Closed-loop optimization of quantum states via efficient state reconstruction

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The generation of high-fidelity quantum states and multi-qubit gate operations is a fundamental requirement for quantum physics experiments. However, most experiments are guided by Hamiltonians containing terms that are either overlooked or imperfectly characterized. These imperfections are exacerbated by stochastic variations of the Hamiltonian or, more broadly, the instrument setup. Quantum optimal control methods offer a solution to mitigate these unwanted effects and achieve high-quality state preparation [1] and gate fidelities [2].

Closed-loop optimization for generating a quantum state necessitates measurements after each iteration. For bosonic modes, this can become prohibitively expensive, as it requires consideration of the entire phase space for state reconstruction. To overcome this issue, we introduce a new state reconstruction method, that iteratively updates the underlying model and chooses the next measurement points in the areas of the largest model uncertainty. It allows obtaining a reliable fidelity estimation within a few minutes only (Fig. 1). In our study, we utilize a high-Q Niobium cavity coupled to a superconducting transmon qubit to generate quantum states in a cavity mode. Employing a closed-loop optimization approach using the QuOCS library [3], we maximize the fidelity of cat states (Fig. 2).

References

[1] Heeres, R. W. et al. Nature Communications 8, 94 (2017)
[2] Werninghaus, M. et al. npj Quantum Inf 7, 14 (2021)
[3] Rossignolo, M. et al. Computer Physics Communications, vol. 291 (2023)

Figures

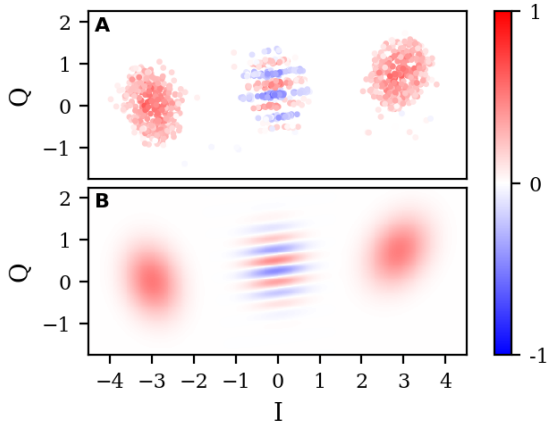

Figure 1: (A) 1000 measured points (B) The Wigner map reconstruction based on (A)

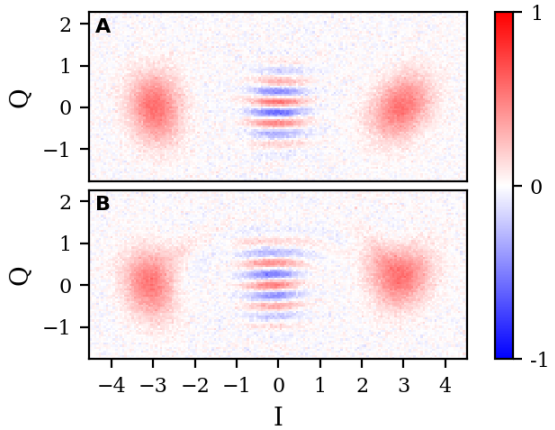

Figure 2: a = 3 cat before (A) and after (B) closed-loop optimization