

Facilitating the calibration of complex quantum photonic circuits with machine learning assisted gate set tomography

By

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Declaration

This dissertation is submitted to the University of Bristol in accordance with the requirements of the degree of MEng in the Faculty of Engineering. It has not been submitted for any other degree or diploma of any examining body. Except where specifically acknowledged, it is all the work of the Author.

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Abstract

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Acknowledgements

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Chapter 1: Notes

1.1 Tomography

Notes taken from [1], only reworded and trimmed down for my benefit.

In the classical world, characterising the dynamics of a system is trivial and known as *system identification*. The general idea is that we wish to know how the system behaves with respect to any input, thus uniquely identifying it. In the quantum world, the analogue of this is called *quantum process tomography*. To understand process tomography, we must first understand *quantum state tomography*.

State tomography is the procedure of determining an unknown quantum state. This is harder than it sounds: if we're given an unknown state ρ , we can't just measure the state and recover it immediately way since measurement will *disturb* the original state. In fact, *there is no quantum measurement which can distinguish non-orthogonal states with certainty*. However, if we have an *ensemble* of the same quantum state ρ , then it's possible to estimate ρ .

If we represent the state of the system using its density matrix ρ , we may expand ρ as

$$\rho = \frac{\text{tr}(\rho)I + \text{tr}(X\rho)X + \text{tr}(Y\rho)Y + \text{tr}(Z\rho)Z}{2} \quad (1.1)$$

Note that $\text{tr}(Z\rho)$ can be interpreted as the *expectation* of the observable Z . Therefore, to estimate $\text{tr}(Z\rho)$, we measure the observable Z m -times to obtain outcomes z_1, \dots, z_m and calculate

$$\text{tr}(Z\rho) \approx \frac{1}{m} \sum_i^m z_i \quad (1.2)$$

In general, this estimate is approximately a Gaussian with mean $\text{tr}(Z\rho)$ and standard deviation $\Delta(Z)/\sqrt{m}$, where $\Delta(Z)$ is the standard deviation of a single measurement. We can apply this same method to estimate $\text{tr}(X\rho)X$ and $\text{tr}(Y\rho)Y$; with a large enough sample size we obtain a good estimate for ρ . Additionally, since density matrices have unit trace, we know that

$$\text{tr}(\rho)I = I \quad (1.3)$$

This process can be generalised to a density matrix on n qubits as

$$\rho = \sum_{\vec{v}} \frac{\text{tr}(\sigma_{v_1} \otimes \sigma_{v_2} \otimes \dots \otimes \sigma_{v_n}) \sigma_{v_1} \otimes \sigma_{v_2} \otimes \dots \otimes \sigma_{v_n}}{2^n} \quad (1.4)$$

where $\vec{v} = (v_1, \dots, v_n)$ with entries v_i chosen from the set $0, 1, 2, 3$, i.e. each σ_{v_i} is a particular Pauli matrix.

Bibliography

- [1] M. A. Nielsen and I. L. Chuang, *Quantum Computation and Quantum Information: 10th Anniversary Edition*. USA: Cambridge University Press, tenth ed., 2011.