

Targets detection and discrimination using laser polarimetric imaging

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Abstract Laser polarimetric imaging can offer additional information of targets compared with the traditional intensity imaging method. It can be used to detect camouflaged targets and distinguish targets with the same reflectivity, which cannot be realized using the traditional imaging method. Based on the dual-rotation retarder technique, we have established a setup to acquire different polarization state images. The polarization degree of the target can be calculated and encoded to get the polarization degree image. Preliminary results and error analysis have been given to validate the system. The results show that the system has rational arrangement and can realize the function of target detection and discrimination. Also, the polarization degree change and spectrum changes have little influence on the system.

Keywords laser polarimetric imaging, polarization degree, spectrum change

1 Introduction

Because of the advantages of discriminating natural targets and artificial targets, capabilities of discovering camouflaged targets, and exploring internal characteristics of targets, etc., laser polarimetric remote sensing technique has been considered as a significant improvement of the traditional remote sensing system [1,2]. The polarization characteristics of targets reflect the surface rugosity feature, physical characteristic and their composition information, which are seldom employed in target detection. For targets with the same reflectivity, intensity imaging cannot distinguish the differences among different targets; however, polarization information can be used to

discriminate those different targets since they usually have different depolarization ratio [3]. Also, polarimetric remote sensing has now revealed great potential in target detection and recognition [3–5], medical applications [6,7], environmental monitoring [8,9], military reconnaissance [10,11], etc.

Since the 1970s, theories and experiments have been conducted to study the polarization changes of light scattered from targets. In the 1990s, USA, UK, France and Japan started to investigate the utilization of polarization in military applications and the atmosphere. The Earth Observing Scanning Polarimeter (EOSP) was developed by the USA for aerosol detection [12]. In 1996, the Polarization and Directionality of the Earth's Reflectances (POLDER) instrument with eight polarization channels, developed by the French space agency, which flew on the Advanced Earth Observation Satellite (ADEOS) developed by the Japanese space agency, was launched and used for aerosol and cloud detection, land and ocean surface measurement [13]. The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite launched by the USA in 2006 is used to detect cloud and aerosol using the dual-wavelength laser radar Cloud Aerosol Lidar with Orthogonal Polarization (CALIOP) [14]. And now, America's army research laboratory is conducting research on the three-dimensional (3D) polarization imaging of terrain and camouflaged targets detection [11].

In this paper, we have proposed an improved experimental setup for polarization imaging based on the dual-rotation retarder technique introduced by Azzam and the two-measurement method modified by Breugnot [15]. Preliminary results have been given.

2 Principle of polarization detection

The depolarization characteristics have the advantage that different targets are slightly influenced by illumination.

They mainly depend on surface roughness, material nature, or direction of incident light. For surface scattering, the rougher the target the more depolarization occurs. For an artificial target the depolarization ratio is usually smaller than a natural target. Volume scattering, the main factor for depolarization, occurs inside the targets. It mainly depends on the material nature, concentration, particle size, absorption ratio and light wavelength. For a target with smaller absorption of light, the incident light reflects multiple times inside the target and the polarization of the emergent light will be depolarized obviously compared with the incident light. This can be explained by Mie scattering theory or Kubelka-Munk theory [16,17]. In order to describe the polarized light, Mueller-Stokes theory is introduced to describe the polarization degree [18].

Light can be expressed by Stokes vector which consists four components I, Q, U, V , corresponding to the total intensity of light, amount of linear horizontal or vertical polarization, amount of linear $+45^\circ$ or -45° polarization, and amount of right or left circular polarization, respectively. Stokes vector can be used to describe any state of light. However, Jones vector can only be used to describe totally polarized light. The Stokes vector can be written as

$$\mathbf{S} = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} = \begin{pmatrix} E_x E_x^* + E_y E_y^* \\ E_x E_x^* - E_y E_y^* \\ E_x E_y^* + E_y E_x^* \\ i(E_x E_y^* - E_y E_x^*) \end{pmatrix}, \quad (1)$$

where E_x and E_y are the components of the electric field of light.

Mueller matrix, a 4×4 matrix, is often used to describe

the interaction between the incident light and the target. The Mueller matrix components consist of the information of depolarization, diattenuation and retardance [15]. It can be written as

$$\mathbf{M} = \begin{bmatrix} m_{00} & m_{01} & m_{02} & m_{03} \\ m_{10} & m_{11} & m_{12} & m_{13} \\ m_{20} & m_{21} & m_{22} & m_{23} \\ m_{30} & m_{31} & m_{32} & m_{33} \end{bmatrix}. \quad (2)$$

The relation between incident light and received light scattered by target can be described as

$$\mathbf{S}_{out} = \mathbf{M}_{Target} \cdot \mathbf{S}_{in}$$

$$= \begin{bmatrix} m_{00} & m_{01} & m_{02} & m_{03} \\ m_{10} & m_{11} & m_{12} & m_{13} \\ m_{20} & m_{21} & m_{22} & m_{23} \\ m_{30} & m_{31} & m_{32} & m_{33} \end{bmatrix} \cdot \mathbf{S}_{in}. \quad (3)$$

If we want to obtain the Mueller matrix of the target, 16 measurements must be made. The polarization degree of the target is expressed as

$$P_d = \sqrt{\frac{\sum_{i=0}^3 \sum_{j=0}^3 m_{ij}^2 - m_{00}^2}{3m_{00}^2}}. \quad (4)$$

With special arrangement of the measurement setup and supposing that there are no birefringent material in the target, the off-diagonal components are nearly zero. Polarization degree can be obtained with two measurements [15].

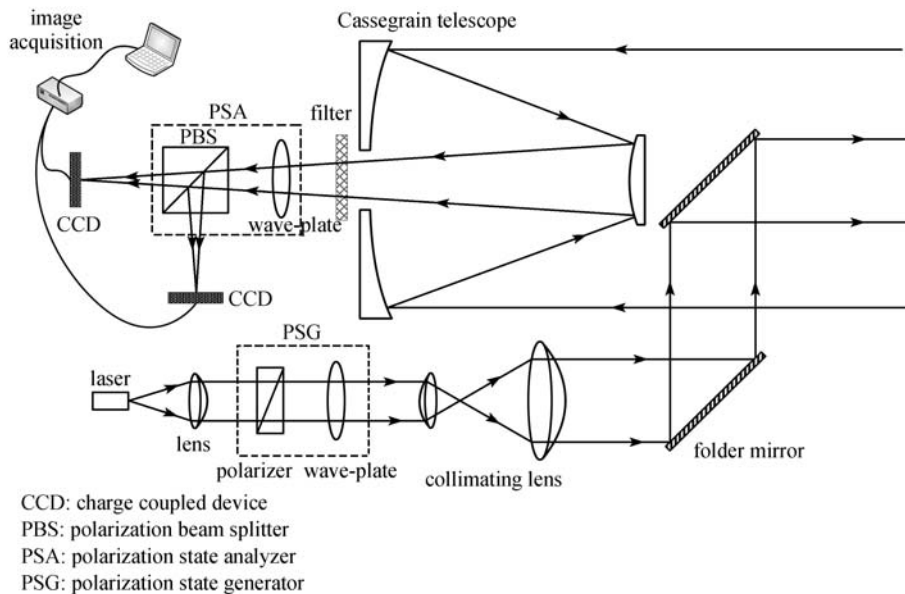


Fig. 1 Schematic of experimental setup

3 Experimental description and results

The laser polarimetric imaging system (Fig. 1) mainly consists of five parts, the emitting laser, polarization state generator (PSG, combination of polarizer and wave-plate), the receiver telescope, polarization state analyzer (PSA, combination of wave-plate and polarization beam splitter (PBS)), and the data processing unit. Light emitted by the laser passes through the collimator and the PSG to generate the wanted polarization state of light. After expanding the light is incident on the target. The backscattered light received by the Cassegrain telescope then goes into the PSA. With this system two images can be acquired once. For special angles of polarizers and wave-plates, the intensity and polarization degree of the target can be calculated through one measurement [19–21]. With these two images, intensity image and polarization degree image can be obtained by the data processing unit.

A series of experiments have been done to demonstrate the system. First, we detect the keys from the grass background, as shown in Fig. 2. Figure 3 shows the experimental results. Figures 3(a) and 3(b) are initial images acquired by the system, which are polarization parallel image and polarization orthogonal image, respectively. Figures 3(c) and 3(d) are images coded with



Fig. 2 Photo of keys in grass background

intensity and polarization degree, respectively. In the intensity image, the keys are not so clearly different from the grass background. From the polarization degree encoded image, the less depolarized target is bright and the more depolarized background is dark. Therefore, we can distinguish the keys obviously, because of less depolarization ratio of the metal keys.

Second, we use this system to distinguish different targets. As show in Fig. 4, the target contains two letters and a coin. One is written with pen and the other is written

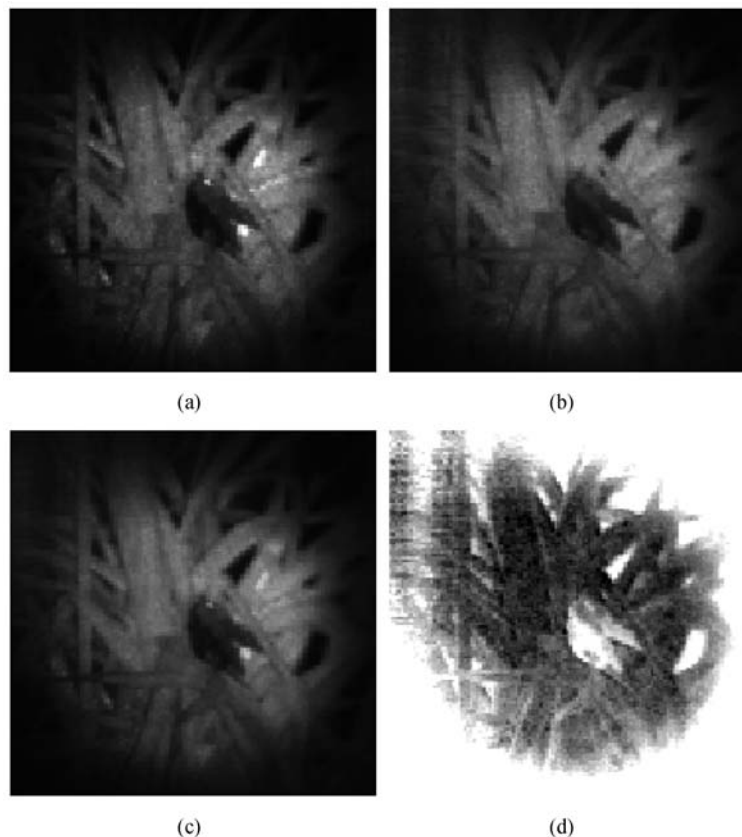


Fig. 3 Experimental results. (a) Polarization parallel image; (b) polarization orthogonal image; (c) intensity coded image; (d) polarization degree coded image



Fig. 4 Photo of a coin and two letters, one is written with pen (the one above the coin) and the other is written with pencil (the one under the coin)

with pencil. Figures 5(a) and 5(b) are the obtained images. In the intensity image Fig. 5(c), the letters are both blurred because of the similar reflectivity. However, due to the difference of depolarization ratio of letters written with pen and pencil, in the polarization degree image Fig. 5(d), the letter written with pencil is clearly displayed. Because the letter written with pencil is less depolarized than the letter written with pen, we can use the depolarization difference of targets to distinguish different targets or detect something camouflaged in the natural background.

4 Error analysis and developing trend

4.1 Causes of errors and analysis

Some errors that have influences on the polarization state are analyzed in previous works [20,22]. The polarization state of incident light is generated by the PSG (the combination of polarizer and wave-plate). The wave-plate is related with the wavelength of the laser source. First, the wavelength of the laser must be accurate and stabilized. In order to generate the required polarization state of light and analyze the backscattered light, the angle of the polarizer and wave-plate must be accurate as well.

Second, the polarization states changes of light passing through the optical system must be considered. The polarization degree of the target is correct only when the system has no influence on the polarization state of light. It has been analyzed in detail in Ref. [22], and what influence most is the telescope. It can be improved by coating with a suitable film, such as silver or aluminum film.

Third, in order to eliminate the interference of stray light, a filter is used, which allows light with the same wavelength as the laser source to pass through. Therefore,

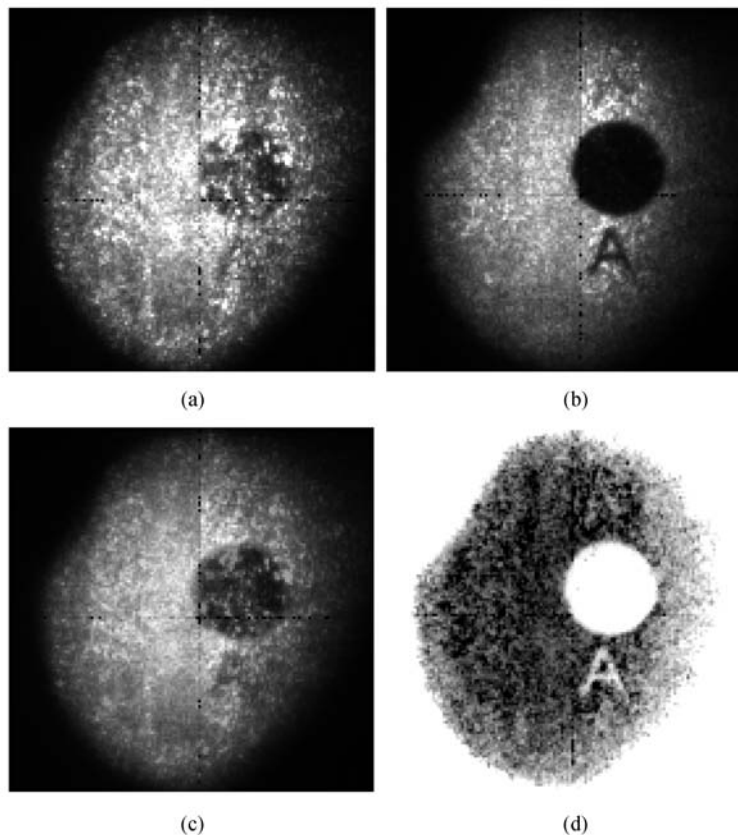


Fig. 5 Experimental results. (a) Polarization parallel image; (b) polarization orthogonal image; (c) intensity coded image; (d) polarization degree coded image

the wavelength passing through the system cannot be changed. Gaussian Schell-Model beam is used to simulate the spectrum changes of light propagating the polarimetric imaging system. Three aspects that may cause spectrum changes are considered. With the real parameters of our

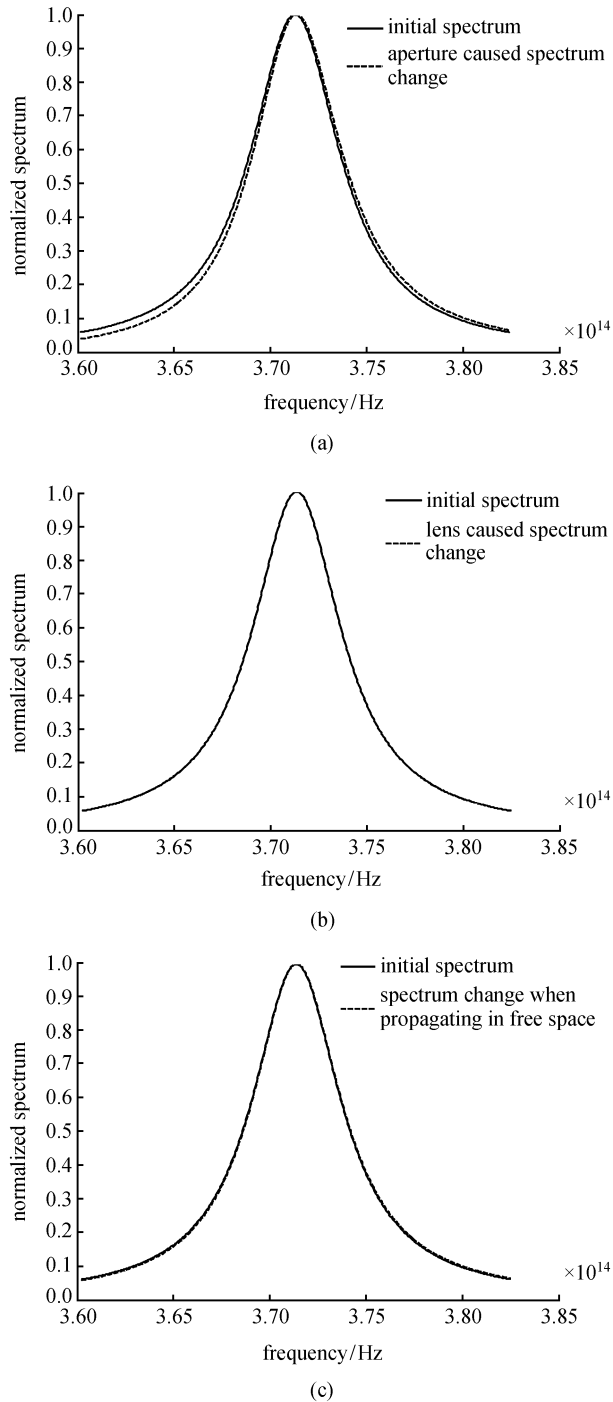


Fig. 6 Simulation of spectrum changes of light when passing through laser polarimetric imaging system. (a) Spectrum change caused by aperture; (b) spectrum change caused by lens; (c) spectrum change when light propagating in free space for a short distance

system and assuming that the initial spectrum of the laser source is Lorentz type, we simulate the influences of aperture, lenses, and light propagating in free space on spectrum changes, as shown in Fig. 6.

Simulation results show that the aperture is the main cause of spectrum change, which changes the spectrum towards the larger frequency, i.e., blue shift. Light passing through lenses and propagating in free space have nearly no influence on spectrum change in our system. Compared with the line width of the laser source, the spectrum shift is extremely small and has little influence on our system.

4.2 Problems and future developing trends

Because of the monochromaticity and coherence of laser, light incident on the target will experience multiple scattering, which will interfere with each other and generate a granular pattern called “speckle”. Speckle degrades the resolution of images and makes it illusive. It must be suppressed with a proper algorithm or system design. The development direction of laser polarimetric imaging is towards 3D polarimetric imaging [11], multi-spectral polarimetric imaging [9], and fluorescent polarimetric imaging [7] with higher resolution.

5 Conclusion

A laser polarimetric imaging system is established. The application prospects in target detection and discrimination of polarimetric imaging are demonstrated in laboratory. It can be used in the field of environmental monitoring, remote sensing, medical imaging, etc. However, due to the resolution of the charge coupled device (CCD) and the affects of “speckle”, the image quality is not perfect, and we are now endeavoring to improve the image quality.

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