Universal Protection of Single Qubit Systems from Decoherence

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The fragility of quantum coherence fundamentally limits the scalability of quantum technologies, as unavoidable environmental interactions induce decoherence and rapidly degrade quantum properties. The Quantum Zeno Effect (QZE) [1] offers a way to suppress quantum evolution and protect coherence through frequent measurements, irrespective of the underlying dynamics. However, the applicability of existing QZE implementations [2-4] is severely restricted, as they require prior knowledge of the initial quantum state to implement them.

We propose a new protection protocol, dubbed Quantum State Universal Protection (QSUP) [5], which is "agnostic" with respect to both the initial state and the decoherence-inducing dynamics, meaning that it can be universally implemented for any initial state and in any kind of noisy environment. The QSUP relies on embedding the system in a larger Hilbert space, temporarily swapping the quantum information from its original degree of freedom (DoF) to a decoherence-free ancillary one, prepared in a known state. This allows protecting the (now known) state of the main system using the QZE, before re-swapping the two DoFs and restoring the (protected) quantum state in its original form. We experimentally validate the protocol on a quantum optical platform, employing single-photon polarization qubits. We estimated the Purity and Fidelity (with respect to the initial state) of the photons at the end of the transmission, with and without the use of QSUP. The comparison demonstrates a robust preservation of coherence for arbitrary polarization-encoded qubits under different decoherence mechanisms, thereby enabling the universal safeguarding of unknown quantum states. The versatility of the QSUP protocol also extends to the choice of the physical support used as a quantum information carrier; indeed, in principle our protocol only requires a decoherence-free/robust DoF and the capability of implementing swap operations and QZE-based protection, without further specification on how to implement them.

The performances and generality of the QSUP protocol make it a very promising tool for a variety of scenarios, potentially leading to more robust and reliable quantum technology implementations.

References

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