Q-CTRL QCHACK CHALLENGE. (Team : Q-Avengers)

We have used BOULDER OPAL to create pulses that implement fidelity NOT and Hadamard gates on the qubit in the cloud.

For NOT Gate:

We initially define for ideal Qubit, then for more realistic Qubit. We can get the error and pulse simulation. Now, for the actual challenge we access a Qubit in cloud.
We tried to perform NOT gates on different control system (mostly taken from OPTIMIZE CONTROLS - Examples) . Their Hamiltonions are:

1) ROBUST CONTROL OF A SINGLE QUBIT :

$$H(t) = \frac{\nu}{2}\sigma_z + \frac{1}{2}(\gamma(t)\sigma_- + \gamma^*(t)\sigma_+) + \frac{\alpha(t)}{2}\sigma_z + \beta(t)\sigma_z\,,$$

2) TIME-SYMMETRIZED PULSES :

$$H(t) = \frac{\nu}{2}\sigma_z + \frac{1}{2}(\gamma(t)\sigma_- + \gamma^*(t)\sigma_+) + \frac{\alpha(t)}{2}\sigma_z + \beta(t)\sigma_z\,,$$

3) NON-LINEAR DEPENDENCE ON CONTROL PULSES :

$$H(t) = \alpha_1(t)\sigma_x + \frac{\alpha_1(t)^2}{\alpha_{\max}}\sigma_y + \alpha_2(t)\sigma_z\,,$$

4) BAND-LIMITED PULSES WITH BOUNDED SLEW RATES

$$H(t) = \frac{1}{2}\alpha_1(t)\sigma_x + \frac{1}{2}\alpha_2(t)\sigma_z + \beta(t)\sigma_z\,,$$

(Generally, taken Hamiltonion from Optimise control Q-CTRL page.). We also try to combine Hamiltonians or form random Hamiltonion, but not included here.

Our Idea: We wanted to run NOT gate by calling different graph objects and calculate error in NOT gate. If we get the control for which we get the lowest error we can define it having high fidelity.

Problems faced : Not able to run above control for NOT Gate. Using graph objects, we cannot see any function to call.

Also, not able to calculate NOT_values . (I.e not understand calculation for real and imaginary part.)

For HADAMARD Gate :

Similarly, We initially define for ideal Qubit, then a more realistic Qubit. We can get the error and pulse simulation fine. Now, for the actual challenge we access a Qubit in cloud.
We tried to perform HADAMARD gates on different control system (mostly taken from OPTIMIZE CONTROLS - Examples) . Their Hamiltonions are:

1) ROBUST CONTROL OF A SINGLE QUBIT :

$$H(t) = \frac{\nu}{2}\sigma_z + \frac{1}{2}(\gamma(t)\sigma_- + \gamma^*(t)\sigma_+) + \frac{\alpha(t)}{2}\sigma_z + \beta(t)\sigma_z\,,$$

2) TIME-SYMMETRIZED PULSES :

$$H(t) = \frac{\nu}{2}\sigma_z + \frac{1}{2}(\gamma(t)\sigma_- + \gamma^*(t)\sigma_+) + \frac{\alpha(t)}{2}\sigma_z + \beta(t)\sigma_z\,,$$

3) NON-LINEAR DEPENDENCE ON CONTROL PULSES : $H(t) = \alpha_1(t)\sigma_x + \frac{\alpha_1(t)^2}{\alpha_{\max}}\sigma_y + \alpha_2(t)\sigma_z\,,$

4) BAND-LIMITED PULSES WITH BOUNDED SLEW RATES $H(t) = \frac{1}{2}\alpha_1(t)\sigma_x + \frac{1}{2}\alpha_2(t)\sigma_z + \beta(t)\sigma_z\,,$

(Generally, taken Hamiltonion from Optimise control Q-CTRL page.). We also try to combine Hamiltonians or form random Hamiltonion.

Our Idea: Similarly, here also we wanted to run Hadamard gate by calling different graph objects and calculate error in H gate. We can define high fidelity for which we get the lowest error.

Problems faced : We were able to do random pulse but was not able to run above controls for H- Gate. Using graph objects, we cannot see any function to call.
Also, not able to calculate NOT_values . (I.e not understand calculation for real and imaginary part.)

Results : We did not come at any conclusion to define best fidelity NOT gate and Hadamard gate on our qubit in the cloud. From the research paper (https://www.researchgate.net/publication/328240748_Quantum_control_for_high-fidelity_multi-qubit_gates) we got best model for Hamiltonian as :

$$\frac{H(t)}{h} := \hat{H}(t) = \sum_{k=1}^{n} \mathcal{P}_{\mathrm{I}}^{\otimes n}(\mathrm{diag}(0,\, \varepsilon_k(t),\, 2\varepsilon_k(t) - \eta,\, 3\varepsilon_k(t) - \eta')) + \frac{g}{2}\sum_{k=1}^{n-1} \mathcal{P}_{\mathrm{I}}^{\otimes(n-1)}(X_k \otimes X_{k+1} + Y_k \otimes Y_{k+1}),$$

Experience with Q-CTRL Workshop, Challenge and BOULDER OPAL :

From The challenge, we learnt to run pulse on Q-CTRL platforms, apply different Noise Characterisation on Circuits. In the BOULDER OPAL platform, we run different notebooks about Optimise control, pulse calibration and pulse optimisation under realistic experiment.
In the challenge, we learnt a lot about different control systems, defining error function and visualisation of plots.

Thanks, for the challenge.