ABSTRACT

A GENERALIZED APPROACH TO INTERACTION- AND MEASUREMENT-FREE QUANTUM LOGIC GATES BASED ON THE QUANTUM ZENO EFFECT

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The concept of using an environmentally-induced quantum Zeno effect to generate entanglement in the presence of strong dissipation was first pointed out by Beige and coworkers [1]. Similar ideas were developed by Gilchrist and coworkers [2] and by Azuma [3], who based their approach on the framework of "interaction-free measurement" or "high-efficiency quantum interrogation" developed and experimentally demonstrated by Kwiat and coworkers [4]. In the presence of dissipation, the Hilbert-space of the system includes a decoherence-free subspace (DFS). Unitary evolution out of this subspace is suppressed by the quantum Zeno effect when the Rabi-frequency is small compared to the dissipation rate, resulting in the system being `frozen' in the DFS. On the other hand, unitary evolution within the DFS remains unaffected. By clever system design, one can use this effect to generate entanglement between two qubits. Previous proposals, however, have many drawbacks that make simple quantum logic gates between identical qubits impractical or difficult at best.

We have developed a generalized approach to designing an interaction- and measurement-free quantum phase-gate. In our approach, each of two logical qubits has the possibility of a strong state-dependent dissipative interaction with a third ancillary qubit. The system is designed so that dissipation occurs only if the ancillary qubit is in state $|1\rangle$ and at least one logical qubit is in state $|0\rangle$, Achieving this form of state-selective dissipation is the primary design challenge for experimental implementation. The ancillary bit is initialized in state $|0\rangle$ and subject to a $\pi/2$ rotation. This rotation imprints a -1 phase onto the logical $|11\rangle$ state, with the $|00\rangle$, $|01\rangle$, or $|10\rangle$ states unaffected due to the quantum Zeno effect. In the end, the ancillary qubit is not entangled with the logical qubits, and the state has been subject to a phase-gate operation. The success probability of the operation is $1\text{-}4\pi^2/(\Gamma t)$, where Γ is the dissipation rate, and t is the gate operation time. Thus arbitrarily high fidelity can be achieved in the limit $t >> \Gamma^{-1}$.

Implementations of this scheme will be presented for two systems: (1) a pair of trapped atoms and a single-photon in a high-finesse ring cavity; and (2) three electron spins in three quantum dots, where the center dot has a different effective electron g-factor. System (1) is based on the interaction-free measurement scheme of [4], and uses standard optical polarization selection rules and polarizing beam-splitters to achieve the necessary state-selective dissipation scheme. System (2) uses LO phonon-assisted decay as a dissipation mechanism, and selectivity is achieved through a combination of Pauli-blocking and applied magnetic field, which creates a spin-sensitive resonant-tunneling mechanism. We will compare and contrast the expected performance of these systems using current experimental parameters.

References:

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