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PeraSwarm: Simultaneous Localization and Mapping in Multi-Agent Swarm Robotic System

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Abstract - SLAM plays a pivotal role in enabling autonomous navigation and exploration. When applied to multi-agent swarm systems, SLAM takes on new dimensions, addressing challenges unique to collaborative robotic networks. Here, we delve into the intersection of SLAM and swarm robotics, illuminating essential concepts and implications.

Simultaneous Localization and Mapping (SLAM):

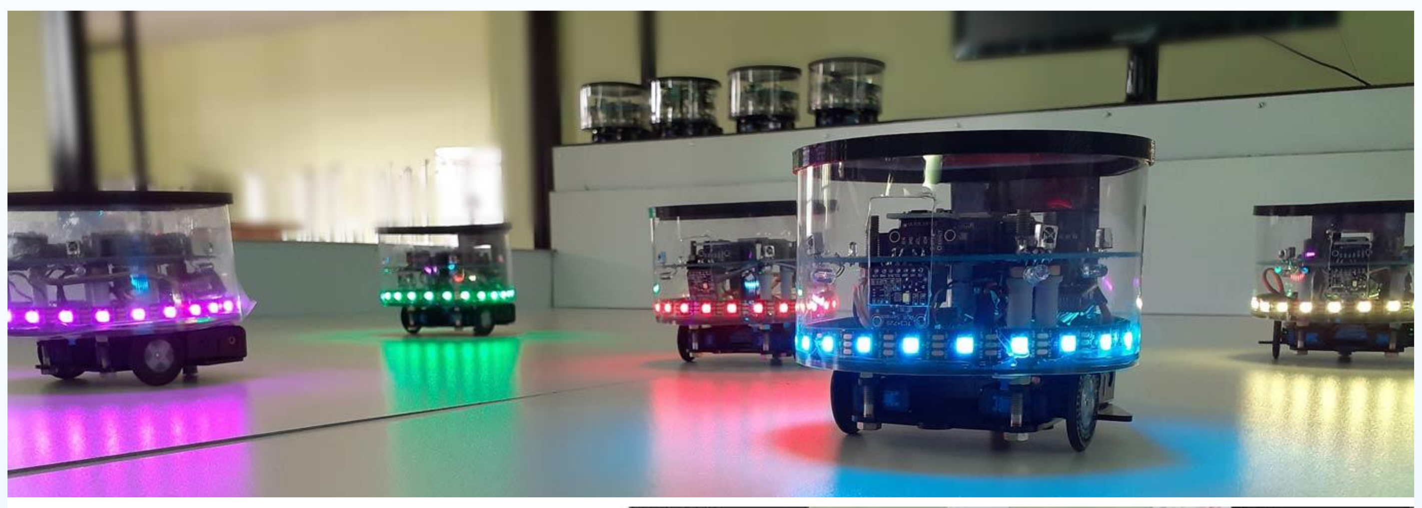
- SLAM is a fundamental problem in robotics, where an agent (such as a robot or drone) simultaneously estimates its own position and constructs a map of its environment.
- Traditional SLAM algorithms often assume a single agent operating in isolation. However, in swarm systems, multiple agents collaborate to achieve common goals.

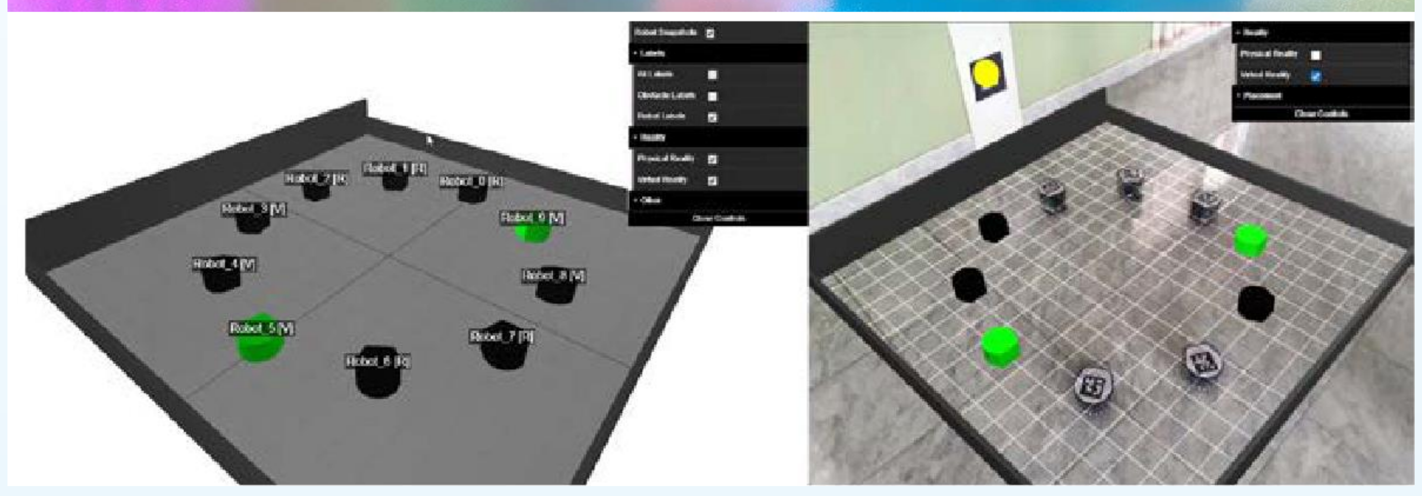
Objective:

- Swarm agents work collectively to explore unknown areas, uncover obstacles, and map features. The objective is to maximize coverage and minimize redundancy.

Features:

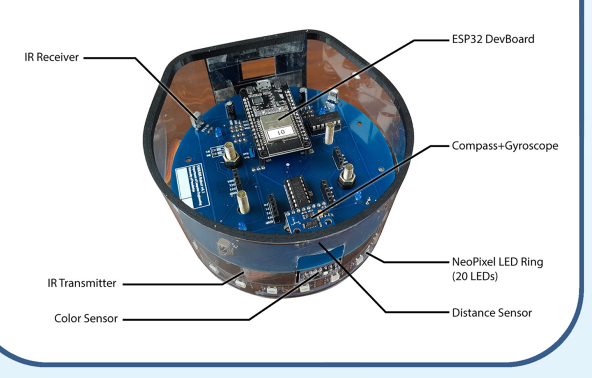
- *Self-organization*: Robots self-adapt via local interactions, resulting in collective behavior.
- *Decentralized*: Each robot independently decides without central control.
- *Cooperation*: Robots work together to achieve tasks beyond individual abilities.
- *Coordination*: Effective communication fosters teamwork.

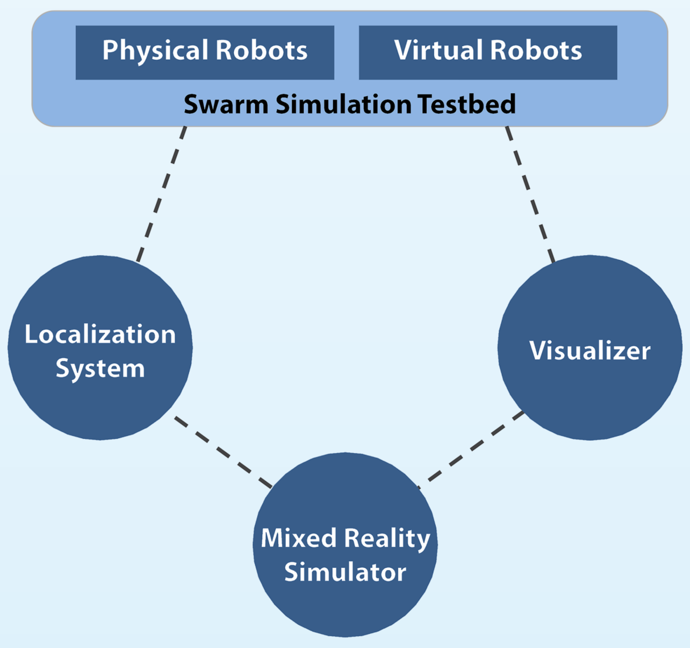




Physical Robots

Low-cost, general-purpose, differential drive robot (especially targeting the swarm behavioral experiments)



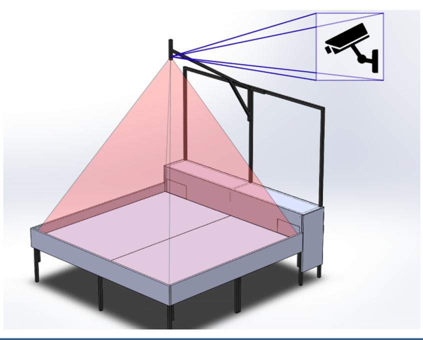


Virtual Robots

Virtual robot agents are the same as physical robots in functionality but only exist in the virtual domain.

Localization System

- An overhead camera with AR markers on top of the robots - to identify the coordinates of the physical robots.
- A mathematical model - to calculate and update the motion of the robots based on the control actions.



Reality Simulator

The simulator is a real-time inter-reality integration framework that facilitates the interactions between 2 realities, including the robots and the environmental elements. This framework consists of communication protocols, data structures, and workflows to support seamless integration.

Visualizer

The visualizer visualizes the robot's movements in both realities in a single environment.

- The VR visualizer - defines at the software level and renders the robots of both realities in that virtual space.
- The AR visualizer- projects the virtual robots into the physical space on top of the video feed taken by a camera.

Applications:

- *Search and Rescue*:
  Map disaster areas, locate victims and navigate hazardous terrain.
- *Precision Agriculture*:
  For crop monitoring, soil analysis and pest detection.
- *Environmental Monitoring*:
  Track pollution, study wildlife habitats and assess ecological changes.
- *Warehouse Management*:
  Map and navigate warehouses, optimizing inventory logistics.
- *Subterranean Exploration*:
  Mapping and self-localization, without external positioning systems.

As a development framework:

The platform facilitates creation, testing, and deployment of swarm systems with tools, libraries, and infrastructure necessary to build, simulate, and optimize different swarm applications for various domains.

Features:

- Agent modeling and simulation with realistic physics
- A robust communication infrastructure including message passing, data fusion, and decentralized decision-making mechanisms.
- Task allocation and scheduling.
- APIs and drivers for interfacing with physical robotic platforms and hardware components.

Mixed Reality in Swarm Robots

- Integration of virtual and physical realities.
- Robots can perceive and interact with both physical and virtual environments.
- Collaborative designs and individual functions can be remotely monitored and debugged.

Advantages

- Reduces experimental and development costs while preserving the scale of swarm intelligence experiments.
- Facilitates the integration of precise individual behaviors with scalable collective behaviors in experiments.
- Allows creating safer and lower-risk environments for extensive testing of swarm behaviors.

Conclusion

- The system enables easy testing of swarm robots in various virtual environments, eliminating the need for physical setups.
- Virtual sensors offer a solution for physical robots with resource and space constraints.
- Researchers can remotely connect to the swarm robotics testbed and conduct experiments.

Visit https://pera-swarm.ce.pdn.ac.lk/ for more details

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