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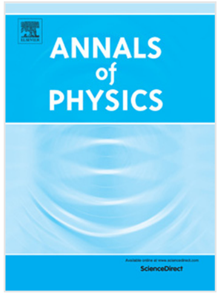

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Deterministic implementations of single-photon multi-qubit Deutsch-Jozsa algorithms with linear optics

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It is very important to seek an efficient and robust quantum algorithm demanding less quantum resources. We propose one-photon three-qubit original and refined Deutsch-Jozsa algorithms with polarization and two linear momentums degrees of freedom (DOFs). Our schemes are constructed by solely using linear optics. Compared to the traditional ones with one DOF, our schemes are more economic and robust because the necessary photons are reduced from three to one. Our linear-optic schemes are working in a determinate way, and they are feasible with current experimental technology.

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I. INTRODUCTION

The power in resolving certain types of problems and the security in cryptography of a quantum computer beats a classical computer largely [1]. Quantum software is a collection of quantum algorithms. It is noted that several quantum algorithms should be designed to perform some required works, such as the Deutsch-Jozsa's (DJ) algorithm [2] used for identifying an unknown function is constant or balanced, the Grover's quantum search algorithms [3] and optimal Long's algorithm[4] allow a quadratic speedup for searching an arbitrary element in unsorted database, and the Shor's quantun factoring algorithm [5] provides a way for efficient factorization. The DJ algorithm derived from the Deutsch's algorithm [6], and it has been implemented in various systems, such as ion traps [7, 8], nuclear spins in magnetic resonance [9–11], superconductors [12], quantum dots [13–15], neutral atoms [16, 17], diamond nitrogen-vacancy defect centers [18], linear optics [19–23], classical light [24, 25], and cluster quantum computers [26–28]. It is significant to seek a scheme that can efficiently and robustly implement the DJ algorithm with minimal quantum resources. Fortunately, this desirableness can be achieved by encoding the qubits in multiple degrees of freedom (DOFs) of one photon [21, 22].

Photon is nowadays recognized as a perfect candidate for encoding qubits in multiple DOF as their flexibility controllability, weak interaction with the environment, interconnection of the atom-like qubits, and many accessible qubit-like DOFs [29], such as polarization, frequency, path, photon number, orbital momentum, transverse, and time bin, etc. The intrinsic weak interactions in single photon level is the main obstacle for deterministic optical quantum information processing. Fortunately, this obstacle can be remedied by encoding the multi-qubit in multiple DOFs of a single photon, which allows one to complete some impossible tasks in traditional ways, for example, complete discrimination of Bell states with linear optics [30–32], deterministic quantum teleportation with linear optics [33], and deterministic implementations of three-qubit universal gates with linear optics [34].

Implementations of the DJ algorithm on photonic system in multiple DOFs has been received great interest in recent years. In 2007, Chen et al. [35] experimentally realized one-way two-qubit DJ algorithm with two-photon four-qubit cluster states. In 2010, Vallone et al. [26] demonstrated two-qubit one-way DJ algorithm with two-photon six-qubit cluster states. Several qubits un-encoded and the creation of the cluster state are necessary in one-way DJ algorithm. In 2006 and 2010, Scholz et al. [21] and Zhang et al. [22] experimentally demonstrated two-qubit linear-optical DJ algorithm in spatial-polarization DOF, respectively, and subsequently, the demonstration in spin-orbital DOF was reported by Zhang et al. [36]. Large-scale quantum algorithm is one of the most challenges in implementing quantum computer, and few works focused on multi-qubit DJ algorithm on one photon in multiple DOFs.

In this paper we design compact schemes for determinately implementing single-photon three-qubit original and refined DJ algorithms with linear optics, respectively. First, a single-photon multi-qubit system is created with linear optics. Subsequently, based on such system, we design schemes for implementing three-qubit original and refined DJ algorithms acting on the polarization and two linear momentums DOFs of a single photon, respectively. In stark contrast with the traditional ones with one DOF, our schemes are more robust and economic because the necessary photons are reduced from three to one. In our schemes, the necessary logic operations between the computational qubits can be achieved by employing linear optics. Moreover, several qubits un-encoded, necessary for the DJ algorithm on cluster states, are not required.

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