Quantum Annealing for Robotic Path Planning Using RRT
Enhancing Path Planning Efficiency and Optimality

Our Team

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Agenda

1. Problem Statement and Complexity
2. Quantum Annealing Overview
3. Formulating Path Planning as a QUBO Problem
4. Results, Insights, and Future Directions

Problem Statement

- Landmines pose a global humanitarian threat, causing thousands of casualties annually.
- Robotic systems can detect and clear mines, saving lives and restoring safe land access

Objective

- Implement the Rapidly-Exploring Random Tree (RRT) algorithm for robotic path planning.
- Explore quantum annealing as a complementary optimization tool to enhance RRT performance.

Path Planning is NP-Hard:

- **Exponential Growth:** Solution space grows exponentially with dimensionality.
- **Obstacle Avoidance:** Collision detection adds computational overhead.
- **Optimality Requirements:** Finding the shortest path increases complexity.
- **Dynamic Environments**: Real-time updates are needed for moving obstacles

Classical RRT* Algorithm

Overview:

- RRT* is an optimized version of RRT for path planning.
- Incrementally builds a tree of possible paths in a 2D environment with obstacles.

Key Components:

- Node Class: Represents points in 2D space.
- RRTStar Class: Implements the algorithm and visualization.

Visualization:

- Obstacles: Red circles.
- Tree edges: Green lines.
- Final path: Blue lines.

Quantum Annealing in Path Planning :

Why Quantum Annealing?

- **Efficient Exploration:** Quantum annealing can sample large spaces quickly, improving path generation in high-dimensional environments.
- **Global Optimization:** Finds globally optimal paths, unlike classical RRT which may settle for local optima.
- **Constraint Handling**: Obstacle avoidance and path connectivity are naturally integrated into the QUBO formulation.
- **Hybrid Potential**: Combines classical RRT with quantum annealing for improved efficiency and scalability

Formulating Path Planning as a QUBO Problem

Quadratic Unconstrained Binary Optimization (QUBO):

- Binary variables represent nodes and edges in the path.
- Objective function minimizes path cost (distance, energy, etc.).
- Constraints (e.g., obstacle avoidance, start/goal points) are embedded in the QUBO matrix

Quantum Annealing Solves QUBO :

- Qubits represent binary variables.
- Quantum annealer searches for the lowest-energy configuration, corresponding to the optimal path.

Results and Insights :

- **Optimized Node Selection**: Quantum annealing improves node selection in RRT*, leading to better path quality.
- **Global Optimization:** Quantum annealing finds globally optimal paths, unlike classical RRT* which may settle for local optima.
- **Constraint Handling:** Constraints are naturally integrated into the QUBO formulation.
- **Improved Path Quality:** Quantum-optimized paths are shorter and more efficient.
- **Real-Time Visualization**: Pygame library used to visualize pathfinding in real-time.
- **Computational Efficiency**: Quantum annealing offers potential speedups in high-dimensional spaces.

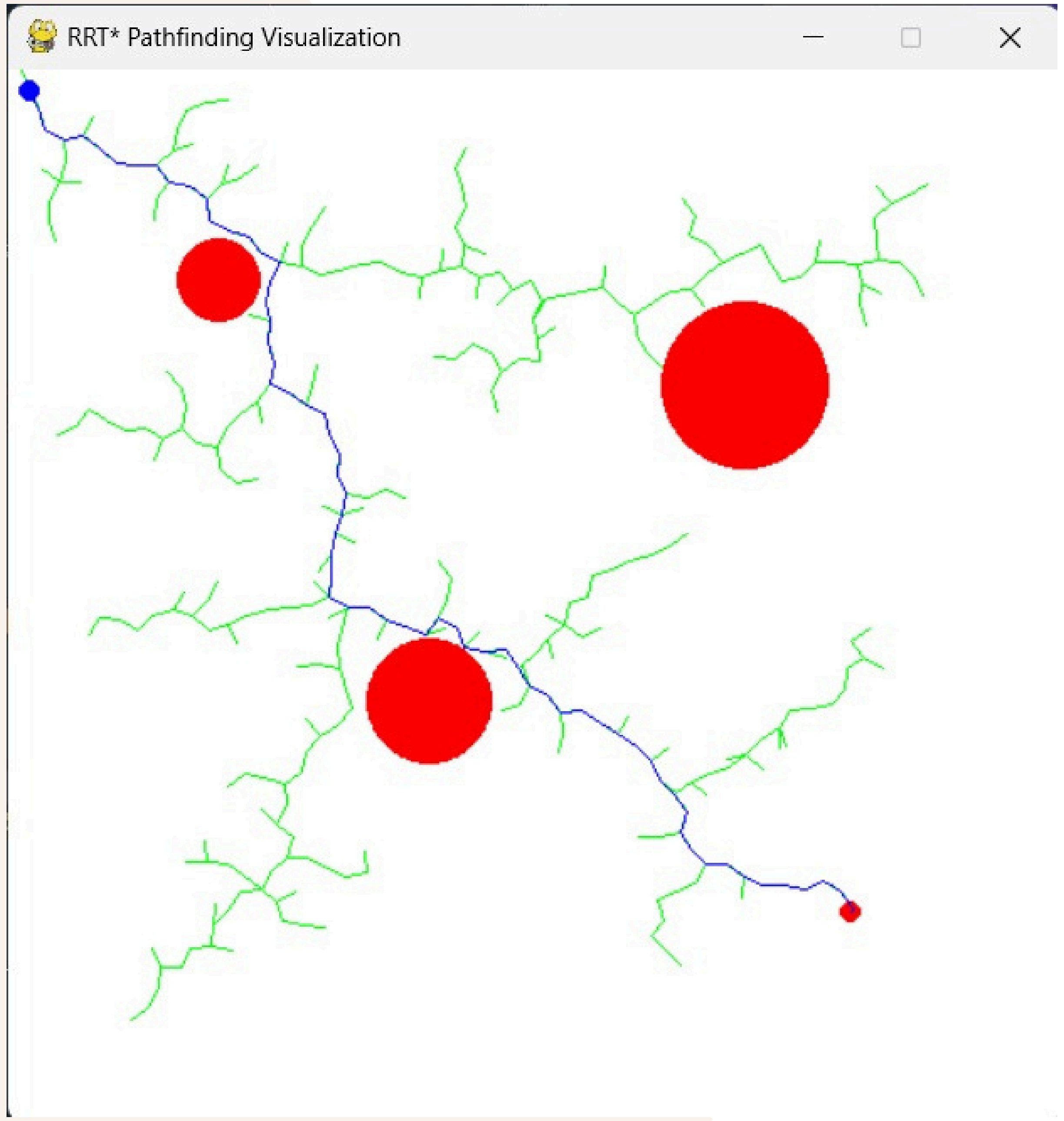
Comparison of Classical and Quantum Approaches

Aspect	Classical RRT*	Quantum Annealing
Optimality	Asymptotically optimal (requires many iterations)	Can find globally optimal solutions faster
Time Complexity	$O(n \log n)$	Potentially exponential speedup for NP-hard problems
Scalability	Degrades with dimensionality and obstacle density	Better suited for high-dimensional spaces
Handling Constraints	Requires explicit collision checking	Constraints can be encoded in the QUBO formulation
Real-World Applicability	Widely used but limited by computational resources	Promising but requires quantum hardware

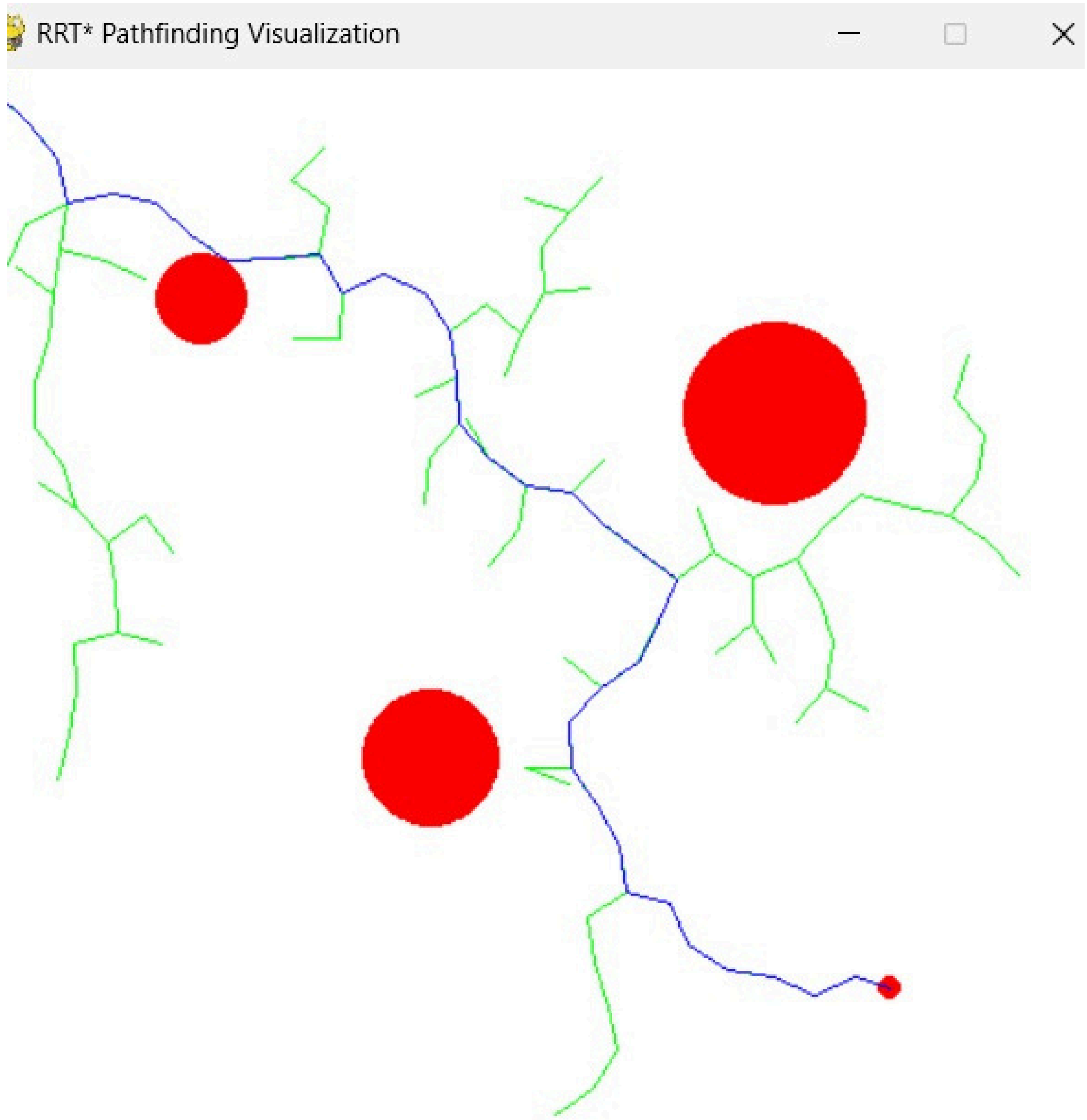
Future Directions

Potential Improvements:

- Advanced Sensors: Integrate LiDAR, cameras, or ultrasonic sensors for better obstacle detection.
- Dynamic Path Planning: Extend RRT* to handle rapidly changing environments.
- Hybrid Quantum-Classical Algorithms: Combine RRT* with quantum annealing for global optimization.
- Scalability for Multi-Robot Systems: Coordinate multiple robots in the same environment.
- Machine Learning Integration: Use ML to predict optimal sampling points.
- Quantum Hardware Improvements: Leverage advancements in quantum computing hardware.



Classic RRT*



Quantum RRT*

Thank you!