Annual Report (PhD Student)

University of Genoa, Italy

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Summary of Research Activities:

Course / Topic	Institute/By/Tool	From-to
Quantum Optics 1- Single Photons (Certificate)	Coursera/École Polytechnique	Feb 2023- Mar 2023
Quantum Optics 2- Two Photons and More (Certificate)	Coursera/École Polytechnique	Feb 2023- Mar 2023
From image processing to noise mitigation: frontiers and challenges in quantum computing	Talk by Simone Roncallo	
Methodology VQA (Variational Quantum Algorithms) for Non-Linear Problems		
Practical Hands-on Related Software including Mathematica		
Future Research Activities and Plans		

I am a foreign PhD student from Pakistan. After completing of my visa process, I landed in Italy and joined the Department of Physics-UNIGE at the end of July 2023.

1. Quantum Optics 1- Single Photons:

I have successfully completed Quantum Optics 1- Single Photons, an online non-credit course authorized by École Polytechnique and offered through Coursera, and got a certificate (https://coursera.org/verify/CXUXVC4NC9B5)

2. Quantum Optics 2- Two Photons and More:

I have successfully completed Quantum Optics 2- Two Photons and more, an online non-credit course authorized by École Polytechnique and offered through Coursera, and got a certificate (https://coursera.org/verify/CVEMFNZ52EYT).

3. Talk by Simone Roncallo

Title: From image processing to noise mitigation: frontiers and challenges in quantum computing.

Abstract: Quantum computers can foster the development of high-performance calculations: from simulations of quantum mechanical and chemical systems to machine learning and image processing. For example, we introduce a novel quantum algorithm for the compression of images encoded in a multiqubit array. As fault tolerance is still out of reach, however, noise sensitivity represents the main bottleneck of quantum computing. Noise mitigation provides a way to reduce errors at the output of a quantum circuit. To this extent, we present a tomographic protocol for the efficient characterization of quantum noisy operations, as well as a deconvolution technique to mitigate them at the data processing stage.

4. Methodology VQA (Variational Quantum Algorithms) for Non-Linear Problems

The methodology for the first year of my PhD has been focused on the variational quantum algorithms based on the variational principle which is a powerful method in quantum mechanics used to approximate the ground state function and ground state energy of quantum systems. This method is used in quantum computers to optimize the parameters of the trial wave function to obtain a minimized expectation value of energy. For this, we learned a method of QNPU that utilizes the quantum processor to optimize the solution for mathematical equation (Non-linear time independent Schrodinger wave equation). For optimization this method combines classical and quantum techniques to calculate the cost function that is based on the trial solutions, employing variational networks to encode trial solutions into quantum states. The QNPU utilizes linear differential operators and measures the cost function for kinetic energy, potential energy, and interaction energies respectively by using ancilla qubits. The variational parameters are updated until the minimum cost function is achieved. The advantage of this method is it doesn't require long-term quantum memory and stores all parameters classically.

5. Practical Hands-on Related Software including Mathematica

I have learned and practiced the software Mathematica, Prepared states for my system (ψ), and proceeded further by taking the complex conjugate of these states (ψ^*), taking the tensor product of those states |ψψ*>and writing the code for CNOT gate that is applied on my states CNOT-|ψψ*> and got some results. Moreover, I have also learned the function of different gates for $n \geq 2$ qubits, like the **Hadamard gate** (to create the superposition of states in the form of |+> and |->), **Tofolli gate** (3-qubit gate in which the first 2 qubits are 'control qubit' and 3rd qubit is 'target qubit' and if control qubit is "1" it flips the target qubit or if control qubit is "0" then it remains unchanged target qubit), **CNOT gate** (2-qubit gate in which 1st is control qubit and 2nd is target qubit when control qubit is "1" it flips target qubit and there is no change in the target qubit if control qubit is "0", Moreover, Cnot gate is used to create the entanglement between two qubits), **Y-rotation gate** (it is single -qubit rotation gate through an angle θ measured in radians around the y-axis) and applied all these gates on my quantum system and got results. Further, I have demonstrated the function of the quantum operator, Unitary operator, Quantum Fourier Transform (QFT), and quantum circuit operator and applied all these techniques to my related work to achieve better results.

6. Future Research Activities and Plans:

Previous studies have shown a working of VQA (Variational quantum algorithm) and a basic principle of QNPU for non-linear problems. Next in the future, we analyze the QNPU logic to solve a 2D non-linear equation, Monte Carlo sampling technique errors that are associated with the measurements of ancilla qubits, and calculate the entropy for maximally bi-partite entangled n-qubit wave functions.