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Machine Learning Applied in Reconstruction of Unitary Matrix for Quantum Computation

H. Zhang¹, H. Cai^{2†}, S. Paesani³, R. Santagati³, A. Laing³, L. C. Kwek⁴ and A. Q. Liu^{1†}

¹*School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 639798*

²*Institute of Microelectronics, A*STAR, Singapore 138634*

³*Quantum Engineering and Technology Laboratories, University of Bristol, BS8 1FD, UK*

⁴*Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, Singapore*

[†]*Email Address: caih@ime.a-star.edu.sg, eaqliu@ntu.edu.sg*

Abstract: Optimal method are applied in characterizing and reconstructing designed unitary matrices on linear optical circuit. The scheme is based on the measurement of single-photon and two-photon statistics using coherent beams.

OCIS codes: (270.5290) Photon statistics; (100.5010) Pattern recognition; (270.0270) Quantum Optics

1. Introduction

Linear optical circuits have recently been applied in many different quantum tasks, including quantum simulation and boson sampling problem for demonstration of quantum supremacy. Literatures come out with some ways of learning an unknown unitary transformation through one-photon and two-photon statistics [1][2]. Most of them were configuring a fixed chip and simplified the relationship between the unitary matrix elements and the corresponding voltage sets as ideal. That means, they use a theoretical ideal (t, α, β) to represent a BS-PS-PS unit. However, in real experiment, the relationship between voltages and matrix elements is complex and hard to characterize and how to implement the optimization on a real chip instead of numerical simulation is still a challenge. Thus, construction a designed unitary matrix on an actual linear optical circuit is still a challenge. Here we propose a system to optimally search for the best voltage set to construct a designed unitary matrix on linear optical circuit. Here we use genetic algorithm as an example. Some other optimal algorithms such as particle swarm and simulated annealing can also help in such problems.

2. Experimental setup

We first describe how the genetic algorithm can be applied to reconstruct a designed unitary matrix on a four-mode linear optical circuit. Since the unitary matrix cannot be directly acquired by simple measurements. The output variables are set to be the one-photon and two-photon statistics to represent a unitary matrix. In our experiment, one-photon and two-photon statistics are estimated by coherent beams. Single photon statistics $I_{j,k}$ describes the transition from input port k to output j . While two photon statistics is defined similar as Hong-Ou-Mandle visibilities, $V_{g,h,j,k} = (C_{g,h,j,k} - Q_{g,h,j,k})/C_{g,h,j,k}$. For coherent beams, two coherent states with the same mean photon number and a randomized relative phase are injected into input ports k and h . The intensity correlation measured at output ports g and j is

$$\Gamma_{g,h,j,k} = I_0^2 Q_{g,h,j,k} + I_{j,k} I_{g,k} + I_{j,h} I_{g,h}$$

The quantum coincidence thus can be accurately estimated.

For a given unitary matrix, we are able to obtain the one-photon and two-photon statistics $(\tilde{I}_{j,k}, \tilde{V}_{g,h,j,k})$ for all g, h, j, k . things we need to do now is to search around the voltage space to make the predicted statistics as close as possible to the expected one. Then we show the genetic algorithms procedures. Genetic algorithm mimics the natural evolution. At the very first, a set of N individuals $V_l: \Phi = \{V_1, \dots, V_N\}$ are randomly chosen to form an initial population. Each individual is composed of 12 different voltages on phase shifters, $V_l = (v_l^1, v_l^2, \dots, v_l^{12})$. The voltage sets will form different unitary matrices following Reck's scheme [3]. When we search around the solution space of voltages sets, the unitarity of the matrix is naturally guaranteed. The searching contains three basic manipulation, the selection to pick out individuals to survive, the crossover to develop new generation and the mutation to bring new genes into the group. Then we define a fitness function $f(V) \in [0, \infty)$ to define similarity between our predicted statistics and expected one and finally decides whether the individual can survive or not.

$$f(V) = \sum_{j,k} |\tilde{I}_{j,k} - I_{j,k}^l| + \sum_{g,h,j,k} |\tilde{V}_{g,h,j,k} - V_{g,h,j,k}^l|$$

By iterations, the final survived individuals can be solutions to our optimal problem.

3. Results and Discussions

We test this scheme on a four-mode scheme and show results here. The experimental measurements consists of $d_1 = 16 = m^2$ single-photon statistics $\tilde{I}_{j,k}$ and $d_2 = 36 = (m(m-1)/2)^2$ two photon statistics $\tilde{g}_{g,h,j,k}$, corresponding to a total amount of $d = d_1 + d_2 = 52$ data. The statistics of the designed U-matrix is shown in Fig 1(a) and 1(b).

Fig. 1. Experimental results of (a) single-photon statistics (b) two-photon statistics of a designed unitary matrix implement on a four-mode linear optical circuit. This matrix as the optimization target will be reconstruct using the complete training set.

Then we try to reconstruct the unitary matrix which is represented by voltage sets and get results as follows, Fig 2(a) shows the comparison of expected and predicted single-photon statistics, Fig 2(b) shows the comparison of two-photon statistics and Fig 2(c) shows the designed voltages at the very first and the predicted one.

Fig. 2. Comparison between expected and predicted (a) single-photon statistics (b) two-photon statistics of and (c) voltages.

The algorithm convergence as shown in Fig 3(a), the best fitness function achieved is 0.26. the Difference of simulated expected U and predicted U is shown in Fig 3(b).

Fig. 3. Diagram of (a) algorithm convergence and (b) Difference between expected and predicted U-matrix.

4. Summary

We propose an optimization method which can be experimentally implemented on silicon chip to reconstruct any designed unitary matrix by the measurement of one-photon and two-photon statistics. Such a method builds the relationship from input voltages on phase shifters to output statistics directly and experimentally.

5. Acknowledgement

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