Multi-Agent Coordination in Robotic Missions

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Motivation & Research goals

Search and Rescue (SAR) operations increasingly leverage **multi-robot systems** to achieve **collaborative mission**s with enhanced efficiency, reliability, and operator safety in hazardous environments [1]. This research aims to investigate **autonomy schemes** for **coordinating hyper-modal robotic systems** by focusing on two critical applications:

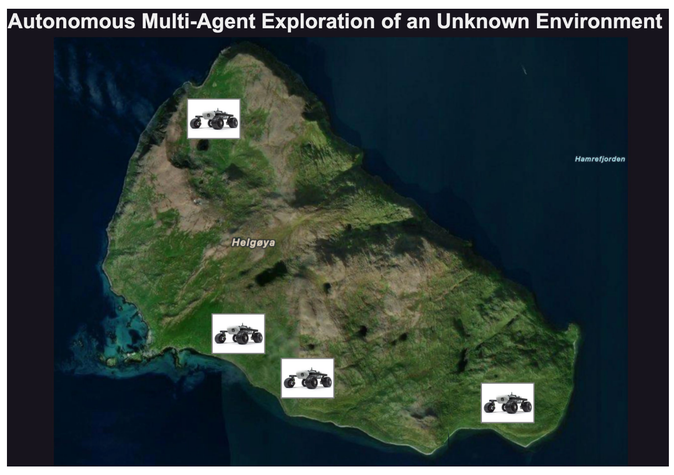
Decentralized Exploration of Unknown Environments
Robots autonomously explore large-scale unknown areas to build a map with the locations of the obstacles. The agents should interact with each other to coordinate their efforts (no central unity), but inter-agent communication is constrained to better model real-world conditions.

Automatic Reconfiguration of Hyper-Modal Robots
Robots change their spatial configuration dynamically to adapt to varying environmental topologies, such as tunnels and mines. This approach facilitates successful mission completion in challenging and unstructured terrains.

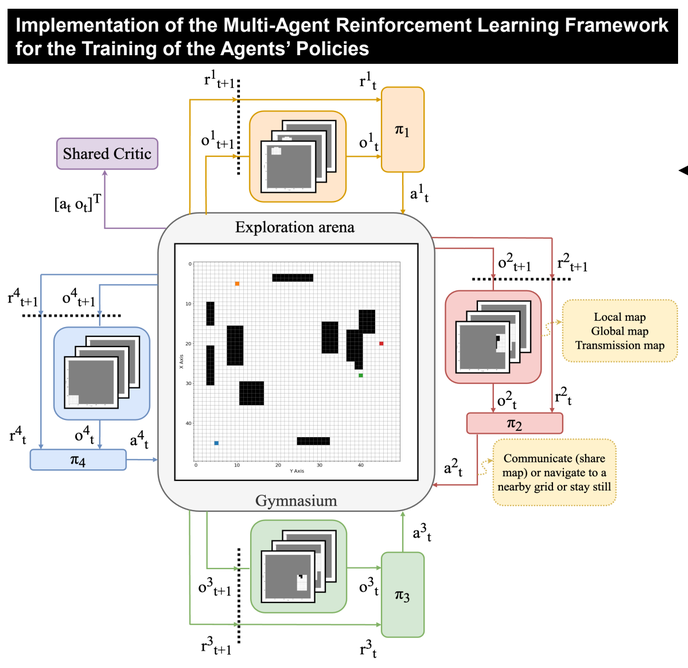
Challenges

- **Efficient Coordination** between hyper-modal robots to execute tasks in dynamic environments
- **Handling of intermittent and unreliable transmissions** between agents for collaborative robotic behaviours
- **System Coexistence** between diverse robotic systems
- Deployment in **unstructured** and **dynamic** scenarios

Autonomous Multi-Agent Exploration of an Unknown Environment



Implementation of the Multi-Agent Reinforcement Learning Framework for the Training of the Agents' Policies



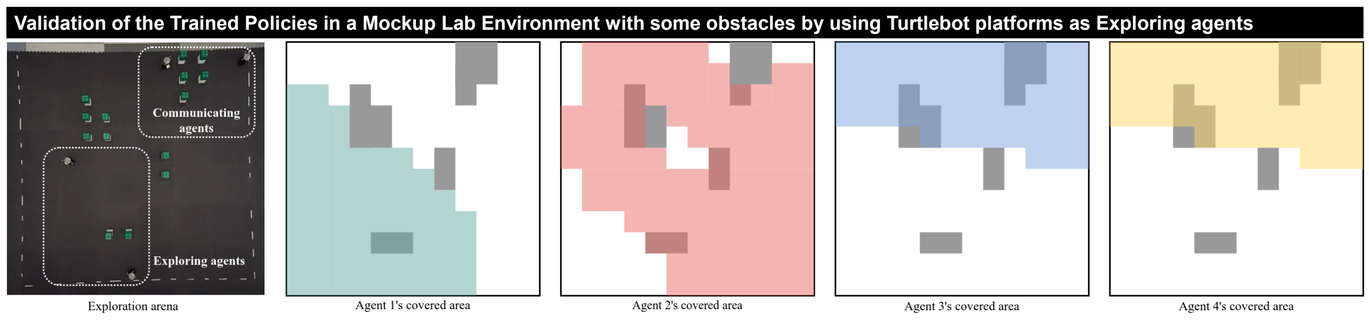
Methods

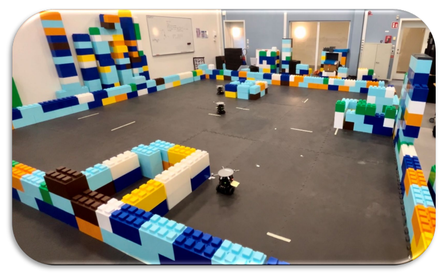
We address the challenge of decentralized exploration by training robots' policies using **Multi-Agent Reinforcement Learning** (MARL). Built on the Centralized Training with Decentralized Execution (CTDE) paradigm and leveraging the **Partially Observable Stochastic Game** (POSG) framework, our model empowers physically homogeneous agents with heterogeneous behavioral policies [2]. At each step, each agent expands its 2D occupancy grid map of the environment according to sensor data and operate a decision. Indeed, it can autonomously select its next navigation goal for exploration or opt to communicate and share its map, enabling collaborative interactions with its neighbors.

Validation

We developed a **framework using ROS 2 Humble and Gazebo** to validate and evaluate the performance of our proposed policies [3]. This implementation currently supports the simulation of four TurtleBots exploring a structured environment in Gazebo and also their deployment on real robots in a reconstructed environment with some obstacles in the Lab [4].

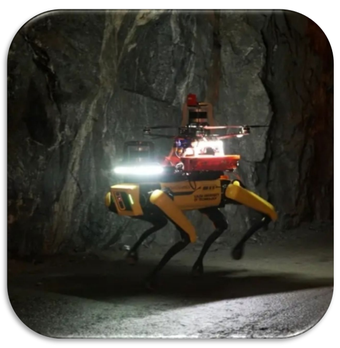
Validation of the Trained Policies in a Mockup Lab Environment with some obstacles by using Turtlebot platforms as Exploring Agents





Future directions

- **Ground and Aerial Collaboration**: Investigate the coordination between ground robots and aerial vehicles to improve the execution of complex missions
- **Robust Decentralized Schemes**: Strengthen the resilience of decentralized approaches by studying the impact of communication constraints and failures
- **Explainable AI**: Enhance the trustworthiness and interpretability of the proposed solutions, ensuring their safe deployment in practical applications



References

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2. G. Calzolari, V. Sumathy, C. Kanellakis and G. Nikolakopoulos, "D-MARL: A Dynamic Communication-Based Action Space Enhancement for Multi Agent Reinforcement Learning Exploration of Large Scale Unknown Environments," *2024 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*
3. G. Calzolari, V. Sumathy, C. Kanellakis, and G. Nikolakopoulos, 'Investigating the Impact of Communication-Induced Action Space on Exploration of Unknown Environments with Decentralized Multi-Agent Reinforcement Learning', arXiv [cs.RO]. 2024.
4. G. Calzolari, V. Sumathy, C. Kanellakis, and G. Nikolakopoulos, 'Reinforcement Learning Driven Multi-Robot Exploration via Explicit Communication and Density-Based Frontier Search', arXiv [cs.RO]. 2024.