Optimal Measurement of Field Properties with Quantum Sensor Networks

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In quantum metrology, we wish to study how quantum mechanics can be used to improve the measurement accuracy of physical quantities such as electric or magnetic fields. These fields, which are usually dependent on a set of unknown parameters, can be measured using quantum qubit sensors. The objective is to extract field properties, typically a function of these parameters, using measurements of these fields with minimal error. Prior studies assumed the fields measured are uncorrelated. As this assumption is not valid in many practical scenarios, we developed a model that accounts for the field correlation in our research. Using the generalized model, we used methods from quantum information theory to derive further reduced lower bounds for the minimal error achievable by any protocol. Taking advantage of the correlations in the fields, we designed a protocol that optimally combined the field measurements to achieve this theoretical bound. Finally, the optimality of our protocol was formally proven using a linear programming duality approach. Academically, this novel linear programming duality approach introduces a new methodology in quantum metrology for analyzing the optimality of existing and future protocols. The proposed protocol also has practical applications in multiple disciplines by enabling accurate field measurements using entangled sensors. In quantum computing, the protocol can improve quantum hardware control precision for applications such as trapped-ion and neutral atom quantum computing. In medicine and chemistry, the protocol can be used to increase the spatial resolution in nanoscale nuclear magnetic resonance imaging to better analyze the structure of molecules.

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