Quantum Error Correction using Linear Optics

T.B. Pittman, B.C. Jacobs, and J.D. Franson
Johns Hopkins University, Applied Physics Laboratory, Laurel, MD 20723
todd.pittman@jhuapl.edu

Abstract: We describe a laboratory demonstration of a quantum error correction procedure that can correct intrinsic measurement errors in linear-optics quantum gates. The procedure involved a photonic two-qubit encoding and fast feed-forward-controlled single-qubit operations.

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Large-scale quantum computing will require quantum error correction (QEC) to protect qubits from the effects of noise and undesired measurements. In linear optics quantum computing (LOQC), the most common errors correspond to situations in which the value of a single-photon qubit is measured in the computational basis (a Z-measurement) [1]. However, these intrinsic measurement errors can be corrected by using the following two-qubit encoding [1,2]: 0→ 00+11, 1→ 01+ 10.

In this code a single-photon qubit with value 0 (or 1) is encoded into a logical qubit represented by a two-photon Bell state. The basic idea is that if an unwanted Z-measurement occurs on one of these photons, fast feed-forward controlled single-qubit operations can be applied to the remaining photon to recover the value of the initial qubit. A conceptual overview of this procedure is shown in Figure 1.

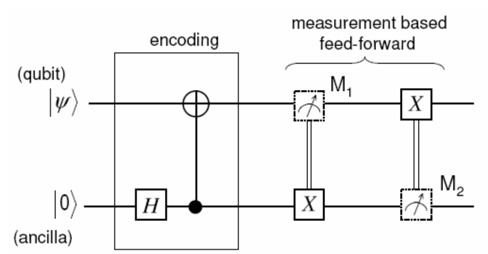

Fig.1. Quantum circuit diagram illustrating protection and recovery from a Z-measurement error in LOQC

As seen in Figure 1, a basic demonstration of this QEC procedure required a single qubit photon, an ancilla photon, an encoding operation, and feed-forward control. In our experiment the qubits were represented by the polarization states of two single-photons from a parametric down-conversion source, and the real-time feed-forward control was implemented using an electro-optic device triggered by the output of single-photon detectors. The encoding operation was based on two-photon quantum interference effects at a polarizing beam splitter. An overview of the experimental apparatus is shown in Figure 2. Using this set up, we were able to demonstrate recovery from Z-measurement errors with high fidelity [3].

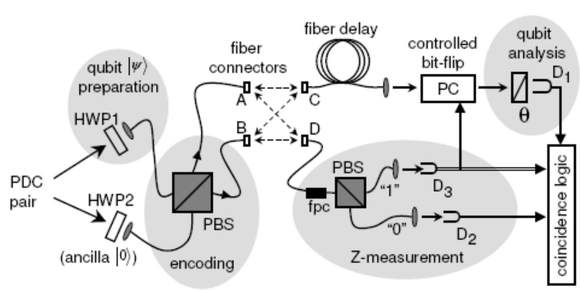

Fig.2. Apparatus used to demonstrate LOQC QEC. The experiment combined two-qubit encoding and real-time feed-forward control.

[1] E. Knill, R. Laflamme, and G.J. Milburn, Nature **409**, 46 (2001)
[2] J.L. O'Brien, G.J. Pryde, A.G. White, and T.C. Ralph, quant-ph/0408064 (2004).
[3] T.B. Pittman, B.C. Jacobs, and J.D. Franson, quant-ph/0502042 (2005).