

The Novel Method of North-finding Based on the Skylight Polarization

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Abstract

A novel technology of north-finding is introduced. Taking the relatively stable distribution of the skylight polarization as the information source, the angle between the carrier's long axis and the solar meridian is obtained by using the polarization-sensitive compass designed firstly. And then the angle is rectified by using the sun's current azimuth to determine the angle between the carrier's long axis and the geographical north-south finally to accomplish the task of north-finding. The experiment result shows that the angle between the carrier's long axis and the solar meridian is achieved effectively and the north can be found instantly.

Keywords: North-finding; Skylight polarization; Polarization compass

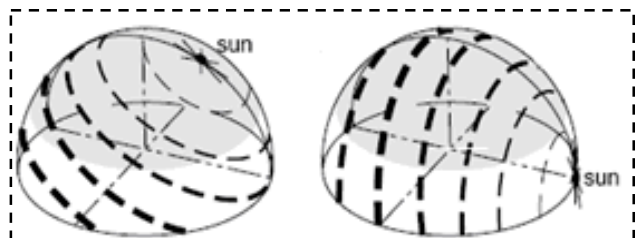
1. Introduction

North-finder is an ideal directional equipment of strategy, tactics and the battle ground mobile launch, which could provide direction reference for missile, radar, artillery, torpedo, aircraft, ships, vehicles and so on. In the 21st century, not only is the military demand of north-finder increasingly urgent, but it also shows a broader application prospect in many civilian engineering such as tunnel construction, mining, surveying, resource exploration. A number of studies have suggested that many animals including ants, bees, cricket and migratory birds have polarization vision system and can gain direction information using the polarization characteristics scattered by the sunlight or moonlight in the atmosphere[1-5]. Polarization navigation has accurate navigation. According to the "Science" reports in August 11, 2006, migratory birds calibrate the accumulated error of their magnetic compass through polarized light pattern of the sunrise and sunset, which make them can still accurately come back to the nest or destination in thousands of kilometers of seasonal migration every year. Research on the sky polarized light navigation in foreign started relatively early and has made some notable achievements. In 2000, D.Lambrions successfully used polarized light sensors in Robot Sahabot2 and the navigation accuracy was tested. It turned out the polarized light sensor is of high navigation precision[6]. The research in this respect in domestic is relatively late, but the present research results have verified the effectiveness of the polarization navigation[7,8], and the error compensation algorithm of polarization navigation sensors has been put forward [9]. Of course, precision and reliability of polarization navigation still need further

research. This paper put forward a novel method of north-finding. The angle between the carrier and north-south direction is confirmed. The research provides theoretical and experimental basis for the practical application of polarization navigation.

2. The distribution model of the skylight polarization

The sunlight is scattered and absorbed by air molecules and aerosol particles when transmitting in the atmosphere. It is because of scattering process that changed the polarization state of the light. The research shows that in a certain day at a certain hour and position, there is a relatively stable polarization pattern in the sky[3], as is shown in figure one (direction and width of the black line respectively stands for the polarization direction and the polarization degree). We can see obviously from the model that there are two symmetrical lines in the polarization pattern of the sky: one is the biggest polarization line with the distance of 90° away from the sun angle, the other is the solar meridian through the sun and zenith.



(a) Sun elevation of 60° (b) Sun elevation of 0°
Fig.1 The skylight polarization pattern at different time

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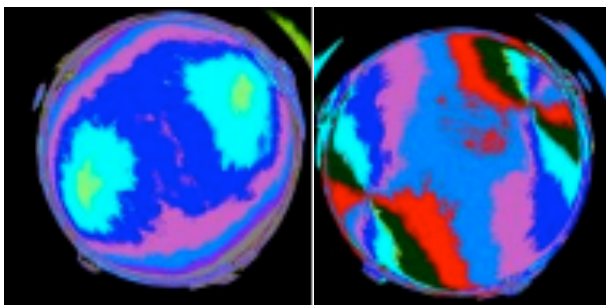
The polarized light's intensity from four different perspective are gained through four different polarization angle measuring, and simultaneous solution of the four

Stokes parameters can be obtained, and then the two parameter—the polarization degree and polarization angle are acquired ,which can be used to describe the skylight polarization characteristics by using the method of the whole sky polarization measuring, adding the fish-eye lens in the front of a digital camera (as shown in figure 2)and being equipped with linear polarizer in front of it.



Fig.2 Measurement system of sky polarized light

The author gained the actual distribution of the skylight polarization through the software process observation, as is shown in figure 3. The survey results show that the actual distribution of the skylight polarization conforms to the theoretical model. Both of them similarly have two symmetrical lines: the biggest polarization line and the sun meridian [10].



(a) Polarization degree (b) Polarization angle

Fig.3 The distribution pattern of sky polarized light

3. Determine the direction parameter by using the sky polarization ideograph

The research shows that insects such as cataglyphis and bees have extremely sensitive visual nervous system for the skylight polarization distribution[11,12]. They perceive the symmetry line of the skylight polarization distribution - the sun meridian through their own polarized vision system, and then determine the angle between the body’s macro-axis and the meridian according to this. Based on the navigation principle by polarization of the cataglyphis, the research group developed a polarization sensitive angular model for the reference of existing research achievements at home and abroad. The basic component of the polarization- sensitive

angular model is polarization-orthogonal unit, as is shown in figure 4.

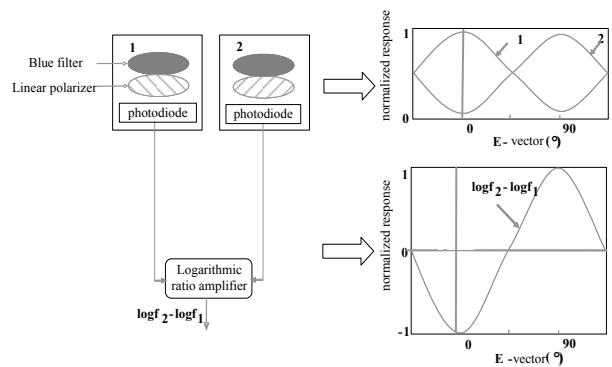


Fig. 4 The model of polarization-orthogonal unit

The polarization-orthogonal unit is similar to the polarization neurons in insects’ nervous system in terms of the function. Each of the units is composed of a pair of polarization light sensors with the logarithmic ratio amplifier, the cataglyphis-imitated three kinds of polarization -orthogonal neural model is made of three-channel polarization-orthogonal unit. If one of the three channels of its principal direction is defined as 0°direction and the principal directions of the other two models as 60°and 120°,the imitated three kinds of polarization -orthogonal neural models are composed of three polarization direction analyzers(0°,60°and 120°),one analyzer in each direction corresponds to one direction’ cataglyphis-imitated optic feeling bar model. We designed imitated three kinds of polarization-orthogonal neurons angular model, as is shown in figure 5.

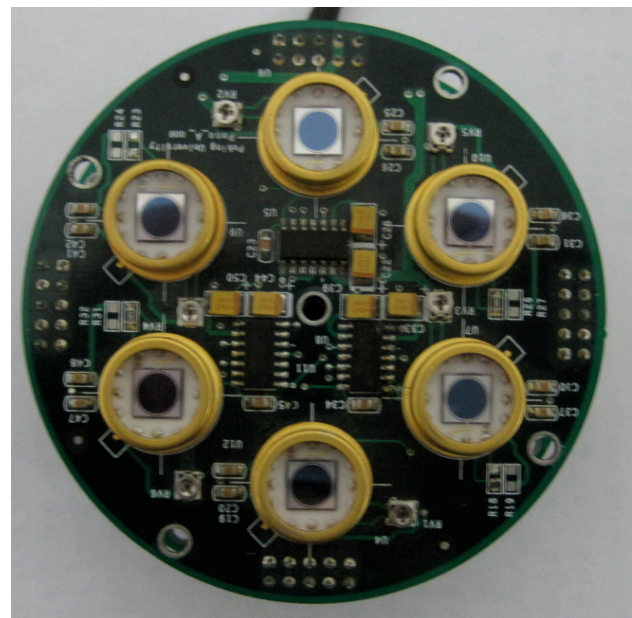


Fig. 5 The polarization-sensitive compass

The output of a polarization sensor can be described as:

$$s(\varphi) = KI[1 + d \cos(2\varphi - 2\varphi_{max})] \quad (1)$$

In which ,*I* means the light intensity; *d* means polarization degree; φ means the current direction of

navigation things' long axis relative to the sun meridian; φ_{max} means the direction which made $s(\varphi)$ obtain the maximum ; K is a constant. So, the output of three polarization-orthogonal units can be described as:

$$p_1(\varphi) = \lg \left[\frac{1 + d \cos(2\varphi)}{1 - d \cos(2\varphi)} \right] \quad (2)$$

$$p_2(\varphi) = \lg \left[\frac{1 + d \cos(2\varphi - 2\pi/3)}{1 - d \cos(2\varphi - 2\pi/3)} \right] \quad (3)$$

$$p_3(\varphi) = \lg \left[\frac{1 + d \cos(2\varphi - 4\pi/3)}{1 - d \cos(2\varphi - 4\pi/3)} \right] \quad (4)$$

In which, $p_1(\varphi)$, $p_2(\varphi)$, $p_3(\varphi)$ is the corresponding outputs of the polarization orthogonal unit when polarization axis is respectively adjusted to 0° , 60° and 120° . In which three equations contain two unknown numbers, so, φ value—the angle between the carrier's long axis and the sun meridian could be gained through the logarithmic transformation and trigonometric calculation, as is shown in the following formula.

$$\varphi = \frac{1}{2} \arctan \left\{ \frac{\bar{p}_1(\varphi) + 2\bar{p}_2(\varphi) - \frac{3}{2}}{\sqrt{3}[\bar{p}_1(\varphi) - \frac{1}{2}]} \right\} \quad (5)$$

4. Rectify the direction parameters by using the solar azimuth

The direction of the sun meridian is constantly changing because of the sun's apparent diurnal motion, the author puts forward the view that the angle calculated could be rectified by using the solar current azimuth , which involves the solution of the solar azimuth .In the celestial navigation[13], we usually get the spherical ascension and declination through querying for "the nautical almanac ", and then make them correspond to the object's projective point position on earth — the longitude and latitude, as is shown in figure 6.

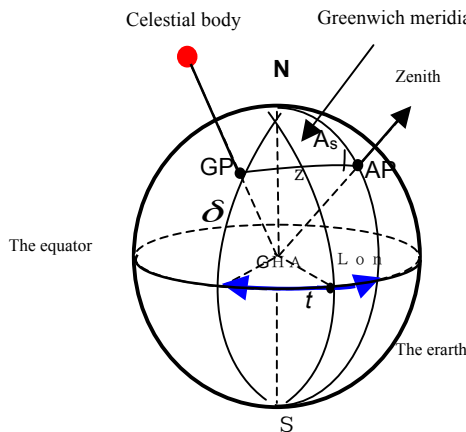


Fig. 6 Projection of celestial body

The celestial altitude angle and azimuth could be gained by calculating astronomical triangle as is shown in figure 7.

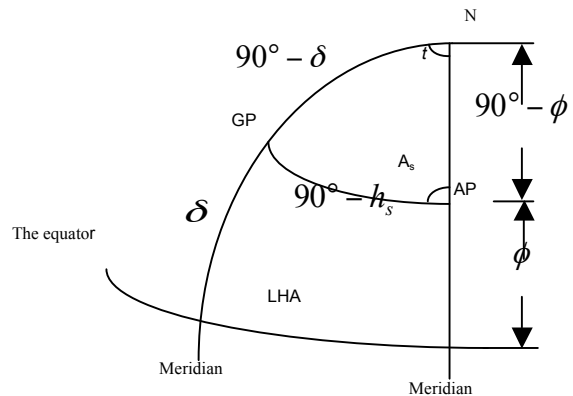


Fig. 7 Navigation triangle

The solar altitude angle h_s ($90^\circ - z$) could be calculated by using the following formula:

$$\sinh_s = \sin \phi \cdot \sin \delta + \cos \phi \cdot \cos \delta \cdot \cos t \quad (6)$$

The solar azimuth A_s could be calculated by using the following formula:

$$\cos A_s = \frac{\sinh_s \cdot \sin \phi - \sin \delta}{\cosh_s \cdot \cos \phi} \quad (7)$$

In which, h_s means the solar altitude angle; A_s means the solar azimuth; t means the local solar hour angle; ϕ means the geographic latitude; δ means the solar declination. So we could determine the angle between the carrier principal direction and the north-south direction when knowing the sun's azimuth A_s and the inclined angle between the carrier's long axis and the sun meridian. That is to say, the inclined angle between the carrier and geographic north-south is certain at any time.

5. The experimental result

In the actual measurement, we use DC motor to control support so that it could rotate uniformly with the speed $30^\circ/s$, driving the polarization-sensitive compass to complete a scan each rotary 360° (12 s).The data in Figure 8 were collected at 10:18 a.m., April 1, 2010 (Beijing time) in northern latitude 39.92° and eastern longitude 116.76° . Testing results show that the output of three polarization-orthogonal units basically accord with the response laws of polarization navigation concurrency models, proving that the inclined angle between the system's current direction and the sun meridian could be resolved by using Type 5. After getting these data, we can gain effective estimate values of the navigation system azimuth by pre-processing them using moving-section Kalman filter algorithm so as to improve the north-finding accuracy further.

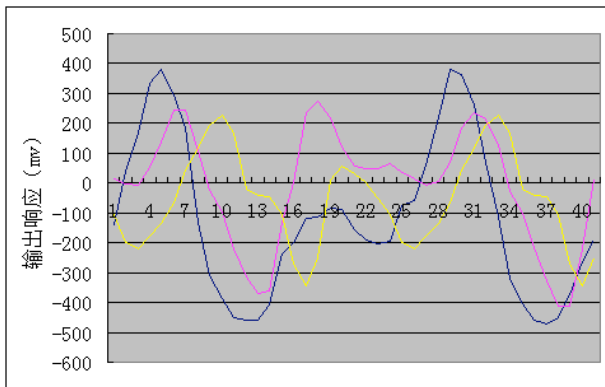


Fig. 8 The outputs of polarization-sensitive compass

Assuming that the angle between the carrier's principal direction and the sun meridian, which is calculated by using the polarization-sensitive compass, is 25° at 10:18 a.m. on April 1, 2010 (Beijing time) in northern latitude 39.92° and eastern longitude 116.76° , we get the sun declination is $2^\circ 35'$ and the time difference is $-2m48s$ at that time in Beijing. Further, the local hour angle is -29.5° at present. Plugging the above parameters into the type 6 and 7, we get the solar current angle is -43.22° and then the inclined angle between the carrier's principal direction and the north-south is $\alpha = A_s + \varphi = -43.22^\circ + 25^\circ = -18.22^\circ$

6. Summary and prospect

The sunlight is scattered and absorbed by air molecules and aerosol particles when transmitting in the atmosphere, making the skylight appear certain polarization characteristics. There is a relatively stable polarization pattern in the sky at a certain hour and position of a day. This paper obtains the direction information north-finding needed using the relatively stable distribution of the skylight polarization, and then rectifies the angle through the sun's current azimuth. Finally the angle between the carrier's principal direction and the geographical north-south is determined to accomplish the task of north-finding.

The work is going on further. Our work mainly focuses on analyzing the influence factors of the polarized light distribution and the measurement error of carrier itself, and then improving polarized light directional accuracy through establishing error compensation model.

Acknowledgment

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