Quantum Coalition Hack 2021: Q-CTRL

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Abstract

This is our entry to the the Q-CTRL challenge as a part of the Quantum Coalition Hack where the challenge is to provide two pulses that implement a high fidelity NOT gate and Hadamard gate on Q-CTRL's qubit in the cloud. The qubit in the cloud is modeled off a superconducting qubit.

I. Approach

We initially defined our ideal gates and then compared those definitions with the gates that we proposed. These gates are rotations in the Bloch sphere and are defined by σ_x, σ_y, σ_z (to represent the three coordinates axes of rotations). To define any gate we needed a Hamiltonian of our system which contains information about the actual rotation we were trying to achieve with the gate and the noise that is present in our environment as the dephasing and the amplitude error.

II. Adopting Robust Control

The initial code cell uses Boulder Opal to generate the plots and the main approach that we used to improve the fidelty of the gates applied to the qubit in the cloud is robust control.

We used the *LinearSmoothing* function over the microwave pulses that were applied on our qubits. The Hamiltonian is divisible into controlled and noisy parts, both of which are dependent on time.

$$H_{\text{total}}(t) = H_{\text{control}}(t) + H_{\text{noise}}(t)$$

$$H_{\text{control}}(t) = \Omega_{\text{I}}(t)\sigma_x/2 + \Omega_{\text{Q}}(t)\sigma_y/2 \tag{1}$$

$$H_{\text{noise}}(t) = \eta(t)\sigma_z/2. \tag{2}$$

Discrete pulse segments were created in the *ComplexSegmentInput* in Q-CTRL with the maximum value of the amplitude and a time duration. We used Boulder Opal to approximate the values of the noisy environment to those of a classical process. Our function then takes in a small value of frequency cutoff against large power. This approximation when plotted showed that that lower frequencies contribute to more dephasing.

We also discovered that the trajectories of the real path diverges from an ideal one under the influence of noise. We optimised the average gate infidelity to show average results through a stochastic simulation in Boulder Opal. Simulation of the noise was done by using a *colored_noise_simulation* function and they were compared against the ideal simulation results. By varying our angle by small values of θ, we studied the average variation which at its peak gave us the infidelity for the proposed gate.

Additionally, we assumed that the noise within the Hamiltonian is constant. We used the filter function as a Fourier transform on the noise Hamiltonian, which allowed us to quantify how the noise affected our final input. By minimizing the infidelity, we were able to create a relatively robust function. We then compared the output of a standard NOT gate and a real gate at low frequencies which made us realise that the infidelity is low for small noises. In order to have a robust design, the infidelity of the noise and control should both be low which, in Boulder Opal, is optimized to obtain the minimum value of the cost function. Using the small cost values and the filter function, we obtained a graph that almost entirely removed the low frequency pulses.

III. Roadblocks encountered

- The primary hurdle that we encountered while working through the challenge was the calibration of our microwave pulses. Although we generated a good approximation of the realistic qubits by simulating the noise on our systems, the actual measurement results were not as desirable since the Rabi rates of the qubit were not known to us.

- We applied the same outline and principle of the NOT gate to find a suitable microwave pulse for the Hadamard gate. However, we did not change the Hamiltonian we had previously used for the NOT gate due to time constraints and therefore, the infidelity rates were beyond acceptable bounds.

- The gate fidelity of our Hadamard simulation was not perfect as we weren't sure about which terms to include for the Hamiltonian.

IV. Reflection and Future Optimisations

We had a tough time with the parsing of the Rabi rates for our qubit correctly within the limited time frame but we would like to be able to understand the format of that calculation and implement it.

Given the time, we would have definitely been able to optimise our approach to realise the general gates and help in producing better computations.