DATE PhD Forum

Enhancing Quantum Cloud Performance through Advanced Techniques

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1. Introduction and Motivation

- **Research background:** Quantum computing cloud services integrate hardware, software, and networks to provide online access to quantum resources. This field is vital for computational technology and can transform multiple industries. It enables cloud-based access to quantum processors without requiring hardware ownership. This thesis explores hardware and software optimizations to enhance the efficiency and reliability of quantum cloud services.
- **Research problem:** The problem to be solved in this paper is how to improve the performance and reliability of quantum cloud services through advanced technologies. Specifically, the research includes automatic calibration through the hybrid mixture of experts (MoE) at the hardware level, function-as-a-service orchestration of quantum servers at the software level to optimize task allocation, and security protection using quantum fingerprint technology in cloud service security.
- **Research challenges:** The research difficulties of this problem include: quantum devices are susceptible to noise in the noisy intermediate-scale quantum (NISQ) era, resulting in performance degradation; traditional quantum error calibration methods are cumbersome and inflexible, and difficult to adapt to changes and errors; quantum task scheduling is inefficient, resulting in resource waste and long waiting time.

2. Hardware Level: MoE Automatic Calibration

Automatic calibration at the hardware level: An automatic calibration method based on the MoE system is proposed to improve the accuracy and efficiency of quantum computer calibration. The MoE system predicts calibration parameters through multiple expert models, thereby realizing automated error detection and tracing. The method includes the following steps:

- ✓ Designing a MoE model for action selection, combining the results of multiple expert models to determine the calibration action.
- ✓ Through historical calibration data analysis, inferring the cause of calibration errors, and automatically performing error regression and adjusting calibration control parameters.
- ✓ Extensive simulation and experimental verification show that the automatic calibration method based on MoE outperforms traditional techniques in error traceability and calibration efficiency.

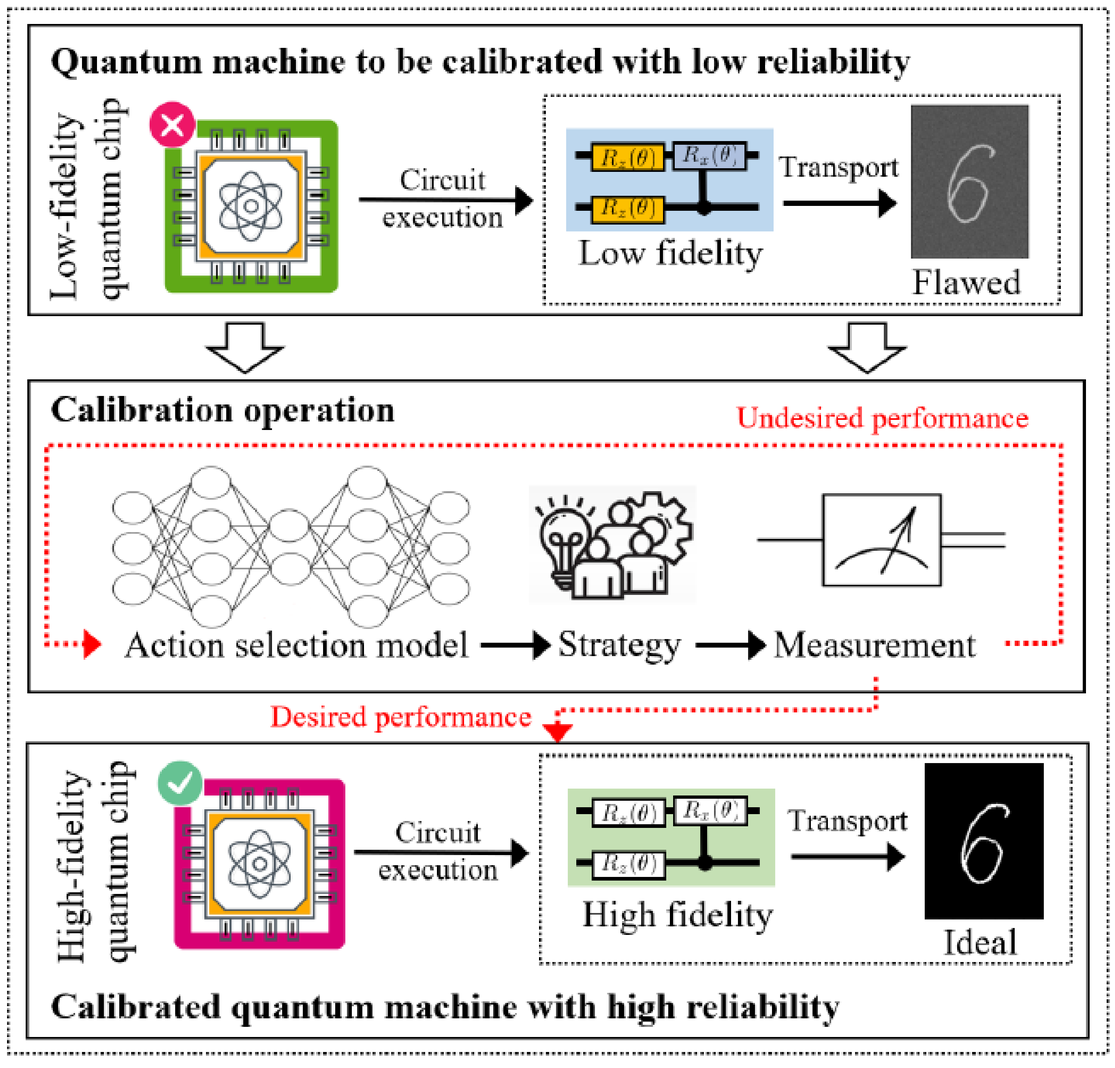

Figure 1: Illustrative explanation of MoE automatic calibration.

3. Software Level: Quantum Task Allocation

A quantum server function-as-a-service (FaaS) orchestration framework called Moirai is proposed to optimize resource allocation for quantum tasks. The framework maximizes performance and scalability by analyzing task allocation and machine characteristics. Specific methods include:

- ✓ A customized circuit representation scheme using directed acyclic graph (DAG) transformation and graph convolutional network (GCN) embedding vector feature extraction.
- ✓ In the device allocation and circuit deployment phase, the chip topology of the selected device and the embedding vector of the circuit are considered to generate a mapping strategy from virtual qubits to physical qubits.
- ✓ By interacting with the environment, changing the state vector of the device, calculating rewards and updating the reinforcement learning (RL) model parameters, an optimized device allocation solution and circuit deployment strategy are provided.

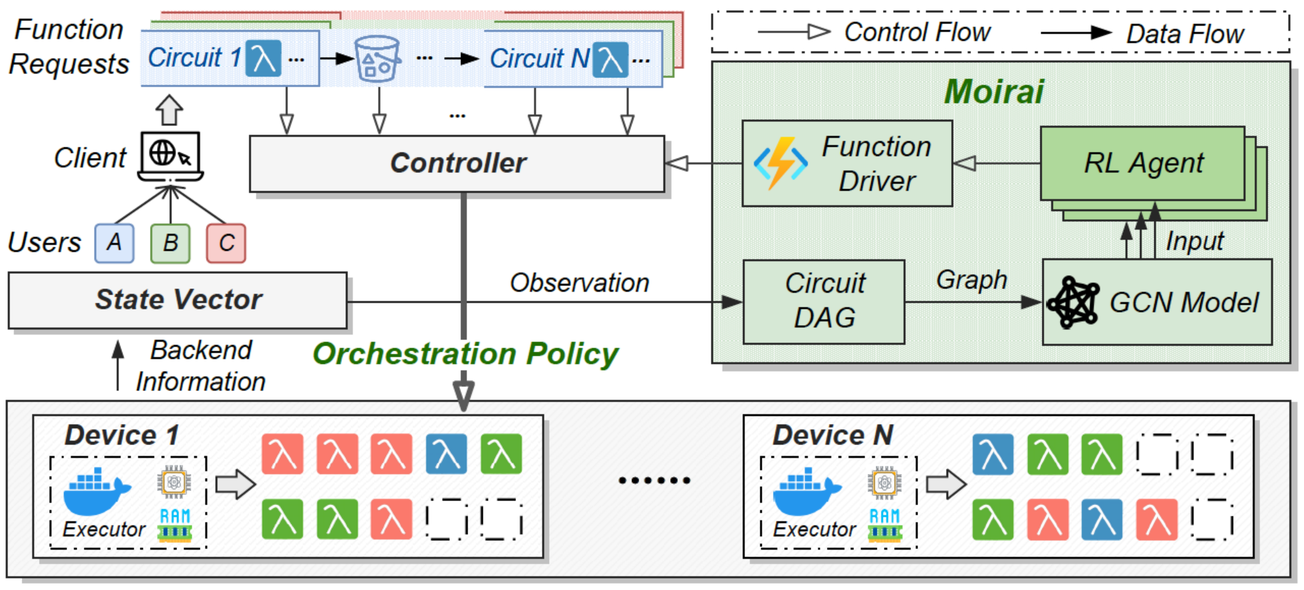

Figure 2: The architecture of circuit deployment.

4. Cloud Service Security: Quantum Fingerprint

Quantum fingerprint technology for cloud service security: A quantum device fingerprint identification method (TD-QDF) based on quantum task output is proposed to detect and defend against malicious activities. This method uses quantum neural network (QNN) to extract fingerprint features from noisy quantum computing results. Specific methods include:

- ✓ Building device fingerprints through quantum task output without relying on any device utilization.
- ✓ Using the output shift caused by quantum noise to represent quantum devices to enhance their practicality.

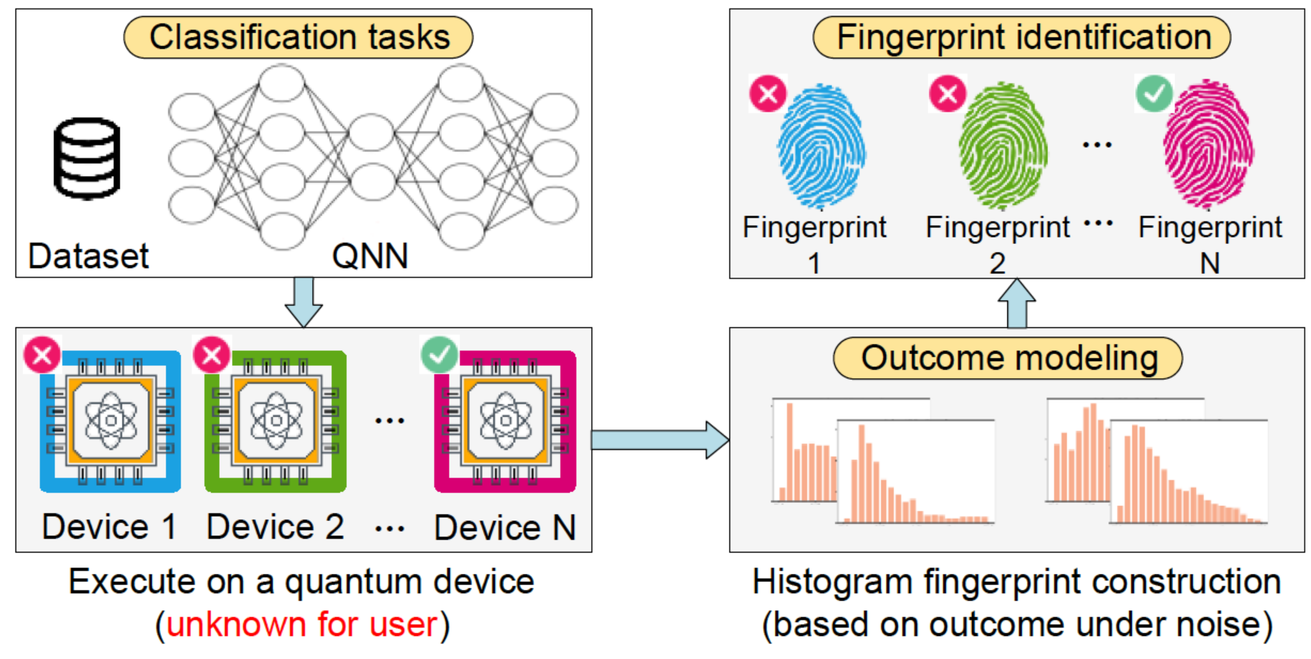

Figure 3: Quantum device fingerprint identification.

5. References

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