Optical Society of Korea Annual Meeting 2005 (2.17～18, 2005)

떨어진 두 원자 사이의 조건부 유니터리 연산

Controlled Unitary Operation between Two Distant Atoms

조재윤, 이해웅
한국과학기술원 물리학과
choooir@laputa.kaist.ac.kr

A quantum optical system utilizing trapped neutral atoms or ions for qubits is one of promising candidates for implementing a quantum computer[1]. Actually, there have been numerous theoretical[2-7] and experimental[8-10] achievements showing the positive prospects for it. The number of qubits in such a system is, however, obviously limited by the size of the trapping structure, while one of the essential factors for a useful quantum computer is the scalability. This difficulty could be overcome by connecting partially implemented quantum computation nodes to form a quantum network.

For any unitary operation for the whole quantum network to be possible, controlled unitary operations between two nodes should be performed as well as local unitary operations at each node[11]. There have been various ways for doing it by means of one or more ancilla qubits[1]. The underlying idea is to use ancilla qubits to transfer the quantum information between two nodes and perform local two-qubit operations at the nodes so that the overall process in effect results in the desired global two-qubit operation. One method to accomplish the task is to shuttle ancilla qubits or a quantum node itself physically to a particular position where local interaction between an ancilla qubit and a quantum node is possible[6-7]. This method, however, cannot be directly applicable to neutral atom quantum computers. Another method feasible for neutral atom quantum computers as well is to exploit a photon-mediated interaction between two nodes, such as in entanglement generation[12-14], quantum state transfer[15-16], and quantum teleportation[17-18]. On the other hand, there have also been a scheme in which no ancilla qubit is involved[19]. The scheme, however, uses a quantum interferometer and the complex atomic structure of several hyperfine levels instead.

In this work, we introduce a scheme to do a controlled unitary operation between two distant atoms in a much simpler way. A common quantum communication setup[15-16], in which two atoms each trapped in an optical cavity directly communicate through a quantum transmission line such as an optical fiber connecting the two cavities, is considered. In contrast to earlier methods, no ancilla qubit is involved in our scheme and the gate operation is done by a simple coherent process without atomic initialization or measurement.

1. C. Monroe, “Quantum information processing with atoms and photons”, Nature 416, 238-246 (2002).
2. J. I. Cirac and P. Zoller, "Quantum Computation with Cold Trapped Ions", Phys. Rev. Lett. 74, 4091-4094 (1995).
3. T. Pellizzari, S. A. Gardiner, J. I. Cirac, and P. Zoller, "Decoherence, Continuous Observation,

and Quantum Computing: A Cavity QED Model", Phys. Rev. Lett. 75, 3788-3791 (1995).
4. J. Pachos and H. Walther, "Quantum Computation with Trapped Ions in an Optical Cavity", Phys. Rev. Lett. 89, 187903 (2002).
5. X. X. Yi, X. H. Su, and L. You, "Conditional Quantum Phase Gate between Two 3-State Atoms", Phys. Rev. Lett. 90, 097902 (2003).
6. J. I. Cirac and P. Zoller, "A scalable quantum computer with ions in an array of microtraps", Nature 404, 579-581 (2000).
7. D. Kielpinski, C. Monroe, and D. J. Wineland, "Architecture for a large-scale ion-trap quantum computer", Nature 417, 709-711 (2002).
8. F. Schmidt-Kaler, H. Häffner, M. Riebe, S. Gulde, G. P. T. Lancaster, T. Deuschle, C. Becher, C. F. Roos, J. Eschner, and R. Blatt, "Realization of the Cirac-Zoller controlled-NOT quantum gate", Nature 422, 408-411 (2003).
9. D. Leibfried, B. Demarco, V. Meyer, D. Lucas, M. Barrett, J. Britton, W. M. Itano, B. Jelenkovi, C. Langer, T. Rosenband and D. J. Wineland, "Experimental demonstration of a robust, high-fidelity geometric two ion-qubit phase gate", Nature 422, 412-415 (2003).
10. J. McKeever, J. R. Buck, A. D. Boozer, A. Kuzmich, H.-C. Nägerl, D. M. Stamper-Kurn, and H. J. Kimble, "State-Insensitive Cooling and Trapping of Single Atoms in an Optical Cavity", Phys. Rev. Lett. 90, 133602 (2003).
11. M. A. Nielsen and I. L. Chuang, "Quantum Computation and Quantum Information" (Cambridge University Press, Cambridge, 2000).
12. J. Hong and H.-W. Lee, "Quasideterministic Generation of Entangled Atoms in a Cavity", Phys. Rev. Lett. 89, 237901 (2002).
13. X.-L. Feng, Z.-M. Zhang, X.-D. Li, S.-Q. Gong, and Z.-Z. Xu, "Entangling Distant Atoms by Interference of Polarized Photons", Phys. Rev. Lett. 90, 217902 (2003).
14. L.-M. Duan and H. J. Kimble, "Efficient Engineering of Multiatom Entanglement through Single-Photon Detections", Phys. Rev. Lett. 90, 253601 (2003).
15. J. I. Cirac, P. Zoller, H. J. Kimble, and H. Mabuchi, "Quantum State Transfer and Entanglement Distribution among Distant Nodes in a Quantum Network", Phys. Rev. Lett. 78, 3221-3224 (1997).
16. T. Pellizzari, "Quantum Networking with Optical Fibres", Phys. Rev. Lett. 79, 5242-5245 (1997).
17. S. Bose, P. L. Knight, M. B. Plenio, and V. Vedral, "Proposal for Teleportation of an Atomic State via Cavity Decay", Phys. Rev. Lett. 83, 5158-5161 (1999).
18. J. Cho and H.-W. Lee, "Quantum Teleportation with Atoms Trapped in Cavities", Phys. Rev. A 70, 034305 (2004).
19. A. Sørensen and K. Mølmer, "Error-free quantum communication through noisy channels", Phys. Rev. A 58, 2745-2749 (1998).