Quantum Control in Zero-Field Nuclear Magnetic Resonance with Hot Vapor Magnetometer

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Experimental characterization of the controllability and quality of the level of coherent control in a specific quantum architecture is a central problem in contemporary experimental physics and an important ingredient to improving performance. As a complementary analysis tool to high-field nuclear magnetic resonance (NMR), this kind of benchmarking experiments has not been demonstrated in zero-field NMR[1]. We use a hot vapor magnetometer to sense nuclear magnetization of samples at zero field. Here we realize a composite-pulse technique for both arbitrary one-spin rotations (Fig. 1**a**) and a two-spin controlled-not (CNOT) gate in a heteronuclear two-spin system at zero field[2,3], which experimentally demonstrates universal quantum control in such a system. Moreover, using quantum-information-inspired randomized benchmarking and partial quantum process tomography, we evaluate the quality of the control, achieving for single-spin control for ^{13}C with an average fidelity of 0.9960(2) (Fig. 1**b**) and two-spin control via a CNOT gate with a fidelity of 0.9877(2) (Fig. 1**c**). Our method can also be extended to more general multi-spin heteronuclear systems at zero field. The realization of universal quantum control in zero-field NMR is important for quantum state/coherence preparation and pulse-sequence design.

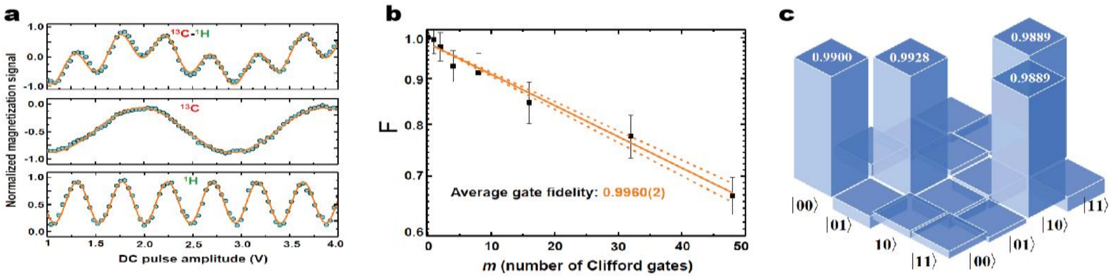

Fig.1*(a)Top: zero-field NMR signal amplitude of the formic acid with different DC pulse amplitude, which is fitted with two cosine functions as both ^{13}C and H are rotated. Middle: ^{13}C is selectively rotated. Bottom: H is selectively rotated. (b) Pulse fidelity estimation with randomized benchmarking testing protocol. Each experiment data point is an average over 32 random sequences of m Clifford gates. The error bars indicate the standard error of the mean.(c) Experimental result of CNOT gate.*

[1] J. W. Blanchard, and D. Budker, Zero-to ultralow-field NMR, eMagRes 5(3): 1395-1410 (2016).

[2] J. Bian, et al. Universal quantum control in zero-field nuclear magnetic resonance. Phys. Rev. A 95, 052342 (2017).

[3] M. Jiang, et al. Experimental Benchmarking of Quantum Control in Zero-Field Nuclear Magnetic Resonance. arXiv:1708.06324 (2017).