A control system for driving dynamic circuits on atom and ion based quantum processors using camera and photodiode-based readout

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Abstract

Atom- and ion-based quantum computing platforms enjoy many advantages, such as high scalability and state-of-the-art fidelities, but suffer from slow readout compared to qubit driving timescales. This limits the possibility of performing mid-circuit measurements, quantum error correction schemes, and lowers the number of achievable circuit layer operations per second (CLOPS). Feedback based on cameras typically suffers from high latency, limited by atom/ion exposure times, camera frame transfer rates, as well as the control system's latency, which limits current systems to readout rates below 100Hz.

Here we show a user-programmable FPGA-based control system designed for executing dynamic circuits on ensembles of trapped atoms and ions, and present an optimistic path toward kHz readout rates for atom- and ion-based processing units. We demonstrate camera and photodiode readout and real-time processing while maintaining the controller's residual latency below 100us, negligible compared to common atom/ion exposure times and camera frame transfer rates.

The users can program complex sequences of gates interlaced with mid-circuit camera/photodiode readout, image processing and arbitrary calculation. Sequences allow for branching, and sub-µs waveform synthesis latencies for atom/ion transport, and qubit driving. Users can preserve defect-free sorted arrays by replacing lost atoms from a reservoir, rather than re-instantiate the whole array for each shot, allowing for higher CLOPS and increased overall system bandwidth. The system supports multiple regions of operation, allowing to separately configure qubit arrays, atom reservoirs, and detection and excitation regions complete with atom shuttling between them.

The proposed control system allows to quickly elevate disordered arrays of atoms and ions into managed QPUs capable of executing dynamic circuits, meshing gates, measurements, atom transport, and real-time processing for next-generation atom- and ion-based devices.