(News Release)

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Nippon Telegraph and Telephone Corporation
Osaka University

Demonstration of Quantum Computation Based on Quantum Teleportation

- New approach for realizing quantum computer using photon -

Nippon Telegraph and Telephone Corporation (hereafter NTT; Chiyoda-ku, Tokyo; President and CEO: Satoshi Miura) and Osaka University (hereafter Osaka Univ.; Suita, Osaka; President: Kiyokazu Washida), demonstrated a teleportation-based quantum computation, which is a promising scheme for overcoming the difficulty of actualizing a quantum computer.[*1]
In this scheme, we can perform quantum computations by operating a quantum teleportation[*2] (Fig. 1) by a very simple procedure after preparing a special quantum entanglement[*3] (Fig. 2). Constructing quantum gates is known to be of great difficulty. However, a new approach for operating quantum gates could be a breakthrough for creating a quantum computer.
This research is a collaborative work of NTT Information Sharing Platform Laboratories, Okamoto Research Laboratories, Dr. Yuuki Tokunaga, and Osaka Univ., Prof. Nobuyuki Imoto's group. This achievement will be published in the US science journal "Physical Review Letters" on May 27, 2008.

<Background>

Quantum information processing[*4] has been of much interest. A quantum computer can perform a kind of super parallel computing using the principles of quantum mechanics, and its computational power would highly surpass current computers for certain problems.
However, difficulties exist for actualizing a quantum computer, which are expected to take a long time to solve. One of the most difficult problems is the achievement of quantum gates. It is known that we can perform universal quantum computation if we have only two basic gates: rotation gates and controlled-NOT gates. A rotation gate is not a difficult task for current technology; however, the controlled-NOT gate, which enables interaction between quantum bits[*5], is difficult to actualize, despite many researchers in the world having tried. NTT has tried to achieve quantum computation using several device candidates, such as nuclear spin, atoms, super conductivity, and semi-conductors, and has presented the results.
The research group of NTT and Osaka Univ. focused on a "one-way quantum computation"[*6] scheme (Fig. 3), which is a teleportation-based quantum computation[*7] (Fig. 4), a promising approach to achieving quantum operation. In this scheme, after preparing the quantum entanglement, we can perform quantum computation by a very easy procedure, i.e., a 1-qubit measurement.
One-way quantum computation was proposed by Russendolf and Briegel in 2001. Several experiments for one-way quantum computing have been presented; however, a clear evaluation for surpassing classical limits (limits that can be reached without quantum entanglement) has not. Therefore, whether quantum entanglement really contributes to quantum operations in the existing results is unclear.

<Results>
In this research, we presented theoretical classical limits for entanglement-assisted quantum computation, such as one-way quantum computation, and performed quantum operation experiments surpassing those classical limits (Fig. 5). This demonstrated for the first time that quantum entanglement really contributes to teleportation-based quantum computing, in this case, one-way quantum computing.
We used four photons for the one-way quantum computation experiments. The following are the main points of our results.

(1) Generation of high-fidelity four-photon quantum entangled state
We generated a four-photon quantum entangled state as a resource for a teleportation-based quantum computation (one-way quantum computation). The scheme was simply constructed by photons from parametric down-conversion[*8], by linear optics, and by photon detectors. There was no path interference and no special optics. The fidelity of the generated four-photon quantum entangled state was over 86%, which was much higher than that of Wien University (63%) and the Max-Plank Institute (74%).

(2) Demonstration of teleportation-based quantum computation (one-way quantum computation) surpassing classical limits
The fidelities of the outputs from quantum operations have been increased by using the high-fidelity four-photon quantum entanglement as a resource for teleportation-based quantum computations. We proposed an evaluation method for entanglement-assisted quantum computation and presented the classical limits of operations for the cases that no quantum entanglement exists as a resource for computation. Then we showed that the experimental data surpassed the classical limits. This demonstrated that quantum entanglement really contributes to quantum operations. For example, the output state fidelity without using quantum entanglement as a resource is at most 85.4%. However, the fidelity in the experiment with quantum entanglement was 89.5%, which surpasses classical limits.

<Future direction>
We will try to increase the number of photonic quantum bits and to generate large-scale quantum entangled states. Then we will try to actualize not only single quantum gates but also quantum algorithm or quantum cryptographic protocols using composite quantum gates.
Moreover, we expect that quantum cipher computation will be an application of teleportation-based quantum computation because it will enable the performance of computations between several parties in separate places.

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<Terminology>

*1 Quantum computer
A quantum computer is a computing device that uses quantum mechanical phenomena, such as superposition and entanglement. If large-scale quantum computers can be built, they will be able to solve certain problems much faster than current classical computers (for example, an integer factorization problem).

*2 Quantum teleportation
Quantum teleportation is a quantum protocol by which quantum information can be transmitted utilizing classical (current) communication channels and quantum entanglement shared between separate places.

*3 Quantum entanglement
A composite quantum state is entangled when the state cannot be described as a product of the states of its subsystems. This leads to non-local correlations between the subsystems.

*4 Quantum information processing
Quantum information processing is information processing using quantum phenomena such as quantum entanglement and superposition. Quantum computing, quantum cryptography, and quantum teleportation are examples.

*5 Quantum bit
A quantum bit is a unit of quantum information. That information is described by a state vector in a two-level quantum mechanical system that is formally equivalent to a two-dimensional vector space over the complex numbers.

*6 One-way quantum computation
One-way quantum computation is a scheme of quantum computation that first prepares a special entangled state, called a cluster state, then performs single qubit measurements on it.

*7 Teleportation-based quantum computation
Teleportation-based quantum computation is a scheme of quantum computation in which a quantum operation is performed through quantum teleportation. Special entangled states are used as resources for this computation.

*8 Parametric down-conversion
Parametric down-conversion is a process in which a nonlinear crystal splits incoming photons into pairs of photons of lower energy whose combined energy and momentum are equal to the energy and momentum of the original photon.

- Fig. 1: Quantum teleportation
- Fig. 2: Quantum entanglement
- Fig. 3: One-way quantum computation
- Fig. 4: Quantum computation based on quantum teleportation
- Fig. 5: Evaluation for one-way quantum computation

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