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Quantum Teleportation: an Alternative Means To Transportation

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Abstract

Transportation systems available at present have been discovered to have their limitations as to the time and space required to transport items from one location to another. Teleportation technology is a fast growing area of research which has the potential to influence the present means of transportation or change it. Recent research development shows the possibility of quantum teleportation, whereby an original object to be teleported disintegrates at a particular location and an exact replica is reconstructed at a remote location instantaneously. The concept of Quantum Teleportation which is based on Quantum Entanglement using Einstein-Podolsky-Rosen effect is reviewed here. Also, discussed is the importance of quantum computing to quantum teleportation. The future possibility of human teleportation is also examined based on the achievements so far in quantum teleportation.

Keywords: Transportation, teleportation, quantum, entanglement, computing, EPR.

1.0 Introduction

Ever since the wheel was invented more than 5,000 years ago, people have been inventing new ways to travel faster from one point to another. The chariot, bicycle, automobile, airplane and rocket have all been invented to decrease the amount of time we spend getting to our desired destinations. These transportation systems shares the same flaw, in the sense that they require us to cross a physical distance, which can take anywhere, from minutes to many hours depending on the starting and ending points. Recently, some scientists are working on methods of travelling, which combine properties of telecommunications and transportation to achieve a system called Teleportation[1].

Teleportation involves dematerializing an object at one point, and sending the details of that object's precise atomic configuration to another location, where it will be reconstructed. This means that time and space could be eliminated from travel, we could be transported to any location instantly, without actually crossing a physical distance.

Teleportation will be very useful in the military and space exploration by drastically reducing time in space exploration and deployment of troops and equipments to battle front. In the 21st century teleportation technology is the alternative to travel which saves organization’s time and money and enhance your internal and external communication network. Teleportation technology systems are very simple to use. All you have to do is click to connect and you can appear within a 3-dimensional setting in a chair or behind a desk on the other side of the world - almost instantly.

Quantum technology will be able to build microscopic machines such as a nano-assembler, a virtually universal constructor that will not just take materials apart and rebuild them atom by atom but also replicate itself. The good news of this self-replication machines means that these nano-machines will cost nothing to build and eventually make any products we might desire at zero cost.

Quantum teleportation can be implemented with a quantum circuit that is much simpler than that required for any nontrivial quantum computational task; the state of an arbitrary quantum bit (qubit) can be teleported with as few as two quantum exclusive-or gates [2, 3]. Quantum computing is meaningful even if it takes place very quickly, indeed its

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primary purpose is increased computational speed and within a small region of space. Although working prototypes of quantum teleportation have recently been demonstrated by Bouwmester*et al* [4] and Boschi*et al* [5], quantum teleportation across significant time and space will have to await a technology that allows for the efficient long-term storage [6] and purification of quantum information [7]. Nevertheless, it may be that short-distance quantum teleportation will play a role in transporting quantum information inside quantum computers. Thus, we see that the fates of quantum computing and quantum teleportation are inseparably entangled, usually explained in terms of Einstein-Podolsky- Rosen non-local quantum states [8] and Bell measurements.

2.0 Einstein-Podolsky-Rosen Effect (EPR)

In order to achieve teleportation, Alice and Bob must share prior quantum entanglement. This is usually explained in terms of Einstein-Podolsky- Rosen nonlocal quantum states [8] and Bell measurements. The Einstein-Podolsky-Rosen (EPR) features a striking case where two quantum systems interact in such a way as to link both their spatial coordinates in a certain direction and also their linear momenta (in the same direction). As a result of this "entanglement", determining either position or momentum for one system would fix (respectively) the position or the momentum of the other [9].

Figure 1 depicts quantum teleportation process whereby one scans out part of the information from object A (the original), which one wants to teleport, while causing the remaining, unscanned, part of the information in A to pass, via EPR entanglement, into another object C which has never been in contact with A. Two objects B and C are prepared and brought into contact (i.e., entangled), and then separated. Object B is taken to the sending station, while object C is taken to the receiving station. At the sending station object B is scanned together with the original object A, yielding some information and totally disrupting the states of A and B. This scanned information is sent to the receiving station, where it is used to select one of several treatments to be applied to object C, thereby putting C into an exact replica of the former state of A. Object A itself is no longer in its original initial state, having been completely disrupted by the scanning process. The process just described is teleportation and not replication.

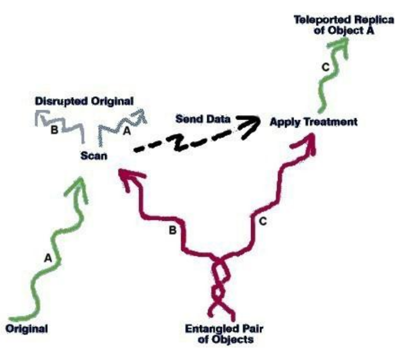

Figure 1: Quantum Teleportation (Modified IBM Press Image)

3.0 How Does Quantum Computing Work

To understand how quantum computing works, we can start with familiar classical computing. In classical computers, data is stored in the form of a digital bit. Digital bits have only one value: true or false, on or off, one or zero; they are typically represented by the presence or absence of a few zillion electrons in silicon transistors. The chip processes one calculation at a time, sequentially, and information is processed in one direction only.

Quantum computing, on the other hand, uses atoms in place of traditional processors. Each bit of information carried in quantum computers is called a 'qubit', which can represent 0, 1, and any value in between at the same time. In a graphical sense, a vector pointing in a direction intermediate between those representing 0 and 1 represents the in-between position known as superposition as shown in Fig. 2

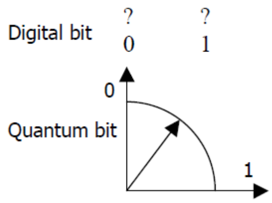

Fig. 2: Digital and Quantum bits Representation

In classical digital computation, for example, a two-bit can only represents one of the following values: 00, 01, 10, and 11. A quantum two-bit, in contrast, can represent any of those numbers simultaneously. Consequently, as the number of quantum bit (qubit) increases, the number of superposition will exponentially increase and result in complicated numbers that current computer technology will never be able to calculate. Using superposition, scientists can use the idea of quantum parallelism in their creation of a new microprocessor. Quantum parallelism could be interpreted as that those atoms in a microscopic world are radiating to many different directions simultaneously.

Quantum computing offers many potential benefits to the organizations of tomorrow. The three main benefits are: increase in computing power, advances in security and the ability for firms to use the sci-fi concept of teleportation.

4.0 Quantum Bits (Qubits) and Quantum Gates

4.1 Quantum Bits (Qubits)

A Quantum Bit (Qubit) is a two-level quantum system. We can label the states $|0\rangle$and $|1\rangle$. In principle, this could be any two-level system. Unlike a classical bit, which is definitely in either state, the state of a Qubit is in general a mix of$|0\rangle$and $|1\rangle$.

$$|\psi\rangle = c_0|0\rangle + c_1|1\rangle \qquad (1)$$

Upon normalization of the state, we get:

$$|c_0|^2 + |c_1|^2 = 1 \qquad (2)$$

For convenience, the basis states can be represented using matrix form, as:

$$|0\rangle = \begin{pmatrix}1\\0\end{pmatrix} \quad |1\rangle = \begin{pmatrix}0\\1\end{pmatrix} \qquad (3)$$

4.2 Quantum Gate

A quantum gate or quantum logic gate is a basic quantum circuit operating on a small number of qubits. They are the building blocks of quantum circuits, like classical logic gates are for conventional digital circuits [10]. Unlike many classical logic gates, quantum logic gates are reversible. Quantum logic gates are represented by unitary matrices. The most common quantum gates operate on spaces of one or two qubits, just like the common classical logic gates operate on one or two bits. This means that as matrices, quantum gates can be described by 2×2 or 4×4 unitary matrices.

4.3 Quantum NOT Gate

As in classical computing, the NOT gate returns a 0 if the input is 1 and a 1 if the input is 0. The matrix representation is:

$$\begin{pmatrix}0 & 1\\1 & 0\end{pmatrix} \qquad (4)$$

Other Quantum Gates

Other gates include the Hadamard-Walsh matrix [10]:

$$\frac{1}{\sqrt{2}}\begin{pmatrix}1 & 1\\1 & -1\end{pmatrix} \qquad (5)$$

And Phase Flip operation:

$$\begin{pmatrix}1 & 0\\0 & e^{i\varphi}\end{pmatrix} \qquad (6)$$

Multiple Qubits

Any useful classical computer has more than one bit. Likewise, a Quantum Computer will probably consist of multiple qubits. A system of nQubits is called a Quantum Register of length n. To represent that Qubit 1 has value b_1, Qubit 2 has value b_2, etc., we will use the notation:

$$|b_1\rangle_1|b_2\rangle_2 \ldots\ldots\ldots\ldots |b_n\rangle_n \qquad (7)$$

For *n*Qubits, the vector representing the state is a *2n* column vector. The operations are then *2n*-by-*2n* matrices. For *n* = 2, we use the representations:

$$|0\rangle_1|0\rangle_2 = \begin{pmatrix}1\\0\\0\\0\end{pmatrix} \quad |0\rangle_1|0\rangle_2 = \begin{pmatrix}0\\1\\0\\0\end{pmatrix} \quad |0\rangle_1|0\rangle_2 = \begin{pmatrix}0\\0\\1\\0\end{pmatrix} \quad |0\rangle_1|0\rangle_2 = \begin{pmatrix}0\\0\\0\\1\end{pmatrix} \qquad (8)$$

4.4 Quantum CNOT Gate

An important Quantum Gate for *n* = 2 is the conditional not gate (CNOT). The conditional not gate flips the second bit if and only if the first bit is on. CNOT is a two-qubit gate that acts on two-qubits according to equation (9).

$$\begin{pmatrix}1&0&0&0\\0&1&0&0\\0&0&0&1\\0&0&1&0\end{pmatrix} \qquad (9)$$

5.0 Quantum Entanglement

Sometimes in Quantum Mechanics the measurement of one particle will affect the state of another particle, even though classically there is no direct interaction. When this happens, the state of the two particles is said to be entangled. Formally, a two-particle state is entangled if it cannot be written as a product of two one-particle states.

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|0\rangle_1|0\rangle_2 + |1\rangle_1|1\rangle_2) \qquad (10)$$

If a state is not entangled, it is decomposable.

$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|0\rangle_1|0\rangle_2 + |1\rangle_1|0\rangle_2) + (|0\rangle_1|1\rangle_2 + |1\rangle_1|1\rangle_2)$$
$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|0\rangle_1 + |1\rangle_1)\ \frac{1}{\sqrt{2}}(|0\rangle_2 + |1\rangle_2) \qquad (11)$$

6.0 Quantum Teleportation

Suppose two parties, Alice and Bob. Alice is in possession of a state, but does not know anything about it.

$$|\Psi\rangle = a|0\rangle + b|1\rangle \qquad (12)$$

Quantum teleportation scheme requires Alice and Bob to share a maximally entangled state beforehand, for instance one of the four Bell states [11].

$$|\Phi^+\rangle_{AB} = \frac{1}{\sqrt{2}}(|0\rangle_A \otimes |0\rangle_B + |1\rangle_A \otimes |1\rangle_B),$$
$$|\Phi^-\rangle_{AB} = \frac{1}{\sqrt{2}}(|0\rangle_A \otimes |0\rangle_B - |1\rangle_A \otimes |1\rangle_B),$$
$$|\Psi^+\rangle_{AB} = \frac{1}{\sqrt{2}}(|0\rangle_A \otimes |1\rangle_B + |1\rangle_A \otimes |0\rangle_B),$$
$$|\Psi^-\rangle_{AB} = \frac{1}{\sqrt{2}}(|0\rangle_A \otimes |1\rangle_B - |1\rangle_A \otimes |0\rangle_B). \qquad (13)$$

Alice desires to send this state to Bob, but cannot do so directly (no Quantum Channel). They can exchange classical data (there is a Classical Channel). Alice cannot observe this state to give the information about it to Bob, since observing it destroys the state. Nor could she, even if given an infinite number of states, reconstruct the state from probability measurements since phase information is lost.

Alice cannot give the state to Bob by classical means. She can, however, communicate the state if Alice and Bob share a register of length 2 that is prepared in an entangled state. Alice and Bob each have access to one Qubit.

$$|\phi\rangle = \frac{1}{\sqrt{2}}|0\rangle_A|0\rangle_B + \frac{1}{\sqrt{2}}|1\rangle_A|1\rangle_B \qquad (14)$$

The full-state then is the product of Alice's Qubit and the shared register given in equation (15).

$$|\phi\rangle|\Psi\rangle = \frac{a}{\sqrt{2}}|000\rangle + \frac{a}{\sqrt{2}}|011\rangle + \frac{b}{\sqrt{2}}|100\rangle + \frac{b}{\sqrt{2}}|101\rangle \qquad (15)$$

The notation is such that the left-most Qubit (of the right hand side of equation (15)) is Alice's mystery Qubit, the second one is Alice's half of register, and the rightmost is Bob's half of the register. Alice then performs a CNOT operation on her half of the register, using her mystery bit as the control. The lone Qubit is Bob's half of the register.

She then applies the Hadamard-Walsh matrix to the state [10]. The result can be written as:

$$\frac{1}{2}|00\rangle(a|0\rangle + b|1\rangle) + \frac{1}{2}|01\rangle(a|1\rangle + b|0\rangle)$$

$$+\frac{1}{2}|10\rangle(a|0\rangle - b|1\rangle) + \frac{1}{2}|01\rangle(a|1\rangle - b|0\rangle) \quad (16)$$

Alice then observes her two Qubits. Note that this destroys her original state. The outcome of this observation is totally unpredictable. After observing her bits, Bob knows what his bit must be, because of the entanglement of the states. If Alice observes 00, then Bob has the original state. Otherwise, Bob has some other linear combination of qubits. The linear combination is known, so Bob can perform a specific operation to retrieve the original state. [4,5]

7.0 Quantum Teleportation Circuit

Figure 3 shows a typical quantum circuit. Let $|\psi\rangle$ be an arbitrary one-qubit state. If $|\psi 00\rangle$ is fed into the circuit, that is if the upper input **a** to $|\psi\rangle$ and both other inputs **b** and **c**to $|0\rangle$. It is a straight forward exercise to verify that state $|\psi\rangle$ will be transferred to the lower output z, whereas both other outputs x and y will come out in state.

$|\phi\rangle = (|0\rangle + |1\rangle)/\sqrt{2}$. (17)

In other words, the output will be $|\phi\phi\psi\rangle$. If the two upper outputs are measured in the standard basis ($|0\rangle$versus$|1\rangle$), two random classical bits will be obtained in addition to the quantum state $|\psi\rangle$ on the lower output.

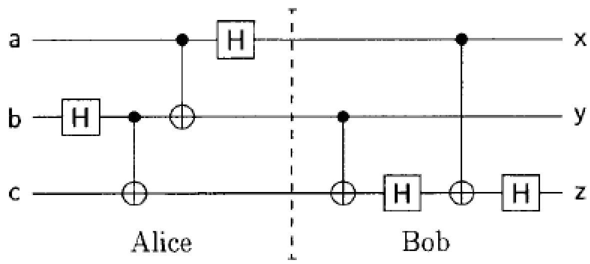

Figure 3: Quantum Teleportation Circuit

8.0 Implementation of Quantum Teleportation

Few years ago, scientists in China have broken the record for quantum teleportation, achieving a distance of about 16 kilometers, according to a new study in Nature Photonics [12]. In May, 2010 a team of 15 Chinese researchers from Tsinghua University in Beijing and the Hefei National Laboratory for Physical Sciences, a government-directed research center, published a research paper announcing a successful demonstration of "quantum teleportation" over 16 kilometers of free space. These researchers claimed to have the first successful experiment in the world. The technology on display has the potential to revolutionize secure communications for military and intelligence organizations and may become the watershed of a research race in communication and information technology.

Although much of the science behind this technology is still young, quantum technologies have wide-ranging applications for the fields of cryptography, remote sensing and secure satellite communications. In the near future, the results from this experiment will be used to send encrypted messages that cannot be cracked or intercepted, and securely connect networks, even in remote areas, with no wired infrastructure, even incorporating satellites and submarines into the link. While the teleportation of physical matter remains science fiction at this point, quantum teleportation could be immediately implemented as a means for secure communications and cryptography.

As a result, the issue has found itself at the center of a rapidly developing geopolitical race to apply quantum technology to military and intelligence work.

9.0 Possibility of Human Teleportation

We are years away from the development of a teleportation machine like the transporter room on Star Trek's Enterprise spaceship. The laws of physics may even make it impossible to create a transporter that enables a person to be sent instantaneously to another location, which would require travel at the speed of light.

For a person to be transported, a machine would have to be built that can pinpoint and analyze all of the 10^{28}atoms that make up the human body. That is more than a trillion atoms. This machine would then have to send this information to another location, where the person's body would be reconstructed with exact precision. Molecules could not be even a millimeter out of place, lest the person arrive with some severe neurological or physiological defect.

In the Star Trek episodes, and the spin-off series that followed it, teleportation was performed by a machine called a transporter. This was basically a platform that the characters stood on, while Scotty adjusted switches on the transporter room control boards. The transporter machine then locked onto each atom of each person on the platform, and used a transporter carrier wave to transmit those molecules to wherever the crew wanted to go. Viewers watching at home witnessed Captain Kirk and his crew dissolving into a shiny glitter before disappearing, rematerializing instantly on some distant planet.

If such a machine were possible, it's unlikely that the person being transported would actually be "transported." It would work more like a fax machine -- a duplicate of the person would be made at the receiving end, but with much greater precision than a fax machine. But what would happen to the original? One theory [13] suggests that teleportation would combine genetic cloning with digitization.

In this biodigital cloning, tele-travelers would have to die, in a sense. Their original mind and body would no longer exist. Instead, their atomic structure would be recreated in another location, and digitization would recreate the travelers' memories, emotions, hopes and dreams. So the travelers would still exist, but they would do so in a new body, of the same atomic structure as the original body, programmed with the same information.

But like all technologies, scientists are sure to continue to improve upon the ideas of teleportation, to the point that we may one day be able to avoid such harsh methods. One day, one of your descendants could finish up a work day at a space office above some far away planet in a galaxy many light years from Earth, tell his or her wristwatch that it's time to beam home for dinner on planet X below and sit down at the dinner table as soon as the words leave his mouth.

10.0 Conclusion

The field of quantum teleportation has made a remarkable progress ever since it has been initiated. The concept on Quantum Teleportation which is based on the well-known concept of Quantum Entanglement using Einstein-Podolsky-Rosen (EPR) effect has been presented. The importance of quantum computing to quantum teleportation is also presented. Recent developments and breakthroughs in entanglement and quantum teleportation were examined. With the aid of quantum computer, teleportation of three dimensional objects might be possible not too far from now.

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