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Preservation of the geometric quantum discord in noisy environments

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HIGHLIGHTS

- Inherent robustness of the trace distance and the Bures distance discord.
- Generating geometric discord from classical states by the noisy process.
- Improvement of the geometric discord in common reservoir.
- The robust pathway for preserving discord in independent reservoirs.

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ABSTRACT

Geometric description of quantum correlations is favored for their distinct physical significance. Geometric discords based on the trace distance and the Bures distance are shown to be well-defined quantum correlation measures. Here, we examine their particular dynamical behaviors under independent as well as common structured reservoirs and reveal their robustness against decoherence. We showed that the two well-defined geometric discords may be preserved well or even be improved and generated by the noisy process of the common reservoir. Moreover, we also provided a strategy for the long-time preservation of these two geometric discords in independent reservoirs.

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1. Introduction

The existence of quantum correlations in a system is one of the most remarkable features of quantum theory which differentiates the quantum world from that of the classical one, and quantifying and understanding quantum correlations remain the subject of active research since the early days of quantum mechanics [1]. In the past two decades, a broad survey of different aspects of quantum correlations, such as the Bell-type correlations [2], the capacity for teleportation [3], and a plethora of measures for quantum entanglement [1], was performed. Particularly, since the pioneering work of Ollivier and Zurek [4], and that of Henderson and Vedral [5], the concept of quantum discord (QD) as a more general quantum correlation measure than that of entanglement prompted a huge surge of people's research interest from different perspectives; see Refs. [6,7] for a comprehensive review.

Originally, the QD was defined through the discrepancy between two expressions of the mutual information that are classically identical and quantum-mechanically inequivalent [4]. This is indeed an entropic measure of quantum correlation and was favored for its operational interpretations [8–11] and potential applications in various quantum tasks [12–14]. But its evaluation is very hard due to the optimization procedure involved, and the closed expressions are known only for certain special (such as the Bell-diagonal [15]) states. Particularly, it has been shown that the analytical evaluation of QD for general states is impossible [16]. Therefore, other measures of quantum correlations which are easy to calculate are needed. In this respect, Luo presented the concept of measurement-induced disturbance [17], where the measurement is induced by the spectral resolutions of the reduced states of a system. As such, it evades the procedure of optimization which is usually intractable.

Another routine for characterizing quantum correlations is via the geometric approach based on different distance measures. The seminal work along this line was that accomplished by Dakić et al. [18]. They proposed to use the square of the minimal Hilbert–Schmidt distance as a basis for defining QD, and subsequently, Luo and Fu presented a variational and equivalent definition for it based on von Neumann measurements and derived a tight lower bound for general bipartite states [19]. The figure of merit for this geometric measure of QD lies in its analytical evaluation for general two-qubit states [18] and certain bipartite states with high symmetry [19,20]. It also plays a crucial role in specific quantum protocols, such as remote state preparation [21]. But this measure of geometric discord may be increased by trivial local operations on the unmeasured subsystem [22], and thus was not a good measure of quantum correlations [5]. To avoid this shortcoming, geometric discord based on other distance measures was proposed, e.g., the modified version of the geometric discord defined by making use of the square root of the density operator [23]. Here, we will consider the geometric discord defined by employing the trace distance [24] and the Bures distance [25]. This way of characterizing quantum correlation has previously been suggested by Luo and Fu in their pursuing analytical solutions for the geometric discord [19] and has been exploited explicitly very recently [24–26]. They can circumvent the problem that occurs for the geometric discord defined in Ref. [18], and therefore can be regarded as well-defined measures of quantum correlations.

From a practical point of view, one may wonder its robustness against decoherence after the introduction of a new well-defined quantum correlation measure. Due to the advantage of the distance measures adopted for defining quantum correlations, it is expected that the aforementioned two geometric discords will exhibit different behaviors under decoherence [26], and a comparative study of this issue may provide us with information that is essential to various quantum protocols, particularly those based only on them.

In this paper, we investigate the above problem. To be explicit, we consider the robustness of the foregoing two well-defined geometric discords for a central two-qubit system coupled to noisy environments. We will compare their particular dynamical behaviors and try to provide effective methods for fighting against the deterioration of them, as this is of special importance to various quantum protocols.

2. Well-defined measures of geometric discord

To begin with, we first briefly review the definitions as well as the general formalism for the trace distance and the Bures distance geometric discords. For a bipartite system AB described by the density