Optik 141 (2017) 147–156

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Measuring solar vector with polarization sensors based on polarization pattern

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ARTICLE INFO

Article history:
Received 24 December 2016
Accepted 21 March 2017

Keywords:
Solar vector
Polarization sensors
Polarization pattern
Scattering

ABSTRACT

It is put forward that solar vector can be obtained with polarization sensors in this paper, which plays an important role as a great clue of navigation. First, the design of the polarization sensor is introduced with the extraction method of azimuth angle from the polarization pattern. Then, it is advanced that solar vector can be attained through observing different directions using one or two polarization sensors. Consequently, an experiment is conducted and the results indicate that both algorithms of measuring solar vector are feasible. For the method of measuring solar vector with two polarization sensors, the accuracy of solar azimuth angle is 0.2°(1σ), and the accuracy of solar elevation angle is 0.4°(1σ) approximately. By contrast, the accuracy is relatively low for the method of using single polarization sensor.

1. Introduction

Polarization pattern, utilized to determine the reference direction to realize navigation by natural animals, is formed after sunlight is scattered by particles in the atmosphere. In the early 20th century, some researchers started investigating the excellent navigation ability of some insects such as ants and bees. As a result, it was discovered that they made full use of the polarization pattern to navigate.

At present, the research about polarization navigation is mainly concentrated on two aspects: one is that structures and behaviors of some animals are researched to cognize principles of polarization navigation ulteriorly; the other is that people focus their attentions on the design of polarization sensors to measure polarization pattern. Since the excellent navigation ability of insects was found, more and more attentions have been fixed on the polarization-sensitive structure of insects. Rüdger Wehner analyzes how bees utilize polarization pattern to navigate through anatomizing compound eyes of bees and carrying out experiments. After finding honey source, they need an azimuth reference to give its direction through dancing, which is determined by E-vector of polarization pattern [1–5]. It is introduced that monarch butterfly in North America senses polarization pattern of ultraviolet band and regards E-vector as the reference direction to aid navigation when they migrate to Mexico [6,7]. Fleur Lebhardt demonstrates that desert ants can make use of polarization pattern to navigate by experiments [8–10]. Certainly, other animals such as spiders and shrimps, can also sense the polarization pattern to navigate [11,12].

Imitating polarization navigation of insects, several polarization sensors are designed to measure polarization pattern. Lambrinos successfully employed a polarization compass on the moble robot Sahabot and tested three models for extracting

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http://dx.doi.org/10.1016/j.ijleo.2017.03.122
0030-4026/

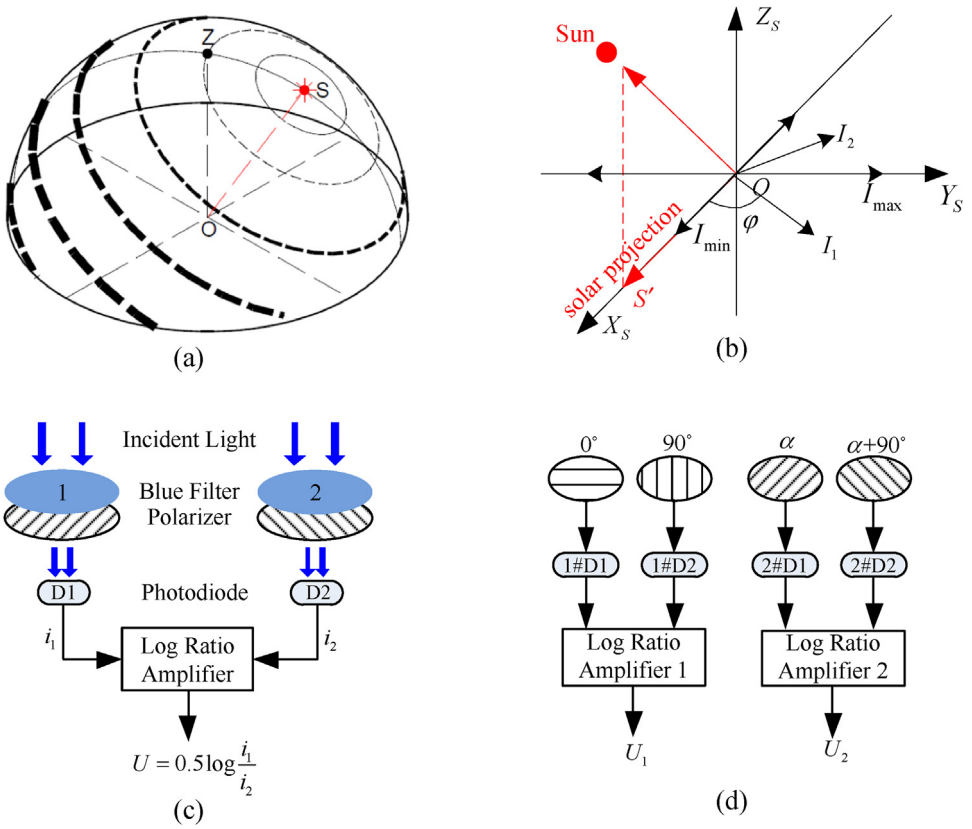

Fig. 1. (a) 3-dimensional polarization pattern. (b) Coordinate system $OX_SY_SZ_S$. (c) Polarization opponent unit. (d) Schematic drawing of polarization sensor.

compass information based on polarization pattern [13]. Kane Usher puts forward that the scanning method with a digital camera is used to measure polarization pattern. Meanwhile, the image information attained is analyzed preliminarily to obtain the degree of polarization and polarization angle [14]. CMOS image sensor is designed, which outputs light intensity information of different polarized directions to achieve the degree of polarization and polarization angle [15–19]. Daobin Wang designs a real-time bionic camera-based polarization navigation sensor to measure polarization pattern through three images of different polarized directions (0°, 45° and 90°), the accuracy of which can obtain 0.3256° [20]. A metal grid polarization sensor is designed, whose accuracy can achieve 0.1° [21–23]. Zhiwen Xian designs a bio-inspired polarization navigation sensor and gives a new method of calculating polarization angle [24,25]. Yinlong Wang presented a combined method that worked independently with the polarized sensor and 3-axis compass united [26]. Jianbin Ren tried to find the approach to attitude determination by means of polarization sensors [27]. Chahl applied the polarization sensor to a UAV and the polarization sensor had proven accurate [28].

Although more and more people focus their attentions on polarization navigation, there are few researches on how to extract solar vector based on polarization pattern. As is known to us, the formation of polarization pattern is closely related to solar vector. Therefore, it is put forward that solar vector can be obtained through the polarization sensor, which is designed to measure the polarized information of the sunlight scattered by particles in the atmosphere.

To demonstrate the feasibility of obtaining solar vector using polarization sensors, this paper is organized as follows. In Section 2, we give a brief overview of the polarization sensor architecture and polarization pattern. In Section 3, two methods of obtaining solar vector using polarization sensors are put forward. In Section 4, an experiment is carried out to demonstrate the feasibility of obtaining solar vector using polarization sensors and the results of both methods are analyzed and compared. Some conclusions are drawn in Section 5.

2. Polarization pattern and polarization sensor overview

Rayleigh scattering occurs when the molecule is much smaller than the wavelength of incident light, which results in polarization pattern. Fig. 1(a) shows the 3D polarization pattern formed based on Rayleigh scattering. $\overrightarrow{OS}$ is solar vector and