Analog Control of the Diamond Quantum Processor

Sophie C. Stearn[a] and Marcus Doherty[a]

[a] *Department of Quantum Science and Technology, Research School of Physics, Australian National University, Acton, ACT, 2600, Australia*

Throughout the development of quantum computers, the universal gate model paradigm has been the primary focus. Its resemblance to classical digital-logic provides a familiar theoretical framework to operate from, reducing the complexity of the difficult task that is quantum programming. However, this developmental focus has made it easy to forget that the true nature of a quantum computer is ultimately analog and continuous. Every gate generates error, resulting in an exponentially growing number of qubits required purely for correction, rapidly increasing algorithmic complexity [1]. While quantum computing technology is still in the NISQ regime, the rate of algorithmic error growth is only amplified, underscoring the need for a more robust paradigm. Instead of relying on a finite set of discretised rotations, AQC (Analog Quantum Computing) continuously evolves the system Hamiltonian in a single pulse to realise any chosen unitary operation. When used appropriately, this simplifies the error mitigation process and reduces the circuit depth as both an algorithm and its corrections can be implemented in a single control step.

While both full and hybrid variations of AQC have been demonstrated [2, 3], the challenge now is to find a systematic, deterministic way of constructing a continuous pulse for AQC. This needs to be done whilst ensuring that the computational overhead from compilation doesn't outweigh the potential error reduction and speed benefits of this technique when compared to the gate paradigm. This work assesses multiple approaches to the problem of analog compilation and whether it offers a substantial benefit to error mitigation on a NISQ regime device. This is done in the context of the diamond quantum processor, which has an Ising model computational topology realised via the spin dynamics of the nitrogen-vacancy centre and its microwave control fields. Additionally, it will be shown that compiled analog Ising control fields can be further optimised via previously established semi-analytical, gate-based optimal control techniques [4]. The use of the diamond quantum processor is motivated by the computational universality of its Ising control Hamiltonian, which has been shown to be capable of quantum annealing [5]. Additionally, it has been widely used in gate model computing for many decades, making it an ideal candidate to assess optimal AQC on NISQ regime devices.

[1] Raymond Laflamme et al, *arXiv:quant-phys 960219,* (1996) 10.48550.

[2] Jonathan J. Burnett et al, *NJP Quantum Information 5*, (2019) 54.

[3] Adrian Parra-Rodriguez et al, *PhysRevA 101*, (2020) 022305.

[4] YunHeng Chen et al, *New Journal of Physics 22*, (2020) 093068.

[5] Sophie C. Stearn et al*, Diamond Quantum Annealing,* (2022) in preparation.