Continuation/Research Progression Projects Form (7)

Required for projects that are a continuation/progression in the same field of study as a previous project.

This form must be accompanied by the previous year's abstract and Research Plan/Project Summary.

Student's Name(s) Fahad Karim

To be completed by Student Researcher: List all components of the current project that make it new and different from previous research. The information must be on the form; use an additional form for previous year and earlier projects.

Components	Current Research Project	Previous Research Project: Year: 2018-19
1. Title	Integrated Optical Setups for Characterizing and Stabilizing Polarization States of Light	Characterizing Polarization States of Light for Quantum Information Applications
2. Change in goal/ purpose/objective	1. Identify the change in polarization after light passes through an optical fiber 2. Theoretically calculate the required wave plate angles to stabilize the polarization through Stokes/Mueller Calculus. 3. Experiementally implement a setup comprised of a quarter-wave plate and half-wave plate at the required angles to stabilize light polarization. 4. Characterize the change in polarization after the polarization passes through the stabilization setup.	1. Design a polarization detection system that determines the characteristics of light polarization inputs through a best fit curve and Fourier transformation of the acquired data 2. Identify the characterized polarization in comparision to the theoretical polarization through Stokes parameters
3. Changes in methodology	1. A Mueller matrix convention is evaluated by multiplying the given Mueller matrices of a QWP and HWP. To calculate the necessary angles, the resultant 4x4 matrix is multiplied with a 4x1 Stokes matrix 2. An additional setup comprised of a QWP and HWP is placed after identifying the drift in polarization and are oriented at the required angles to stabilize polarization.	1. 795 nm of light passing through an Acousto-Optic Modulator and Electro-Optic Modulator, where an applied voltage encodes a desired polarization 2. To characterize the polarization, light passes through a quarter-wave plate, linear polarizer, and detector. 3. A best fit curve and Fourier transformation of the acquired data is used to calculate the polarization state.
4. Variable studied	An applied polarization state of light passes through a single-mode non-polarization maintaining optical fiber, which significantly alters the polarization state. The main variable in this year's study involves identifying the change/drift in light polarization after passing the optical fiber, and after discovering the drift in polarization, designing a means to stabilize the drift. The motivation for studying this variable comes from the trends identified in last year's data sets - particularly the right-hand and left-hand circular polarization states. The measured polarization for such states were significantly different than the theoretical polarizations. Therefore, this year, I look to stabilize the polarization states which is commonly drifted due to single-mode optical fibers.	Commercial polarimeters are only able to confirm whether or not a polarization is present instead of quantitatively assessing the amount of a particular polarization. Additionally, conventional methods such as dividing amplitude based on four-detectors demonstrate adjustment difficulties, have delayed response times, and are unable to be tuned for varying experimental necessities. Therefore, the main variable in last year's study involved designing a method to measure light polarization states through Stokes Parameters, addressing the difficulties associated with conventional/commercial methods.
5. Additional changes	1) An optical fiber couples light from Figueroa's undergraduate laboratory to Figueroa's graduate laboratory for identifying changes in polarization. 2) An additional setup of a quarter-wave plate and half-wave plate is mounted following the characterization setup from 2018-19. 3) Stabilization involves Stokes/Mueller Matrices	1) The polarization of light is measured solely at Figueroa's undergraduate laboratory 2) No further setup is used besides the characterization setup comprising a quarter-wave plate, linear polarizer, and photodetector, 3) Characterization only incorporates Stokes Matrices

Attached are:

☑ Abstract and Research Plan/Project Summary, Year 2018-19

I hereby certify that the above information is correct and that the current year Abstract & Certification and project display board properly reflect work done only in the current year.

Fahad Karim — Student's Printed Name(s)

Fahad Karim — Signature

Digitally signed by Fahad Karim
Date: 06-19-2019 11:51 AM

06/19/19 — Date of Signature (mm/dd/yy)

OFFICIAL ABSTRACT and CERTIFICATION

Characterizing Polarization States of Light for Quantum Information Applications

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The ability to characterize polarization qubits is essential for developing photonic-based quantum technologies which are expected to yield tremendous societal impacts. This study developed a polarization detection system for determining light polarization states in terms of its Stokes Parameters. Qubits were produced using independent Acousto-Optic Modulator units to temporally shape probe fields and then their outputs were applied to Electro-Optic Modulators where an applied voltage encodes a desired polarization state on these probe pulses. Qubit characterization incorporated a Quarter-Wave Plate (QWP), Linear Polarizer, and Detector. Stokes Parameters of light were evaluated via a Fourier transformation and best-fit curve of the transmitted light intensity/integrated photon counts concerning the QWP angle. $|H\rangle$, $|V\rangle$, $|D\rangle$, $|A\rangle$, $|R\rangle$, and $|L\rangle$ states were characterized to confirm accuracy of the system. The experimental S1 parameter output for $|H\rangle$ and $|V\rangle$ were 0.95115 ± .00365 and -1.0047 ± .0002, with ≈ 90.471% and 100% linear polarization, respectively. The experimental S2 parameter output for $|D\rangle$ and $|A\rangle$ were 0.99245 ± 0.00535 and -0.96555 ± 0.02565, with ≈ 98.4985 and 93.296% 45° polarization, respectively. The experimental S3 parameter output for $|R\rangle$ and $|L\rangle$ were 0.81395 ± .00685 and -0.7415 ± 0.0108, with ≈ 66.264% and 54.9975% circular polarization, respectively. All experimental verifications rendered precision and accuracy of the inputted photonic quantum state. This study developed a polarization detection system that could be applied in fabricating early models of photonic quantum information systems. Future works include fully automating the QWP and incorporating optical detection signals to address experimental polarization drift.

Category
Pick one only—mark an "X" in box at right

- Animal Sciences ☐
- Behavioral & Social Sciences ☐
- Biochemistry ☐
- Biomedical & Health Sciences ☐
- Biomedical Engineering ☐
- Cellular & Molecular Biology ☐
- Chemistry ☐
- Computational Biology & Bioinformatics ☐
- Earth & Environmental Sciences ☐
- Embedded Systems ☐
- Energy: Chemical ☐
- Energy: Physical ☐
- Engineering Mechanics ☐
- Environmental Engineering ☐
- Materials Science ☐
- Mathematics ☐
- Microbiology ☐
- Physics & Astronomy ■
- Plant Sciences ☐
- Robotics & Intelligent Machines ☐
- Systems Software ☐
- Translational Medical Sciences ☐

1. As a part of this research project, the student directly handled, manipulated, or interacted with (check ALL that apply):

   ☐ human participants ☐ potentially hazardous biological agents

   ☐ vertebrate animals ☐ microorganisms ☐ rDNA ☐ tissue

2. I/we worked or used equipment in a regulated research institution or industrial setting: ■ Yes ☐ No

3. This project is a continuation of previous research. ☐ Yes ■ No

4. My display board includes non-published photographs/visual depictions of humans (other than myself): ☐ Yes ■ No

5. This abstract describes only procedures performed by me/us, reflects my/our own independent research, and represents one year's work only ■ Yes ☐ No

6. I/we hereby certify that the abstract and responses to the above statements are correct and properly reflect my/our own work. ■ Yes ☐ No

This stamp or embossed seal attests that this project is in compliance with all federal and state laws and regulations and that all appropriate reviews and approvals have been obtained including the final clearance by the Scientific Review Committee.

Abstract from 2018-19

Characterizing Polarization States of Light for Quantum Information Applications

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 computational power of quantum information processes is far beyond traditional computing models [1]. Quantum computing is expected to solve complex problems that current systems cannot. This includes searching and processing overwhelmingly large databases, revolutionizing encryption and decryption techniques, and fabricating solutions to seemingly impossible tasks in all scientific disciplines [2]. A conventional computer processes information by encoding it into bits (0 and 1). The addition of bits to a conventional computer increases the computing power linearly, as it deals with one state at a time [3]. A quantum computer processes information using qubits, which can be in a superposition of 0 *and* 1. Superposition allows for qubits to represent multiple quantum states simultaneously. As qubits are added to a quantum system, the computing power grows exponentially [4].

Physical implementation of qubits include, but are not limited to, neutral atoms, trapped ions, electron spins, superconducting qubits, topological qubits, and polarization qubits [5]. The advantages of an optical approach to quantum computing, as opposed to other implementation means, include a natural integration of quantum computation/communication, and allow quantum information systems to be directly connected using optical fibres or waveguides. Alternative approaches are much more complex in the transfer of qubits [6]. Additionally, the quantum state of a single photon is not as delicate as other quantum states [7].

The information support of a single photon is the polarization mode it occupies [8].

Photonic quantum states include |H⟩, |V⟩, |D⟩, |A⟩, |R⟩, and |L⟩. Each state has a specific oscillation along the direction of propagation. Polarization qubits may be generated via tuned optical components, such as Acousto-Optic Modulators (AOM) and Electro-Optic Modulators (EOM) [8].

Although much progress has been made in the field of photonic quantum computing, current quantum devices still present significant limitations [9]. The ability to accurately characterize polarization qubits is necessary for the development of photonic quantum technologies. Trusting state inputs is simply ineffective in the performance of delicate quantum experiments, where the qubit state ought to be preserved [10]. Additionally, current optical characterization techniques involve light wave characterization, which is not cooperative with single photon pulses [11]. Thus, this project attempts to develop a measuring system for characterizing polarization states of light using readily available “off-the shelf” optical components in order to ensure that qubits are accurately characterized. The measuring system is easily removable after verification without modulating the qubits.

Through accurate characterization techniques, quantum storage systems are able to store accurate polarization qubits. The fabrication of accurate quantum storage systems is fundamental for the development of quantum computers, which will function to address current societal problems [12].

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

Research Question(s):

1. What is the composition of the polarization qubit characterization technique?
2. How will the development of this measuring system improve current limitations?

Hypothesis(es):

1. The polarization qubit characterization technique involves a quarter-wave plate (QWP) connected to a dc servo motor for control of the angle, a linear polarizer, and a photodetector connected to a digital oscilloscope for the display of individual light pulse intensity. Then, a computational system is used to determine the original input using a Fourier transformation best fit curve of the acquired data.
2. This measuring system uses simple optical components that can be removed from a complex setup once the input is verified. This will ensure verification of the quantum state of light for qubit storage in quantum memories, networks, etc.

Engineering Goal(s):

1. To successfully mount the optical components on a portabile breadboard so that it is of appropriate measurement to detect the light intensities.
2. To assemble a computational characterization technique given QWP angles and intensities for each angle.

Expected Outcomes:

1. Accurate light intensity values for each QWP angle (data acquisition).

2. Successful verification of the EOM input for different applied voltages to shape the probe pulses.
3. Fourier transform and best fit curve technique precisely measure the Stokes Parameters of light.

C. Describe the following in detail:

Procedures: Detail all procedures and experimental design including methods for data collection. Describe only your project.
(1st two steps is not going to be done by me, but is necessary for my project)

- A 795 nm diode laser will pass through a qubit preparation system.
- The qubit preparation is comprised of an AOM to temporally shape probe fields (400 ns), and an EOM which encodes the desired polarization on probe pulses on the basis of an applied voltage (0-500V).
- The qubit characterization setup is going to be comprised of a QWP, linear polarizer, and photodetector.
- For control of the QWP, a DC Servo Motor will be used, and a digital oscilloscope will measure the gaussian pulses.
- Four EOM inputs (horizontal, vertical, diagonal, and anti-diagonal) will be verified.
- After the qubits pass through the characterization setup, a computation analysis via MATLAB will be written to encompass the Fourier transform and best fit curve technique for ensuring accurate characterization.

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

The researcher will wear protective laser goggles at all times inside of the lab.

Additionally, the researcher will conduct any computational means outside of the lab after data acquisition. The researcher will be directly supervised at all times by the qualified scientist.

Data Analysis:

- The data analysis will be done on MATLAB, and will include a computational system that is able to determine the Stokes parameters after each experimental test.
- The first method used to determine the polarization of the EOM input will be a Fourier transformation of transmitted light intensity concerning the rotation of the QWP.
- The second technique will be a best fit curve of the QWP and intensity plot to determine coefficient values of a regression model to verify that the Stokes parameters are accurate.
- The computational setup will be able to state the type of polarization (partially or completely polarized), the Stokes parameters of light, and the percent polarization.

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] C. Williams, Explorations in quantum computing. London: Springer, 2011.

[2] "Quantum technology – popular science description", 2018. [Online]. Available: https://www.chalmers.se/en/news/Documents/quantum_technology_popdescr_171114_eng.pdf. [Accessed: 10- Sep- 2018].

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