Erasmus Mundus Master QuanTEEM
Master Internship

TITLE	Limits and energetic costs of quantum operations
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INSTITUTION	Université de Bourgogne (uB)
LAB / DEPARTMENT / TEAM	ICB Lab / Quantum Interactions and Control (ICQ) / Quantum Dynamics and Technologies (DyTeQ)
TYPE OF PROJECT (theory / experiment)	Theory

Scientific context

Quantum technologies aim at exploiting special properties of quantum systems to enhance key operations like information processing, computation, simulation, communication, cryptography, and sensing. Such upcoming technologies rely ultimately on one’s ability to control and manipulate quantum systems. Controlling quantum systems means to be able to prepare specific initial states, to precisely induce well chosen dynamics, and to measure them. Fundamental questions such as the limit of precision of a given control operation, the minimum time required for such control operation, and the minimum energy and resource expenditure associated to such control operation are still widely open. Additionally, for useful and practical implementations, one has to take into account experimental constraints such as available energy, limited setup complexities, doable signal control, and last but not least, diverse sources of noise like experimental imperfection and quantum decoherences (environement-induced dissipation). Addressing these questions is essential for the development and viability of quantum technologies. Answering them is the core purpose of optimal quantum control and quantum thermodynamics, making these raising topics strategic fields for quantum technologies.

Central problem

To start with, we will focus on Hamiltonian transformation, widely use in quantum thermodynamic protocols for quantum engines as well as in quantum erasure protocols. The target system could be qubits, central system in quantum technologies. In a first time, we will neglect external noise, meaning that we will work in close dynamics (unitary evolution). Then, for a given Hamiltonian transformation to be realized, say $H_i \rightarrow H_f$, what is the control which minimizes the resources (work and thermodynamic cost [1, 2])? How does it depend on the duration of the operation? What is the influence of quantum friction [3]? Is the quantum speed limit [4] achievable? Can we design such control robust to experimental uncertainties and imperfections? The aim will be to answer these questions and compare some of the results with a previous study [5] as well as with the “shortcut-to-adiabaticity” [6].

Extension and long-term vision

A long-term goal would be to answer similar questions but in open quantum dynamics.

Motivations: Open quantum dynamics describes the evolution of a quantum system subject to the influence of its environment, like the (in)famous quantum decoherence. In most experimental applications, the influence of the environment is a tremendous issue, extremely challenging to circumvent. Controls robust to such influence would be very useful. Additionally, although in most platforms used for quantum computers the typical timescale of quantum gates is much smaller than the environment-induced dissipation timescale, tiny residual effects are still expected [7]. Then, since the required fidelity of quantum gates is very high, the effects of the environment-induced noise, as tiny as it can be, must be avoided. Optimal control in open dynamics is therefore crucial for quantum technologies. The results could be tested and used in cold atom platforms (BEC, Rydberg atoms), supraconducting circuits, or magnetic nuclear resonance.

Additional information

This project is part of a recently established Junior Professor Chair on Quantum Technologies at Université de Bourgogne and will be conducted in collaboration with Pr. Dominique Sugny and Pr. Stéphane Guérin, also member of the DyTeQ team. It can be followed by a fully funded PhD thesis.

References

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[7] G. Di Bartolomeo, M. Vischi, F. Cesa, R. Wixinger, M. Grossi et al.: A novel approach to noisy gates for simulating quantum computers. arXiv:2301.04173 (2023)