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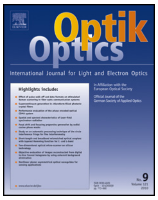

Improved quantum discord via weak measurement

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ABSTRACT

We investigate the dynamical behavior of quantum discord with weak measurement under various environments. We find that the quantum discord closely relates to the interaction between qubits, measurement strength and the correlation rate between environments of qubits. The interaction results in oscillation of quantum discord and avoids quantum discord sudden death for certain initial states. The stronger the interaction is, more intense the oscillation is. The increase of measurement strength will lead to the decrease of quantum discord. The correlation rate also affects the quantum correlation significantly. Stronger correlation is favor to improve the quantum correlation between qubits. Not only the amplitude of quantum discord is increased, but also the time for zero quantum discord is greatly delayed.

1. Introduction

Quantum systems exhibit diversified correlations without classical counterparts. Recent reports reveal that quantum entanglement, the most well known measure of quantum correlations that plays essential roles in quantum information processing, cannot describe all nonclassicality in the correlations. Quantum discord, which can describe quantum correlations in separable states, is subject to intensive theoretical studies [1–4]. Despite different attitudes toward the effects of quantum discord in quantum information processing, quantum discord seems practical for describing quantum correlation in several quantum algorithms. In addition, quantum discord can improve the efficiency of the quantum Carnot engine and better comprehend quantum phase transition and Grover searching. In-depth analysis of quantum discord, especially its dynamical features, is anticipated because quantum correlations can be used in investigating the basic properties of quantum systems.

Quantum measurement is essential for the process of quantum information processing. Traditional quantum measurement technologies exploit von Neumann projection measurement to gain information. Undoubtedly, they may not the optimal measurement schemes since these crude methods cause unrecoverable destructions to the quantum states as the information is acquired. In Ref. [5], a brand-new weak measurement was constructed. Although the gained information was less than the von Neumann projection measurement, the perturbation was much lesser. More significantly, the quantum states after weak measurement were recoverable. Pryde et al. managed to measure the polarization weak value of photons in linear optical system [6]. Korotkov and Jordan proposed a scheme of weak measurement in superconducting qubits [7], and experimentally realized by Katz et al. [8]. Recently, it is pointed out that weak measurements, together with quantum measurement reversals, protect quantum states of single quantum systems [9,10], and it is extended to protect entanglement of two-qubit systems [11,12]. Very recently, weak measurement and a subsequent reverse operation are found to be able to improve the fidelity of teleportation when one or both qubits of a maximally entangled state shared between the sender and the receiver undergo amplitude damping [13,14]. The protocol is shown to work even for the Werner state.

In this paper, we implement weak measurement on coupling qubits. Our purpose is to compare and investigate the dynamical behavior of quantum discord in an open system. The paper is arranged as follows. We review the result the definitions of weak measurement in Section 2. And in Section 3, a description of the suggested model is introduced. Subsequently, in Section 4, we develop the theory to study the dynamics of quantum discord of the two interacting qubits and calculate the time evolution of the quantum discord under the influence of environmental perturbations by means of weak measurement. Finally, we conclude in Section 5.

2. The model

Considering the coupling qubits (denoted as A and B) that initially produced in a entangled state seeing Eq. (3), the Hamiltonian is given by ($\hbar = 1$) [15]

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$$H_0 = \omega_0\left(\sigma_A^z+\sigma_B^z\right)+g\left(\sigma_A^+\sigma_B^-+\sigma_B^+\sigma_A^-\right), \tag{1}$$

where σ_j^z, $\sigma_j^\pm$ (j = A, B) are Pauli matrix for the qubit, g represents interacting strength between two qubits, respectively.

The qubits are inevitably affected by uncontrollable degrees of freedom from the environment. In general, the time evolution of quantum open system can be described by a super-operator L. Taking into account the coupling between system and external environment, the master equation describing the dynamical evolution of system writes [16]:

$$\dot{\rho} = -i\left[H_0, \rho\right] + L\rho, \tag{2}$$

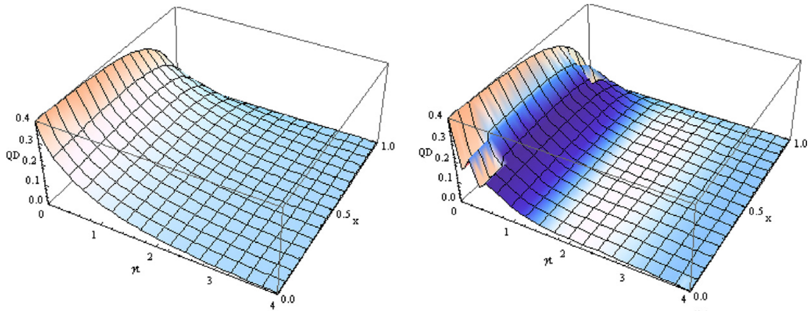
where the first term is a usual unitary evolution. The second term describes all possible transitions that the open system may undergo due to the interaction with its reservoir. The super-operator L depends on the environments of the two-qubit system. In this paper, we mainly discuss instantaneous decay mode, correlated dephasing decay mode and correlated instantaneous decay mode, which will be described by the different super-operators. The specific expression of super-operators could be seen in Section 3.

The solutions of Eq. (2) depend on the initial state. In this paper, we consider the initially entangled qubits to be in a mixed state given by the density matrix

$$\rho(0) = \frac{1}{3}\begin{pmatrix} a & 0 & 0 & 0 \\ 0 & b & z & 0 \\ 0 & z^* & c & 0 \\ 0 & 0 & 0 & d \end{pmatrix}, \tag{3}$$

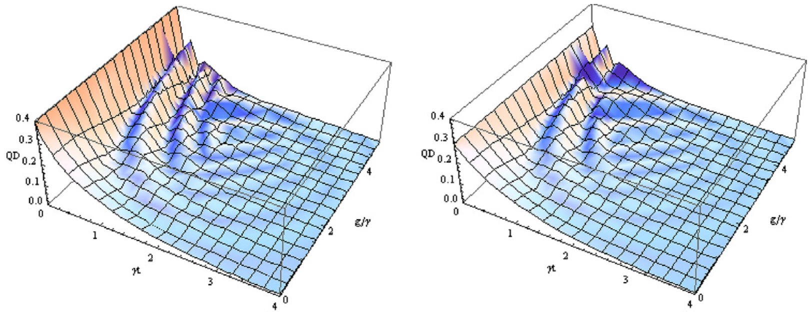
where a, b, c, d and z are the initial parameters of the two entangled qubits with the relations $a+b+c+d=3$. For the convenience of discussion, setting $b = c = |z| = 1$. Here $z = e^{i\chi}\sqrt{bc}$ are the single photon coherences, in which the entangled part of the state depends on the initial phase χ.

To best manipulate the entanglement of qubits we perform a weak measurement on each qubit right after their preparation. In practice, a weak measurement can be implemented by a device that indirectly monitors a qubit. If the device signals, we know that the qubit transition $\left|1\right\rangle \to \left|0\right\rangle$ |occurred and discard the result. If the device does not signal (null outcome), the qubit state was only



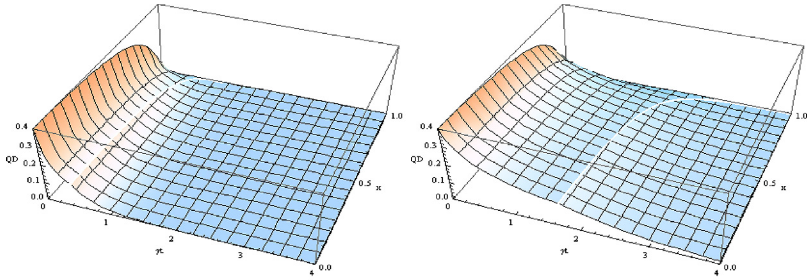
(a) (b)

Fig. 1. Dynamics of quantum discord as functions of γt and measurement strength x for an instantaneous decay model with different interaction g by means of weak measurement with a = 0.4, $b = c = |z| = 1.0$.



(a) (b)

Fig. 2. Dynamics of quantum discord as functions of γt and interaction g for an instantaneous decay model with different measurement strength x by means of weak measurement with $a = 0.4$, $b = c = |z| = 1.0$.



(a) (b)

Fig. 3. Dynamics of quantum discord as functions of γt and measurement strength x for the correlated dephasing decay mode with different correlation rate γ_0 by means of weak measurement with a = 0.4, $b = c = |z| = 1.0$ and g = 0.