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The measurement error induced by intensity scintillation for single-pass and double-pass imaging polarimetry

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ABSTRACT

The imaging polarimeter is an important tool to measure polarization properties to reconstruct solar magnetic field in solar observation, to discriminate between benign and malignant moles in the living human eye, and so on. In single-pass imaging polarimetry, the intensity scintillation induced by the source's instability or the seeing during the signals obtaining period will induce severe measurement error. Double-pass imaging polarimetry can significantly decrease this influence. In this paper, we have analyzed the measurement error induced by the intensity scintillation for single-pass and double-pass imaging polarimetries. And the simulation and experiment are presented. Their results are coincident with each other.

1. Introduction

The polarimetry as a noninvasive monitoring technique is playing an important role in the field of medicine. The University of Alabama in Huntsville had developed a Muller matrix imaging polarimeter to discriminate between benign and malignant moles [1]. They have measured the full Muller matrix of some different samples successfully. And Juan M. Bueno et al. presented an imaging polarimeter to study the living human eye beinduce the ocular media and the retina exhibit rather complicated polarization properties [2]. In another field, the polarimetry is used to measure solar magnetic field at some special spectral lines, which should be sensitive to the Zeeman effect [3]. Right now many large aperture solar telescope have been developed (such as VTT [4], GREGOR [5], NST [6]) or have being developed (such as DKIST [7], EST [8]), and the polarimeter is their most important observational device for determining the magnetic field.

In general a measurement with a polarimeter means demodulation, and demodulation involves the subtraction of intensity signals which were obtained under at least 4 different configurations modulated in sequence. However, for the time-sharing polarimetry, the intensity of the source will change and the seeing also will induce intensity scintillation which will induce significant measuring error. Take the laser for example, the source intensity will shining in high frequency as approximately 1‰ to 5%. In 2011, Yang Huaju have measured the solar intensity scintillation induced by seeing [9]. The result shows that the scintillation is approximately 0.05% to 0.15% when the parameter of seeing $r_0 \approx 6$ cm. Therefore it is necessary to analyze the influence of the source intensity scintillation to the polarimetry. Now days, Ferroelectric Liquid Crystals (FLC) and Liquid Crystal Variable Retarders(LCVR) are used to replace the traditional rotatable wave-plate to get a higher modulation frequency so that to reduce the influence of intensity scintillation [4,10]. It means that a high quality detector is necessary. Besides, a four-detector photopolarimeter is also proposed by Safronich I. N. to measure the Stokes vector simultaneously [11]. But, it is not suitable for imaging polarimetry. What's more, the

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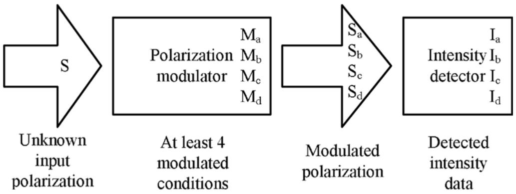

Fig. 1. Polarimetry concept.

dual-pass polarimeter based on polarizing beam splitters have also been used on many solar telescopes to improve the signal to noise ratio.

In this paper, we analyzed the polarimetry error for single-pass polarimeter induced by source intensity scintillation, and proposed a modified arithmetic based on the dual-pass polarimeter to eliminate this influence. The outline of this paper is as follows: In Section 2, we will briefly introduce the polarimetry method. In Section 3, we will analyze the influence of the source intensity scintillation for single-pass polarimeter. And an emulational result will be given. Then in Section 4, we analyzed the method of eliminating this effect with a dual-pass polarimeter. And in Section 5, the experimental results and discussions are presented.

2. Polarimetry method

The polarized light can be described by a Stokes vector $S=[I,Q,U,V]^T$ which has four components and each of which has the physical dimension of an energy flux, i.e. intensity. Besides, intensity is an observable which means that S can be measured with an appropriate detector.

Traditionally the time-sharing polarimeter consists of a polarization modulator and an intensity detector. And the conditions of the modulator will change in time. Fig. 1 shows the polarimetry concept.

The function of the modulator can be described by a 4 × 4 Muller matrix M. After an incident light marked as $S=[I,Q,U,V]^T$ passes through the polarimeter which in condition a, the Stokes vector of the out light becomes $S_a=[I_a,Q_a,U_a,V_a]^T$ which comply with the following formula

$$S_a = M_a S. \tag{1}$$

Here we suppose the parameter of the Muller matrix

$$M_a = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix}. \tag{2}$$

However the detector can just detect the intensity value i.e. the parameter I of the Stokes vector which comply with the formula (3)

$$I_a = a_{11}I + a_{12}Q + a_{13}U + a_{14}V. \tag{3}$$

After at least 4 times modulation we can get 4 intensity data as

$$\begin{bmatrix} I_a \\ I_b \\ I_c \\ I_d \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ b_{11} & b_{12} & b_{13} & b_{14} \\ c_{11} & c_{12} & c_{13} & c_{14} \\ d_{11} & d_{12} & d_{13} & d_{14} \end{bmatrix} \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix}. \tag{4}$$

The Eq. (4) can be simplified as

$$I_m = AS. \tag{5}$$

Only if the matrix A is invertible i.e.

$$rank(A) = rank\left(\begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ b_{11} & b_{12} & b_{13} & b_{14} \\ c_{11} & c_{12} & c_{13} & c_{14} \\ d_{11} & d_{12} & d_{13} & d_{14} \end{bmatrix}\right) = 4. \tag{6}$$

the unique solution of Stokes vector S can be calculated from (7).

$$S = A^{-1}I. \tag{7}$$