

# Quantum-Guided Autoencoding for Enhanced Neutral Atom Reservoir Computing in Medical Image Classification

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*Abstract—*

***Index Terms—Reservoir Computing, Quantum-Guided Autoencoding, Neutral Atoms, Autoencoder, Dimensionality Reduction, Quantum Machine Learning, Hybrid Quantum-Classical Algorithms, Medical Image Classification***

## I. INTRODUCTION

- A. Background and Motivation*
- B. Challenges in Quantum-Classical Hybrid Systems*
- C. Contributions of This Work*

## II. BACKGROUND

- A. Quantum Computing with Neutral Atoms*
- B. Principles of Reservoir Computing*
- C. Quantum Reservoir Computing*
- D. Dimensionality Reduction for Image Data*
  - 1) Principal Component Analysis:*
  - 2) Autoencoder Architectures:*

## III. METHODOLOGY

- A. System Architecture Overview*
- B. Quantum Guided Autoencoder*
  - 1) Loss Function Design:*
  - 2) Balancing Reconstruction and Classification:*
- C. The Gradient Barrier Problem*
- D. Surrogate Modeling for Quantum Layers*
  - 1) Architecture and Training:*
  - 2) Gradient Flow Through Surrogate Models:*
- E. Rydberg Hamiltonian and Quantum Dynamics*
- F. Data Encoding Schemes*
- G. Quantum Readout Methods*
  - 1) Single-atom Measurements:*

Identify applicable funding agency here. If none, delete this.

*2) Two-atom Correlations:*

*3) Three-atom Correlations:*

## IV. EXPERIMENTAL SETUP

- A. Datasets*
- B. Implementation Details*
  - 1) Quantum Simulation Parameters:*
  - 2) Classical Network Architectures:*
- C. Comparison Methods*
- D. Performance Metrics*
- E. Parameter Sweep Strategy*

## V. RESULTS AND DISCUSSION

- A. Classification Performance Comparison*
- B. Ablation Studies*
  - 1) Impact of Guided Lambda Parameter:*
  - 2) Effect of Quantum Update Frequency:*
  - 3) Influence of Quantum Parameters:*
- C. Dimensionality Reduction Comparison*
- D. Surrogate Model Fidelity Analysis*
- E. Generalization to Unseen Data*

## VI. THEORETICAL ANALYSIS

- A. Information Encoding in Quantum Reservoirs*
- B. Gradient Flow in Quantum-Classical Hybrid Systems*
- C. Computational Complexity*
- D. Quantum Resource Requirements*

## VII. LIMITATIONS AND FUTURE WORK

- A. Current Limitations*
- B. Potential Extensions*
- C. Hardware Implementation Considerations*

## VIII. CONCLUSION

## REFERENCES