Experimental quantum state engineering via discrete-time quantum walks in the angular momentum of a single-photon

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Abstract: Generation and manipulation of quantum states in high-dimensional Hilbert spaces are fundamental for the development of quantum technologies. Here we affirm the potential of discrete-time quantum walks for quantum state engineering purposes, exploiting the encoding of the dynamics in the angular momentum degree of freedom of photons. Such approach has been successfully tested in an experiment implementing a five-step quantum walk. Our results confirm the feasibility of the protocol for generating high-quality qudit states.

The preparation of high-dimensional quantum states is crucial in quantum information science and technology. A promising way to achieve a paradigm for quantum state engineering independent from a particular physical platform is the use of the rich dynamics offered by quantum walks [1]. The latter are the quantum counterpart of classical random walks: here a walker (represented by a qudit state) moves on a lattice conditionally to its internal degree of freedom, named as the coin. Such state engineering protocol produces a pure walker state with the desired features by a proper arrangement of step-dependent coin operations and a final projection in the coin space. Here we report the experimental implementation of this novel approach to state engineering [2]. We use the orbital angular momentum (OAM) degree of freedom of single-photon states as a convenient embodiment of the walker, while logical states of the coin are encoded in circular-polarization states $\{|L\rangle, |R\rangle\}$ [3]. Arbitrary coin operators are achieved through a sequence of suitably arranged and oriented quarter and half-waveplates. The shift operator acting on walker position is instead implemented using a q-plate, an active device that can conditionally change the values of the OAM according to the polarization state (see Fig. 1). We showed the effectiveness of the protocol, demonstrating its ability to synthesize high-quality six-dimensional qudit states. Further improvements of our approach can be envisaged by identifying appropriate routines to optimize the state engineering process in the presence of actual experimental imperfections. To this end, machine learning algorithms can be a promising add-on to our numerical optimization approach to adapt the coin operators to a given experimental implementation.

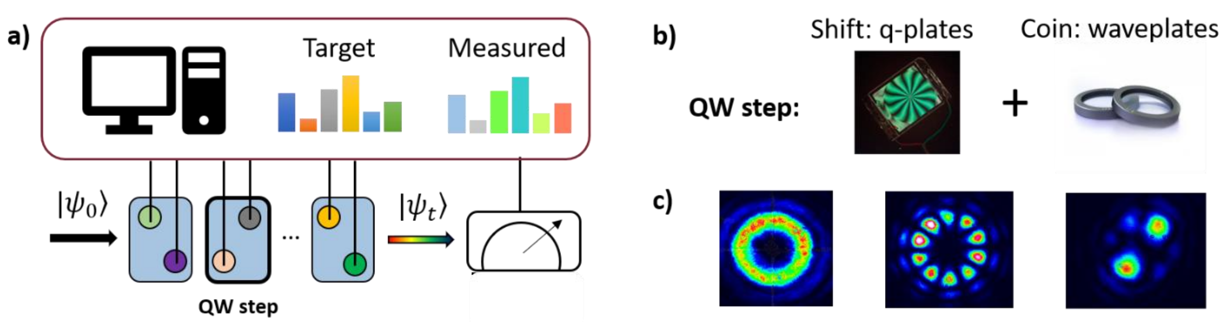

Figure 1. a) Conceptual scheme of the state-engineering protocol: by varying properly the coin operator at each step different output states can be obtained. b) The quantum walk dynamics is made up of consecutive steps, in which a q-plates modifies the position of the walker (the OAM) according to the coin state (the polarization). c) Some output states recorded with classical light during the alignment of the experiment.

References

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