3-D SURFACE PROFILOMETRY EMPLOYING THE POLARIZATION PHASE SHIFTING TECHNIQUE

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Abstract: (250 Words)

Optical measurement techniques have become indispensable tools in many areas of science and engineering. The whole-field, non-contact and highly accurate measurement are among the principal features of these techniques. The purpose of this research is to analyze the case when the sample under study presents polarization properties, as retardance or diattenuation. The use of phase shifting modulated by polarization has the advantage of not requiring mechanical components, such as a piezoelectric transducer (PZT), to obtain the phase shifts. The main purpose of introducing polarization phase shifting techniques, added with replication systems, is to collect all the phase-shifted data in a single exposure in order to minimize time-varying environmental effects. When the sample under study changes the polarization properties of the object-beam, errors associated at the contrast and phase shift values on the final interferogram are obtained. The main purpose of this work is to find a suitable model in charge to modelate when the sample presents polarization properties as retardance or diattenuation. A model based in find a Mueller matrix of the polarization phase shifting interferometer is introduced in order to settle the basis for a non-ideal model.

Keywords: Interferometry, Polarization Analysis, Phase Shifting Technique

1. INTRODUCTION

Phase-shifting interferometry techniques (PSI) require several phase-shifted interferograms to retrieve the optical phase information of the sample. This task has been usually performed by stages with great success, but presents the inconvenient of require a series of sequential shots of the object under study. Time-varying phase distributions are excluded from this schema and a single-shot PSI technique need to be used. The most common single-shot PSI technique is based on polarization principles to modulate the phase-shift on the interferograms. The direct capability of these systems is to retrieve the phase data map instantaneously by obtaining replicas of the interferograms under study. Some configurations encountered in the literature are based in obtain replicas of the interferogram under study by using a pixelated phase mask attached to the CCD camera or by using phase/amplitude gratings. The main characteristic of these systems is to obtain the interference of orthogonal linear polarization states between the reference and object beams by using polarization components. When the sample under study changes the polarization properties of the object-beam, errors associated at the contrast and phase shift values on the final interferogram are obtained.

2. POLARIZATION PHASE SHIFTING PRINCIPLE

The most common polarization phase shifting (PPS) techniques are based on controlling the phase shift by rotating polarization components, such as linear polarizers or half-wave retarders placed at the output of the interferometer, whose reference and object beams have orthogonal linear polarization states[1]. Studies have been done before taking into account the usage of elements not centered on the wavelength of the laser source [2] and also a thorough phase error analysis by the polarization and interferometric components.[3] In the implementation of the rotating polarizers (or half wave plates) problems arise when the interfered beams don't have circular polarization states, mostly obtained by retardances changes.

Figure 1 shows a diagram of the phase shifter that could be used at the exit of an interferometer, where the reference and test beams have orthogonal linear polarization. A quarter-wave plate converts one of the two interfering beams into right-handed circularly polarized beam, and the other interfering beam into a left-handed circularly polarized beam. As a polarizer is rotated an angle θ, the phase difference between the test and reference beams changes by 2θ. The polarizer also makes it possible for the two beams to interfere.

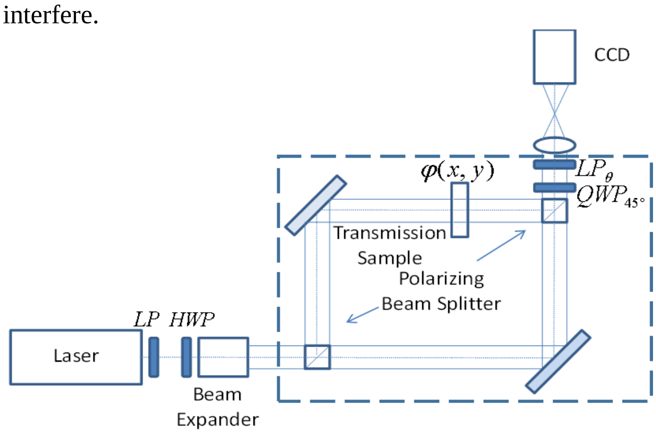

Figure 1 Mach-Zehnder interferometer where the phase shift is controlled by the angle of the linear polarizer, LP_θ , placed at the exit of the interferometer.

By using the Jones calculation approach, a QWP_θ and a linear polarizer (P_θ) at desired angle can be represented as [27]:

$$QWP_\theta = \frac{1}{\sqrt{2}}\begin{pmatrix} 1+icos2\theta & isin2\theta \\ isin2\theta & 1-icos2\theta \end{pmatrix};$$

$$P_\theta = \begin{pmatrix} cos^2\theta & sin\theta cos\theta \\ sin\theta cos\theta & sin^2\theta \end{pmatrix}. \quad (1)$$

Following the polarization state of each part of the interferometer, dotted square of Fig 1, the Jones matrix of the interferometer can be obtained as:

$$JM_{int}(\theta) = P_\theta QWP_{45^\circ}\left(P_{90}P_{90} + P_0\begin{bmatrix} e^{-i\varphi(x,y)} & 0 \\ 0 & e^{i-\varphi(x,y)}\end{bmatrix}P_0\right)$$

$$JM_{int}(\theta) = \frac{1}{2\sqrt{2}}\begin{bmatrix}1+e^{i2\theta} & ie^{-i\varphi(x,y)}\left(1+e^{-i2\theta}\right) \\ i\left(1-e^{i2\theta}\right) & e^{-i\varphi(x,y)}\left(1-e^{-i2\theta}\right)\end{bmatrix}. \quad (2)$$

$\varphi(x,y)$ is the phase information of the transparent sample and θ the angle of the polarizer at the output. The sample is treated as a pure phase sample with no polarization properties.

Equation 2 represents the Jones matrix of the interferometer presented in Fig. 1. As normal, if the input beam is a linear polarization state at 45°, $\vec{J}_{45^\circ} = \frac{1}{\sqrt{2}}\begin{pmatrix}1\\1\end{pmatrix}$, the output intensity will correspond to the equation of the interferogram with a controllable phase shift by the angle of the last polarizer.

$$\mathrm{I(x,y)} = \left|JM_{int}(\theta)\cdot\frac{1}{\sqrt{2}}\begin{pmatrix}1\\1\end{pmatrix}\right| = \frac{1}{2} + \frac{1}{2}sin(\varphi(x,y) + 2\theta) \quad (3)$$

By representing the interferometer as a Jones Matrix, it is possible to find the non-depolarizing Mueller matrix

$$MM_{int}(\theta) \leftrightarrow JM_{int}(\theta)$$

$$\begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44}\end{bmatrix} \leftrightarrow \begin{bmatrix} j_{11} & j_{12} \\ j_{21} & j_{22}\end{bmatrix}, \quad (4)$$

following the proper transformation[4]:

$$\mathrm{m11} = \left(j_{11}j_{11}^* + j_{12}j_{12}^* + j_{21}j_{21}^* + j_{22}j_{22}^*\right)/2$$
$$\mathrm{m12} = \left(j_{11}j_{11}^* + j_{21}j_{21}^* - j_{12}j_{12}^* - j_{22}j_{22}^*\right)/2$$
$$\mathrm{m13} = \left(j_{12}j_{11}^* + j_{22}j_{21}^* + j_{11}j_{12}^* + j_{21}j_{22}^*\right)/2$$
$$\mathrm{m14} = \mathrm{i}\left(j_{12}j_{11}^* + j_{22}j_{21}^* - j_{11}j_{12}^* - j_{21}j_{22}^*\right)/2$$

$$\mathrm{m21} = \left(j_{11}j_{11}^* + j_{12}j_{12}^* - j_{21}j_{21}^* - j_{22}j_{22}^*\right)/2$$
$$\mathrm{m22} = \left(j_{11}j_{11}^* - j_{21}j_{21}^* - j_{12}j_{12}^* + j_{22}j_{22}^*\right)/2$$
$$\mathrm{m23} = \left(j_{11}j_{12}^* + j_{12}j_{11}^* - j_{21}j_{22}^* - j_{22}j_{21}^*\right)/2$$
$$\mathrm{m24} = \mathrm{i}\left(j_{12}j_{11}^* + j_{21}j_{22}^* - j_{22}j_{21}^* - j_{11}j_{12}^*\right)/2$$

$$\mathrm{m31} = \left(j_{11}j_{22}^* + j_{21}j_{11}^* + j_{12}j_{22}^* + j_{22}j_{12}^*\right)/2$$
$$\mathrm{m32} = \left(j_{11}j_{21}^* + j_{21}j_{11}^* - j_{12}j_{22}^* - j_{22}j_{12}^*\right)/2$$
$$\mathrm{m33} = \left(j_{11}j_{22}^* + j_{12}j_{21}^* + j_{21}j_{12}^* + j_{22}j_{11}^*\right)/2$$
$$\mathrm{m34} = \mathrm{i}\left(-j_{11}j_{22}^* + j_{12}j_{21}^* - j_{21}j_{12}^* + j_{22}j_{11}^*\right)/2$$

$$\mathrm{m41} = \mathrm{i}\left(j_{11}j_{21}^* + j_{12}j_{22}^* - j_{21}j_{11}^* - j_{22}j_{12}^*\right)/2$$
$$\mathrm{m42} = \mathrm{i}\left(j_{11}j_{21}^* - j_{12}j_{22}^* - j_{21}j_{11}^* + j_{22}j_{12}^*\right)/2$$
$$\mathrm{m43} = \mathrm{i}\left(j_{11}j_{22}^* + j_{12}j_{21}^* - j_{21}j_{12}^* - j_{22}j_{11}^*\right)/2$$
$$\mathrm{m44} = \left(j_{11}j_{22}^* - j_{12}j_{21}^* - j_{21}j_{12}^* + j_{22}j_{11}^*\right)/2 \quad (5)$$

In order to check the validity of the model, a simulation was made. Figure 2 a) represent the phase variation, $\varphi(x)$, 2b) the simulated interferogram and its corresponding Mueller matrix 2c). Figure 3 shows simulations introducing a phase shift of 45°, 90° and −45°

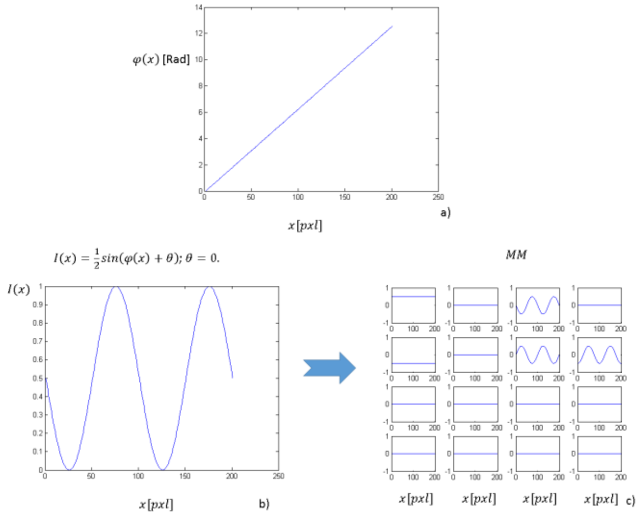

Figure 2. Simualted interferogram. a) Phase variation, $\varphi(x)$, b) Simulated interferogram and c) its corresponding Mueller matrix.

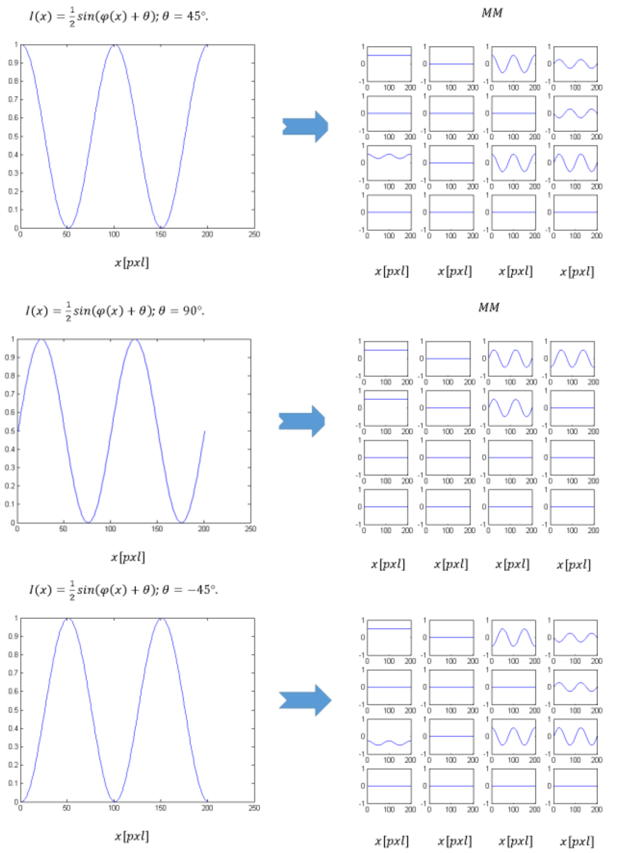

Figure 3. Mueller matrix obtained by introducing a phase shift of θ = 45°, θ = 90° and θ = −45°.

3. CONCLUSIONS

A preliminary model was introduced to represent a polarization phase shifter interferometer by taking into account the overall components on a typical interferometer by using the Jones Matrix approach. By a transformation to a non-depolarizing model, a theoretical Mueller matrix model was proposed. Simulated results with the ideal case was presented with the purpose of introduce retardance, diattenuation and experimental validation in the future.

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