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Methods of Imaging with Photoelastic Modulators

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In this brief, we highlight a range of options to utilize photoelastic modulators with imaging systems to generate full field polarimetric measurements using photoelastic modulators.

Photoelastic modulators (PEMs) are resonant polarization modulation tools. PEMs operate by the photoelastic effect controlled with a piezoelectric actuator at the resonant frequency of both the optical window and piezoelectric actuator. Due to the resonant nature of the polarization modulation, the change in polarization can not be directly controlled and happens at the natural resonant frequency of the device. The resonant frequency of most polarization modulation devices is in the range of 40 kHz to 60 kHz, and as such, the change in polarization is often faster than most imaging systems frame rate.

Introduction

Full field polarization images have been shown to have a wide range of applications from remote sensing, target identification, in situ medical diagnosis, materials analysis and more. Often full field polarimetric imaging makes use of beam splitters or rotating waveplates as the polarization modulator. Those tools work well but numerous applications such as cancer detection require particularly high signal to noise. For these precision applications, active modulation of the polarization allows for heterodyne detection which can increase the signal to noise of an application by order of magnitude.

The PEM is a natural fit for lock-in detection. As the photoelastic modulator is a resonant device which continuously oscillates the retardance of an optical window along a single axis. The instantaneous retardance of a PEM is given below:

$$\delta = A \sin(\omega t + \phi)$$

Figure 1: The time dependent retardance of a photoelastic modulator

Where δ is the instantaneous retardance, A is the amplitude of modulation, ω is the angular frequency which can be related to frequency as $\omega = 2\pi f$, ϕ is the phase offset between the reference waveform and the instantaneous retardance, and t is time.

In the above equation, the frequency is often in the range of 40 kHz to 60 kHz. For a full field image to treat the retardance as approximately static, a frame must be taken in less than about 200 nanoseconds using the approximation that $\sin(\pi) = 0$, $\sin(2\pi) = 0$. This exposure time is too short for many applications including those using very high frame rate cameras, and even these applications will require high light flux in order to generate a low noise image.

To overcome this limitation of a fast frame rate, there are a couple of viable solutions: source modulation or low frequency mixing. Source modulation has been highlighted by a number of authors [1,3,4,5]. Frequency mixing has been applied by Chipman and used successfully in remote sensing applications [2], but shall not be covered herein.

Each method can be understood using a similar theoretical framework: Mueller matrices and optical system matrices. The fastest method suffers from the inherent weakness of low light throughput, but this can be significantly overcome using LED light sources which can handle high intensity pulses. Work by Hinds highlighted a robust solution: the use of square wave modulated LED light sources [6]. By utilizing a light source modulated at the fundamental or mixed harmonics of the PEMs with a square waveform, the optical properties of a sample can be measured with a high light throughput.

Methods of Imaging with Photoelastic Modulators

This paper highlights a range of options to utilize Photoelastic Modulators (PEMs) with imaging systems to generate full field polarimetric measurements. Due to the resonant nature of the polarization modulation, the change in polarization cannot be directly controlled and happens at the natural resonant frequency of the device. Typical resonant frequencies of PEMs are 40 kHz to 60 kHz, and as such, the change in polarization is often faster than most imaging systems frame rate.

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