

Polarization Ghost Imaging System Based on Compressed Sensing

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Abstract: Polarization ghost imaging system combines the strength and the polarization detection, expanded the obtained information from the ghost imaging system, can effective target detection and identification. The conventional correlation polarization ghost imaging system requires a large amount of sampling data, and signal to noise of the restored result is low. Polarization ghost imaging system based on compressed sensing is proposed to get the intensity and polarization information of the object using the detected information from the point detector. In the simulation experiment, the same reflectivity but different polarization characteristics of objects are employed. The results show that the high quality of the object intensity and polarization information can be obtained with fewer sample number compared with the correlation method, and it can improve the real-time performance. Finally, using image fusion algorithm to merge the intensity and polarization information, recognized by fusing information can be effectively carried out a variety of objects.

Keywords: Ghost imaging, Compressed sensing, Polarization detection.

1. INTRODUCTION

The ghost imaging system as a name for correlated imaging or single pixel imaging attracts extensive attention worldwide by domestic and overseas scholars [1-3]. The light source modulates in the ghost system, The beam of light is divided into two parts using the beam splitter, one beam is detected with a resolution of CCD, and the other is obtained strength by the single pixel detector after shining objects. Light distribution using the CCD detector and shining the objects is relevant. The image of exposure scenarios is acquired by the relevant algorithm. If the light distribution is predicted at the location of shining objects, the CCD optical path can be omitted, the ghost imaging system is achieved. The structure of the ghost imaging system is easy, it can be imaged at the waveband which conventional CCD cannot imaging, therefore it has important application. In addition to this, single detecting are quickly responding, and can compensate for the shortcomings of matrix CCD which has low response time, can image with high resolution in the three-dimension structure. In 2013, British scientist has build up the three-dimension ghost imaging system using the algorithm from multiple perspective, and carry on the face high resolution 3d imaging, The results of the study is published in Science, and is highly appreciated by domestic and foreign scholars. The same year, three-dimensional ghost imaging technology is realized by the pulse time sequence at Shanghai Institute of OpticsFine Mechanics, China, they gained the image which has the lateral resolution of 2cm and the longitudinal resolution of 60cm at one thousand metres.

At present, Related research has already covers all aspects of the ghost imaging system, and the theoretical system has been built up perfectly [1].

In recent years, the polarization detection technology which adding the polarization diversity between different objects at the same time of using albedo object properties has received the most attention in the field of traditional plane array imaging, and it has been widely used in the field of object identification, classification and so on [4]. However, in a lot of ghost imaging studies, Object image is generally obtained by the albedo features, Only a few studies focus on the influence of light polarization characteristics on the system imaging, Theoretical and experimental results show that polarized light can be used to provide the system of image contrast. In the case that two different objects have the same albedo, If imaging by traditional ghost imaging technology, we are unable to recognize the target effectively, so Polarization detection ghost imaging technology is presented and the simulation experiment results are given by Anhui light machine of Chinese academy of sciences, and the result of the simulation Confirmed that the different material objects can be identified by the polarization detection, the related algorithm is adopted for image restoration [6], Because the relevant algorithm needs a large number of hits, so it reduces the system real-time nature. The compression sensing algorithm in ghost imaging has been widely used in the ghost imaging system [7-13], The algorithm assumes that the object information under certain transformation is sparse, that is to say, it contain very small amounts of non-zero elements, This hypothesis is correspond with most object information in real life. The paper [7-13] confirmed that this algorithm can not only effectively reduce the sampling number but also improve the image resolution and signal-to-noise ratio. Compression sensing algorithm is adopted in this paper to deal

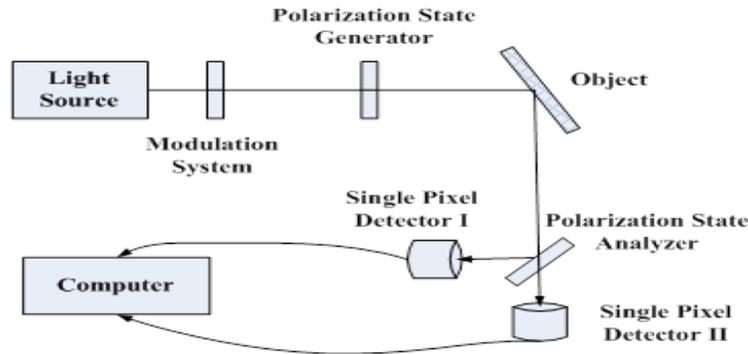


Fig. (1). Sketch-map of polarimetric ghost imaging.

with the polarization ghost imaging system to obtain the image information. Finally we will get a variety of different information for data fusion, That can distinguish objects of different material by data fusion [5].

2. THE CALCULATION OF POLARIMETRIC GHOST IMAGING

Fig. (1) shows the structure of polarization ghost imaging system. The light of laser light source exit via the phase modulation system, then go through the polarization state of generator, generate specific polarization of light to illuminate the object, The reflected light is divided into two orthogonal polarization state beam respectively by two single pixel detector for intensity information after polarization analysis system. According to the results of analysis in literature [6], we can get two normalized strength obtained from the detector respectively.

$$\begin{aligned} I_1 &= \frac{1}{2} \left[1 + \frac{1}{3} (2m_{11} + m_{33}) \right], \\ I_2 &= \frac{1}{2} \left[1 - \frac{1}{3} (2m_{11} + m_{33}) \right]. \end{aligned} \quad (1)$$

Where m_{11} and m_{33} are the characteristic parameters of linear polarization and circular polarization respectively, I_1 and I_2 are the total light intensity information of the two detectors. Can be said a detector for the light intensity distribution of single pixel information II and polarization difference between IP. We derive from (1) that the light intensity distribution of single pixel detector I_I and the polarization difference I_P is as follows

$$\begin{aligned} I_I &= I_1 + I_2, \\ I_P &= I_1 - I_2. \end{aligned} \quad (2)$$

In order to get the information of object using the detected information from the point detector, we need to learn that the light intensity distribution at illuminating objects. The Calculation of ghost imaging is derived that the phase information is accurately controlled that phase modulation system applied on the light beam. It can be obtained the speckle

distribution of the objects through the related computer simulation program. According to the wave transmission equation, we can get the intensity distribution by the computer program. By the light intensity distribution and single pixel detector information can be obtained according to the relevant calculation formula to obtain the inversion. We can get the information of object using the detected information from the point detector through the intensity distribution and single pixel detector. The formula is as follows

$$G(x) = \frac{1}{N} \sum_{n=1}^N I_B^{(n)} I^{(n)}(x) - \frac{1}{N^2} \sum_{n=1}^N I_B^{(n)} \sum_{n=1}^N I^{(n)}(x). \quad (3)$$

Where x is two-dimension coordinate, N is the number of sampling, $I_B^{(n)}$ indicates the information obtained from the single pixel detector. We use the the strength information of the two single pixel detector and the polarization difference information instead of I_B in (3), thus the intensity distribution of information and the polarization distribution of the objects is achieved. when the formula (3) is used to get the information of object using the detected information from the point detector, in order to gain the high quality information of objects, the number of sampling we needed is far greater than the number of total pixels, it greatly reduces real-time performance of the polarization ghost imaging system.

3. POLARIZATION GHOST IMAGING SYSTEM BASED ON COMPRESSED SENSING

According to the above image retrieval process, the N th sampling intensity can be expressed as

$$\sum_x I^{(n)}(x) G(x) = I_B^{(n)} \quad (4)$$

Where $G(x)$ is the strength information of the object or the polarization information. Using the matrix form to transform (4), we can obtain the following statement

$$IG = I_B^{(n)} \quad (5)$$

Where I is the row vector distribution of light intensity distribution, G is the column vector representation of objects. In the ghost imaging system, we need to carry out the illumination of different light intensity distribution for the scene repeatedly, and in turn, get the light intensity information through single pixel detector. The total process of N -light intensity information collection can be indicated as matrices

$$I_N G = I_{BN} \quad (6)$$

Where, I_N is n -times measurement matrix, line s (less than N) means the row vector form of the s -th collection of illumination intensity distribution, I_{BN} is the column vector form of the intensity distribution acquired from the N -th single pixel detection, $I_{BN} = [I_B^{(1)}, I_B^{(2)}, \dots, I_B^{(N)}]^T$, T is the matrix transpose operation. Assume K is the total pixels for the inversion image, In order to obtain that the number of sampling N is greater than or equal to K accurately. Based on the related formula (3), the sampling number could be far greater than K . For sample number less than K , When conducting matrix solution, multiple solutions exist, namely the underdetermined equations have no unique solution. Most of the image information in some transform (such as Fourier transform and discrete cosine transform) is sparse, namely the matrices contain a large number of zero elements, so based on this property, the compression perception algorithm provides the solution of underdetermined equation accurately [12, 13]. The sparse transform of the signal can be represented as

$$G = \psi \alpha \quad (7)$$

Where ψ is sparse matrix. Using the formula (6) and (7), we can convert the problem of solving the object information G for solving the problem of sparse signals α , that is

$$\hat{\alpha} = \arg \min \|\alpha\| \quad \text{subject to } I_N \psi \alpha = I_{BN}, \quad (8)$$

For the solution of (8), matching pursuit algorithm, interior-point method and gradient method can be adopted. By solving the sparse signal α , the object information G can be solved by the sparse transform formula of signal.

Inserting the the single pixel detector for intensity distribution information and polarization difference information into the formula (8) respectively, the intensity distribution of the information and polarization difference information can be obtained. Compression algorithm can be used to get high quality image information in a few hits, it can be verified through the simulation experiment in the next section.

4. SIMULATION EXPERIMENT

In the process of the simulation experiments in this section, we study on the relevant methods under different

Table 1. Three objects of polarization parameters.

| | m_{11} | m_{33} |
|-------|----------|----------|
| steel | 0.975 | 0.99 |
| stone | 0.385 | 0.35 |
| wood | 0.215 | 0.16 |

sampling number and compression method to obtain the object information. We compare using the sampling rate in the experiment. The definition is as follows

$$\beta = N / K \quad (9)$$

Polarization ghost imaging system can obtain a variety of object information, G_I and G_p is the intensity information and polarization information of the object respectively. In order to understand the nature of the object preferably, we need to integrate a variety of information effectively. In this section, we carry on the multiple information fusion by RGB principle, Intensity information G_I is channel R information, polarized information G_p is the information of channel G , $G_I + G_p$ is the information of channel B . GR is the fusion image, it means

$$\begin{aligned} GR(:,1) &= G_I, \\ GR(:,2) &= G_p, \\ GR(:,3) &= G_p + G_I. \end{aligned} \quad (10)$$

We compose the scenario with three kinds of material (steel, stone, wood) in the simulation experiment, two objects are made of steel and stone, and the background are made of wood. We represent the polarization properties of three kinds of material by polarization parameters (Table 1) which is obtained from the indoor experiment. We get the experiment to scenario in two case separately, in the first case, two objects have the same reflectivity and have small differences with background reflectivity, and in the second case, two objects have the same reflectivity and background reflectivity has big difference. Fig. (2) is the result of the simulation in the two case.

Fig. (3) is the result of the simulation experiment, it process the result of the two algorithm unitarily. Line A and B in Fig. (3) is the scenario intensity information and the polarization information using the detected information from the point detector. The column 1 to 5 express the samples 200, 400, 600, 800, 1000 respectively. The row C and D is the scenario intensity information and the polarization information using the detected information from the point detector, the column 1 to 5 is the samples 4000, 8000, 12000, 16000, 20000. Experimental results show that high quality image information can be obtained by compressed sensing algorithm with small sampling number (600 groups of sampling number, sampling rate $\beta \approx 15\%$). Although the relevant

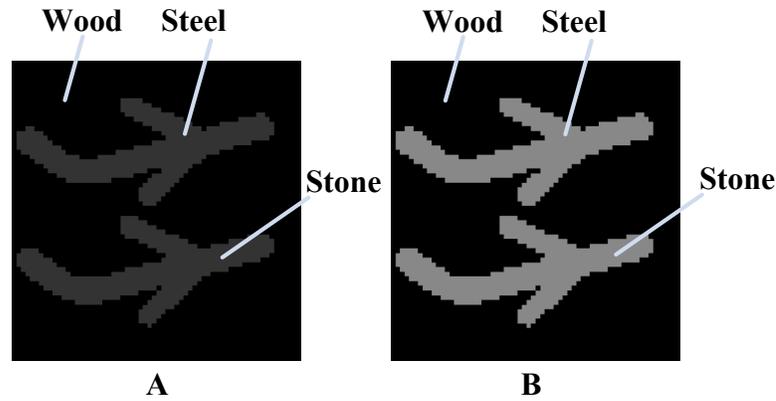


Fig. (2). Two different case scenarios: **A)** The first case; **B)** the second case.

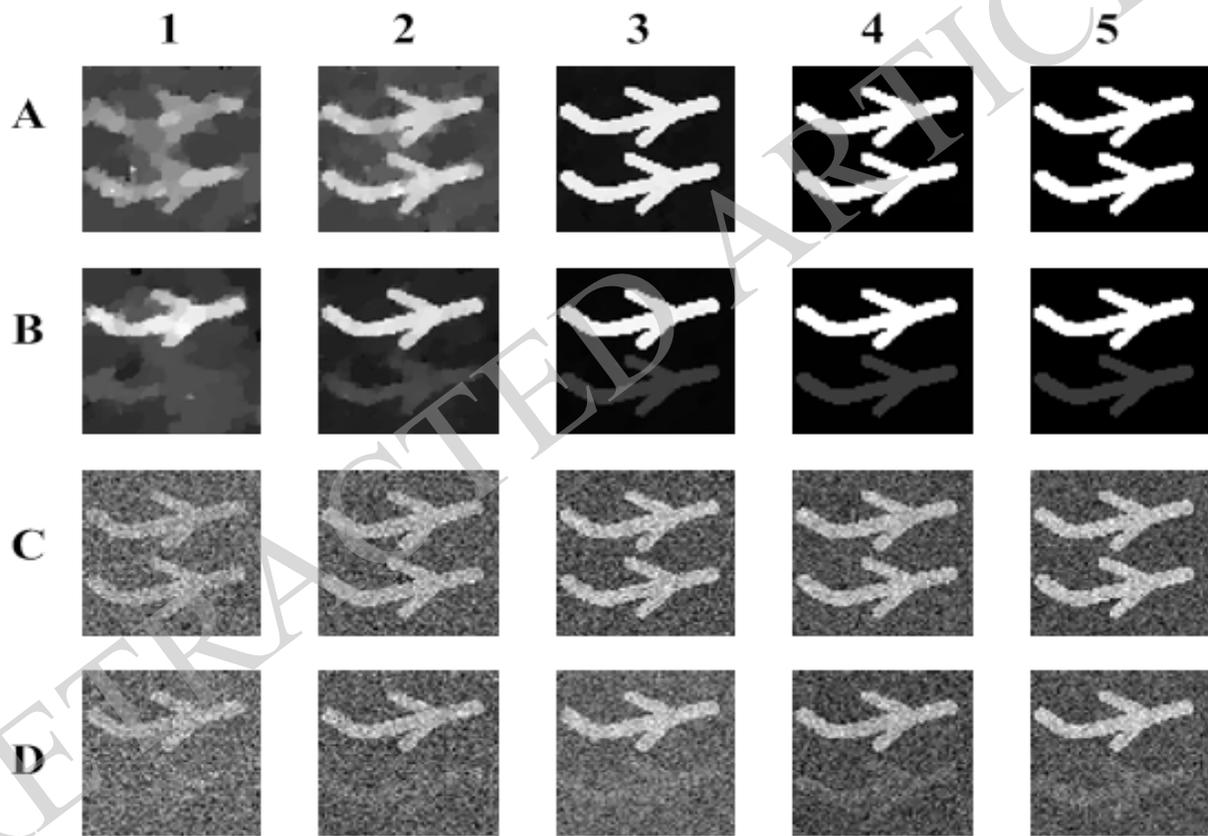


Fig. (3). Experiment results: **A** and **B** show the results obtained by compressed sensing algorithm, **C** and **D** show the results obtained by correlated algorithm. The 1-5 columns indicate different sampling numbers.

hits (20000 groups of sampling number, sampling rate $\beta \approx 500\%$) is very big, the SNR of the image information is still very low. The results of the algorithm verify that compressed sensing can reduce the number of sampling effectively. At the same time can improve the resolution of the object and the signal-to-noise ratio. Through the polarization information obtained from the two kinds of methods, it is different to distinguish the stone object and background

in the result when recovering by the correlation algorithm. On the other hand, it is easily distinguished that the scenario has three different material composition In the polarization information which obtained by the compressed sensing. Comparing the intensity with polarization information, we can observe that it is different to identify and distinguish of the object only by the intensity information in the case that the objects has the same reflectivity. Moreover, it can

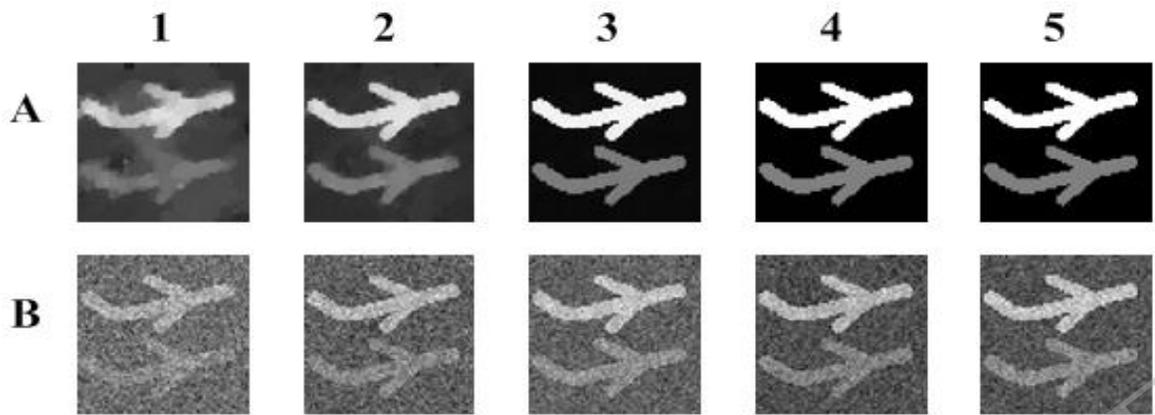


Fig. (4). Image fused results: **A)** fused results obtained by compressed sensing algorithm; **B)** fused results obtained by correlated algorithm. The 1-5 columns indicate different sampling numbers.

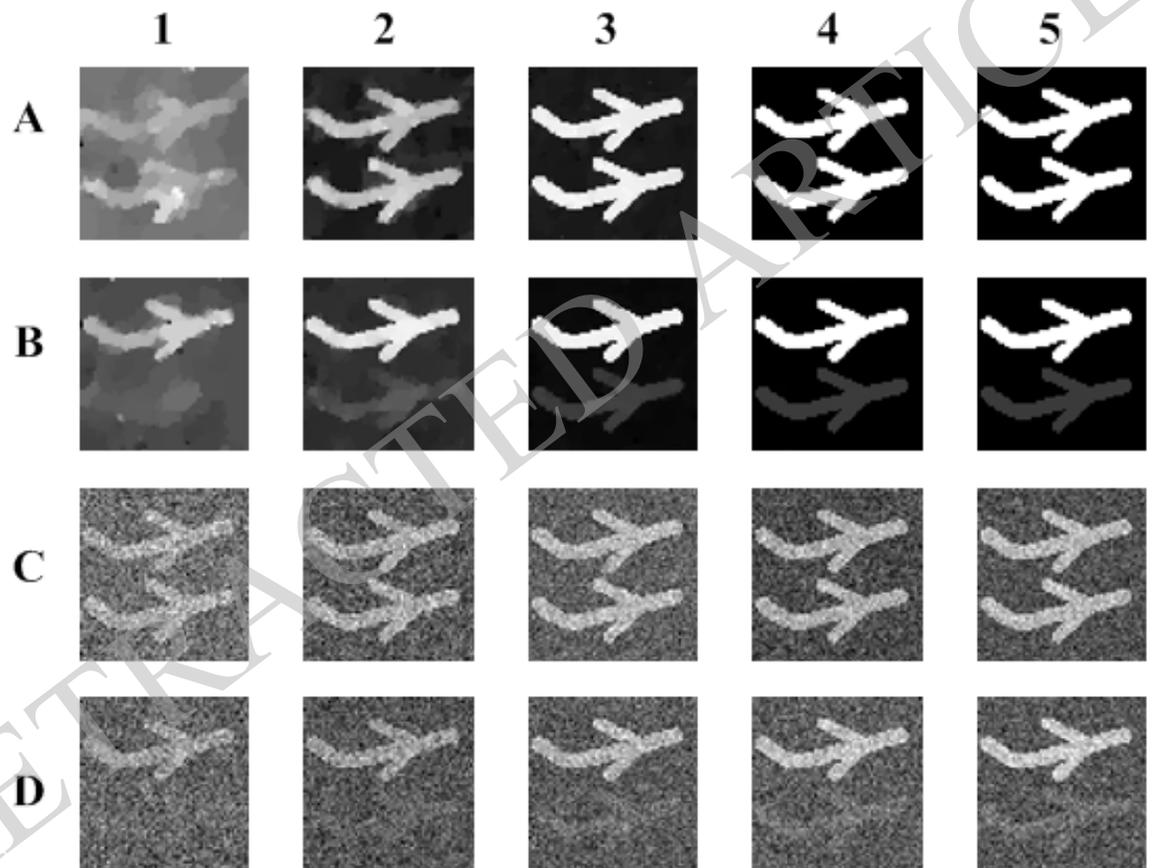


Fig. (5). Experiment results: **A** and **B** show the results obtained by compressed sensing algorithm, **C** and **D** show the results obtained by correlated algorithm. The 1-5 columns indicate different sampling number.

effectively distinguish between different material objects when combining the polarization information. The polarization information in the figure indicates the degree of polarization, The greater the intensity, the greater the degree of polarization, it verify that the steel has a high degree of polarization, secondly the stone, and the degree of polarization of the wood is minimal. In case with more information, data fusion is in need, so it is effectively to identify scenes through the result of the fusion. Fig. (4) shows the two algorithms for

the strength of the information and the polarization information of the fusion results, the results show that although the fusion image obtained from the relevant algorithm can distinguish different material object, the SNR is very low, while the fusion image obtained by compression perception has a high signal-to-noise ratio, it is more easier to recognize the different material object.

Fig. (5) shows the results of the experimental simulation in the second case. Line A and B in Fig. (5) is the scenario

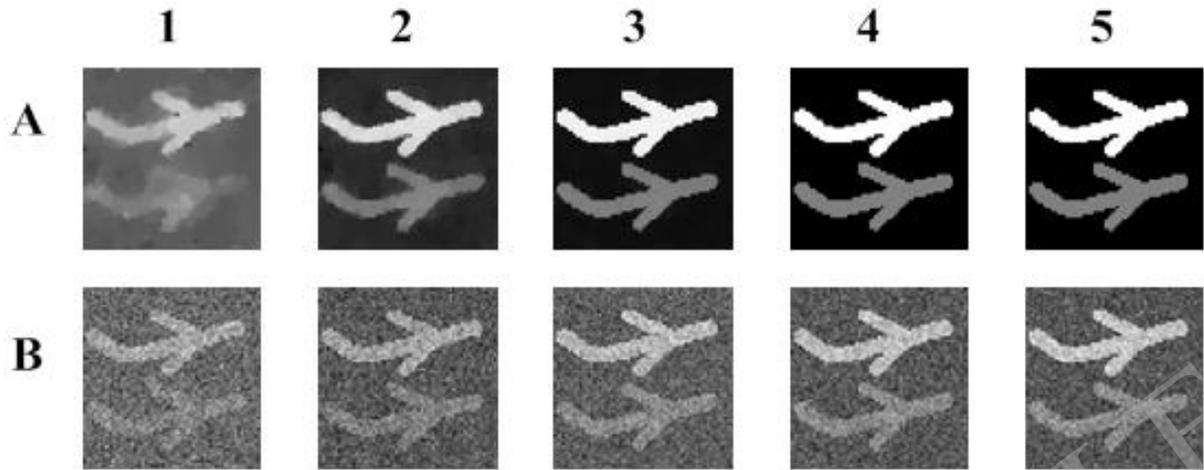


Fig. (6). Image fused results: **A)** fused results obtained by compressed sensing algorithm; **B)** fused results obtained by correlated algorithm. The 1-5 columns indicate different sampling number.

intensity information and the polarization information using the detected information from the point detector, The column 1 to 5 express the samples 200, 400, 600, 800, 1000 respectively. The row C and D in Fig. (5) is the scenario intensity information and the polarization information using the detected information from the point detector, the column 1 to 5 is the samples 4000, 8000, 12000, 16000, 20000. Because of the normalized processing to the results, the results can be seen that the experimental results and laws are basically identical with the first case, it shows that the difference of contrast has little influence upon the inversion results of the normalized through the two kinds of algorithms. Fig. (6) shows the two algorithms for the strength of the information and the polarization information of the fusion results, it is recognize the different material objects, But the signal to noise ratio of the image obtained from the relevant methods is low, and the signal-to-noise ratio obtained by compressed sensing algorithm is very high.

Through the analysis of the simulation experiment, it can be seen that the high quality of the object intensity and polarization information can be obtained with fewer sample number when recovering the information by compressed sensing algorithm, Which can satisfy the real-time requirement of polarization ghost imaging system. Multiple information fusion algorithm is used to collect the results to recognize a variety of different polarization characteristics of objects with the same reflectivity effectively.

CONCLUSION

According to the characteristics of the polarization ghost imaging system, Polarization ghost imaging system based on compressed sensing is proposed to get the intensity and polarization information of the object using the detected information from the point detector. It overcome the conventional algorithms need a large number of hits, and the problem of low SNR image. Comparing the compressed sensing method with the method in this paper in the simulation experiment, it can get high quality image information in the case of low

sampling number obtained by compressed sensing algorithm. Finally using digital image fusion algorithm to obtain a variety of different information fusion, it can effectively identify and distinguish the same reflectivity but different polarization characteristics of objects through the fusion results.

CONFLICT OF INTEREST

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

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