Contribution ID: **247** Type: **not specified**

Quantum many-body systems: from characterization to control

Monday, 3 July 2023 12:20 (40 minutes)

Quantum many-body control is among most challenging problems in the field of quantum technologies, yet it is absolutely essential for further developments of this vast field. In this work, we propose a novel approach for solving control problems for many-body quantum systems. The key feature of our approach is the ability to run tens of thousands of iterations of a gradient-based optimization of a control signal within reasonable time. This is achieved by a tensor-networks-based reduced-order modeling scheme allowing one to build a low-dimensional reduced-order model of a many-body system, whose numerical simulation in many orders of magnitude faster and more memory efficient than for the original model; these reduced-order models can be seen as “digital twins”of many-body systems. The control protocols developed for the “digital twins”can be then directly applied to the quantum many-body system of interest.

We validate the proposed method by demonstrating solutions of control problems for a one-dimensional XYZ model, such as controllable information spreading/transmission over the system, and for a spin chain in many-body localization phase, such as controllable dynamics inversion. Interestingly, our approach by design uses environmental effects (such as non-Markovianity) to make control protocols more efficient: instead of fighting against a potential loss caused by the interaction with the environment, the method uses interaction as a communication protocol with environment that is used as a “memory”for storage of quantum information. We expect that our results will find direct applications in the study of complex many-body systems, specifically, in probing non-trivial quasiparticle excitations, as well as in development control tools for quantum computing devices.

We acknowledge the support by the RSF Grant No. 19-71-10092 and Russian Roadmap on Quantum Computing.

1. I.A. Luchnikov, E.O. Kiktenko, M.A. Gavreev, H. Ouerdane, S.N. Filippov, and A.K. Fedorov. “Probing non-Markovian quantum dynamics with data-driven analysis: Beyond “black-box”machine learning models”. Physical Review Research 4, 043002 (2022); arXiv:2103.14490.
2. I. A. Luchnikov, M.A. Gavreev, and A.K. Fedorov, Controlling quantum many-body systems using reduced-order modelling, arXiv:2211.00467.

Summary

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Session Classification: Plenary

Track Classification: Plenary