Real-time quantum control of qubits

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Abstract

Quantum computing relies on developing quantum devices that are robust against small and uncontrolled parameter variations in the Hamiltonian. We focus on real-time closed-loop feedback protocols [1] to estimate uncontrolled fluctuations of semiconducting-spin or superconducting qubit Hamiltonian parameters, followed by enhancing the quality of qubit rotations.

First, we coherently control a spin qubit with a low-latency FPGA-powered controller. The protocol uses a singlet-triplet spin qubit implemented in a gallium arsenide double quantum dot. We establish real-time feedback on both control axes and enhance the resulting quality factor of coherent spin rotations [2]. Even with some components of the Hamiltonian purely governed by noise, we demonstrate noise-driven coherent control.

Next, we present a protocol for a physics-informed real-time Hamiltonian estimation [3]. We estimate the fluctuating nuclear field gradient within the double dot on-the-fly by updating its probability distribution according to the Fokker-Planck equation. We further improve the physics-informed protocol by adaptively choosing the free evolution time of the electrons singlet pair, based on the previous measurement outcomes. The protocol results in a ten-fold improvement of the estimation speed compared to former schemes.

Finally, we present adaptive Bayesian schemes for efficiently tracking frequency [4] and relaxation times fluctuations in transmon qubits. In real time, we implement the Bayesian algorithm to estimate low-frequency magnetic flux noise in a flux-tunable transmon qubit, whose coherence and fidelity are improved by feedforward of the updated qubit frequency. We also perform fast estimation of relaxation times averaging 0.17 ms and exceeding 0.5 ms in only a few milliseconds, more than two orders of magnitude faster than previous nonadaptive methods. We observe significant relaxation time fluctuations on timescales much faster than previously reported.

Our work emphasizes the need for online Hamiltonian learning to enhance the performance and stability of quantum devices affected by quasistatic noise, and to identify the lowest-performing qubit outliers in quantum processing units.

References

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