Polarized Skylight Navigation

***Abstract*—**

I. Introduction

Sun position, stars and sky patterns are hold as navigational cues for the past centuries. Indeed, before the discovery of magnetic compass, these natural cues were the solitary source of navigation used by our ancestors [2, 7]. Skylight polarized pattern that is created due to scattered sunlight, is recognized as a navigation tool of some insects [21, 8]. The studies show that some insects such as desert ants (cataglyphis), butterflies and dragonflies among others, are able to navigate through their paths, efficiently and robustly by using the polarized pattern of sky, despite their small brains [8, 21, 5].

Acknowledging the nature, numerous studies have been conducted on polarized skylight pattern [9, 4, 22, 20, 3, 1, 18, 11, 13, 19, 10, 5]. These studies, often used the polarized pattern to create a sort of compass and estimate the solar azimuth angle and mainly have been shared in optic filed. Estimating polarized patterns, however, have been a difficult and complex task. The primary studies report the use of several photodiodes [9, 4, 22, 20, 3], while later either multiple cameras [1, 18, 19] or manual rotating filter [11, 13, 10, 5] were used. As a consequence of difficult and troublesome setups, exploiting the advantages of polarized patterns in our environment have been very limited. An example refers to the lack of using polarized sensors in Unmanned Aerial Vehicle (UAV).

However, recent introduction of division-of-focal-plane (DoFP) micropolarizer cameras has offered an alternative solution [15, 14, 12]. In such cameras a micropolarizer filter array, composed of a pixelated polarized filters oriented at different angles (see Fig. I), is aligned with a detector array. Thus they can simultaneously acquire linear polarization information (i.e S_0, S_1, S_2) or full stokes parameters in one image capture.

This study presents the primary results of using the polarization by scattering and Rayleigh model Rayleigh sky scattering for attitude estimation. Polarization by scattering and Rayleigh model are explained in Sect. II while our theoretical model is presented in Sect. **??**.

II. I dont know the tite exactly

The unpolarized sunlight passing through our atmosphere gets scattered by different particles within the atmosphere. Beside deviating the direction of propagate wave, this transition also changes the polarization state of the incident light. This transition can be explained using Rayleigh scattering model. Rayleigh scattering describes the scattering of light or any electromagnetic waves by particles much smaller than their transmission wavelength. Accordingly it assumes that scattering particles of the atmosphere are small, homogeneous particles much smaller than the wavelength of the sunlight. Despite its simplification and assumption, this model proved to be sufficient for describing skylight scattering and polarization patterns [16, 6].

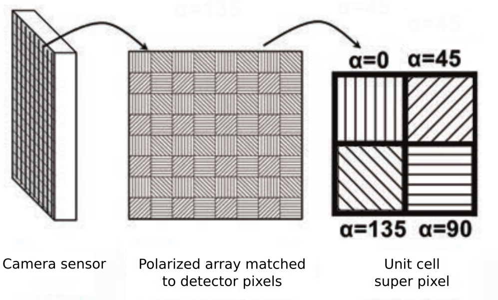

Fig. 1. Structure of DoFP sensors

The Rayleigh model predicts that the unpolarized sunlight becomes linearly polarized passing through the atmosphere. Equation 1 shows the stokes vector for natural light after and before passing through the atmosphere, since the last stokes parameter is 0 after scattering, the light is considered to be linearly polarized.

$$s_{unp} = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \xrightarrow{\text{scattering}} s_p = \begin{bmatrix} s_0 \\ s_1 \\ s_2 \\ s_3 \end{bmatrix} \tag{1}$$

Having the stokes parameters the degree of linear polarization (dopl) (ρ_l) in terms of stokes parameters and the scattering angle (λ), respectively is presented as:

$$\rho_l = \frac{\sqrt{s_1^2 + s_2^2}}{s_0} = \frac{\sin^2(\lambda)}{\cos^2(\lambda) + 1} \tag{2}$$

and the dopl, ρ_l, varies from 0 to 1 depending on the scattering angle, λ, ($\rho_l = 0$ while $\lambda = 0, \pi$ and $\rho_l = 1$ while $\lambda = \pi/2$) [17, 13]

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