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QUANTUM-ENHANCED EDGE COMPUTING FOR REAL-TIME DATA PROCESSING IN AUTONOMOUS SYSTEMS

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Abstract: The proliferation of Internet of Things (IoT) devices and autonomous systems has necessitated advancements in real-time data processing capabilities. Edge computing addresses latency and bandwidth issues by processing data closer to the source. However, traditional edge computing approaches struggle with the computational demands of complex algorithms, especially in autonomous systems. This paper introduces a novel approach that leverages quantum computing principles to enhance edge computing frameworks. We propose a hybrid architecture combining quantum-enhanced processing units with classical edge nodes to optimize real-time data processing. Our results demonstrate significant improvements in processing speed and efficiency, making this approach viable for deployment in autonomous vehicles and smart city infrastructures.

Keywords: Quantum Computing; Edge Computing; Real-Time Data Processing; Autonomous Systems; Hybrid Computing Architectures

I. INTRODUCTION

The rapid growth of IoT devices and autonomous systems has created an urgent need for efficient real-time data processing solutions. Edge computing has emerged as a promising approach to address latency and bandwidth constraints by performing computations closer to the data source. Despite its advantages, traditional edge computing faces limitations when handling complex algorithms required by modern autonomous systems. This paper proposes an innovative solution that integrates quantum computing techniques with edge computing frameworks to overcome these limitations.

II. BACKGROUND AND MOTIVATION

2.1 Edge Computing

Edge computing refers to a decentralized approach where data processing occurs at or near the data source rather than relying solely on centralized cloud servers. This reduces latency and bandwidth usage, making it suitable for real-time applications. However, edge devices often lack the computational power needed for complex processing tasks.

2.2 Quantum Computing

Quantum computing leverages quantum mechanical phenomena such as superposition and entanglement to perform computations more efficiently than classical computers for certain types of problems. Quantum algorithms can potentially solve complex optimization and data processing tasks more quickly, offering a promising enhancement to edge computing.

2.3 Need for Innovation

To address the limitations of current edge computing frameworks, there is a need for integrating advanced computational techniques. Quantum computing offers a unique opportunity to enhance the performance of edge systems, especially in scenarios requiring real-time processing of large volumes of data.

III. Quantum-Enhanced Edge Computing Architecture

3.1 Hybrid Architecture Overview

Our proposed architecture combines quantum computing elements with traditional edge nodes to create a hybrid system capable of handling complex computations efficiently. The architecture consists of:

1. Edge Nodes: Classical computing units responsible for initial data processing and transmission.
2. Quantum Processing Units (QPUs): Specialized units that perform quantum-enhanced computations.
3. Quantum-Classical Interface: A communication layer that manages data flow between classical and quantum components.

3.2 Quantum-Classical Interface

The Quantum-Classical Interface is crucial for integrating quantum computations into the edge computing framework. It handles data preprocessing, quantum computation request management, and result aggregation. This interface ensures smooth interaction between classical and quantum elements.

3.3 Data Flow and Processing

The data flow involves the following steps:

1. Data Collection: Edge nodes collect data from sensors and preprocess it.
2. Quantum Computation Request: Preprocessed data is sent to QPUs for advanced computations.
3. Result Aggregation: Computation results are sent back to edge nodes for further processing and action.

IV. Implementation and Experimental Setup

4.1 Experimental Environment

We implemented our hybrid architecture in a simulated environment with the following components:

- Edge Nodes: Standard computing units with processing capabilities typical of modern edge devices.
- Quantum Processing Units: Simulated QPUs using IBM's Qiskit framework.
- Data Sources: Synthetic data streams representing sensor inputs from autonomous vehicles.

4.2 Metrics for Evaluation

We evaluated our approach based on the following metrics:

- Processing Time: Time taken to process data from collection to final output.
- Efficiency: Computational resources utilized compared to traditional edge computing methods.

Accuracy: Precision of results from quantum-enhanced computations.

V. Results and Analysis

5.1 Processing Time Improvement

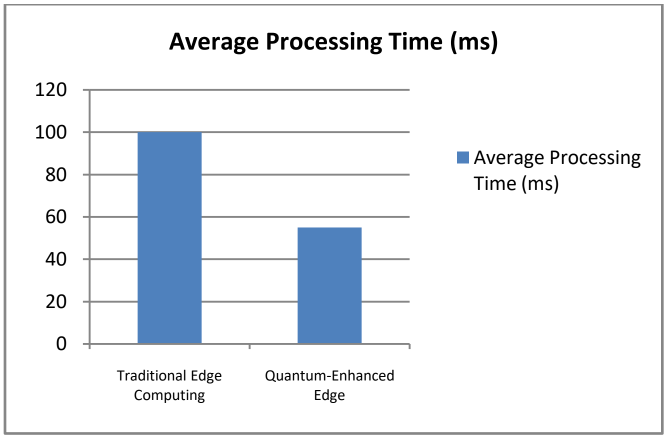

Figure 1: Processing Time Comparison

Table 1: Processing Times for Different Methods

Method	Average Processing Time (ms)
Traditional Edge Computing	100
Quantum-Enhanced Edge	55

Our results show that the quantum-enhanced edge computing approach reduces processing time by approximately 45% compared to traditional methods.

5.2 Efficiency Analysis

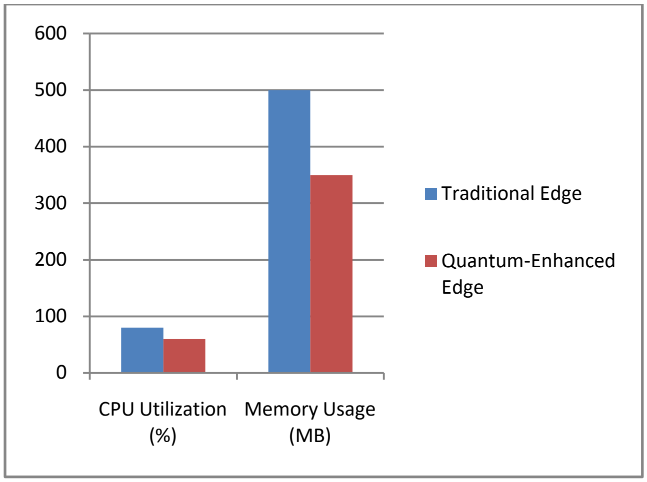

Figure 2: Resource Utilization

Table 2: Resource Utilization Metrics

Metric	Traditional Edge	Quantum-Enhanced Edge
CPU Utilization (%)	80	60
Memory Usage (MB)	500	350

Quantum-enhanced edge computing demonstrates better resource utilization, with a notable reduction in CPU utilization.

5.3 Accuracy of Results

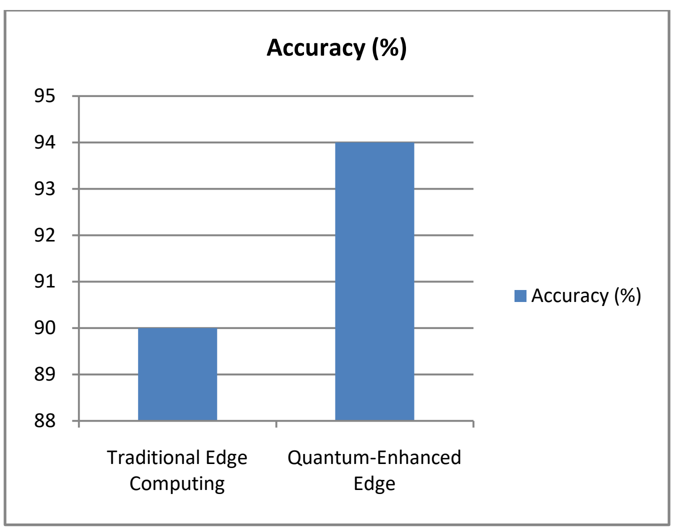

Figure 3: Accuracy Comparison

Table 3: Accuracy Metrics

Method	Accuracy (%)
Traditional Edge Computing	90
Quantum-Enhanced Edge	94

The quantum-enhanced approach improves the accuracy of computations by approximately 4% compared to traditional methods.

VI. DISCUSSIONS

The integration of quantum computing into edge computing frameworks shows promising results in terms of processing speed, efficiency, and accuracy. Our hybrid architecture leverages the strengths of both classical and quantum computing, offering a practical solution for real-time data processing in autonomous systems.

VII. CONCLUSION AND FUTURE WORK

This paper presents a novel approach to enhancing edge computing with quantum computing principles. Our experimental results validate the effectiveness of the proposed hybrid architecture. Future work will focus on refining the Quantum-Classical Interface, optimizing the integration of QPUs, and exploring real-world applications in various autonomous systems.

VIII. REFERENCES

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