Contribution ID: **38** Type: **Oral Presentation**

Quantum Error Mitigation Through Autoencoder

Thursday, 20 March 2025 14:40 (20 minutes)

Quantum computing has gained significant attention in recent years, with numerous algorithms and applications under active development. Limited by the current quantum technology, quantum noise and readout error have become critical issues. Various methods have been proposed to address readout error through error mitigation techniques, typically involving post-processing of measurement data. However, most of these methods increase the quantum hardware overhead, leading to higher computational costs. In this work, we present a machine-learning-based approach that minimizes hardware overhead while improving computational efficiency. We employed a convolutional neural network (CNN) autoencoder, commonly used for image denoising, as our baseline model. The datasets were derived from 4-qubit random circuits with depths ranging from 1 to 18, generated using Qiskit Aer and Lima fake backends for target and noisy measurement data, respectively. The model was trained using mean squared error (MSE) as the loss function and Adam optimizer over 500 epochs, achieving an average noise reduction by 95% across the test set, with no signs of overfitting. To validate the model's effectiveness across diverse quantum states, we conducted extensive tests on both typical quantum circuits and algorithms, including Grover's search algorithm, Quantum Fourier Transform, Haar random circuits and symmetry protected topological states. The results demonstrated consistent and robust denoising in noisy measurement data, indicating that the autoencoder model is well-suited for efficient quantum error mitigation for current noisy quantum computers. For future studies, attention mechanisms offer a promising solution by accommodating variable-length data and enhancing spatial feature extraction. This work contributes to the advancement of quantum error mitigation techniques using machine learning.

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Session Classification: Physics & Engineering

Track Classification: Track 1: Physics and Engineering Applications