Integrated Optical Setups for Characterizing and Stabilizing Polarization States of Light;
Category: Embedded Systems

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a. RATIONALE: Include a brief synopsis of the background that supports your research problem and explain why this research is important and if applicable, explain any societal impact of your research.

The polarization states of light reveal essential findings for many scientific and technological applications [1-5]. Light polarization provides details on the size and distribution of particles in the atmosphere [2], isolates synthetic materials from natural surfaces [3], exhibits intelligence about the interactions between excited states of atoms [4], and issues disease diagnostics by measuring scattered light in biological tissue [5]. Polarized light also encodes and transmits information for optical communications [6]. Detecting and stabilizing light polarization is currently limited by (i) the inability to measure sufficiently produced polarization states and (ii) to retain polarization upon transmission in optical fibers [6,7], impeding the development of essential optic-based technologies.

(I): *Polarization State Production*

Optical modulators are widely used to produce polarization states due to the tuning ability of experimental variables, including light frequency and intensity. However, the stability of optical modulators is susceptible to arbitrary factors such as temperature changes which hinder polarization generation [8,10]. Aillerie *et al.* [8] demonstrated the thermo effects in electro-optic systems, signifying that upon miniscule temperature changes, dramatic variations in birefringent material are associated with the same applied voltage to create a distinct polarization. The inability to sufficiently generate a polarization state has implications in measurements. Last year, for the right hand circular and left hand circular polarization applied inputs, the characterization setup I designed detected a misalignment in the polarization alignment of the photon pulses. Thus, the motivation of this year's project is to stabilize the polarization state generated by optical modulators.

(II): ***Polarization Transmission Along Optical Fibers***

The lack of polarization retainment is not just common in polarization production sources, but also in optical fibers. Optical fibers are useful in long and short propagation distances; however, small birefringent effects within the fiber and external perturbations describing the physical environment cause polarization to drift [9-11]. Multiple fibers have been reconstructed over the past decades to maintain polarization but are limited by supporting only a single polarization [12-14]. Optical communications involve sequences of altering polarizations, thereby utilize single-mode non-polarization-maintaining optical fibers, despite an essential component of retaining their polarized state [15-20]. Thus, a stringent condition is to stabilize the drift in polarization when light is transmitted through optical fibers.

b. RESEARCH QUESTION(S), HYPOTHESIS(ES), ENGINEERING GOAL(S), EXPECTED OUTCOMES: How is this based on the rationale described above?

Research Question(s):

1. How will the use of multiple waveplates correlate to the change in polarization states?

2. How can the Mueller Matrix convention that describes the change in polarization after passing an optical element be used to stabilize light polarization?

3. How will an optical fiber cause drift in light polarization?

Hypothesis:

1. If the Stokes/Mueller Matrices of the quarter-wave plate and half-wave plate were multiplied, then the required angles necessary to compensate for the drift in polarization may be determined using the resultant matrix.

2. If light of a particular polarization is coupled using a single-mode non-polarization maintaining fiber, the polarization will drift to a state that is ineffectual in storing information.

Engineering Goal(s):

1. To mount a quarter-wave plate (QWP) and half-wave plate (HWP) on a portabile breadboard for realigning the fast axes of the setup after analyzing the drift in polarization.

2. To couple light into an optical fiber to transmit the inputted polarization input.

3. To characterize the polarization input and output before and after passing the fiber.

Expected Outcomes:

1. After calculating the polarization before and after passing the fiber using last year's setup, the Stokes parameters of light will alter in its respective polarization parameter.

2. When the drifted light passes through a setup comprising a QWP and HWP, the polarization will realign.

C. DESCRIBE THE FOLLOWING IN DETAIL:

Procedures: Detail all procedures and experimental design including methods for data collection. Describe only your project.

Polarization Production:

- A diode laser (Toptica, DLC TA Pro 795nm) will generate 795*nm* of light which will pass through acousto-optic modulator (G&H, 308-125) units (AOMs), to temporally shape the probe fields.

- Signal wave generators (Tektronix, AFG3051C) will modulate the amplitude of the AOMs. Wave generators will be triggered by the Field Programmable Gate Array (FPGA) to produce $400ns$ gaussian envelopes of the probe pulses.
- The outputs will be applied to electro-optic modulator (Thorlabs, EO-PM-NR-C1) units (EOMs) where an applied voltage (in the range of $\approx 0-500V$) encodes a desired polarization on these probe pulses.

Polarization Characterization:

- After the EOM applies a polarization, light pulses first will travel through a rotating quarter-wave plate (QWP) (Thorlabs, WPQ10M-780/PRM 1Z8) connected to a DC servo motor (Thorlabs, TDC001) for control of the angle.
- Light pulses will then travel through a linear polarizer (Thorlabs, LPUV050/RSP05/M) set at 0° to transmit the desired polarization .
- Depending on the modulated frequency and power, light will pass through a standard photodetector (Thorlabs, PDA10A Si Amplified Detector) or a single photon counting module (SPCM) (Thorlabs, SPCM50A) .
- The detectors convert light into a current for measuring the transmitted intensity using a digital oscilloscope (BK, Precision 2532B; Figure 2B).
- The QWP will be rotated iteratively in increments of 2°, 5°, or 10° for a 180° rotation. Horizontal, vertical, diagonal, antidiagonal, right-circular, and left-circular polarizations will be characterized.
- Data analysis to acquire Stokes parameters will involve a non-linear least fit regression (BFC) and Fourier transformation (FT) of the acquired data.

Polarization Stabilization:

- Upon characterization, the polarized pulses will be delivered to Figueroa's graduate laboratory using a 30*m* long single-mode non-polarization-maintaining optical fiber from Figueroa's undergraduate laboratory (Thorlabs, S630-HP) to determine changes in polarization.
- After retrieval, the polarization drift will be calculated by averaging the BFC and FT polarization parameter which described the inputted polarization and then subtracting the averaged polarization parameters before and after passing the optical fiber.
- A setup comprising a QWP followed by a half-wave plate (HWP) will compensate for the change in polarization after calculating the Mueller Matrix angles for the setups.

Risk and Safety: Identify any potential risks and safety precautions needed.

- The diode laser may not necessarily be stable at all times - therefore, the qualified scientist will calibrate the laser source for all experimental procedures.
- The student research will wear laboratory goggles provided by the lab to prevent any exposure to high intensity light.

Subject-Specific Guidelines

1. Human participants research - Not Applicable

2. Vertebrate animal research - Not Applicable

3. Potentially hazardous biological agents research - Not Applicable

4. Hazardous chemicals, activities, and devices - Toptica TA Pro 795 nm diode laser (High Power; up to 4W; 660-1495 nm) may be unstable and can cause eye impairments if deliberately stared at.
Safety Precaution: The student will not turn on the laser source and will wear safety googles at all times inside the laboratory and will only remove safety googles once exiting the laboratory.

Data Analysis: Describe the procedures you will use to analyze the data/results.

-The MATLAB (R2018A) code developed in the summer of 2018 by the student researcher will be used to analyze the data.

-Data analysis involves a non-linear least fit regression and Fourier transformation of the raw data in order to extract the Stokes parameters of light used to characterize light polarization.

Addendum Statement: No changes were made after the original research plan and approvals.

BIBLIOGRAPHY: List major references (e.g. science journal articles, books, internet sites) from your literature review. If you plan to use vertebrate animals, one of these references must be an animal care reference.

[1] E. Hecht, Optics. San Francisco: Addison Wesley, 2002, pp. 325-379

[2] C. F. Bohren, D. R. Huffman, Absorption and Scattering of Light by Small Particles, 1983.

[3] W. Osten, ed. Optical Inspection of Microsystems, 2006.

[4] J. W. Maseberg and T. J. Gay, Journal of Physics B, 2006.

[5] M. Losurdo *et al.* "Spectroscopic ellipsometry and polarimetry for materials and systems analysis at the nanometer scale: state of the art, potential, and perspectives,", 2009

[6] J. S. Baba, J.-R. Chung, A. H. DeLaughter, B. D. Cameron, and G. L. Cote, "Development and calibration of an automated Mueller matrix polarization imaging system," 2002.

[7] R. W. Collins and J. Koh, "Dual rotating-compensator multichannel.

[8] Saadon, H., Théofanous, N., Aillerie, M. and Fontana, M.. Thermo-optic effects in electro-optic crystals used in an intensity-modulation system. – Application in LiTaO3, 2006

[9] Turchette, Q.A., *et al.* "Measurement of Conditional Phase Shifts for Quantum Logic", Phys. Rev. Lett. 75, 4710-4713, 1995.

[10] Franson, J.D., "Cooperative Enhancement of Optical Quantum Gates", Phys. Rev. Lett. 78, 3852-3855, 1997.

[11] Knill, E., LaFlamme, R., and Milburn, G.J., "A scheme for efficient quantum computation with linear optics", Nature 409, 46-52, 2001.

[12] Pittman, T.B., Jacobs, B.C., and Franson, J.D., "Demonstration of feed-forward control for linear optics quantum computation", Phys. Rev. A 66, 052305, 2002.

[13] Franson, J.D., Donegan, M.M., Fitch, M.J., Jacobs, B.C., and Pittman, T.B., "High Fidelity Quantum Logic Operations using Linear Optical Elements", Phys. Rev. Lett. 89, 137901, 2004.

[14] Pittman, T.B., Jacobs, B.C., and Franson, J.D., "Probabilistic quantum logic operations using polarizing beam splitters", Phys. Rev. A 64, 062311, 2001

[15] Einstein, A., Podolsky, B., and Rosen, N., "Can Quantum Mechanical Description of Physical Reality be Considered Complete?", Phys. Rev. 48, 696-702, 1935.

[16] Pittman, T.B. and Franson, J.D., "Violation of Bell's Inequality with Photons from Independent Sources", Phys. Rev. Lett. 90, 24041, 2003.

[17] Pittman, T.B., Fitch, M.J., Jacobs, B.C., and Franson, J.D., "Experimental Controlled-NOT logic gate for single photons in the coincidence basis", Phys. Rev. A 68, 032316, 2003.

[18] D.N. Klyshko, Photons and Nonlinear Optics, Gordon and Breach Science, New York, 1988.

[19] Pittman, T.B., Jacobs, B.C., and Franson, J.D., "Demonstration of non-deterministic quantum logic operations using linear optical elements", Phys. Rev. Lett. 88, 257902 (2002).

[20] Pittman, T.B., Jacobs, B.C., and Franson, J.D., "Probabilistic quantum encoder for single-photon qubits", Phys. Rev. A 69, 042306, 2004.