Quantum Variational Optimization of Ramsey Interferometry and Atomic Clocks

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We report a theory [1] - experiment [2] collaborative effort to devise and implement optimal N-atom Ramsey interferometry with variational quantum circuits on a programmable quantum sensor realized with trapped-ions. Optimization is defined relative to a cost function, which in the present study is the Bayesian mean square error of the estimated phase for a given prior distribution, i.e. we optimize for a finite dynamic range of the interferometer, as relevant for atomic clock operation. The quantum circuits are built from global rotations and one-axis twisting operations, as are natively available with trapped ions. On the theory side, low-depth quantum circuits yield results closely approaching the fundamental quantum limits for optimal Ramsey interferometry. Our experimental findings include quantum enhancement in metrology beyond squeezing and GHZ state interferometry, and we verify the performance of circuits by both directly using theory predictions of optimal parameters, and performing online quantum-classical feedback optimization to 'self-calibrate' the variational parameters for up to $N = 26$ ions. Successfully demonstrating operation beyond standard squeezing using on-device optimization opens the quantum variational approach to application across a wide array of sensor platforms and tasks.

[1] R. Kaubruegger, D. V. Vasilyev, M. Schulte, K. Hammerer, and P. Zoller, arXiv:2102.05593

[2] C. D. Marciniak, T. Feldker, I. Pogorelov, R. Kaubruegger, D.V. Vasilyev, R. van Bijnen, P. Schindler, P. Zoller, R. Blatt, and T. Monz, unpublished