Send Orders for Reprints to reprints@benthamscience.ae

The Open Automation and Control Systems Journal, **2015,** *7,* **1943-1947**

Experimental Study on Polarization Mode Detection Based on Image of the Sky

Gao Chi[1,*], Zhang Rongtao[2] and Cui Yongliang[2]

[1]*The Department of Electrical Engineering, Laiwu Vocational and Technical College, Laiwu, Shandong, 271100, P.R. China;* [2]*Department of Information Engineering, Laiwu Vocational and Technical College, Laiwu, Shandong, 271100, P.R. China*

Abstract: The detection model of sky polarization based on image as a new navigation technology, has a relatively good stability and high research value. In order to improve the accuracy and reliability of the polarization mode measurement and continuous measurement, it constructs a set device of polarized light detection based on image's real-time synchronous acquisition. Besides, it has carried on the preliminary research on sky light polarization mode detection and navigation, according to the detection method and formation mechanism of polarized sky light. It has high research value in the measurement of polarization distribution of the sky.

Keywords: Detection, image, polarization mode, sky polarization.

1. INTRODUCTION

Research shows that the sky polarized light distribution pattern of relative stability, contains a wealth of information, mainlyreference to the polarizationdegree and angle of polarization, and it has far-reaching significance for air navigation. Ants and other insects can perceive the sky polarized light intensity and the distribution pattern of direction [1]. At present, many scholars have done a lot of researches on the sky polarization [2-7]. The detection methods of sky light polarization distribution pattern include the main point source type and image type. The scholar from Lapland of Finland, Jozsef Gal [8], and the Swiss scholar, Rudiger Wehner [9], made a navigation sensor based on the point source and the feasibility of polarized light. Brines and Gouldl Mo probed the polarization state at a point in the sky using Polari meter. Horvath proposed a measurement method of the whole sky polarized light [10, 11]. Zhu Jinkui research group at Dalian University of Technology built the sky polarized mode detection device. They detected the sky polarized mode and applied it to robot navigation, which is based on point source type. Guan Guixia, Yan Le of the Peking University [11] and Cui Yan of Dalian University of technology proved the existence of a stable model of the sky polarization using the distribution model of skylight polarization image type test [12]. But now the detection mode used is mainly the point source type. Image detection has started to be used in recent years with the development of digital technology and lower cost. Image detection is a new method for detecting sky light polarization distribution pattern. There are less researchers in this field who can realize area measurement with high stability. According to the forming mechanism and detection methods of polarized sky light polarization mode, imitating the design scheme of polarization detection instruments at home and abroad, this paper puts forward design of a device based on a set of image's real-time synchronous acquisition of the sky polarized light detection, and has carried on the preliminary research on sky light polarization mode detection and navigation.

*Address correspondence to this author at the Department of Electrical Engineering, Lai Wu Vocational and Technical College, Lai Wu, Shandong, 271100, P.R. China; Tel: +86 634 6427409; Fax: +86 634 6268816; E-mail: wwwgc119@163.com

2. THE DETECTION MECHANISM OF POLARIZED LIGHT

Under cloudless conditions, atmospheric scattering is mainly the Rayleigh scattering, which means scattering of the light is mainly partially polarized light, when the sky has a relatively stable polarization mode in a fixed time and space, and hence it is a Rayleigh model. According to this model, there are two relatively distinct symmetric lines in the sky polarization distribution: one is the Line of maximum polarization degree, which makes a great circle, its angle from the sun point or the anti-solar point is 90° degree angular; the other is Solar meridian which, makes a connection between the sun and the anti-solar point; in the symmetric line, the polarization angle is vertical.

Rayleigh model well explains some of the characteristics of polarized light's distribution in the sky. However, through the observation and study of the sky polarized light distribution, we found that the polarization distribution is not strictly based on the degree of polarization and the sun line maximum radial symmetry. As shown in Fig. (**1**), there are a large number of irregular regions even in cloudless weather.

This irregular region provides abundant characteristic information. The present studies have considered that the sky polarization distribution is polarization degree of a position and distribution of polarization direction. And the sky has a relatively stable polarization mode in a fixed time and space. There are a large number of irregular regions in the sky polarization distribution, which has the features of rich infor-

1874-4443/15

mation. The sky polarization distribution model we detected is the sky polarization distribution with the local characteristics.

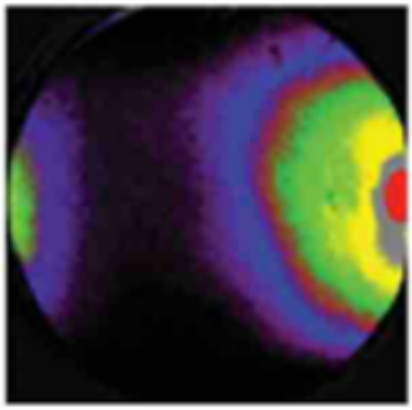

Fig. (1). All-sky observation map of polarization mode.

Since the polarization mode of the sky is stable for a short time, the change in the polarization pattern observed in the sky is caused by the change in the position and angle of the observer. The relationship between the sky polarization distribution pattern map and the locations of the observer is shown in Fig. (**2**). The Fig. (**2**) shows the outer side of the sphere, which is the celestial sphere; internal ball represents the earth; the red circle is the solar meridian; the largest degree of polarization is the blue curve line which is at a 90° degree angle between the sun point and the anti-solar point; the sun's orbit is yellow curve; the moving trend of the sun is from East to West; and the gray area is the observation area relative to the observer position.

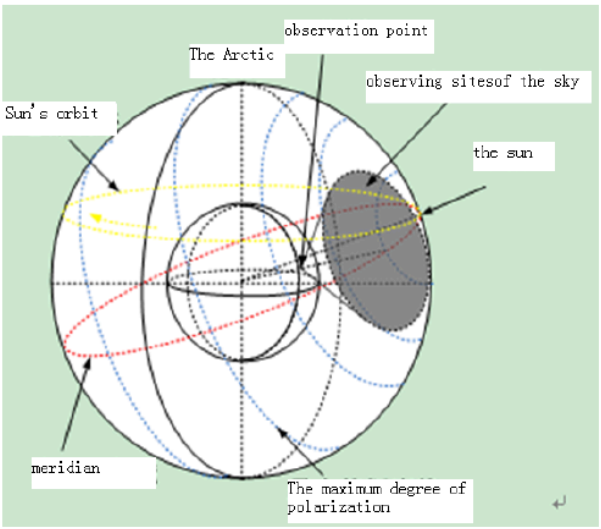

Fig. (2). Schematic diagram of the sky polarization distribution.

The sky polarization distribution can be achieved by adding the polarizer in front of the camera. The celestial sphere radius, R, can be calculated through the calibration experiment. Usually, the more the resolution of the image is, the greater its value, and the higher its positioning precision is. Polarized light is represented by the Stokes vector, which is usually written as follows:

$$S = (I, Q, U, V)^T \tag{1}$$

Where I is non-polarized light intensity; Q and U are respectively two linearly polarized lights of different direction; V is a circularly polarized light. Usually the circularly polarized component is negligible in the instrument detection range, in any small x0y coordinate plane; Light intensity observed in the angle α along with the axis of X is the direction that can be expressed as (2):

$$I(\alpha) = \frac{1}{2}(I + Q\cos(2\alpha) + U\sin(2\alpha)) \tag{2}$$

Using the formula (2), according to the Stokes vector from different azimuth α, we can measure 3 linearly polarized light intensities in different α angles, which can be calculated from the 3 I of the four Stokes parameters, I, U and Q. Because V is negligible, the intensity polarization of P and polarization azimuth angle Φ can be obtained as follows:

$$P = \frac{\sqrt{Q^2 + U^2}}{I} \tag{3}$$

$$\varphi = \frac{1}{2}\arctan\left(\frac{U}{Q}\right) \tag{4}$$

Although the distance is distant between the sun and the observation location, yet it's not sensitive to the change of the position of Observation. In order to obtain enough information about the characteristics of the sun, high resolution telemetry function camera has been used in this project. In this way, the acquired image data is very large, which will significantly affect the real-time performance of the system. So we need to study the appropriate modeling method in order to obtain the sky polarization distribution pattern diagram required for selecting the attention mechanism and sparse perception.

3. THE DESIGN OF DETECTION DEVICE

Component detecting device is composed of a computer processing system and mechanical structure, as shown in Fig. (**3**). The 3 sets of identical polarization image acquisition systems have their mechanical structure composed of a base, a camera bracket, color filters and polarizes [1-3]. Among the three, the camera fixed on the bracket is in connection with the base, that is every camera with a Gigabit Ethernet interface is in connection with computer processing system by a network cable respectively. Polarized light source is composed of a polarizing film and optical filter. With the visible light which containing polarization component in the sky through the blue filter into a blue light, which is then passed through the linear polarizer, and then respectively through lens optical system of projector to the imaging sensor. The different pixels show different brightness levels giving the corresponding pixel inspection light after partial intensity. Image acquisition system with three cameras having axes-parallel to each other, and the projection at the bottom of the equilateral triangle, which the shorter the distance the better. The measuring light of the detection system actually uses solar light as the light source. However, since the sun is distant, based on the edge length of central axis of equilateral triangle, the distance between the sun and the

observation point is compared, but it is not worth mentioning. So, the deviation of light direction and angle of light entering the three cameras' lens can be ignored. The light entering the three cameras' lens can be seen as parallel light rays. According to the Stokes principle requirements, linear polarizer and polarization of polar angle must meet the following conditions:

$$0^0 \le \varphi_1 \prec \varphi_2 \prec \varphi_3 \prec 180^0 \tag{5}$$

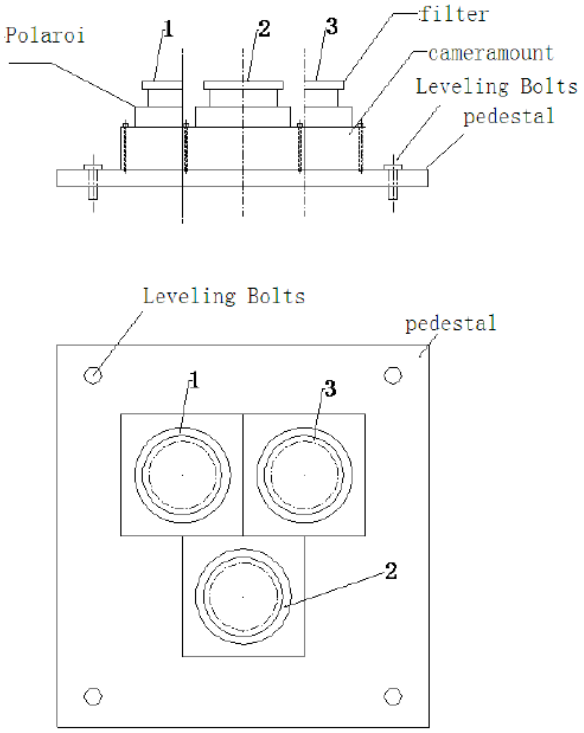

Fig. (3). Schematic diagram of detection device.

Therefore, the equation (5) can satisfy the Stokes principle requirement as long as the proper position of 3 sets polarizing film is setting up of the detection device. Because the direction of polarization on specific locations for a certain period of time and the sky observation point for sunlight are certain at the same time, their image acquisition is possible with the detection device respectively. Its strength is equivalent to 3 measuring value of light intensity on different linear polarization angles about Stokes vector. By the equations (2), (3) and (4), the degree of polarization P and polarization angle φ can be obtained. For the convenience of the calculation, 3 sets of polarization of polar angle are respectively 0°, 30°, 45°. The equation (6) obtained according to the formula (2):

$$\begin{cases} I(0^\circ) = \frac{1}{2}\left[I + Q\cos(0^\circ) + U\sin(0^\circ) \right] \\ I(30^\circ) = \frac{1}{2}\left[I + Q\cos(60^\circ) + U\sin(60^\circ) \right] \\ I(45^\circ) = \frac{1}{2}\left[I + Q\cos(90^\circ) + U\sin(90^\circ) \right] \end{cases} \tag{6}$$

By solving the equation (6), the Stokes vector can be obtained by which the solution of polarization angle and degree of polarization parameters, such as the field of view of each point, is calculated. The light intensity I (a) required to experimentally measure the calibration and real-time measurements, is obtained. The information of sky polarization distribution model embedded with the detection device, is obtained at the same time. The traditional error of polarized light polarization information acquisition device is effectively avoided. Three cameras that are tightly integrated ensure the synchronization of information acquisition, meet the measurement requirements and have higher practicability.

4. EXPERIMENT

The study used a full sky polarization measurement method, refer to Fig. (**3**). In principle, we manufactured a measuring device for which Nikon D7000 digital camera was selected as a sensor coming with a high-speed network interface. Fisheye lens are installed before digital code camera. Moreover, polarization sheet is installed in front of the camera. The computer system is connected to the camera through the switch and high-speed communication interface. Before measuring, turn off the light source for Zero drift before the calibration experiment is performed in the laboratory. Stability of polarized light source is obtained by a linear polarizer. Multiple sets of data are obtained through multiple measurements. A set of data is measured when the detection device rotates 10° around the fixed position, and each data set contains a data of 3 images. In order to reduce the random noise pixel, based on the camera calibration, 9 pixels were selected in the central position of the original region extraction, for the measurement of light intensity. By calculating their average value, the light intensity value I(n) is determined, the same as the polarized light intensity of corresponding position and time. As shown in Fig. (**4**), the curve changes represent the average light intensity, which is calculated for each set of values. The strength has a regular change with the position of the light source and the acquisition system (The angle is about to the left rotating 90 °degrees between the starting position and the light source; In turn it rotated to 360 °, measured 1with every clockwise rotation 10°). That is when the angle is 90° and 270° respectively, it is equivalent to the largest polarization scattering angle.

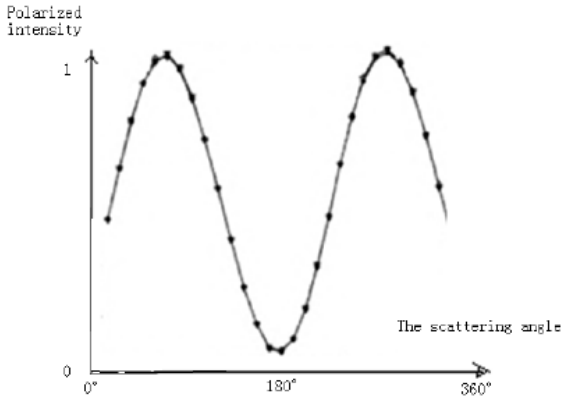

Fig. (4). Variation curves of average light intensity value.

Outdoor experiments were performed at 4 p.m. in the afternoon. During the experiment, the sky is clear, and the illumination is good with a little white clouds. Before the experiment, we choose a lens direction for the reference direction; the other lens polarizing direction and the angle of incident light were adjusted to meet the angle's requirements. Synthetic image of simultaneously acquired 3 polarization images measuring device is shown in Fig (**5**). Fig. (**6**) shows the intensity of polarization diagram obtained by calculating the result of 3 polarization images. The data of some experiments is shown in Table **1**. The results show that the polarization mode is in accord with Rayleigh scattering law. In order to perform calibration of error measurement equipment, the latitude and longitude is determined using GPS devices. Then the actual polarization information can be obtained by calculation. It means that polarization of azimuth Angle is calculated. The practical results of the experiment show that error range is more than $\pm 0.5°$. But the experiments prove that the measuring method is feasible, and has further research value.

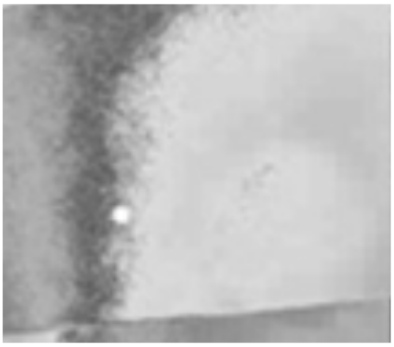

Fig. (5). Polarized synthetic map.

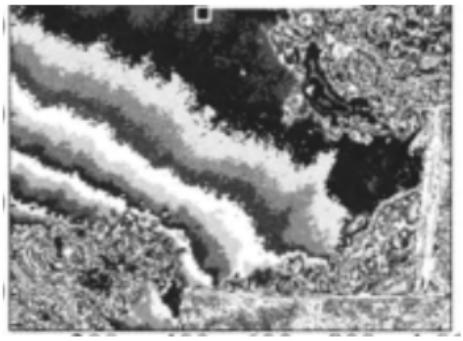

Fig. (6). The intensity of polarization.

Table 1. Result of Experiments

Intensity of polarization (%)	3.42	2.95	3.34	2.23	4.09	8.32
Polarization azimuth angle of calculated (°)	-8.69	-23.5	-60.9	24.0	53.5	8.94
Polarization azimuth angle of measured (°)	-9.60	-24.4	-59.9	23.1	54.4	9.14

CONCLUSION

According to the principle of the sky polarized light distribution, we made a detecting device based on skylight polarization pattern image. The detection experiment is performed based on local feature of skylight polarization pattern. Compared with the traditional [1-14] measurement method, it not only has advantage of being fast and convenient, but also it is applicable to research in space navigation technology. The study has made the certain exploration and measurement of the sky polarization distribution, it has higher feasibility and further research value. Due to the limited conditions, of course, the experiment failed to highlight the regional continuity model of polarization information.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

This work was financially supported by the natural science foundation of Shan dong Province (ZR2013FM002).

REFERENCES

[1] H. Y. Yao, "*Research on the Skylight Polarization for the Bionic Micronano Navigation System*", M.S. thesis, Dalian university of technology, Dalian, ON, China, 2006.

[2] G. S. Smith, "The polarization of skylightan example from nature," *Am. J. Phys.,* vol. ED-75, no. 1, pp. 25-35, 2007.

[3] X. Cheng, and X. Z. H. Wang, "Numerical study on the wavelength-dependent polarization of light scattered by aqueous droplets for RGB spectrums," *Opt. Int. J. Light Electron. Opt.,* vol. ED-121, no. 11, pp. 974-979, 2010.

[4] N. N. Cao, "*Research on Polarized Characteristics of Scattering Skylight for the Bionic Navigation*", M.S. thesis, Dalian university of technology, Dalian, ON, China, 2008.

[5] R. Heged, S. Akesson, and G. Horvath, "Polarization patterns of thick clouds : overcast skies have distribution of the angle of polarization similar to that of clear skies," *J. Opt. Soc. Am. A*, vol. ED-2, no. 48, pp. 2347-2356, 2007.

[6] R. Hegedus, R. Akesson, and R. Wehneret, "Could Vikirlgs have navigated under foggy and cloudy conditions by skylight polarization on the atmospheric optical prerequisites of polarimetric Viking navigation underfoggy and cloudy skies," *Proc. R. Soc. A.* vol. ED-463, pp. 1081-1095, 2007.

[7] G. Horvath, A. Barta, and J. Gal, "Ground based fuIl-sky imaging polarimetry of rapidly changing skies and its use for polarimetric cloud detection," *Appl., Opt.*, vol. ED-41, no. 3, pp. 543-559, 2002.

[8] J. Gal, G. Horvath, V. B. Meyer-Rochow, and R. Wehner, "Polarization patterns of the summer sky and its neutral points measured by full-sky imaging polarimetry in Finnish Iapland north of Arctic Circle," *R. Soc.,* vol. ED-457, pp. 2085-2099, 2011.

[9] R. Wehner, "Po1arization vision—a uniform sensory capacity," *J. Exp. Biol.,* vol. ED-204, pp. 2589-2596, 2011.

[10] J. K. Chu, W.J. Chen, H. Q. Wang, and C. G. Rong, "Mobile robot navigation tests with polarization sensors," *Opt. Prec. Eng.*, vol. ED-19, no. 10, pp. 2419-2426, 2011.

[11] J. K. Chu, W. Wang, Y. Cui, W. Zhi, and Q. Gao, "Measurement for influence of aerosols on polarized sky radiance," *Opt. Prec. Eng.*, vol. 20, no. 3, pp. 520-526, 2012.

[12] Y. Cui, N. N. Cui, J. K. Chu, K. C. Zhao, and T.C. Wang "Design of skylight polarization measurement system," *Opt. Prec. Eng.,* vol. ED-17, no. 6, pp. 1431-1435, 2009.

[13] J. Chu, K. Zhao, Q. Zhang, and T. Wang, "Construction and performance test of a novel polarization sensor for navigation," *Sensor Actuat. A Physic.,* vol. ED-148, no. 1, pp. 75-82, 2008.

[14] L .Yan, G. Guan, J. Chen, X. Shao, and T. Wu "The bionic orientation mechanism in the skylight polarization pattern," *Acta Scientiarum Natur. Univ. Pekinensis,* vol. ED-45, no. 4, pp. 616-620, 2009.

Received: July 16, 2015 Revised: August 11, 2015 Accepted: September 29, 2015