

Quantum Process Tomography with Digital Twins of Error Matrices

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Abstract

Accurate and robust quantum process tomography (QPT) is crucial for verifying quantum gates and diagnosing implementation faults in experiments aimed at building universal quantum computers. However, the reliability of QPT protocols is often compromised by faulty probes, particularly state preparation and measurement (SPAM) errors, which introduce fundamental inconsistencies in traditional QPT algorithms. We propose and investigate enhanced QPT for multi-qubit systems by integrating the error matrix in a digital twin of the identity process matrix, enabling statistical refinement of SPAM error learning and improving QPT precision. Through numerical simulations, we demonstrate that our approach enables highly accurate and faithful process characterization. We further validate our method experimentally in superconducting quantum processors, achieving at least an order-of-magnitude fidelity improvement over standard QPT. Our results provide a practical and precise method for assessing quantum gate fidelity and enhancing QPT on a given hardware [1].

References

- [1] Tangyou Huang, Akshay Gaikwad, Ilya Moskalenko et.al., Phys. Rev. Lett. **135**, 230601 (2025)

Figures

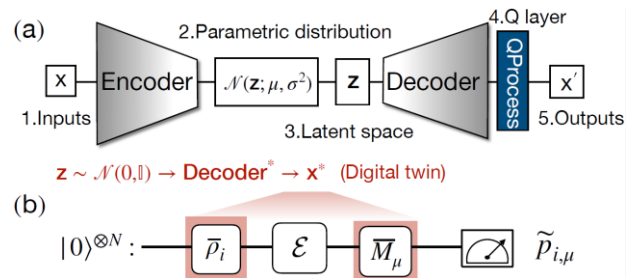


Figure 1: Digital twin-enhanced QPT. (a) The variational autoencoder (VAE) structure. (b) The digital twin of the error matrix $x^* \rightarrow \chi'_{DT}$.

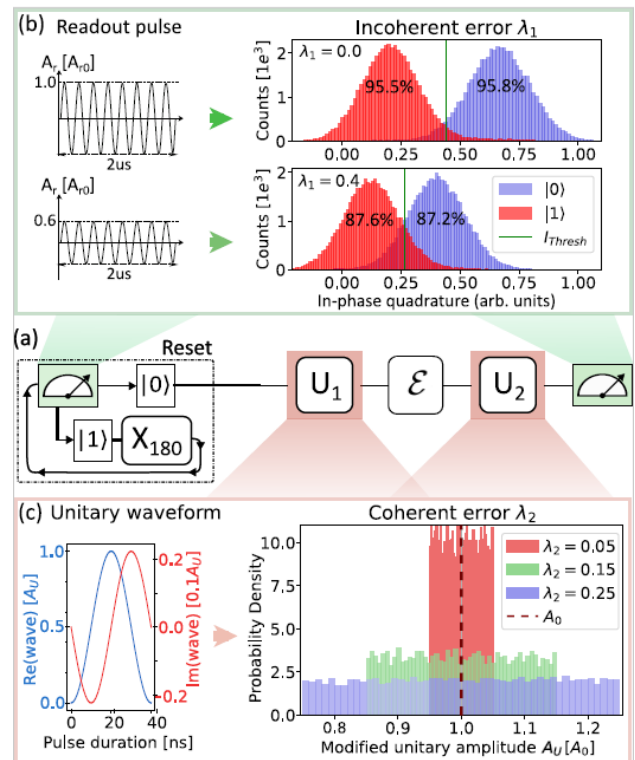


Figure 2: Implementation of noise channels. (a) QPT with active reset. (b) Incoherent noise channel: $A_r = A_{r,0}(1 - \lambda_1)$. (c) Coherent noise channel: $A_U = (1+r) A_0$ $r \sim \mathcal{U}(-\lambda_2, \lambda_2)$.