Quantum Enhanced Measurement of Many-Body Observables

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In different areas of science the problem of finding the expectation value of an operator corresponding to an observable of a system is of utmost importance. For example, in many tasks in condensed matter physics, materials science, quantum chemistry and combinatorial optimization, the goal is to find spectral properties, the ground state energy or the lowest eigenvalue of a Hamiltonian. Direct estimation of the expectation value of observable decomposed into weighted sum of N Pauli strings is not straight forward and for complex system, it deemed to be nearly impossible [1,2].

In this project we propose an alternative approach to the current method of individually measuring each Pauli string, with a further classical summation of all values (we call this approach classical method). Our idea is to sum all the Pauli strings coherently. Using the phase kickback method in quantum phase estimation (QPE) [3], each Pauli string is encoded in the phase and written into an ancilla qubit in such a way that the sum of all Pauli strings is encoded in one phase as a sum of nonlinear functions. Our circuit contains two parts (see Fig.1) : a target quantum system with a short coherent time qubits and a measurement device with a memory ancilla qubit that has a long coherent time enough to encode each Pauli string and to proceed the QPE.

As a result, our approach promises linear improvement in N comparing to the classical one.

References

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[3]   S. Kimmel, G. H. Low, and T. J. Yoder., Phys. Rev. A, 92:062315, (2015)
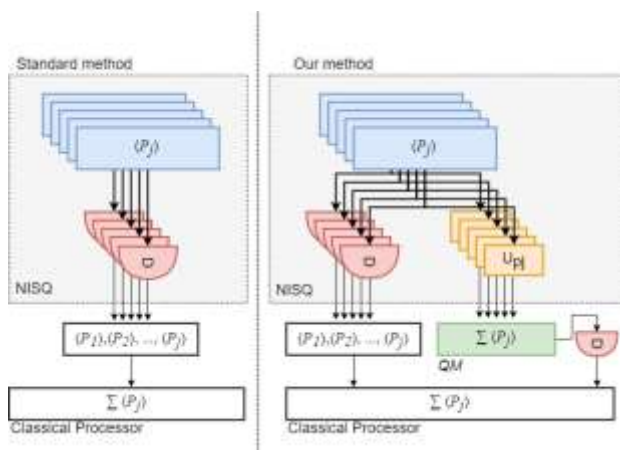
Figures

Figure 1: The comparison of standard and our method. On the left figure, the standard method, in which each Pauli circuit is prepaid in NISQ device is shown. The expectation value of each Pauli is estimated and the summation of all Pauly means is done classically. In contrast to it, in our method, shown on the right figure, we encode each Pauli string in the long coherence time memory qubit, using encoding operators U for every Pauli string. Then, we perform a single measurement on a memory qubit to estimate the desired observable.