Project Information
Project Type: Team
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Research Title: Quantum-Enhanced Graph Optimization for Trustworthy Multi-Agent Coordination in Digital Twin Robots

Problem Statement
As robotic systems become central to high-stakes operations—such as autonomous delivery, search and rescue, smart healthcare, and industrial automation—the need for secure, trustworthy, and scalable multi-agent coordination becomes critical. These systems often rely on digital twins: real-time virtual replicas of physical robots, environments, and tasks that support simulation, planning, and monitoring.

However, ensuring reliable multi-robot and human-robot collaboration in dynamic, uncertain environments remain a major challenge. This is further complicated by increasing risks around cybersecurity, data integrity, and trust erosion—where digital twins may become desynchronized or manipulated by adversarial attacks (e.g., sensor spoofing or communication interference), compromising decision-making and safety.

This research investigates how Quantum AI, particularly quantum-enhanced graph-based optimization, can be used to:

1. *Improve task allocation, path planning, and load balancing in real time across robot teams and human collaborators.*
2. *Enable trust-aware coordination by detecting anomalies and optimizing decisions using secure graph structures within a digital twin framework.*

We will construct dynamic, multi-layered knowledge graphs that represent physical robots, digital twins, environmental objects, task flows, and human operators—allowing for both operational efficiency and the detection of inconsistencies or adversarial manipulation.

Literature Review

1. Modeling and Evaluating Trust Dynamics in Multi-Human Multi-Robot Task Allocation

- Authors: Ike Obi, Ruiqi Wang, Wonse Jo, Byung-Cheol Min
- Publication Year: 2025
- Summary: This paper introduces the Expectation Confirmation Trust (ECT) model to analyze trust dynamics in multi-human, multi-robot (MH-MR) teams. The ECT model is grounded in the idea that trust plays a critical role in communications between MH-MR teams. These communications include things like effective coordination, adaptive decision making, and overall team performance in complex environments; the study demonstrates that incorporating trust models into task allocation algorithms improves

task success rates and reduces completion times across various team configurations. The authors evaluated ECT against five other existing models and found that the ECT model is consistently better than the other models in performance. However, the study was limited to simulations and does not test with any real world deployment. Our work will extend on this study to test how well the ECT model does when tested with real deployment, not just simulations.
- Link: arXiv:2409.16009arxiv.org+2arxiv.org+2arxiv.org+2

2. Attacking Digital Twins of Robotic Systems to Compromise Security and Safety

- Authors: Christopher Carr, Shenglin Wang, Peng Wang, Liangxiu Han
- Publication Year: 2022
- Summary: This study explores potential cyber-physical attacks on digital twin systems, specifically using the Robot Operating System (ROS), highlighting vulnerabilities that could lead to safety and security breaches. The paper emphasizes the need for robust security measures in digital twin implementations, as they become easy attack vessels when not properly secured. The paper displays how person-in-the-middle (PiM) attacks can be used to expose vulnerabilities in the ROS; they showed how PiM attacks can effect velocity control and joint control, and both the PiM attacks can be remotely done by the attacker. All of this conveys that attacks are possible, and that vulnerabilities in digital twin systems exist; however, they do not offer a solution, just a call to action to be aware of how secure that the systems are. Our work will extend on this study by figuring out how to stop these attacks on our own digital twin system.
- Link: arXiv:2211.09507

3. Exploring the Synergy of Human-Robot Teaming, Digital Twins, and Machine Learning

- Authors: Evan Langas, Muhammad Zafar, Filippo Sanfilippo
- Publication Year: 2025
- Summary: This paper discusses the integration of human-robot teaming with digital twin technology and machine learning. It highlights how these technologies can enhance perception, prediction, and decision-making in human-centric industrial systems. The methodology consists of a progressive framework: they start with exploring human-robot interaction (HRI), to human-robot collaboration (HRC), to physical HRC (pHRC), to true human-robot teaming (HRT). By integrating real time sensing, simulation, and intelligent decision-making, digital twins and machine learning can enhance robot perception, safety, and adaptability in dynamic industrial environments. They also discuss the ethical considerations of giving a robot autonomy, privacy, and how the designs have to be human-centric to make it more ethical. Some of the limitations include the fact that this paper is mostly conceptual; there is no real empirical data, no tests/experiments really conducted. Our work will extend on this by attempting to enhance digital twin technology using machine learning using some of the conceptual ideas they have came up with for enhancements.
- Link: Springerlink.springer.com