POLARIZATION IMAGING WITH PANORAMIC LENS

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ABSTRACT:

In the defence and security field, the polarization of light can convey additional information in order to discriminate manmade objects against different natural backgrounds and thus it is a valuable asset for target acquisition and contrast enhancement of manmade objects. For these reasons we are studying how a panamorph lens performs under different polarization properties of object in the scenery.

Hemispheric lens such as the panomorph have, by definition, a very wide angular field of view. Different field position yield different rays angles in respect to the different optical surfaces of the lens. This affects the imaging properties at different field for polarization sensitive targets. The polarization axis orientation of the transmitted light will be rotated around the optical axis of the system at the imaging plane. Also, the relation between the orthogonal polarization components of incident rays and their respective final values at the sensor level will be evaluated both theoretically and experimentally in this paper. This study will also look at how polarization can affect the characterization of wide-angle optical systems in standard performance tests. Finally, a comparison of these results for a panamorph lens, a regular wide angle lens and standard lens will be presented.

1. INTRODUCTION

Polarimetric information informs about the surface features, shape, shading and roughness of a scene (object). Such information about scenes cannot be extracted easily from the intensity distribution or spectral content of an image. Consequently, the polarized light reflected from scenes is a valuable imaging concept useful in several remote sensing applications[1-3].

Using the well known Stokes vector model, we can determine the polarization state of the scene [4]. Most of the time, linear polarization imagery is acquired by measuring light at multiple polarizations – typically linearly polarized at 0º, 45º, 90º, and 135º to express Stokes parameters ($\boldsymbol{S}=[S0,S1,S2,S3]^T$). S0 gives the intensity of the image, S1 represents the difference in intensity through polarizers (analyser) oriented in x and y direction (image plane is defined in the plane x and y), S2 is similar to S1 but for the 45 degrees and -45 degrees orientation, and S3 is the difference in circular polarizations (generally zero for passive imager).

Stokes image information from the scene collected by a polarimetric imager can be displayed (S0, S1 and S2) and the degree of linear polarization (DOPL) can be calculated. This method is the standard approach which can be used for imager with modest field of view (FOV). When the FOV is larger than 130 degrees (estimation), the imager is mostly a panoramic lens which is used to transfer a hemispheric FOV on a 2D sensor. In fact, the hemisphere is imaged as a circle. Then the orientation of the polarization vector in the scene is not defined anymore by X and Y direction but rather by a 3D projection.

For example, we have a fisheye lens facing up or down with 180degrees FOV (it is easier to figure with up or down orientation but it is the same if the fisheye is wall mounted). If we project a linear (x axis) polarisation from the image plane (sensor) up to the object (hemisphere), the orientation of the projected polarisation on the hemisphere will vary on the hemisphere. A vertical polarization of the scene will have a radial orientation on the detector as shown in figure 1 (added red arrows). Horizontal polarisation will be azimuthally oriented (perpendicular to radial direction).

This paper shows a preliminary report about the behaviour of two panoramic imagers, a panomorph and a fisheye lens. Section 2 presents some background about the panoramic lenses and particularly the panormorph lens. Section 3 describes how the experiment was modelled in Zemax. The experimental setup is presented in section 4. Section 5 shows the experimental and theoretical results as well as a discussion. The paper is completed with a conclusion of this preliminary work.

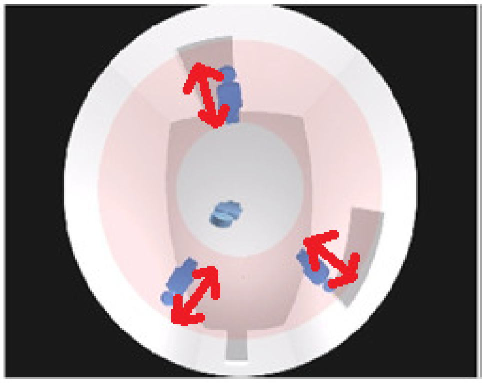

Figure 1: Image footprint on the sensor

2. PANORAMIC LENSES PARTICULARITIES

Panoramic lenses are used for optical systems having a field of view (FOV) 130 degrees or more. Panoramic lenses have an inherent large distortion, but the distortion should not be considered as an aberration but rather the result of the projection of a hemispheric field (3D) on a 2D sensor. Distortion, by itself, does not degrade image quality; it only changes the image height in respect to the field angle [5]. However, when the distorted image is sampled by an imaging array like a CCD, the object space angle subtended by a given pixel varies with its position within the field of view. This produces a variation in the resolution (pixel per degrees) of the observed scene. Panoramic lenses having a controlled distortion are called panomorph lenses. These lenses are also categorized as anamorphic imagers, relating to the fact that the distortion profile is not rotationally symmetrical.

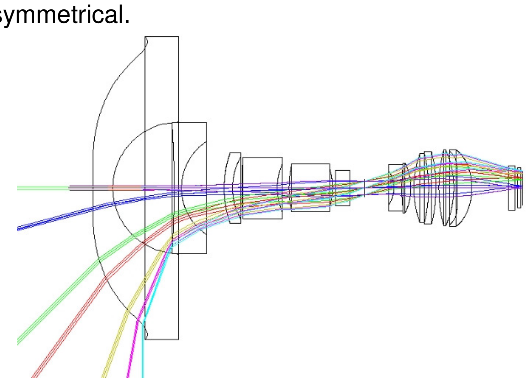

Figure 2: Layout of a typical panomorph lens

Distortion profile of panomorph lenses is primarily determined by the front surface of the first lens of the system which controls the chief ray's direction at a given field position. The surface of a panomorph lens is typically an aspheric, like the one shown in Fig. 1. The combining effect of an aspherical frontal surface and large FOV causes a large variation in the ray's angle of incidence (AOI) for different field angles. Reflection and transmission coefficients of rays differ in regards to their polarization state with respect to the plane of incidence which is spanned by the surface normal and the propagation vector of the incoming radiation. Thus, in a large FOV system, the intensity of a given polarization state changes with the field angle.

3. MODELING (Zemax)

In order to model how large FOV system performs with polarization in a surveillance or security task, the polarization state of the incoming light must be defined in global coordinates and be the same for every field angle in regards to these global coordinates. However, in the optical design software Zemax, the polarization state of a light ray is defined in terms of the orthogonal unit vectors K, S and P where K refers to the ray vector [6]. These polarization coordinates are therefore locally defined by the ray vector associated to a given field angle. Globally defined polarization coordinates are calculated by projecting the orthogonal polarization components along the S and P vectors onto the global X and Y vectors using the direction cosine of the incoming ray direction of propagation along these global coordinates' vectors. The implementation of this method in Zemax was done using a Zemax programming language (ZPL) script.

4. EXPERIMENTS

A setup was devised to measure how polarized light coming from different field angles is imaged by a panomorph optical system and by a fisheye lens. The setup is comprised of a computer screen situated at a fixed position at 75 cm in front of the tested lens. This distance is large enough to be considered as infinity. A linear polarizer sheet is placed in front of the computer screen with its polarization axis at an angle of 45 degrees where the light output intensity was maximized. The tested lens and camera system was mounted on a motorized rotary stage that turns around a vertical axis and another rotary stage that lets the optical system rotate around its optical axis. The combined rotary stages permit a full FOV coverage of the system. Finally a second linear polarizer, usually called the analyzer, is placed between the lens and the sensor of the system. The analyzer's polarization axis can be rotated around the optical axis.

Images are captured at an increment of 2.5 degrees on both axes of rotation and the intensity at the center of the polarized screen is measured along with its position on the sensor. These measurements were repeated with the polarization axis of the analyzer along the horizontal and vertical axes of the sensor for both fisheye and panomorph lenses.

5. RESULTS

This section presents the measured and calculated imaging intensities.

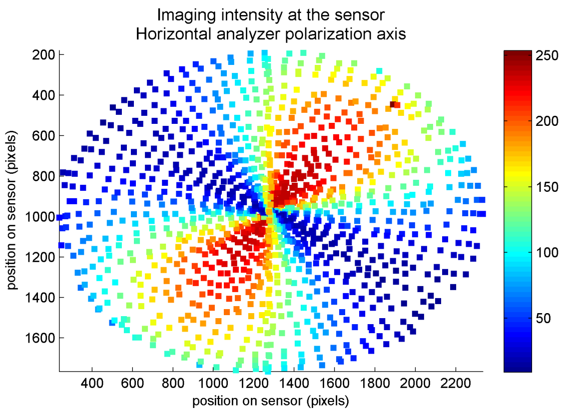

Figure 3: Measured intensities averaged on a 10X10 pixels zone of a panomorph lens. The polarization axis of the analyzer is horizontal.

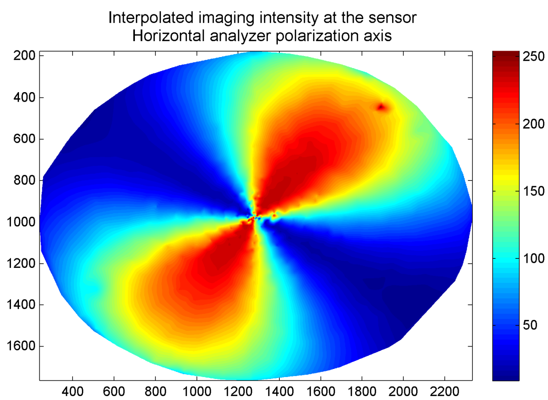

Figure 4: Interpolated imaging intensity for a panomorph lens. The polarization axis of the analyzer is horizontal.

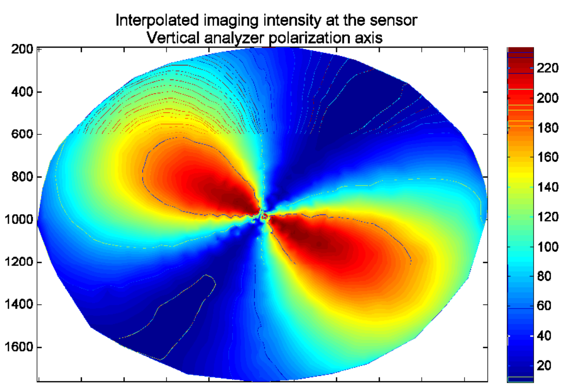

Figure 5: Interpolated imaging intensity for a panomorph lens. The polarization axis of the analyzer is vertical.

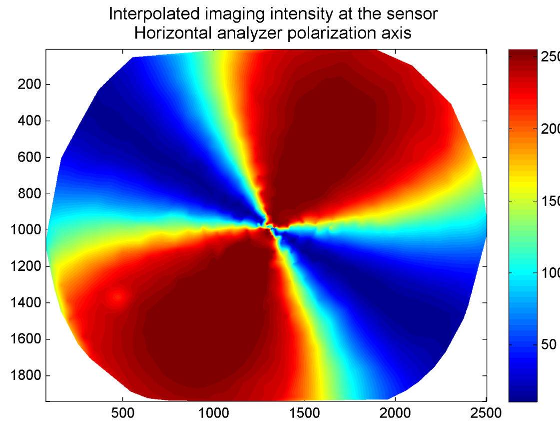

Figure 6: Interpolated imaging intensity for a fisheye lens. The polarization axis of the analyzer is horizontal.

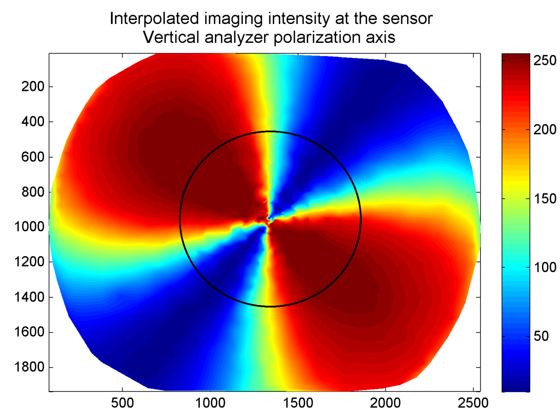

Figure 7: Interpolated imaging intensity for a fisheye lens. The polarization axis of the analyzer is vertical.

The experimental results show mainly that the polarization state varies on a circle (or elliptical) as drawn on the figure 6.. For the fisheye lens, the modulation of the intensity is following a sinusoidal function of the azimuthal angle. For the panomorph lens, the azimuthal intensity modulation is not exactly a sinusoidal function due to the anamorphosis.

The measured field-wise polarization dependent intensities for the panomorph lens were also simulated using Zemax and are presented in figure 7.

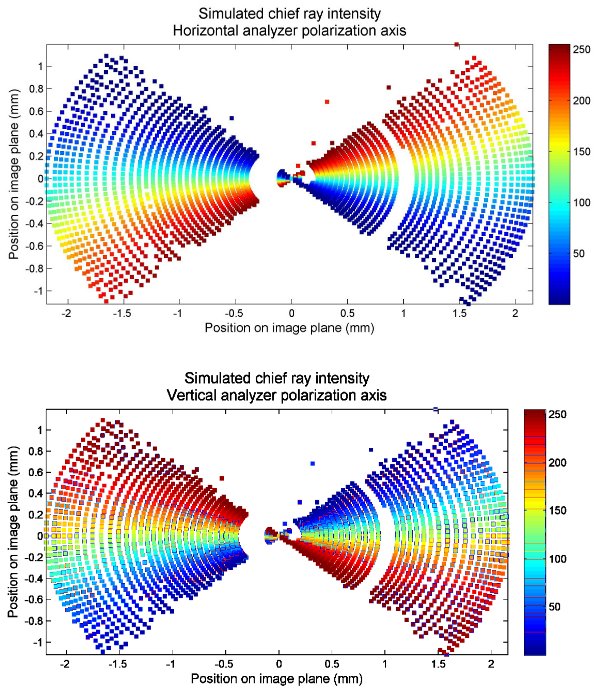

Figure 8: Simulated results for the panamorph lens with the analyzer horizontal (top) and vertical (bottom) polarization axis.

However, these simulations were prone to many ray tracing errors and thus numerous points are missing at given field angles and for the extremities of the field of view from 100 to 120 degrees. The ray tracing errors are mostly due to the particular entrance pupil shift with the field of view for panomorph lenses. In a typical wide-angle lens the entrance pupil moves away from the optical axis as field angle increases [7-8]. However, the displacement of the entrance pupil position for a panomorph lens is more complicated, as it is shown on figure 8.

6. CONCLUSION

In conclusion, we have conducted very preliminary experiment on the polarisation behaviours of two panoramic refractive lenses. The experimental results show that the polarisation state from the scene to the sensor is not standard. Consequently, it seems that an additional transfer function for the polarisation state must be used to properly establish the Stokes parameters of the scene. This is mainly due to the fact that the panoramic imager is used to image an hemisphere (3D scene) rather that a plane (2D) on a 2D sensor. Consequently, the object coordinate and the polarisation state of the scene are imaged on the sensor through a set of transfer function which could be taking into account.

Work is under progress to study how the panoramic polarimetric imager can be used in remote sensing.

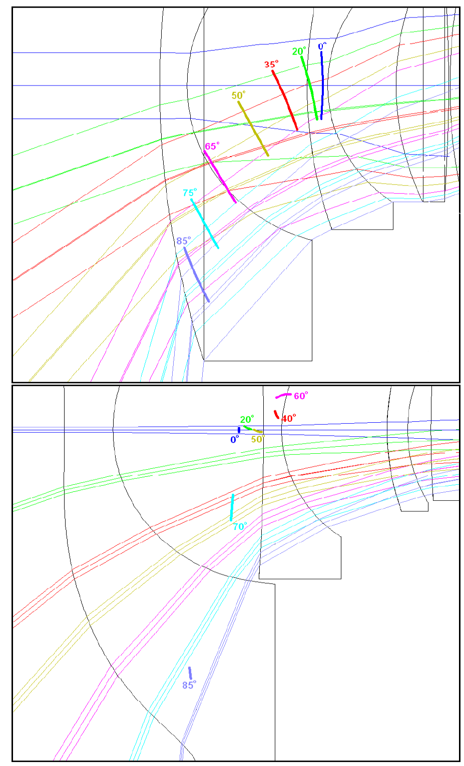

Figure 9: Entrance pupil displacement at various fields of views for a standard wide-angle fisheye lens (top) and the Panomorph lens (bottom). Figure taken from Parent et al.[8]

7. REFERENCES

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