Quantum State Tomography of Qudits via Hong-Ou-Mandel Interference

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Hong-Ou-Mandel (HOM) interference [1] is a bunching phenomenon based on the bosonic nature of photons. When two photons that are perfectly indistinguishable from each other are mixed using a half beam splitter (HBS), they always bunch and exhibit the absence of coincidence resulting in a specific interferogram called HOM dip. The important property of the HOM interference is that the decrease in coincidence reflects the degree of indistinguishability of the input photons, i.e., it provides information regarding the probability of overlap of the input photons. Thus, this property should enable the estimation of a target photon in an unknown quantum state using a probe photon in a known state. In this work, we realize the above concept as the quantum state tomography (QST) applicable to $d$-dimensional photonic qudits, which we call HOM-QST [2]. Interestingly, we observe that HOM-QST is robust against various imperfections and that the probe photon can be replaced by classical light. Furthermore, we confirm this by demonstrating a proof-of-principle experiment using two-dimensional polarization qubits.

The concept of the HOM-QST is shown in Fig.1(a). For simplicity, we consider the HOM-QST of a polarization qubit as an example. The target photon under test and the probe photon in known polarization state are mixed by a HBS followed by a coincidence measurement. By denoting the polarization of the target photon and probe photon by $\rho$ and $k$, respectively, the depth of the HOM dip is given by

$$\Delta_k = \eta n_s n_p^2 \rho_k,$$

where $\eta$ is a product of the quantum efficiencies of the detectors, $n_s$ and $n_p$ are the average photon numbers of the target photon and probe photon, respectively. $\rho_k = \langle k | \rho | k \rangle$ is the probability of the $k$-polarized portion of the target photon. Here, $|k\rangle$ is the $k$-polarized single-photon state. The feature of HOM-QST is that no prior knowledge of the probe light is needed, such as $n_p$ and its intensity correlation function $g^{(2)}(0)$; moreover, there is no theoretical requirement on these values. We perform the proof-of-principle demonstration of the HOM-QST of polarization qubits. We prepare diagonally (D) polarized heralded single photons as the target and compare the estimation results obtained by the conventional QST [3] with HOM-QST using a laser-light probe. The real parts of the reconstructed density matrices are shown in Fig.1(b) and (c). The estimated fidelity ($F$) by HOM-QST is above $F=0.99$. Hence, it is shown that, regardless of the values of $n_p$ and $g^{(2)}(0)$, HOM-QST can realize the precise estimation as our theoretical prediction. Our method serves as an alternative to perform the QST with a passive measurement setup and is applicable to QST of various degrees of freedom.

![Fig. 1](image-url)

Fig.1 (a) The model of the HOM-QST. (b, c) Estimated density matrices of D-polarized target state using conventional QST (b) and HOM-QST with laser-light probe (c). The label HV indicates $Re\langle H | \rho | V \rangle$ for example.

References
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