Distance-Based Feedback Model for Adaptive Quantum State Preparation

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Abstract

We propose a simple yet effective distance-based feedback model for adaptive quantum circuit control. Our method utilizes Hamming distance between the dominant output state and a user-defined target state to iteratively adjust the quantum circuit via rotation gates. Through repeated simulations using Qiskit, we demonstrate that the circuit progressively aligns its output distribution toward the desired state. The statistical significance of this convergence is verified through ANOVA and t-tests. This model presents a noise-resilient and hardware-feasible alternative for state preparation in NISQ devices, suggesting further applications in quantum control and hybrid quantum learning systems.

1 Introduction

Quantum state preparation is a critical component of quantum computing and simulation. Especially in the NISQ era, shallow and adaptive circuits are vital for controlling quantum systems under hardware constraints. We introduce a feedback-based model that iteratively brings a quantum circuit's output distribution closer to a target quantum state, using a distance-driven mechanism rather than cost-function minimization or gradient descent.

2 Methodology

- **Initial Circuit:** A 3-qubit quantum circuit is initialized with Hadamard gates and entangling gates (CX and Z).
- **Measurement and Dominant State Detection:** The circuit is measured to identify the most frequent (dominant) output state.
- **Distance Computation:** Hamming distance between the dominant state and the target state is computed.
- **Rotation Adjustment:** A parameterized Ry rotation is applied to all qubits, with angle $\theta = \frac{\pi \cdot d}{3}$, where d is the Hamming distance.
- **Iteration:** The process is repeated for 100 steps across multiple target states ('000', '101', '111').

3 Results

Output probabilities for the target state were recorded across repetitions. Grouped by Hamming distance, the mean and standard deviation of the target state's appearance were computed. Statistical analyses via one-way ANOVA and independent t-tests confirmed that smaller distances correlate with significantly higher target probabilities ($p < 0.01$).

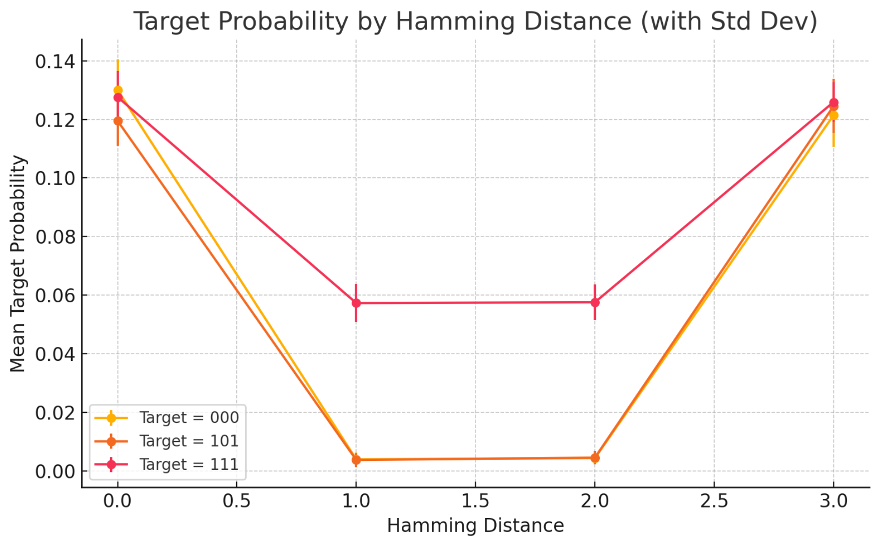

Figure 1: Target probability by Hamming distance across target states ('000', '101', '111'), with standard deviation as error bars.

4 Discussion

This model demonstrates the ability of a simple quantum circuit to adaptively steer its output toward a predefined quantum state using distance-based control. Unlike traditional variational methods, our approach requires no gradient evaluation and operates with fixed, low-depth circuits, making it highly compatible with noisy quantum devices.

5 Conclusion and Outlook

The proposed feedback model offers a novel approach to quantum state control, using observable output statistics to iteratively align circuit behavior. This paves the way for research into self-regulating quantum circuits, reinforcement-like adaptive protocols, and dynamic quantum state tracking.

Keywords

quantum control, state preparation, feedback model, Hamming distance, NISQ, quantum learning, variational alternatives