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Geometric quantum discord and non-Markovianity of structured reservoirs

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HIGHLIGHTS

- Dependence of GQDs on a factor determined by spectrum of the structured reservoir.
- Connection between the direction of information flow and variation of the GQDs.
- Non-Markovianity with the backflow of information enhances GQDs in a wide region.
- The GQDs are enhanced with the information loss in a very narrow region.

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ABSTRACT

The reservoir memory effects can lead to information backflow and recurrence of the previously lost quantum correlations. We establish connections between the direction of information flow and variation of the geometric quantum discords (GQDs) measured respectively by the trace distance, the Hellinger distance, and the Bures distance for two qubits subjecting to the bosonic structured reservoirs, and unveil their dependence on a factor whose derivative signifies the (non-)Markovianity of the dynamics. By considering the reservoirs with Lorentzian and Ohmic-like spectra, we further demonstrated that the non-Markovianity induced by the backflow of information from the reservoirs to the system enhances the GQDs in most of the parameter regions. This highlights the potential of non-Markovianity as a resource for protecting the GQDs.

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1. Introduction

Quantum correlations occupy an important position in understanding fundamental characteristics of a quantum system. For this reason, they remain the research focus of people from the early days of quantum mechanics to now. Today, when we mention to quantum correlations, we know that in addition to entanglement [1], the concept of quantum discord constitutes another representative class of quantum correlation measure [2]. The related studies on this subject are mainly carried out around its quantification, its particular behaviors, and the control of it in various quantum systems [3]. Particularly, there has been an increasing interest of people on quantifying quantum discord from different perspectives, and to date there are a number of discord-like correlation measures being proposed [2,4–9]. On the other hand, the behaviors of quantum discord in the spin chain [10], the two-level atoms [11], and the NMR system [12] have also been studied extensively.

From an applicative point of view, quantum discord is an invaluable resource for implementing many quantum tasks [13–18]. But it is very fragile, and the unavoidable interaction of a realistic system with its environment leads to irretrievable deterioration of the correlations in most cases [19–24]. This makes understanding of the connection between the environmental effects and evolution of quantum discord a vital problem. In fact, many studies have already been performed in this respect, and there were evidence indicating that sometimes the non-Markovian character of an environment may serve as a resource for protecting quantum discord from being destroyed completely [25–28]. It has also been observed that with elaborately chosen spectrum of the reservoir, the quantum discord can be frozen for an interval of time [22,29] or be frozen permanently [30].

Although it is evident that sometimes the non-Markovianity can be used to enhance quantum discord of a system to some extent, we must to say that this is not always the case [30–32]. Searching a general connection between non-Markovian character of an environment and the variation tendency of quantum discords is still an open subject in the quest for reliable ways to protect them. Toward that end, in this paper we establish an explicit dependence of the geometric quantum discords (GQDs) [6–9] of a two-qubit system on non-Markovianity of the zero-temperature bosonic structured reservoirs, and unveil the connections between the direction of information flow and enhancement of the GQDs for different initial states. Actually, with the rapid developments of the reservoir engineering technique [33–35], nowadays it is feasible to adjust experimentally frequency distribution of a reservoir to the desired regime such that the decay time for the quantum discord can be prolonged, provided that we know the explicit dependence of it on spectral density distribution of the reservoir.

The structure of this paper is arranged as follows. In Section 2 we recall briefly measures of the GQDs, while in Section 3 the model for the system–reservoir coupling is presented. Section 4 is devoted to a derivation of the GQDs and their dependence on a reservoir-determined factor. Then in Section 5, we illustrate via two explicit examples our main findings. Finally, Section 6 is devoted to a summary.

2. Measures of the GQD

There are many discord measures being proposed until now. We recall here three measures of the GQD. They are defined, respectively, by the trace distance, the Hellinger distance, and the Bures distance [6–9]. For simplicity, we will call them the trace distance discord (TDD), the Hellinger distance discord (HDD), and the Bures distance discord (BDD).

To begin with, we list some notations we used. We denote by ρ the density operator of a bipartite system AB, and $\Omega_0 = \sum_k p_k \Pi_k^A \otimes \rho_k^B$ the set of zero-discord states [5], with Π_k^A the orthogonal projector in the Hilbert space $\mathcal{H}_A$, and ρ_k^B an arbitrary density operator in $\mathcal{H}_B$, $0 \le p_k \le 1$ and $\sum_k p_k = 1$. Moreover, $\|X\|_p = [\mathrm{Tr}(X^\dagger X)^{p/2}]^{1/p}$ is the Schatten p-norm, which reduces to the trace norm for $p = 1$, and the Hilbert–Schmidt norm for $p = 2$.

The first GQD measure we considered is the well-accepted TDD. Its definition is as follows [6]

$$D_{\mathrm{T}}(\rho) = \min_{\chi \in \Omega_0} \| \rho - \chi \|_1, \tag{1}$$

and for the two-qubit states ρ^X with the X-shaped matrix form (i.e., ρ^X contains nonzero elements only along the main diagonal and anti-diagonal), the TDD can be obtained analytically [36].