Safe and Secure Open-Access Multi-Robot Systems

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www.robotarium.org

Backdrop

- Lower the barrier to entry in robotics through a remote-access testbed.
- Users can access a team of mobile robots remotely.
- Cyber-physical security concerns must be addressed.
- Minimally invasive verification and collision avoidance.

Personnel

A collaborative effort among faculty and students at the Schools of Electrical and Computer Engineering, Aerospace Engineering, and Mechanical Engineering at the Georgia Institute of Technology:

Principal Investigators
Magnus Egerstedt - Multi-agent robotics
Aaron Ames - Collision avoidance
Raheem Beyah - Cyber-security
Eric Feron - Formal verification

Post-Doc
Daniel Pickem

Graduate Students
Li Wang
Daniel Pickem
Eric Quires
Mark Mote

Broader Impact

The remote-access Robotarium will:

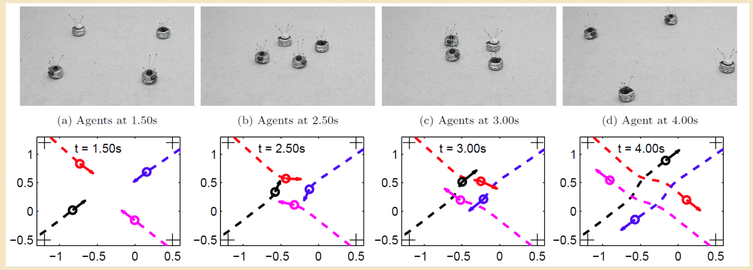
- Provide researchers access to a start-of-the-art robotics facility.
- Provide novel tools for both research and education at all levels.

Project Results

Minimally Invasive Collision Avoidance

Remote-access users must be allowed to safely deploy their coordinated control code with minimal intervention

- Barrier certificates for decentralized collision avoidance.
- Distributed and heterogeneous versions.
- Safety and feasibilty.



(A) Implementation of safety-critical controllers on a mobile robot swarm with experimental results (top) and the corresponding data (bottom)

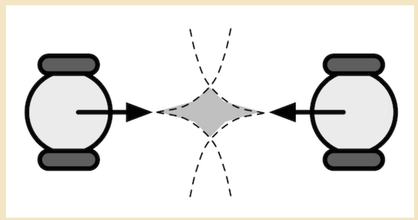
(B) Implementation of safety-critical controllers autonomous scale-model cars in the context of adaptive cruise control

HoneyBots

By attracting security risks to dedicated HoneyBots, a targeted defense system is developed.

Formal Verifcation

- Verification at different layers.
- Sample-based trusted users.
- Outsource the certificates to the users.

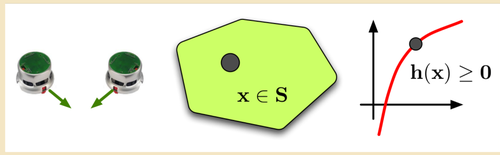


The Robotarium

- Remote-access swarm robotics research testbed: **www.robotarium.org**

Barrier Certificates

$$\mathbf{x} \in S \;\Leftrightarrow\; \mathbf{h}(\mathbf{x}) \geq 0$$



With individual robots:

$$\mathbf{x} \in S \;\Leftrightarrow\; h(\mathbf{x}_i, \mathbf{x}_j) \geq 0,\ \forall (i,j)$$

User intent:

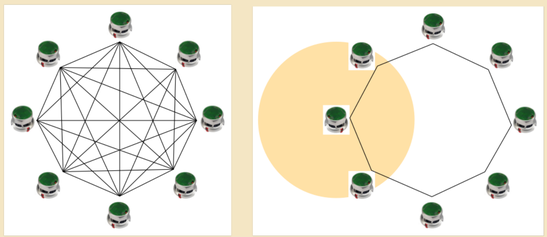
$$\min_{\mathbf{u}} \|\mathbf{u} - \mathbf{u}_n\|^2$$

subject to ZCBF

$$\dot{h}(\mathbf{x}_i, \mathbf{x}_j, u_i, u_j) \geq -\gamma h(\mathbf{x}_i, \mathbf{x}_j)^3,\ \forall (i,j)$$

Enough to only consider near-by robots:

$$\dot{h}(\mathbf{x}_i, \mathbf{x}_j, u_i, u_j) \geq -\gamma h(\mathbf{x}_i, \mathbf{x}_j)^3,\ \forall j \in N_i(\Delta)$$



Decentralized and feasible version:

$$\min_{u_i} \|u_i - u_{ni}\|^2$$

s.t.

$$\dot{\tilde{h}}(\mathbf{x}_i, \mathbf{x}_j, u_i) \geq -\gamma \tilde{h}(\mathbf{x}_i, \mathbf{x}_j)^3,\ \forall j \in N_i(\Delta)$$

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Future Work

- Safety, Feasibility, and Deadlock Avoidance
- Grow and sustain Robotarium user community
- Formal verification at different levels of trust

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