Temporal ghost imaging over long-distance optical fibers

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ABSTRACT

Temporal ghost imaging is demonstrated over 50-km optical fibers by two ways, based on quantum and thermal light sources, respectively. It provides a novel way for information transmission over fiber link by single photons.

Keywords: Quantum correlation; four-wave mixing.

1. INTRODUCTION

Ghost imaging (GI) retrieves the image of an object placed in one path by correlating two separated beams, while either beam cannot singly image the object[1]. Traditional GI is based on position-position or momentum-momentum correlations, which limits its realization over optical fiber networks with large geographical scale. Recently, we propose a temporal GI scheme based on frequency correlation[2], which is a stable degree of freedom when photons propagate over fibers. We demonstrate its feasibility with both quantum light source and thermal light source.

2. EXPERIMENT OF QUANTUM TEMPORAL GI

The quantum temporal GI setup is illustrated in Fig. 1(a). It is based on a telecom-band quantum light source, which generates frequency-correlated photon pairs. It is realized by spontaneous four-wave mixing (FWM) in a piece of silicon waveguide under continuous-wave (CW) pumping. The quantum state of the photon pairs has a broad spectrum, hence, the two photons in a pair has broadband frequency correlation. The signal and idler photons are separated by a filter system, which are centered at 1510 nm and 1550 nm, respectively, with a bandwidth of 16 nm at both sides.

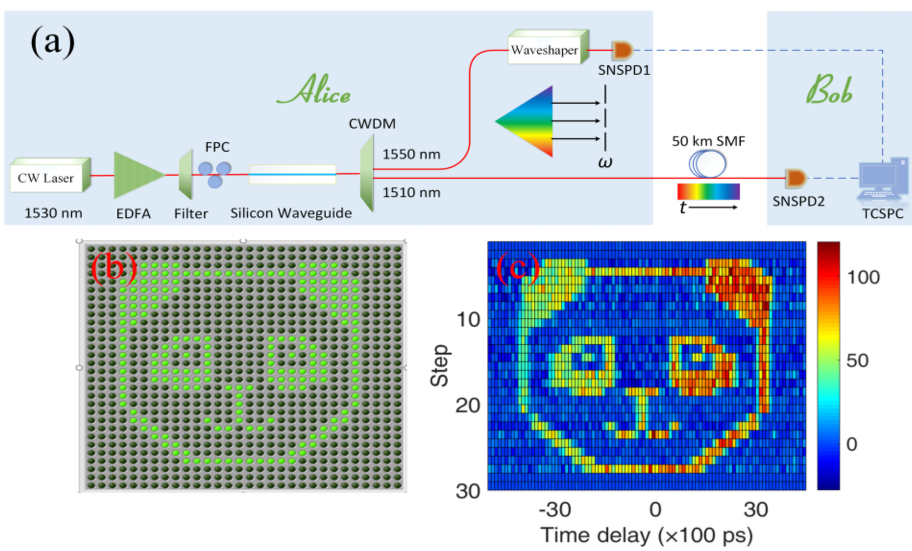

Fig. 1. (a) Experimental setup for long-distance temporal quantum ghost imaging. EDFA: Erbium doped fiber amplifier; FPC: fiber polarization controller; CWDM: coarse wavelength division multiplexing filter; SMF: single-mode fiber; SNSPD: superconducting nanowire single-photon detector; TCSPC, time-correlated single-photon counting module. With the programmable filter (Waveshaper), Alice sends a pattern with 30×30 pixels (b) and Bob obtains its image by temporal GI (c)

Alice holds the quantum light source and keeps the signal photons, she sends the idler photons to Bob over optical fibers of 50 km. At Alice side, the object is a 2-D pattern with 30×30 pixels, shown in Fig. 1(b). Each line of the pattern (30 pixels) is encoded on the spectrum of signal photons (1544 nm ~ 1558 nm) by a programmable optical filter. The grey (green) pixels in Fig. 1(b) indicate that the photons with corresponding frequencies are blocked (transmitted) in the programmable filter. Then the signal photons are detected by a superconducting nanowire single photon detector (SNSPD2). The idler photons are sent to Bob over the fiber link. They pass through a temporal dispersion component (the transmission fiber introduce the temporal dispersion in this experiment), then are detected by another SNSPD. Their arrival times at the detector are shifted according to their frequencies due to the large dispersion they have experienced. Hence, the frequency correlation of the photon pairs is transferred to the correlation between frequencies of idler photons at Alice side and arrival times of idler photons at Bob side. By the coincidence of the single photon detection events at both sides, temporal GI can be realized in time domain. The measurement time of GI for one line in Fig. 1(b) is 20 seconds, by this way the pattern is imaged line by line. The result is shown in Fig. 1(c), showing that the image can be clearly distinguished.

3. EXPERIMENT OF THERMAL TEMPORAL GI

The temporal GI scheme is based on frequency correlation of two beams, which can also be realized by thermal light sources. Fig. 2(a) shows the experimental setup of this experiment. In the experiment, the thermal light source is realized by SFWM in the silicon waveguide, since both signal and idler photons generated by SFWM are under thermal statistics[3]. The pump light of the source is generated by a mode-lock fiber laser with a repetitive rate of 40 MHz. Two optical filters (F1 and F2) are used to control the linewidth of the pulsed pump light and select the signal photons, by which the linewidth of the selected signal photons is 3 nm and they are under single-mode thermal state. The purity of the thermal light source is indicated by the Hanbury Brown–Twiss (HBT) measurement, the result is shown in the inset of Fig. 2(a) with $g^{(2)}(0)$=1.80. The generated thermal photons are directed to Alice and Bob through a 50:50 fiber coupler. At Alice side, a bandwidth-variable tunable filter (BVTF), which has a variable bandwidth and a tunable central wavelength, is used as the object. The photons pass through the BVTF, then are detected by the SNSPD. The other half of photons are sent to Bob over single mode fibers of 50 km and are detected by another SNSPD. By the coincidence of the single photon detection events at both sides, the shape of the BVTF could be imaged by temporal GI in time domain. Fig. 2(b) shows the results when the bandwidth of the BVTF is set as 0.1 nm and its center-wavelength varies from 1528.8 nm to 1531.2 nm with an interval of 0.6 nm. These peaks shown in Fig. 2(b) are obtained by subtracting the average accidental coincidence counts. It can be seen that the position of the peak moves in the time domain with the variation of the center-wavelength of the BVTF, showing that the profile of transmission spectrum of BVTF can be imaged successfully by the coincidence measurement between Alice and Bob, demonstrating the feasibility of the thermal temporal GI.

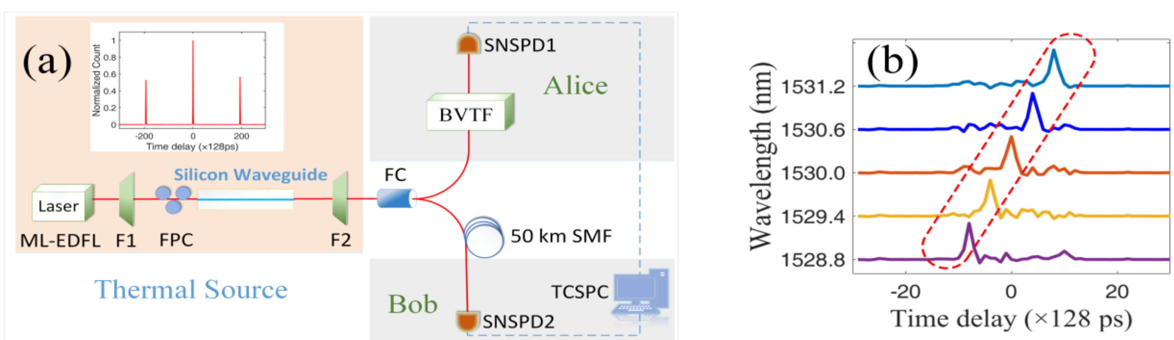

Fig. 2. (a) Experimental setup for long-distance thermal temporal ghost imaging. ML-EDFL, mode-locked erbium doped fiber laser; F1-2, optical filters; FC, 50:50 fiber coupler; BVTF, bandwidth-variable tunable filter to simulate the spectral modulation; FPC, fiber polarization controller; SNSPD, superconducting nanowire single-photon detector; SMF, single-mode fiber; TCSPC, time-correlated single-photon counting module. The inset shows a HBT measurement result of the thermal source and $g^{(2)}(0)$=1.80. (b) Experiment results with different center-wavelengths of the BVTF.

4. CONCLUSION

To conclude, the scheme of temporal GI is proposed, which is based on the frequency correlation between the two beams, hence it can be realized over long-distance fiber link. It is demonstrated by two ways, based on quantum light source and thermal light source, respectively. In both experiments, the temporal GI is realized over fibers of 50 km. As a novel way for information transmission over fiber link under single photon level, it has the potential on applications of quantum communications.

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