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Enhancing Robustness in Ion Trap Quantum Logic through Optimal Control of Two-Qubit Operations

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In quantum information processing, the controlled and isolated environment provided by cold trapped ions is pivotal for extending coherence times and reducing error rates, thus advancing the capabilities of quantum computing. We use two calcium ions in a string confined in a radio-frequency trap and prepared in their ground state of motion (with motional quantum number close to zero) using the sideband cooling technique. In order to showcase high-fidelity quantum logic gates employing two trapped ions, our qubit configuration utilizes the quadrupole electron transition at 729 nm or the Raman transition between the Zeeman sublevels of the ground state S1/2 to probe the Zeeman qubit. In attempts to improve the fidelity of the quantum logic gate, we implement optical filtering of unwanted frequency components in the laser driving the Raman interaction, thus enhancing coherence times by reducing scattering effects. Additionally, efforts are directed towards compensating for magnetic field fluctuations, primarily induced by the mains supply at 50 Hz, aiming to further extend coherence times and enable experiments without the necessity of line triggering. We aim to improve the fidelity of a standard Mølmer-Sørensen gate and subsequently demonstrate the resilience of strongly-coupled polychromatic gate beyond the Lamb-Dicke regime.

These developments represent significant strides towards more robust and reliable two-qubit quantum gate operations. The combination of improved laser spectral purity, long coherence times, better magnetic field compensation, and advanced gate designs paves the way for higher fidelity quantum computations.

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