Vaughn, Brian G. Hoover, J. Scott Tyo, "Classification using active polarimetry," in Proc. SPIE, vol. 8364, 83640S (2012).

4. Richard P. Stead, ”An Investigation of Polarisation Phenomena produced by Space Objects,” Thesis presented to the Faculty of the School of Engineering of the Air Force Institute of Technology Air University (1967).
5. A. Speicher, M. Matin, R.D. Tippets, F.K. Chun, D. Strong,“Results from an experiment that collected visible-light polarisation data using unresolved imagery for classification of geosynchronous satellites,” in Proc. SPIE, vol. 9460, p. 946006 (2015).
6. Pasqual M.C., Kahoi K.L., Hines E.L., “Active Polarimetry for Orbital Debris Identification,” in Proc. AMOS, Hawaii, US (2015).
7. M. Cegarra, I. J. Vaughn, A. Alenin, A. Lambert, “On-sky evaluation of passive polarimetry as a technique to characterise space debris,” in Proc. ESA European Conference on Space Debris, Darmstadt, Germany (2017).
8. https://thinklucid.com/product/phoenix-5-0-mp-polarized-model/ (accessed 14.01.2019).
9. Israel J. Vaughn, Andrey S. Alenin, and J. Scott Tyo. “Focal plane filter array engineering I: rectangular lattices,” Optics Express 25.10 (2017): 11954-11968.