Fine-tuning a Programmable Quantum Sensor

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Motivation

- Quantum sensors that deploy entanglement can attain enhanced precision levels unreachable by conventional sensors.
  - In the absence of decoherence, quantum sensors *wwwwNN*entangled probes can attain the *Heisenberg limit* $\Delta\varphi\varphi \propto 1/NN$, as opposed to the *shot noise limit* $\Delta\varphi\varphi \propto 1/\sqrt{NN}$ associated with *NN*independent probes.
- Nitrogen vacancy (NV) center spin qubits in diamond are potent magnetic field sensors.
  - **KEY QUESTION:** For optimal sensor operation, how to prepare entangled states of NV qubits using gate operations native to the platform, and how to measure the NV qubits?

Project Description

- We will consider variational circuits for the NV-based sensor involving native single qubit rotations and dipolar interactions.
- Entanglement preparations and measurements can be tailored to maximize different cost functions [1]
- In a Fisherian setting, optimal entangled state preparations that maximize the *Quantum Fisher information* are *spin squeezed states* and *GHZ states*, and corresponding optimal measurements are *separable measurements* [2]
  - Not the case in a *Bayesian setting* with non-trivial prior distributions in a dynamic range [1].
  - Also, whatever the theoretical optimal state, it is difficult to precisely engineer operations between the NV qubits using native gates to prepare the optimal state as interactions depend on spatial distribution of the qubits.
  - Variational circuits extremely effective in tackling this challenge [1,2].

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We will explore programmable variational quantum circuits for a magnetic field sensor based on Nitrogen Vacancy (NV) center qubits. Our goal is to optimally fine-tune the sensor circuitry for random spatial distributions of the NV qubits and for different true values of the sensed signal within a finite dynamic range.

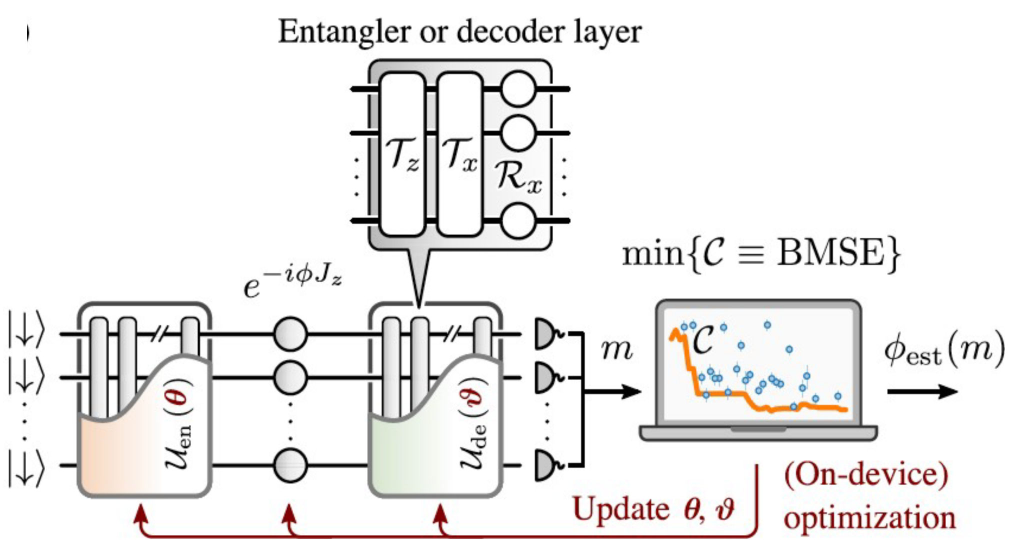

Figure: (Courtesy [1]) A variational quantum sensor where optimal entanglement preparations and entangled measurements are approximately achieved by low depth circuits involving native gates. (BMSE: Bayesian mean square error)

Project Deliverables

- **Goal for the funding period:** Determine optimal settings for a variational quantum-enhanced NV sensor for Bayesian estimation across a dynamic range with precision approaching the Heisenberg limit (in the absence of decoherence).
- **Mid point goal during funding period:** Furnish codes for simulation of the variational sensor that can determine the optimal setting. Compile the optimal settings on quantum processors available through AWS Amazon Braket and test performance of the sensor circuitry.
- **Goal beyond the funding period:**
  - Extend work to include decoherence of qubits and noise in measurement readouts.
  - In-situ demonstration of the quantum enhanced variationally optimized NV-based sensor.

Potential Impact

Magnetic field sensors with
- nano-Tesla precisions
- nano-scale spatial resolution
- optical interrogation
- room temperature controls
- and a wide range of temperature operations from mK to 600K.

References

1. R. Kaubruegger, D. V. Vasilyev, M. Schulte, K. Hammerer, and P. Zoller, *Phys. Rev. X 11, 041045 (2021).*
2. T.-X. Zheng, A. Li, J. Rosen, S. Zhou, M. Koppenhöfer, Z. Ma, F. T. Chong, A. A. Clerk, L. Jiang, and P. C. Maurer, *http://arxiv.org/abs/2203.03084.*