HQC-NBV: A Hybrid Quantum-Classical View Planning Approach

Supplementary Material

0.1. Detailed Experimental Configurations

Experimental Scenes

We design three distinct scenes with varying levels of complexity to comprehensively evaluate the robustness and scalability of the proposed methods.

- Scene 1 (S1): Surrounding obstacles in area 20×20 unit^2, Fig.1(a);
- Scene 2 (S2): Central obstacle in area 20×20 unit^2, Fig.1(b);
- Scene 3 (S3): Complex walls with surrounding obstacles in area 20×20 unit^2, Fig.1(c);
- Scene 4 (S4): Surrounding and central obstacles in larger area 40×40 unit^2, Fig.1(d).

Ablation Configurations

To investigate the impact of entanglement structure in our approach, we implement four variants of Ansatz architecture while maintaining identical Hamiltonian formulations and identical optimization procedures:

- Full Architecture (FA): Our proposed bidirectional alternating entanglement pattern with both intra-group and inter-group CNOT gates;
- Non-Entangled (NE): A circuit with the same number of parameterized rotations but without any entangling gates, equivalent to independent qubit rotations;
- Intra-Group Only (IG): Preserving parameter group coherence through intra-group entanglement but removing connections between different parameter groups;
- Inter-Group Only (EG): Maintaining only the connections between parameter groups while removing intra-group entanglement.

To assess the contribution of quantum coherence-preserving terms in our cost Hamiltonian, we conducted a systematic ablation study by modifying the $\hat{H}_{\text{coh}}$ component:

- Complete Hamiltonian (CH): Including all coherence-preserving terms (X and XX operators with adaptive weights);
- No Coherence Terms (NC): Removing all $\hat{H}_{\text{coh}}$ components, retaining only the problem-encoding Z-based terms;
- Single-Qubit X Only (SQX): Preserving the $\sum_i \alpha_{X_i} \hat{X}_i$ terms while removing two-qubit XX interactions.

0.2. Visualized Results

We present two groups of continuous views planned by HQC-NBV in S1 and S2, respectively. It demonstrates the effectiveness of our viewpoint planning algorithm in progressively expanding coverage across different scenes, over several iterations. The samples start from an initial status where only a few areas have been explored, the algorithm efficiently selects viewpoints that maximize the coverage of unobserved regions. With each subsequent iteration, the coverage area grows substantially with feasible movement.

0.3. Classical Fallback Strategy

To ensure physical feasibility of the quantum-optimized solutions, we impose a hard constraint that projects quantum solutions onto the manifold of known free configurations. Formally, let $v_q = (x_q, y_q, \theta_q) \in \mathcal{C}$ be the viewpoint generated by quantum optimization, and let $\mathcal{F}_t \subset \mathcal{C}$ denote the known free configuration space at iteration t, defined as:

$$\mathcal{F}_t = \{v = (x, y, \theta) \in \mathcal{C} \mid \mathcal{M}_t(x, y) = 1\} \tag{1}$$

where $\mathcal{M}_t(x, y) = 1$ indicates that position (x, y) is observed and confirmed to be obstacle-free in the observation map at iteration t.

When $v_q \notin \mathcal{F}_t$, we apply a constrained projection operator $\mathcal{P} : \mathcal{C} \to \mathcal{F}_t$ that preserves directional intent while ensuring feasibility:

$$v_{t+1} = \mathcal{P}(v_q) = \arg\max_{v \in \mathcal{F}_t} \{\|v - v_t\|_2 \mid (v - v_t) \cdot (v_q - v_t) > 0\} \tag{2}$$

subject to:

$$\theta_{t+1} = \theta_q \tag{3}$$

This formulation identifies the furthest point along the ray from v_t to v_q that remains within the known free space $\mathcal{F}_t$, while preserving the orientation component θ_q from the quantum solution. The constraint $(v - v_t) \cdot (v_q - v_t) > 0$ ensures that the projected solution maintains the same directional intent as the original quantum solution.

This projection-based fallback strategy represents a hard constraint that guarantees physical feasibility while minimally perturbing the quantum-optimized exploration strategy, embodying the complementarity between quantum-derived global navigation policy and classical geometric constraint satisfaction.

0.4. Quantum Computing Preliminaries

0.4.1. Basic Concepts and Properties

Quantum bit (qubit) is the basic computational element in quantum computers. Different from the classical bit, a qubit has the state of a superposition formed by two basis states $|0\rangle = [1\ 0]^T$ and $|1\rangle = [0\ 1]^T$. Qubits can be prepared via

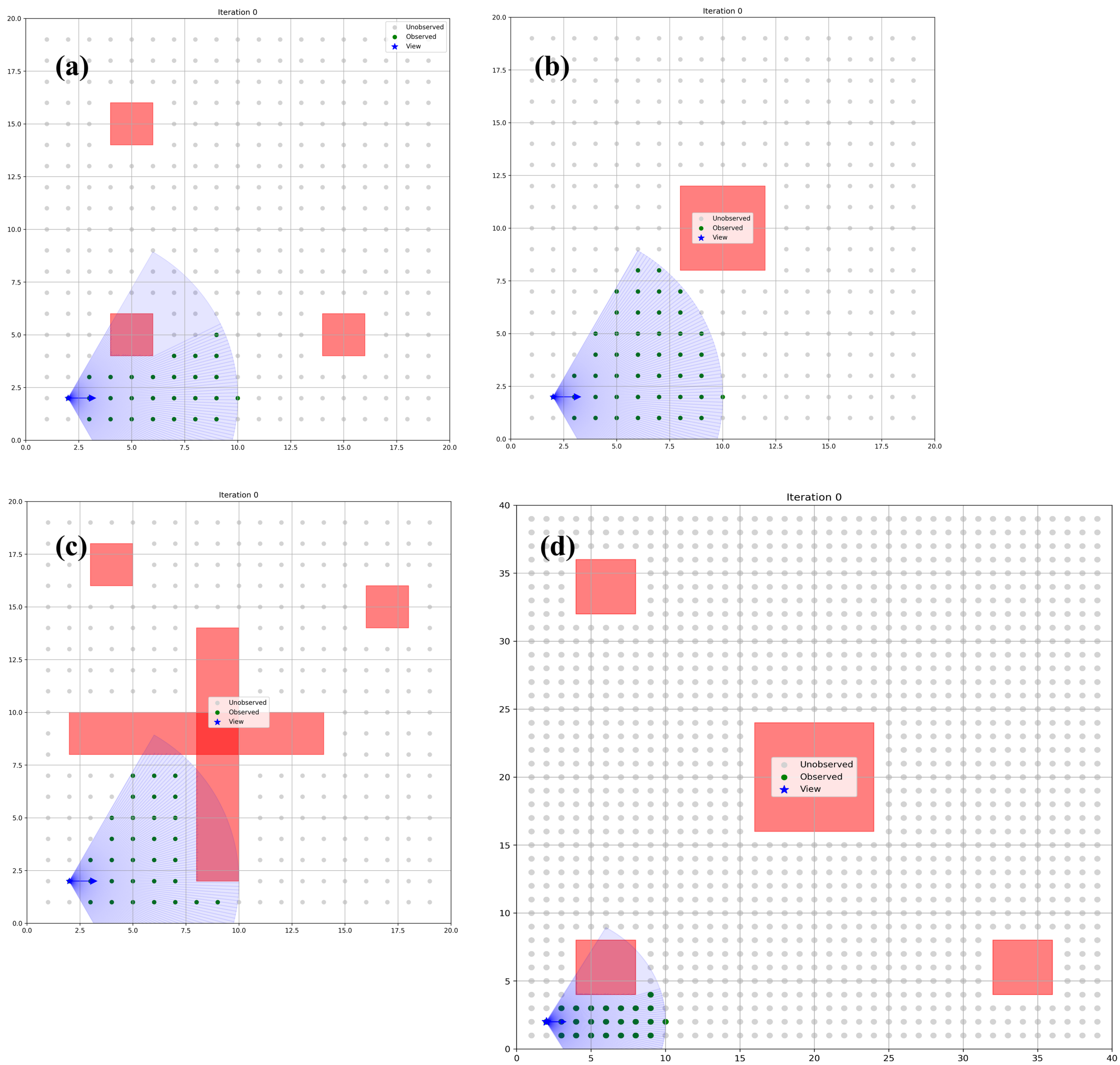

Figure 1. Visualized experimental scenes: (a) Scene 1; (b) Scene 2; (c) Scene 3; (d) Scene 4.

different kinds of approaches, including but not limited to photons, trapped ions, Si-based quantum dots, and superconducting circuits. In the NISQ era, the most widely used one is the superconducting circuit approach, leveraging its advantage in scalability.

Superposition refers to the property of the quantum state that can be a linear combination of the corresponding basis states. i.e. a qubit state $|\psi\rangle$ can be described as:

$$|\psi\rangle = c_1|0\rangle + c_2|1\rangle \tag{4}$$

c_1 and c_2 are complex numbers, named probability amplitudes, with $|c_1|^2 + |c_2|^2 = 1$.

Entanglement is the critical property for quantum computing. In an entangled system, the state of each qubit is interconnected with the states of the other qubits without space limit, meaning that no qubit can be described independently of the rest of the system.

Measurement the state of a qubit yields one of the basis states, either $|0\rangle$ or $|1\rangle$. The probability of measuring $|0\rangle$ and $|1\rangle$ are given by $|c_1|^2$ and $|c_2|^2$ respectively. Once a

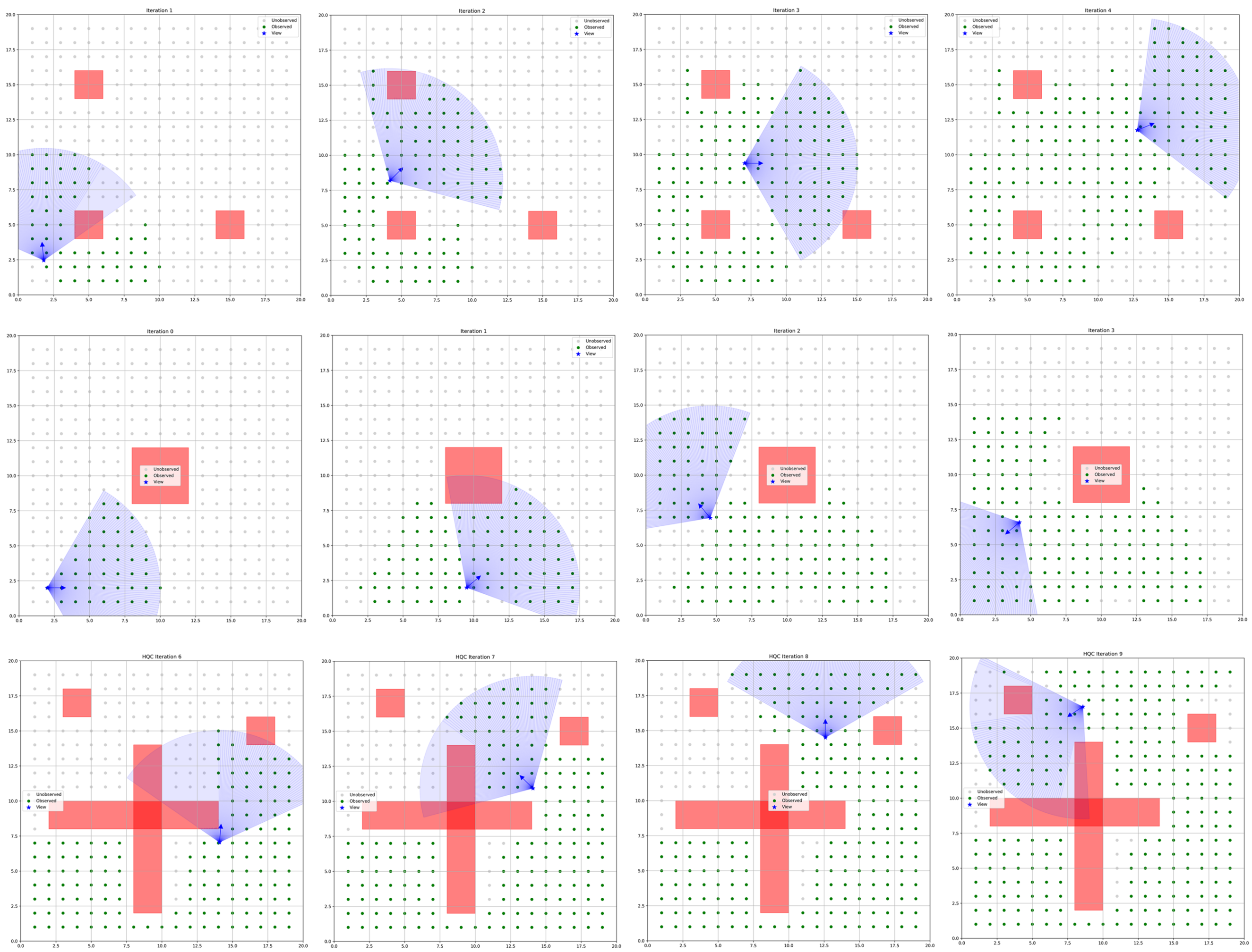

Figure 2. Sample continues views planned by HQC-NBV in S1 and S2. The red rectangles denote the obstacles, the blue wedges represent the FOV of the viewpoint, and the green dots are the observed grid.

measurement is performed, it corresponds to an observation of the qubit, leading to the collapse of its wave function.

0.4.2. NISQ and AQC

Adiabatic Quantum Computing (AQC) is a paradigm that focuses on solving optimization problems by evolving a quantum system from a known initial state to a final state encoding the solution. This is achieved by slowly evolution the system's Hamiltonian $H(t)$, ensuring the ground state of the initial Hamiltonian H_0 evolves to the ground state of the final Hamiltonian H_f.

$$H(t) = (1 - t/T)H_0 + (t/T)H_f \tag{5}$$

The Noisy Intermediate-Scale Quantum (NISQ) era represents the current stage of quantum technology, characterized by quantum computers with a moderate number of qubits (typically a few dozen to a few hundred) that are prone to noise and errors. Despite these limitations, NISQ devices show promise in solving practical problems using variational quantum algorithms and quantum approximate optimization algorithms, which are resilient to noise and can be implemented on current hardware. Variational quantum algorithms (VQAs) are a class of hybrid quantum-classical algorithms designed to work on NISQ devices. They use a parameterized quantum circuit $U(\theta)$ to prepare a quantum state $|\psi(\theta)\rangle$ and then measure an observable O. The goal is to minimize the expectation value $E(\theta)$ of a given Hamiltonian H:

$$E(\theta) = \langle\psi(\theta)|H|\psi(\theta)\rangle \tag{6}$$

The parameters θ are optimized using a classical optimizer to find the minimum energy state.