Single Photon Orbital Angular Momentum Transfer Based on Information Processing Technology

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Abstract. The orbital angular momentum state (OAM) of the photon can be theoretically evaluated from minus infinity to infinity, and the different orbital angular momentum states are orthogonal to each other. Therefore, in recent years, it has attracted wide attention from the academic circle and the industry. The purpose of this paper is to study the characteristics of single photon orbital angular momentum transfer based on information processing technology and to provide Suggestions for its technical optimization. Based on the characteristics of the angular momentum state of photon orbit, this paper studies its application and related problems in information processing and transmission. In this paper, quantum multiuser communication technology is studied, and a multiuser communication scheme based on photon orbital angular momentum state is proposed. The scheme takes advantage of the orthogonality of different orbital angular momentum states of the photon and assumes that the sender and receiver share a pair of entangled orbital angular momentum states. On this basis, the spatial light modulator is used to modulate it to the entangled photon of the sender, so that the sending photon carries all the user's information at the same time. Finally, the receiver accurately extracts the information of each sender by measuring the coincidence count and according to the specific receiving rules. Numerical simulation and experimental results show that the coincidence rate of different coding schemes is between 0 and 0.66, which proves the feasibility of the scheme.

Keywords: Orbital Angular Momentum, Quantum Multi-user Communication, Correlation Imaging, Compressed Sensing

1. Introduction
In the field of quantum information, people are particularly interested in quantum information processing based on single photon and entangled photon pairs, which can be obtained by superposition of states with specific orbital angular momentum \[^{[1-2]}\]. The study of the orbital angular momentum properties of photons is of great help to the study of the properties of quantum entanglement. The phenomenon of quantum entanglement has been confirmed by many scholars' studies. Although the exact meaning of quantum entanglement is still not fully understood, its important role in quantum information is becoming more and more obvious, attracting more and more attention \[^{[3-4]}\].

Tang, Yong systematically studied information processing technology and its application. Contents include: time model, calculus, logic; Temporal data model, the semantics of the temporal variable "now"; Temporal database concept; Temporal query language, a typical temporal database management system :TempDB; Time extension of XML, workflow, and knowledge base;) The implementation pattern of temporal application, a typical example of temporal application. Tang, Yong is a database for researchers, practitioners and graduate students, data/knowledge management and time information processing \[^{[5]}\]. Photon orbital angular momentum has generated many new insights and applications in quantum measurement. The resolution and sensitivity of angular rotation measurement can be improved by photon orbital angular momentum. The quantum measurement strategy can further exceed this limit and improve the resolution of angular rotation measurement. Feng Wang first proposed and demonstrated the odd-even calibration measurement method in the angular rotation measurement scheme. Parity measurements can push the resolution beyond the limits of existing methods \[^{[6]}\]. Giammanco F describes an atomic spectroscopy experiment aimed at determining whether the orbital angular momentum of a photon has the same properties of interacting with atoms or molecules as the spin angular momentum. In the experiment of Giammanco F, the laser radiation of different combinations of OAM and SAM was used to excite rubidium vapor, especially to suppress or enhance the fluorescence according to the selection rules of the electric dipole transition between the ground state and the first excited dual state\[^{[7]}\].

Based on this, this paper studies the quantum information processing and transmission platform, completes the experimental platform construction and platform verification scheme based on photon orbital angular momentum state entanglement, and gives the description of core devices and important optical components \[^{[8-9]}\]. Then, the entanglement characteristics and non-locality based on the angular momentum state of the photon orbit are verified by the bell inequality violation experiment and the double-slit interference experiment \[^{[10]}\].

2. Proposed Method

2.1. Single Photon Orbital Angular Momentum

The ideal single-photon source is a device that emits only one photon at a time, with a photon energy of about $10^{10}$ -10j. Laser pulse excitation or electrical impulses to stimulate a single hybrid implementation based on self-organization semiconductor quantum dot and spectral filtering, also can be used in an electric injection luminescence diode, the use of color heart or crystal defect also can produce single photon and launch, currently developed a precise control of the strong attenuation technology, can generate the required sequence of single photon.

The spiral phase plate is a kind of diffraction optical element, whose thickness increases with the
increase of azimuth. The phase of the spiral phase plate changes continuously along the angular direction, which can generate optical vortex field. The light field of the stepped spiral phase plate can be expressed as:

\[ u(r, \theta) = \text{Circ} \left( \frac{r}{R} \right) \exp \left( i \Delta \varphi \text{Im} \left( \frac{M \theta}{2 \pi} \right) \right) \]  

\( \text{(1)} \)

The vortex strength \( Q \) of the stepped spiral phase plate can cause incident light field is:

\[ Q = \Delta n \frac{h}{\lambda} \]  

\( \text{(2)} \)

2.2. Information Processing Technology

It is mainly composed of sending end, channel and receiving end. The sender and the receiver share of entangled quantum, the sender information for each user to use the OAM state encoding, and constitute the OAM modulation to specific photon state of superposition, the superposition to channel together, after the quantum channel, using a beam splitter to divide superposition to each user, the receiver receive the output of the beam splitter, each user to use his or her own particular measurement to measure, eventually restore to send the user's information.

Let's say I have \( N \) users communicating at the same time. At the sending end, we encode their respective information using the poincare equatorial states. Because poincare balls have different sizes (different \( l \) values), any two users will not physically interfere with each other. Both the sender and receiver share a pair of entangled photons.

3. Experiments

3.1. Experimental Background

Similar to classical multiuser communication, quantum multiuser communication is a problem of information transmission via quantum channel under the condition of available resources. The biggest difference between quantum communication and classical communication is that quantum channel can transmit both classical and quantum information. Therefore, there are two basic multiuser detection problems in quantum communication: one is quantum multiuser detection under the classical communication model, and the other is quantum multiuser detection under the quantum communication model. Based on the classical communication model, using the quantum information processing method, the conclusion can be used as the reference of pure quantum communication processing. However, the communication model based on pure quantum only applies quantum information theory, which is only in the research and exploration stage at present.

3.2. Experimental Design

Let's say I have \( N \) users communicating at the same time. At the sending end, we encode their
respective information using the poincare equatorial states. Because poincare balls have different sizes (different l values), any two users will not physically interfere with each other. Both the sender and receiver share a pair of entangled photons. For each user, we use M different sector states to represent M different symbol information to be sent. After each user has encoded his information to the poincare equator, all of the OAM states are added up to act as the user state at the sending end. The superposition state is transmitted through a quantum channel and can be detected by the receiving end. Some of the experimental simulation results are shown in Table 1.

| The symbol of A | In line with the probability | The symbol of B | In line with the probability |
|-----------------|-----------------------------|-----------------|-----------------------------|
| 0               | 1                           | 0               | 1                           |
| 1               | 2/3                         | 1               | 2/3                         |
| 2               | 1/3                         | 2               | 1/3                         |
| 3               | 0                           | 3               | 0                           |

4. Discussion

4.1. Analysis of Single Photon Orbital Angular Momentum Transfer Characteristics Based on Information Processing Technology

As shown in Figure 1, at the receiving end, user A and user B respectively use the pre-prepared measurement base. Through the coincidence measurement, we can obtain the result of the coincidence count. As shown in the above table, it can be seen that A and B correspond to different symbols of the coincidence probability results. The results show that user A and user B can recover their information at the receiving end through different coincidence probabilities. When user A sends the symbol '0', he will get A coincidence probability of 1.000, send the symbol '1', and get A coincidence probability of 0.666, send the symbol '2', and get A coincidence probability of 0.333, and send the symbol '3', and get A coincidence probability of 0.000. The characteristics of user B are similar to those of user A. From the derivation of equation (1), it can be seen that the coincidence probability is only related to the sector state selected by the sending user, so the symbol value selected by the sending user can be derived according to the coincidence probability. In the experiment, in order to encode the user information into the OAM sector state, we used the method of placing different holograms on SLM to load the sector state information to the photon. The hologram used in our experiment and the detection conforms to the theoretical normalization value of counting.
Figure 1. Coincidence probability measured by user A and user B

As can be seen, the distribution in accordance with the probability set is at the positions of 0.05, 0.33, 0.66 and 0.9. It deviates from the theoretical values of 0, 0.33, 0.66 and 1 in the minimum and maximum values. The minimum deviation of coincidence probability is caused by quantum noise, and the maximum deviation is caused by the selection of the maximum coincidence count as the normalization factor during normalization. The degree of concentration of user A is obviously better than that of user B, because the orbital angular momentum value used by user A is 1, while the orbital angular momentum value used by user B is 2. In the actual experiment, due to the limitation of equipment, the larger the orbital angular momentum, the smaller the coincidence count, so the degree of differentiation. The OAM value of user A is 1, and it can be seen from Figure 2 that one is randomly selected (corresponding to its sending sequence), while the OAM value of user B is 2, and one is randomly selected (corresponding to its sending sequence) among 4 holograms. The results selected by user A and user B are applied to the signal branch beam. The hologram of the receiver detector ACTS on the idle branch beam. We can get a coincidence count for each communication, and give the normalized value of coincidence count theory for the detection of different signals sent. In this paper, we give the normalized coincidence count distribution obtained under several actual experimental measurements. The horizontal axis indicates the number of occurrences of different coincidence values.
As an angular momentum, OAM is an essential property of wave fronts with different spiral phases. For a single photon, an infinite number of OAM states can be simultaneously contained, which makes it possible to transmit information about multiple users on a single photon. In this paper, a novel multiuser quantum communication scheme is proposed, in which each user encodes his information using Poincare spheres of different moduli and designs his sending symbols using different OAM sector states. All user information is in a superposition state. At the receiving end, the information of the user at the sending end can be recovered according to the coincidence count by synchronously measuring the received photons. Through theoretical analysis, numerical simulation and experiments, it can be seen that the proposed method is feasible in the noiseless quantum channel. It provides a new method for quantum multiuser communication in the future. However, since we encode the information of each user into a separate OAM state, in order to achieve the simultaneous communication of as many users as possible, the OAM state converted through the BBO crystal needs to contain as many independent OAM states as possible. In fact, BBO crystals can indeed convert an infinite number of independent OAM states, but with the increase of the OAM value, the conversion efficiency becomes lower and lower. In the current experimental environment, after the OAM value exceeds 10, it can hardly be effectively detected. In order to realize the method proposed in this paper, it is necessary to find another method to convert the photon OAM state, or to improve the conversion efficiency of BBO, which will be the key to apply this scheme to practice. In practical application, due to the influence of atmospheric turbulence, the information between different users will interfere with each other, so we need to apply the multi-user detection method to detect the signal. This is something we need to consider further.

4.2. Suggestions on Single-photon Orbital Angular Momentum Transfer Characteristics Based on Information Processing Technology

In order to realize quantum multiuser communication scheme, the superposition function of photon
orbital angular momentum is needed. Since the receiving end USES coincidence counting as a means to recover the information of the sending end, Len represents lens, so BBO is a nonlinear crystal, BS represents a beam splitter, SLM is a spatial light modulator, SMF is a single-mode fiber, and PD is a single-photon detector. In order to complete the communication of 2 users, 4 SLMS need to be used. Because the hologram used by the receiver is predicted and determined, "user-1 receive" and "user-2 receive" can be replaced by a fork-shaped grating, so that only N SLMS are needed for the communication of N users. The spatial light modulator changes the corresponding phase of the incident light and then reflects it out. The beam is focused by a lens with a focal length of 50 cm and then passes through a filter to filter out the remaining 355 nm laser. After filtering, the light is concentrated on the optical core of single-mode fiber. Because the diameter of single-mode fiber is very small, the beam waist of those non-gaussian light is too large to enter the single-mode fiber, and only those photons that are changed into gaussian light after the phase is changed by the spatial light modulator can enter the single-mode fiber.

The single-mode fiber transmits the received photons to the single-photon detector. When a photon enters the single-photon detector, the single-photon detector outputs a positive pulse of 15 nanoseconds. The data acquisition card is used to record these pulses and calculate the number of photons arriving per unit time. The data acquisition card inputs the collected pulse train to a counter logic circuit. The coincidence count logic circuit performs a time correlation operation on the input two-channel impulse train and outputs the number of coincidence counts received per unit time. We use the data collected by the two data acquisition CARDS and the data output by the counting logic circuit to recover the information of the pure phase object.

5. Conclusion

The biggest difference between quantum communication and classical communication is that quantum channel can not only transmit classical information, but also transmit quantum information. In this paper, a quantum multiuser communication scheme based on OAM is proposed. In this scheme, the sender and receiver share entangled quantum pairs, and each user encodes his information onto the poincare sphere, forming an OAM state in which the same photon can carry all users' information at the same time. By preparing a pair of entangled photons at the sending end and the receiving end, each user superpositions his photon state information onto the photon at the transmitting end, through a noiseless channel, and at the receiving end, through a specially prepared measuring base, the information of the user at the sending end can be accurately demodulated in the receiving photon. This scheme provides a new method of quantum multiuser communication.

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