DESIGNING ERROR CONTROL CIRCUITS FOR 4-QUBIT QUANTUM COMPUTING

UNIVERSITY OF SASKATCHEWAN

MARINA SCHMIDT AND R. SPITERI   DEPARTMENT OF COMPUTER SCIENCE

Numerical Simulations Research Lab

INTRODUCTION

Quantum computers hold a promising advantage to solving hard problems, such as prime factorization, within a sufficient amount of time. This is because of their ability to harness the quantum states of subatomic particles (e.g. photons and electrons) to represent a quantum bit (qubit). A qubit can be in a zero or one or both states when not being measured because of quantum superposition. Because of this quantum property, when a qubit is added to the system it can interact with the other qubits to create superposition states that will increase the amount of information provided to the system. The ability to interact with other qubits is also problematic because it can interact with other environmental subatomic particles from which it is impossible to isolate a qubit system. When this undesired interaction occurs, decoherence or loss of information causes errors in the information read from the system. To prevent the major loss of information from decoherence, error correction operations are applied to obtain the resulting information from the system. Some constraints of the error correction design are:

- Gate time must not exceed decoherence time
- Intrinsic fidelty exceeds 99.99%
- Cannot use redundcy because of the no-cloning theorem

In this poster the Tofolli single shot gate constants is optimized to obtain an intrinsic fidelity of 99.99%. It promises enough robustness in the error correction gate to guarantee fault tolerance without losing too much gate time so as to stay lower than the decoherence time.

CONTACT INFORMATION

Web simlab.usask.ca
Email mts299@mail.usask.ca
Phone +1 (306) 716-3561

TOFFOLLI SINGLE SHOT MODEL

The CCZ gate is component of the toffoli single shot circuit that deals with error correction. The gate can be repersented as a controlled Hamiltonian matrix as a vector operator: $\hat{\mathbf{H}}^{\mathbf{c}}$, that is influenced by the controlled parameters $\varepsilon(t)$. These parameters determine the phase of the frequency to correct the qubit system with. The drift Hamiltonian, $\hat{H}^{dr}$ then reperesent the non-controlled qubit system. Therefore, the overall Hamiltonian of the qubit system is reperesented as:

$$\hat{H}(\varepsilon(t)) = \hat{H}^{dr} + \varepsilon(t) \cdot \hat{\mathbf{H}}^{\mathbf{c}}$$

The system can further be expressed over time by unitary evolution operator:

$$\tilde{U}(\varepsilon(t);\tau) = Te^{\left(-i\int_0^\tau \hat{H}(\varepsilon(t))dt\right)}$$

To determine how well the system is corrected, the target unitary evolution operator, U, is chosen based on the gate design. The fidelity of the simulation is then defined as:

$$\mathscr{F}(\varepsilon(t)) = \frac{1}{N} Re\Big(Tr\big(U\tilde{U}(\varepsilon(t))\big)\Big)$$

Representing the objective function that optimizes for the maximum intrinsic fidelity that exceeds 99.99%.

2-QUBIT INTERACTION

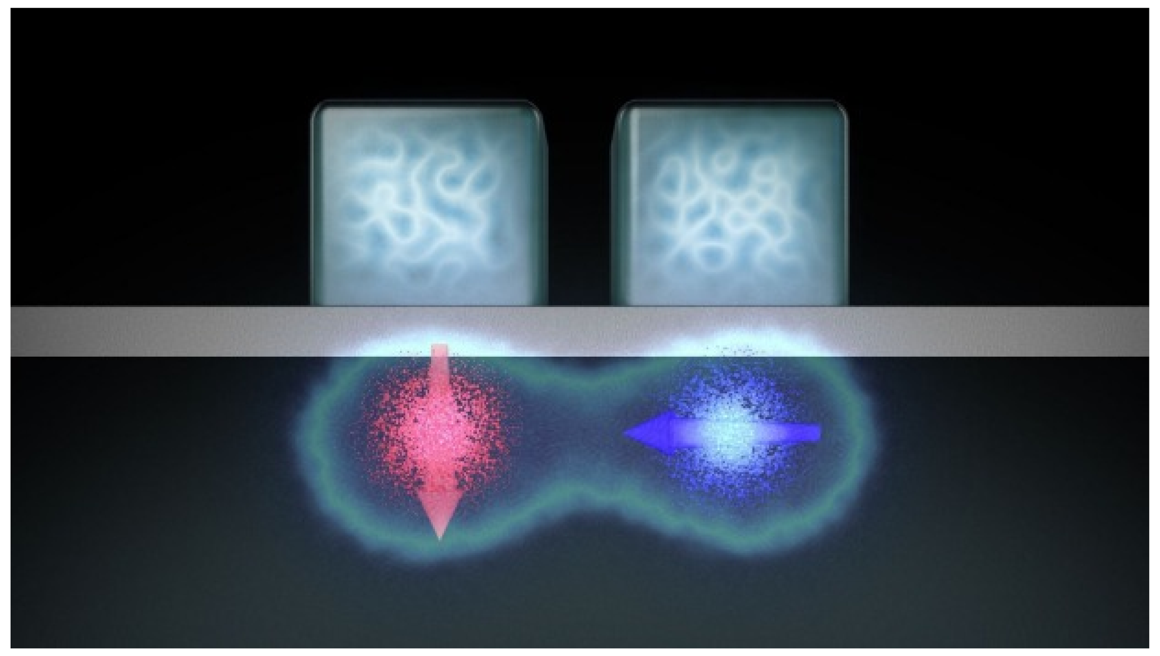
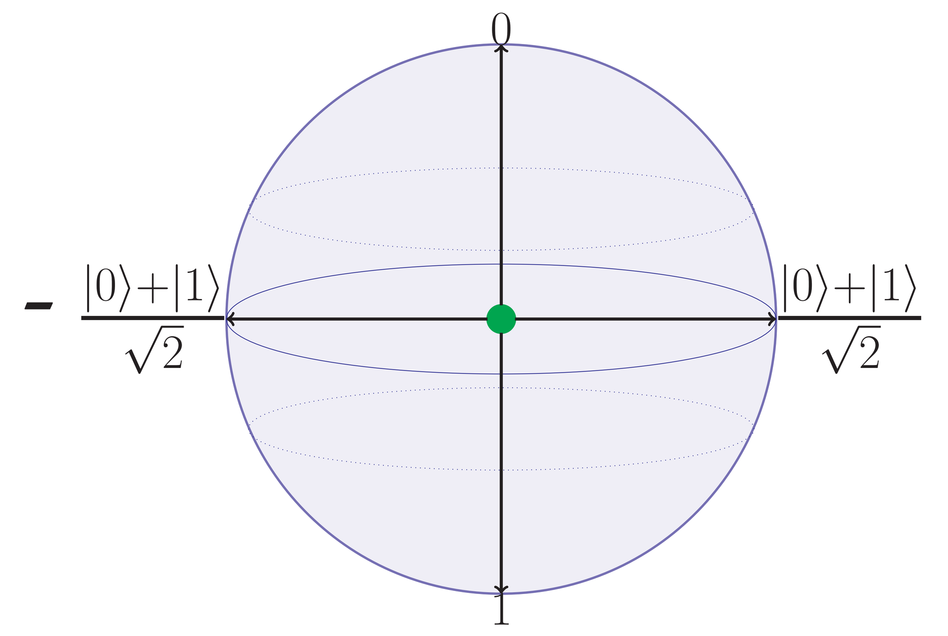


FIGURE 1



OPTIMIZATION SCHEME

The chosen software to solve this problem was Global Search from MATLABs global optimization toolbox because of the ability to apply constraints. The constraint in four qubit system is that the intrinsic fidelity needs to exceed 99.99%:

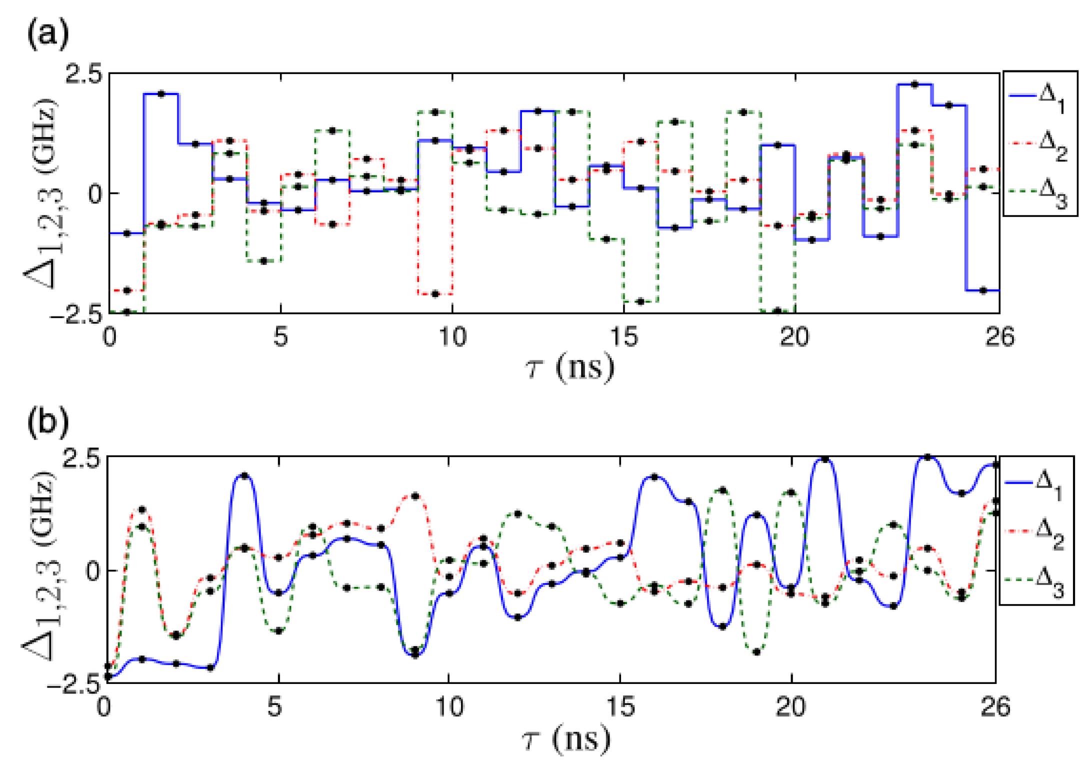
$$\mathscr{F}(\varepsilon(t)) \geq 0.9999$$

This is because of the trade off between overall gate time for correcting the system and acceptable level of robustness for fault tolerance. The global search algorithm is a hybrid method that uses fmincon as the local solver. The objective function in this optimization scheme is defaulted to zero:

$$f(x) = 0$$

because the actual calculation is done in the constraint function.

3-QUBIT PULSE SIGNAL



RESULTS & CONCLUSIONS

We obtained solutions for the circuit constants that exceeded the 0.9999 threshold in the following table:

T (ns)	Intrinsic fidelity	CPU time
150	1.0	1 week
120	0.999977	1 week
75	0.999908	3 months
65	0.999907	1 week
60	0.999978	1 week

The following table shows the current running optimizations:

T (ns)	Intrinsic fidelity	CPU time
59	0.920909	1 week
58	0.885026	1 week
57	0.805161	1 week
56	0.715306	1 week
55	0.99953	3 months

By treating the four qubit system as a feasibility problem in the optimization solver. We obtained a solution for various gate processing times with 60 nanoseconds being the current lowest gate time. Currently we are also looking at lower times to obtain the minimal gate time for the four qubit system.

FUTURE RESEARCH

With this new scheme of optimizing the qubit system further work is being done on to minimize the gate time, as well a way to reformulate the objective function to consider the gate processing time; currently set as parameter before the optimization.
Another system to solve is the five qubit system; by solving this system the four qubit system can be used for encoding purposes in quantum computers and the five qubit system will decode the message. This can lead into using quantum computers for security for the main computer calculations and even the internet purposes.