Quantum control of continuous systems via nonharmonic potential modulation

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The preparation of a continuous-variable system in a non-Gaussian quantum state is of paramount importance in various aspects of quantum science. The generation of non-Gaussian states requires a nonlinear resource, often introduced through coupling to an auxiliary degree of freedom, such as a two-level system. On the other hand, some continuous-variable systems already possess intrinsic nonlinearity in the potential of a canonical variable. These nonharmonicites in the potential are typically used to define a qubit within continuous-variable systems. In contrast, we explore methods for utilizing this intrinsic nonlinearity to generate and control states beyond the two-dimensional subspace.

Specifically, we present a theoretical proposal for preparing and manipulating a state of a single continuous-variable degree of freedom confined to a nonharmonic potential [1]. By utilizing optimally controlled modulation of the potential's position and depth, we demonstrate the generation of non-Gaussian states, including Fock, Gottesman-Kitaev-Preskill, multi-legged-cat, and cubic-phase states, as well as the implementation of arbitrary unitaries within a selected two-level subspace. Additionally, we propose protocols for single-shot orthogonal state discrimination and algorithmic cooling and analyze the robustness of this control scheme against noise. Since all the presented protocols rely solely on the precise modulation of the effective nonharmonic potential landscape, they are relevant to several experiments with continuous-variable systems, including the motion of a single particle in an optical tweezer or lattice, or current in circuit quantum electrodynamics. Moreover, the proposed protocols can be utilized in systems with very weak nonharmonicities, e.g., levitated nanoparticles.

References

[1] P. Grochowski et al., arXiv:2311.16819

Figures

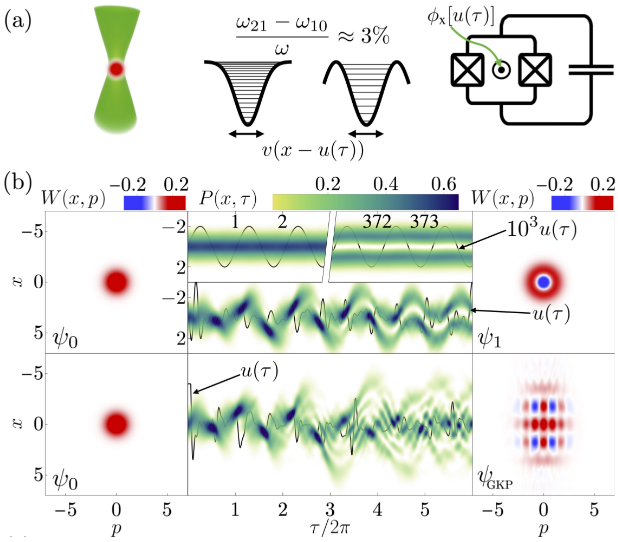

Figure 1: (a) Examples of systems that can be optimally controlled without the need of auxiliary systems—single atoms in optical tweezers and flux-tunable transmons. (b)Time-evolved probability density during the state preparation with the snapshots of Wigner functions. The potential's controlled position is depicted via a solid black line. The top panel shows a comparison between sinusoidal drive resonant with the ground-first excited state transition and an optimized much faster control. The bottom panel presents an optimal control leading to the GKP state.