Design and verification of 2Π space all-sky polarization observation system

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Abstract: The sky polarization pattern is an important feature of the atmospheric effect of remote sensing observation. It describes the distribution of polarization information in all sky. The atmospheric effect on polarization observation is immense, and analysis of the method of the atmosphere acting on polarized light is the basis, it can provide a new idea for reducing the impact of atmospheric effect on polarization images. Because different regions and different observation situations correspond to different sky polarization patterns, it is a prerequisite to develop instrument to research the polarization pattern of the sky. The emphasis of this paper was on the design of an all-sky polarization observation system and validating it through precision measurement. It introduced main parts of the instrument firstly, including mechanical structure, optical design and circuit control, then the instrument control accuracy was described by analyzing control strategy and control precision of the instrument. At last, by contrast experiments, the results prove the reliability of polarization observation instrument.

Key words: polarizing instrument; system design; control strategy; test analysis

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2Π 空间全天空偏振观测系统研制与验证

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摘 要： 在遥感观测中，天空偏振模式是大气效应的重要特征。它描述了全天空的偏振信息分布，大气效应对偏振观测的影响巨大，因此研究大气的偏振光效应是根本，它可以为减小大气效应对偏振图像的影响提供新思路。由于不同的区域和不同的观测条件对应于不同的天空偏振模式，研制天空偏振模式观测的仪器则成为了必要的前提。文中的重点在于设计一个全天空偏振观测仪器，通过精度测量，验证它的可用性。文中首先介绍了仪器的主要组成部分，包括仪器机械结构，光学设计以及电路控制，然后分析仪器的控制策略以及控制精度，最后通过对比试验，结果显示该天空偏振观测仪器可靠。

关键词： 偏振仪器； 系统设计； 控制策略； 测试分析

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0 Introduction

In the radiation from the target, including the light intensity, frequency and phase and polarization of the four properties, in which the polarization has not been paid enough attention and in full use. In fact, nature is covered with a variety of natural polarizers, such as vegetation, liquid, rock, buildings, snow, clouds, fog and so on. Solar radiation in the arrival of these media surface reflection, scattering or through the media after the refraction, the light wave shows a certain degree of polarization[1]. And the polarization state corresponds to some characteristics of the medium. According to the property, we can determine the interface or the existence of the state and nature of the media[2-3]. Polarized remote sensing technology is based on this principle to identify the target characteristics of detection[4-5].

The sky polarization pattern is an important feature of the polarized remote sensing observation of the sky effect, which describes the distribution of the polarized signal in the whole sky[6]. In the present study, Guan Guixia et al. used the all-sky polarization measurement method to study the distribution of sky polarized light under different conditions, and discussed the relationship between sky polarization distribution and various factors[7]. In 2009, Wu Taixia, Yan Lei proposed atmospheric polarization neutral ground - atmosphere separation method, according to the lower polarization characteristics of atmospheric polarization neutral point, they proposed that observations from this area can reduce the impact of the atmosphere on polarization images [8]. Miyazaki used the fisheye lens to evaluate the sky polarization effect [9-10]. In 2010, Chen Wei and Yan Lei used polarized signals to isolate the aerosol information in the atmosphere. For the marine and terrestrial characteristics, they utilized different ground -atmosphere separation method. The results of the separation experiments are based on the Research Scanning Polarimeter (RSP) polarized flight data developed by NASA, it reflected that the polarization flight data are preliminary valid ation for sea and land aerosol inversion results[11].

However, the current polarized remote sensing imaging system is usually relatively simple, usually using ordinary camera, fisheye lens and polarizer combination, observation of real-time is not strong, the error is large, and the human work cumbersome. The aim of this paper is to construct the 2Π space all-sky polarization observation system.

1 Structure of 2Π space polarization observation system

The 2Π space all -sky polarization observation system (as shown in Fig.1) studied in this paper mainly includes the following parts: optical system, electronic control system. The overlap between the observed areas is 30%, and the multi-spectral observations cover 3 channels at 400-1 000, 550, 670, and 860 nm. The observation system can accurately coincide with the observation area in 2Π space, and the positioning accuracy is 0.5 °.

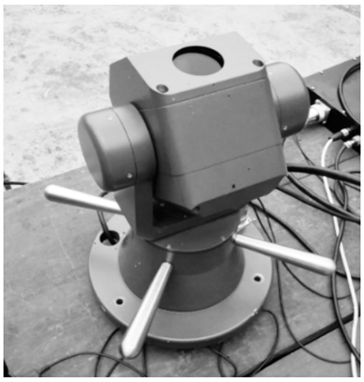

Fig.1 2Π space all-sky polarization observation system

1.1 Optical system

Figure 2 shows the schematic structure of the

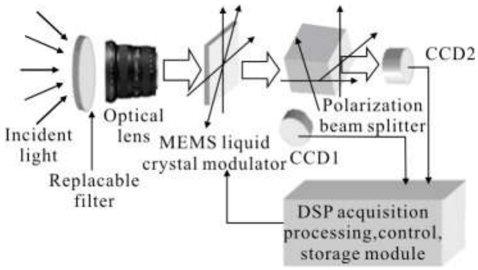

Fig.2 Optical design

polarization parameter detection imaging system. Passing across an optical lens group, a liquid crystal modulator and a polarization beam splitter, the target information is filtered through two optical windows, and is imaged on CCD1 and CCD2. The DSP processor is used as the core to realize data acquisition and storage, polarization information processing, liquid crystal modulator control. The basic principle is that the incident light passing through a liquid crystal electro-optic modulator (EOM) can be modulated into different phases of the light emitted by the polarization prism to obtain two mutually orthogonal polarization components, the two polarized light components are received from two surface array CCDs. This can be carried out on the CCD filter processing, in order to obtain different wavelengths of the polarization image, and achieve full polarization spectrum detection.

1.2 Electronic control system

The electronic control system can be divided into following several parts: the main control circuit module, the strength weak electric isolation module, the power actuation module, the current monitoring module and the position detection module. The main control circuit module takes the DSP as the core, and the peripheral circuit mainly includes the power supply module circuit, the JTAG interface circuit, the external memory expansion circuit, the serial communication interface circuit, the pulse quantity, the analog control interface and the digital analog conversion circuit. The power driving circuit comprises an inverter main circuit and a rotor position detecting circuit. The position detection module mainly comprises a Hall signal interface circuit and an incremental encoder interface circuit. The overall design of the electronic control system is shown in Fig.3(a).

A single neuron PID control algorithm is adopted in the position closed loop, and the algorithm adopts the supervised Hebb learning rule. In order to ensure the position precision and servo bandwidth of the servo system, the disturbance observer and velocity feedforward control method are adopted. The feedforward control method uses the simple position command signal to differentiate. The closed-loop control loop is shown in Fig.3(b).

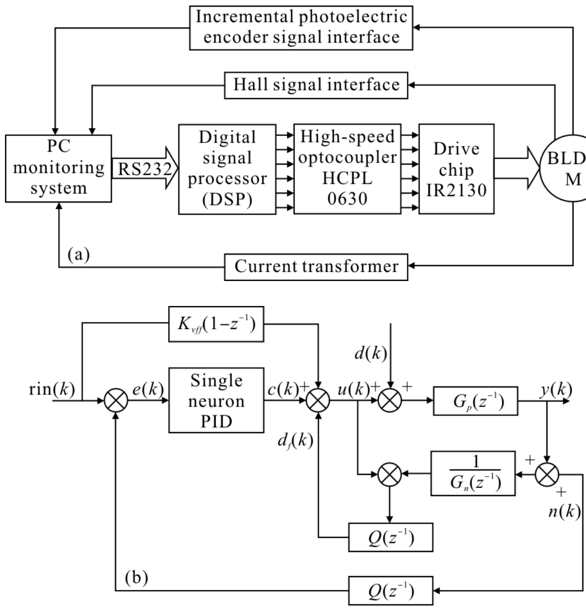

Fig.3 (a) Control circuit system and (b) closed-loop control

2 Verification of precise positioning characteristics of 2Π space observation instrument

2.1 Mathematical model of angle depression measurement by frequency domain method

Frequency domain method is used to test the speed loop frequency characteristics of the depression control system. The TMS320F28335 processor generates sinusoidal pulse modulated signals with different amplitude and frequency, and is input to the double angle motor through the power amplifier circuit. The angular velocity of the motor output is controlled by the optical fiber rate gyro measurement. The influence of the nonlinearity caused by the frictional moment and the load imbalance is neglected in the low frequency range. According to the transfer function of the angle control system, when the two motors are driven by the formula, the control system can be regarded as two inertial links and the transfer function of the depression control system with load is:

$$G(s)=\frac{y(s)}{u(s)}=\frac{0.001\ 99}{(0.152\ s+1)(0.005\ s+1)}$$

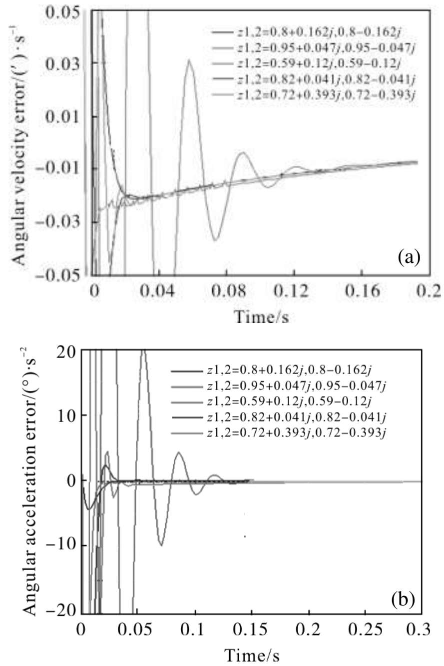

Fig.4 s plane distribution of closed-loop poles

2.2 Analysis of pole assignment of state observer

For a linear continuous steady-state closed-loop system, the stability of the system depends on the position of the closed-loop poles in the s plane. If the closed-loop poles are located strictly in the left half s plane, the system is stable, if the closed-loop poles are located in the right half s plane, the system is unstable, and if the closed-loop poles are on the imaginary axis of the s plane, the system is critical and stable. For a linear discrete system, the stability of the system can be determined by the pole of the closed-loop pulse transfer function. From the relation $z=e^{Ts}$ of complex variable z and s, we can see that the mapping from s plane to z plane is: $j\omega$ axis in s plane is mapped to unit circle of z plane, which is $|z|=1$, s plane left half plane is mapped to $|z|<1$; The right half plane of the s plane is mapped to the unit circle, which $|z|>1$(as shown in Fig.4).

From the stability analysis of the state observer, as long as the feedback gain vector G is selected so that the eigenvalues of the matrix Φ are all within the unit circle, the observer error convergence can be realized. The error convergence rate is controlled by adjusting the position of the eigenvalues of the matrix Φ in the unit circle. The zero initial state of the system is an ideal state. If the initial state condition of the system is zero, the observer can track the state of the system quickly and observe it.

3 Instrument accuracy evaluation

3.1 Turntable positioning accuracy

The turntable can calibrate its position in real time by the feedback of photoelectric encoder, so the positioning accuracy depends on the photoelectric encoder. To ensure the accuracy and stability of the turntable, selecting the incremental photoelectric encoder produced by the international well-known Germany Heidenhain company, it have high precision, good stability, and fast response advantages to maintain the long-term accuracy. From Tab.1, we can see the encoder can meet the needs of precision instrument in the accuracy, the highest mechanical speed and angular resolution and other technical indicators.

Tab.1 Main performance parameters of the encoder

Performance parameters	Model	En-graved number	Accuracy /(″)	Allow mechanical speed	Angle resolution /(°)
Two-axis high-precision turntable	ERN180	5 000	±3	4 000	0.000 1

3.2 Imaging accuracy

We photographed the clear weather on January 11, 2017, and the cloudy weather on February 28, 2017. Both of the locations are the remote sensing building of Peking University (latitude N39°59′, east longitude E116°18′). Using 2Π space all-sky polarization observation system to photograph the zenith direction, and using digital camera with fisheye lens to photograph the zenith direction, fisheye lens has been calibrated, the degree of polarization error is within 0.1. Through contrast by the two imaging methods, the accuracy evaluation can be acquired. The experiment date is April 14, 2017(as shown Fig. 5(a)), from 15:01 to 15:20, the location is still at remote sensing building of Peking University. Collecting the data every minute, solving the images to acquire the degree of linear polarization (DOLP) time sequence, the result is shown in Tab.2.

From Fig.5(b), the zenith polarization is plotted to scatter plot with time, the average value of the DOLP is 0.174 3, and the standard deviation is 0.033 7. Although the zenith polarization fluctuated, it could be found that the trend is steady and there is a tendency to increase gradually, it satisfied the stability and the gradient of the zenith polarization, because with the sun′s height decreasing, the DOLP of the zenith direction will become larger. From Fig.5(c), at the same time and location, using the digital camera with fisheye lens, we also acquired the polarization distribution, it had larger field of view. In the

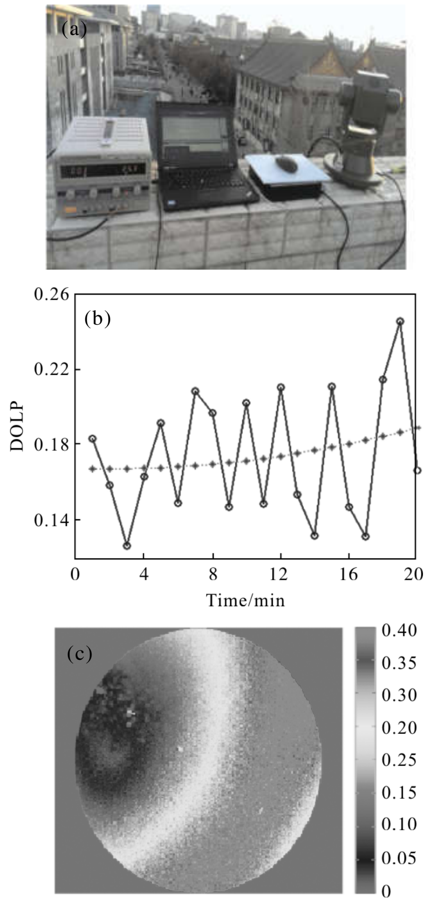

Fig.5 (a) Experiment situation, (b) DOLP time sequence acquired by 2Π instrument, (c) DOLP image acquired by digital camera with fisheye lens

Tab.2 Trend of zenith polarization changes with time

Time	DOLP	Time	DOLP
15:01	0.183 1	15:11	0.148 8
15:02	0.158 6	15:12	0.210 4
15:03	0.126 7	15:13	0.153 9
15:04	0.163 0	15:14	0.132 1
15:05	0.191 4	15:15	0.210 6
15:06	0.149 4	15:16	0.147 1
15:07	0.208 3	15:17	0.131 6
15:08	0.196 6	15:18	0.214 5
15:09	0.147 1	15:19	0.245 2
15:10	0.202 1	15:20	0.166 4

central area of the images, the DOLP fluctuated around 0.2, the contrast showed the values are very close, and the deviation is within 0.05, it preliminarily verify the reliability of the instrument.

4 Conclusion

As a new detection method, polarization remote sensing can acquire richer information, the sensitivity to the atmosphere may make it as a source of data for detection, it can solve the cloud and aerosol particle size distribution problems which other traditional optical remote sensing cannot solve. The paper mainly gives the system composition, structure frame, precision positioning and electronic control system of the instrument design. Firstly, the influence of the atmospheric polarization effect on the spectral characteristics of the target is analyzed to determine the composition of the system device. Secondly, by selecting the appropriate control of the measurement and control parameters, the ultimate realization of the turntable precise control from the control strategy of the controlled object, the precise positioning characteristics of the device are tested. At last, the design results of the instrument are validated, the appearance of the instrument design, in the complete machine working condition, respectively verify the imaging performance and precision positioning equipment. Seen from the results, the image quality is good and the polarization error is less than 0.1, the instrument basically meet the observation requirements.

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