QUANTUM STATE TOMOGRAPHY OF SINGLE QUBIT WITH LASER IR 808nm USING DENSITY MATRIX

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Author:

SYAFI'I FAHMI BASTIAN

15690044

PHYSICS EDUCATION DEPARTMENT

FACULTY OF SCIENCE AND TECHNOLOGY

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KEMENTERIAN AGAMA
UNIVERSITAS ISLAM NEGERI SUNAN KALIJAGA
FAKULTAS SAINS DAN TEKNOLOGI
Jl. Marsda Adisucipto Telp. (0274) 540971 Fax. (0274) 519739 Yogyakarta 55281

PENGESAHAN TUGAS AKHIR

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yang dipersiapkan dan disusun oleh:

Nama	: SYAFI'I FAHMI BASTIAN
Nomor Induk Mahasiswa	: 15690044
Telah diujikan pada	: Kamis, 12 September 2019
Nilai ujian Tugas Akhir	: A

dinyatakan telah diterima oleh Fakultas Sains dan Teknologi UIN Sunan Kalijaga Yogyakarta

TIM UJIAN TUGAS AKHIR

Ketua Sidang

Joko Purwanto, S.Si., M.Sc.
NIP. 19820306 200912 1 002

Penguji I

Dr. Widayanti, S.Si. M.Si.
NIP. 19760526 200604 2 005

Penguji II

Rachmad Resmiyanto, S.Si., M.Sc.
NIP. 19820322 201503 1 002

Yogyakarta, 12 September 2019
UIN Sunan Kalijaga
Fakultas Sains dan Teknologi
Dekan

Dr. Murtono, M.Si.
NIP. 19691212 200003 1 001

Universitas Islam Negeri Sunan Kalijaga

SURAT PERSETUJUAN SKRIPSI/TUGAS AKHIR

Hal : Persetujuan Skripsi
Lamp :

Kepada
Yth. Dekan Fakultas Sains dan Teknologi
UIN Sunan Kalijaga Yogyakarta
di Yogyakarta

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Nama	: Syafi'i Fahmi Bastian
NIM	: 15690044
Judul Skripsi	: QUANTUM STATE TOMOGRAPHY OF SINGLE QUBIT WITH LASER IR 808nm USING DENSITY MATRIX

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Yogyakarta, 26 Agustus 2019
Pembimbing

Joko Purwanto, M.Sc
NIP. 19820306 200912 1 002

CERTIFICATE OF ORIGINALITY

I certify that this paper is definitely my own work. I am completely responsible for the contens of this paper. Other writers' opinions of finding included in the paper are quoted or cited in accordance with ethical standarts.

Yogyakarta, 26 Agustus 2019

The author,

METERAI TEMPEL

67FDAAFF930741901

6000 ENAM RIBU RUPIAH

Syafi'i Fahmi Bastian

MOTTO

Never give up!

DEDICATION

Dedicated to:

My beloved parents

All of my families

My almamater

UIN Sunan Kalijaga Yogyakarta

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Author

<u>Syafi'i Fahmi Bastian</u>

15690044

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Syafi'i Fahmi Bastian
15690044

ABSTRACT

The quantum state tomography is an essential component in the development of quantum technologies. It is a representation of polarization state which can be used to know the characterization of small particle called photon in the nanoscale. In this research, photon number has been measured in order to create the states tomography. Optical devices and quantum-mechanical approaches were used to accomplish the image of quantum state tomography. Due to a single qubit state density matrix can be represented by Stokes parameters, so there are four set-ups to measure the Stokes parameters for each sample. The density matrix in this work is used because the pure state only happen in theoretical idea. And in the real experiment, It always shows a mixed state. The density matrix will represent seven samples in this work. The samples of tomography measurements consist of horizontal state, vertical state, diagonal state, anti-diagonal state, right-circular state, left-circular state and the tomography of laser IR 808nm. In this work, state tomography is shown by 2x2 density matrix. This research also shows the fidelities between theory and experiment result. And it shows the good agreement. From this research, the state of laser beam has known. The laser that used is showing a vertical state with fidelity F=97,34%.

Keywords: quantum state tomography, density matrix, a single qubit

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CHAPTER I

PRELIMINARY

A. Background

Physics is the study of natural phenomena in the world. This branch of science learns about the behavior of materials in this world which is then obtained by a mathematical pattern that represents the behavior of these objects. The behavior of particle in the universe has different characters. There are particles that can be observed directly with the naked eye, but some are not directly observable. An observer must have limitations in observing an object, therefore, there needs to be a different method to formulate the behavior of material. In physics there is a branch of science that studies about an observation object that has a very small scale and also a very large scale, that branch of physics is quantum physics. For example, particles of light called photons that have very small sizes can be formulated with quantum mechanics. At the early 20th century, a new dicipline was born in physics. This new discipline explains some fundamental questions that cannot be explained by classical mechanics and Maxwell's equations (Mayorga, 2018).

Research in the nanophotonics field has positive contribution for technological developments. In this digital era, technology is getting smaller and smaller in size, but it has very efficient performance. For example, the computer at the beginning of its existence has a very large size, It is different with computers that exist today. Now, computers have a size that is much smaller but can exceed the capabilities of previous computers. The development of computer technology that exists today is certainly supported by research in the field of physics, especially in the field of nanophotonic which examines the behavior of very small objects which were then developed into artificial intellegents and also computer components that have certain logic in accordance with the wishes of users. Where in its development, a quantum mechanics is one that makes a big contribution. Lack of nanotechnology manufacturing and analysis equipment is a roadblock to innovation, as is lack of modeling tools. New characterization tools are needed to analyze nanoscale interaction. (Pomrenke, 2004)

Quantum physics is able to explain the behavior of particles of light that classical physics cannot explain (Gillespie, 1988). For examples, an entanglement and superposition. These two things are phenomena that can only be explained by quantum physics. So, the presence of quantum physics is considered capable for solving the problems of microscopic and macroscopic physics. Nevertheless, there are still some problems that can only be solved by mathematical solutions and cannot be proven in the experiments. This is due to the difficulty of making a set of experiments capable of observing particles on a microscopic or macroscopic scale. The behavior of particles of light is sometimes very strange and unexpected. How can there be two particles that are spaced apart but the state of the two particles is related to one another. So that scientific work was written by

Albert Einstein with the title "Spooky action of a distance". Although it's strange but that's what happened.

Quantum computing is an application of quantum-mechanical phenomena, such as a superposition and entanglement. In analogy to the basic unit of information in computer science, the state of a quantum system is called a “quantum bit” or “qubit” for short (Niggebaum, 2011). This concept, a qubit, is a part of quantum mechanics. A pure qubit state is a coherent superposition of the basis states. This means that a single qubit can be described by a linear combination of $|0\rangle$ and $|1\rangle$. Quantum computing exploits quantum-mechanical effects in particular superposition, entanglement, and quantum tunneling to more efficiently execute a computation (Eidenbenz, 2018). Improvement in realization of the properties of state, especially about state tomography, the quantum computer can be developed.

A quantum state is a parameter that can be measured to obtain information related to the behavior of photons on a microscopic scale. Light that is initially not polarized will change the direction of its polarization when it passes through optical devices such as polarizing beam splitters (PBS), beam splitters (BS), half wave plate (HWP) and quarter wave plate (QWP). All of them have numerous applications invarious optical system like which used in optical computing, optical information, metrology, and holography (Shabestari, 2013). To explain the changes in quantum conditions, a quantum mechanical approach is needed. The quantum state can be represented by using a matrix so that the quantum state as input can be simulated against optical equipment which mathematically acts as an operator. In quantum mechanics, a quantum state can be represented by dirac notation, bra-ket. So in theory the change in the quantum state after passing through optical equipment can be operated to get the predicted output of a quantum state.

The tomography of a quantum state is a process of making a image of a quantum state. The laser which is fired certainly has a quantum state and the image can be produced. The observer can not see the quantum state of the laser directly and also can not measure it by using an instan tool. So, the optical set-up will be needed. The quantum state can be changed using optical devices and each has a different tomography. In theory, in quantum mechanics, something that changes the quantum state is the operator. In producing tomographic images of quantum states, a quantum mechanical approach is needed.

There are some methods to represent the quantum state. Quantum state tomography can be represented by using Poincare or Bloch Sphere which has been introduced by Alexander Niggebaum (Niggebaum, 2011). This method shows the quantum state in sphere which indicated by an arrow as follows:

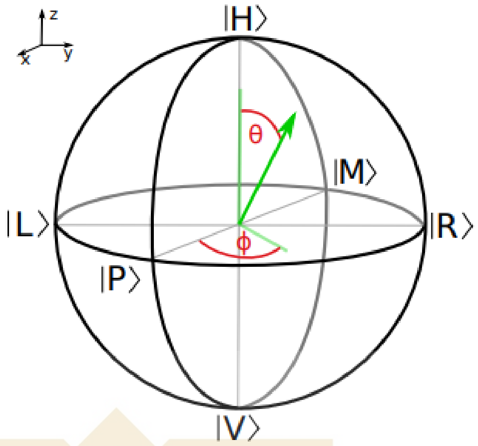

Figure 1.1 Representation of the base vector set on the Poincaré or Bloch Sphere.

Lack of this representation is the amplitude is difficult to see because it only shows one arrow and some angles. In other hand, density matrix can show the quantum state tomography with the measured number and gives more information about the state. In this research, the density matrix is expected can show more information about the state. When the quantum tomography is successfully created, It can be known the signal characterization of a laser beam. However, the theory can not be the same with the experiment result because the experiment have a mix state. The density matrix will be needed to represent the mix state. It is used for this experiment because in the real experiment there are some noises. This cannot be guaranteed the polarized light that already set will give one hundred percent a pure state.

The work in quantum state tomography is an application of quantum mechanics which also give benefit in educational field as additional contents. The concept of this work can be developed become a additional contents for students who study physics. Due to the quantum mechanics is so many mathematical concept, so the real experiment will be help to give description about what happen in the nanoscale world. Optical devices also can be shown to the student in order to give more information about quantum mechanics especially in the use of density matrix, operators, and diract notations (bra-ket).

B. Problem Identification

1. There is no instant tool for the tomography of the quantum state of a single qubit.
2. The quantum state in experiment is a mix state that cannot be represented by pure state.

C. Scopes

1. This research was conducted for creating the tomography of laser IR 808nm light, horizontal, vertical, diagonal, anti-diagonal, right circular, and left circular input objects.
2. The density matrix that used is 2x2 matrix

D. Problem Formulation

1. How are the verifications of the quantum state tomography of a single qubit with laser IR 808nm using matrix density from the real experiment to the theory?
2. How to represent a mix state for quantum state tomography of single qubit using density matrix?

E. Objectives

1. To know the verification of the quantum state tomography of a single qubit with laser IR 808nm using a density matrix from real experiment to the theory.
2. To find out the 2x2 matrix which represent a mix state of quantum state tomography of single qubit.

CHAPTER V

CONCLUSION AND SUGGESTION

A. Conclusion

1. This project has shown the descriptions and results of single qubit quantum state tomography using density matrix with samples horizontal state, vertical state, diagonal state, anti-diagonal state, right circular state, left circular state, and directly from a laser IR 808nm. The fidelity of density matrix verifies that the experiment results have a good agreement with the theory.
2. The density matrice for all samples has found using optical devices and quantum mechanics approach which the results already shown in equation 4.47 to 4.61 that consist of real and imaginary part.

B. Suggestion

For the suggestion, this project would be better if it could proceed to the next relevant discussion and to be improved. It is hoped that it can be continued for two qubits measurement and quantum entanglement study. Good devices will be very useful for obtaining better results to explore a study of photon at the nanoscale.

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