



# 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

Austin Jones

### 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 a novel tools for both research and education at all levels.

## Contact Information

### Email:

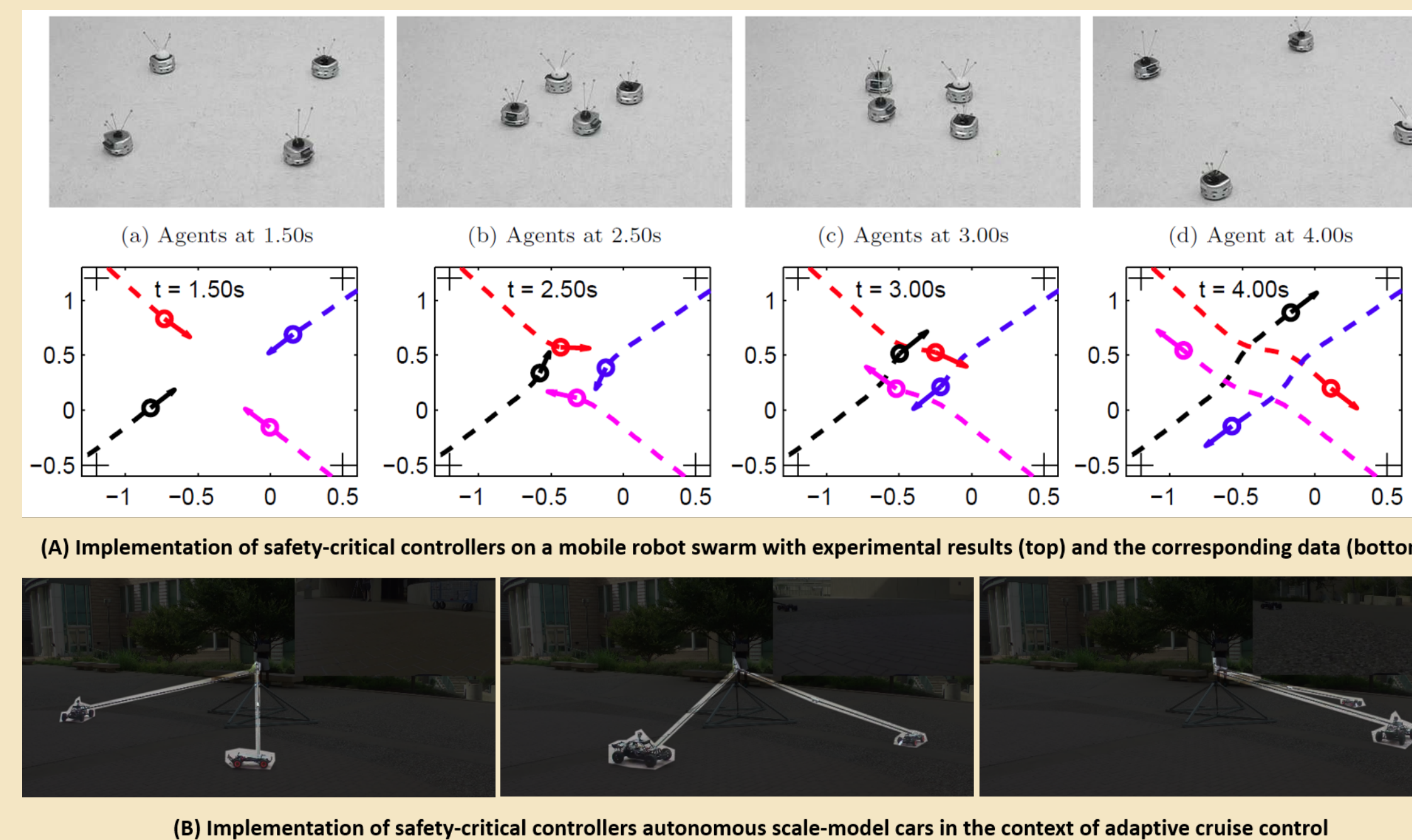
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## Project Results

### Minimally Invasive Collision Avoidance

Remote-access users must be allowed to test their code with minimal intervention

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

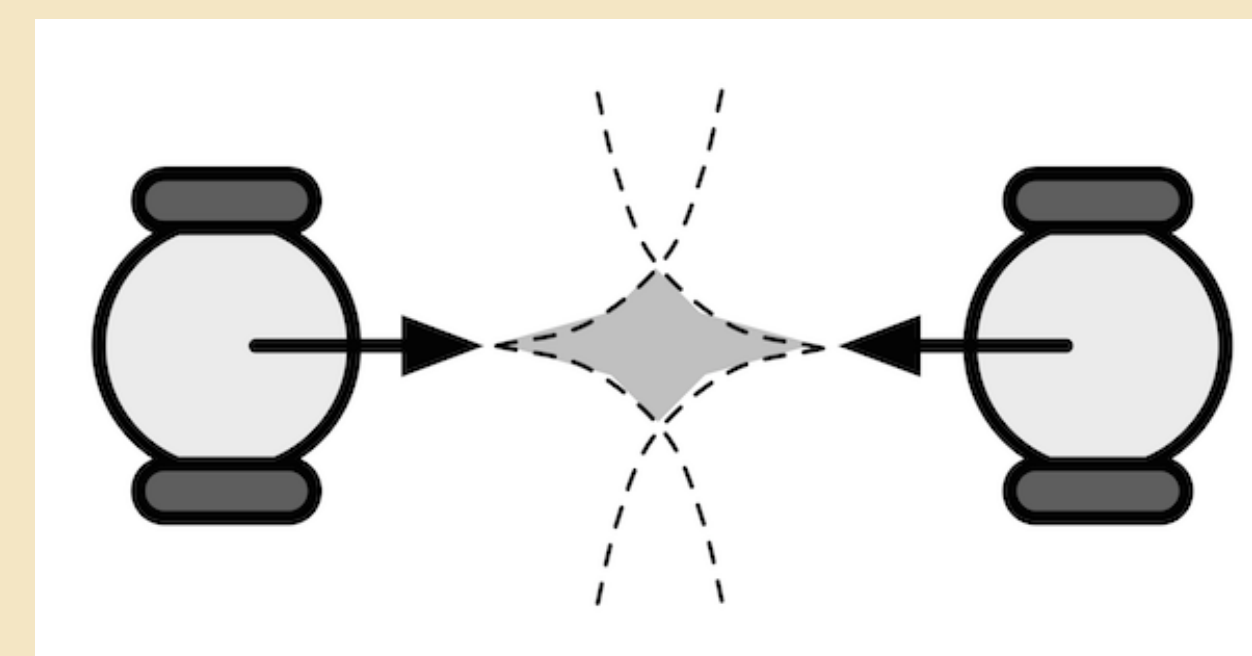


### HoneyBots

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

### Formal Verification

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



### The Robotarium

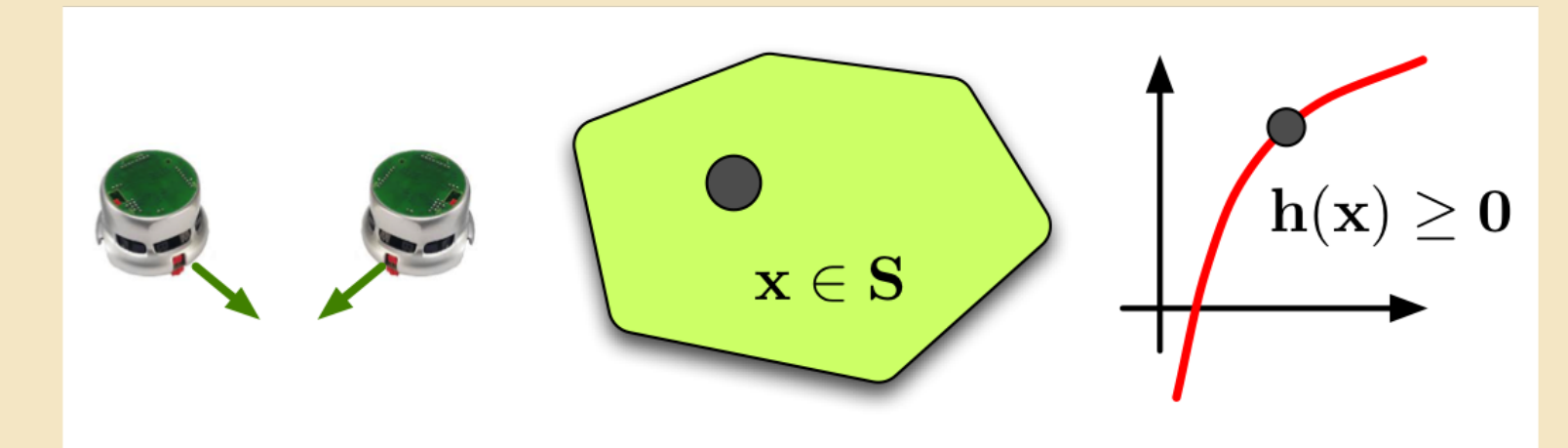
- Remote-access swarm research testbed: [www.robotarium.org](http://www.robotarium.org)

## Future Work

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

## Barrier Certificates

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



Or with individual robots:

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

User intent:

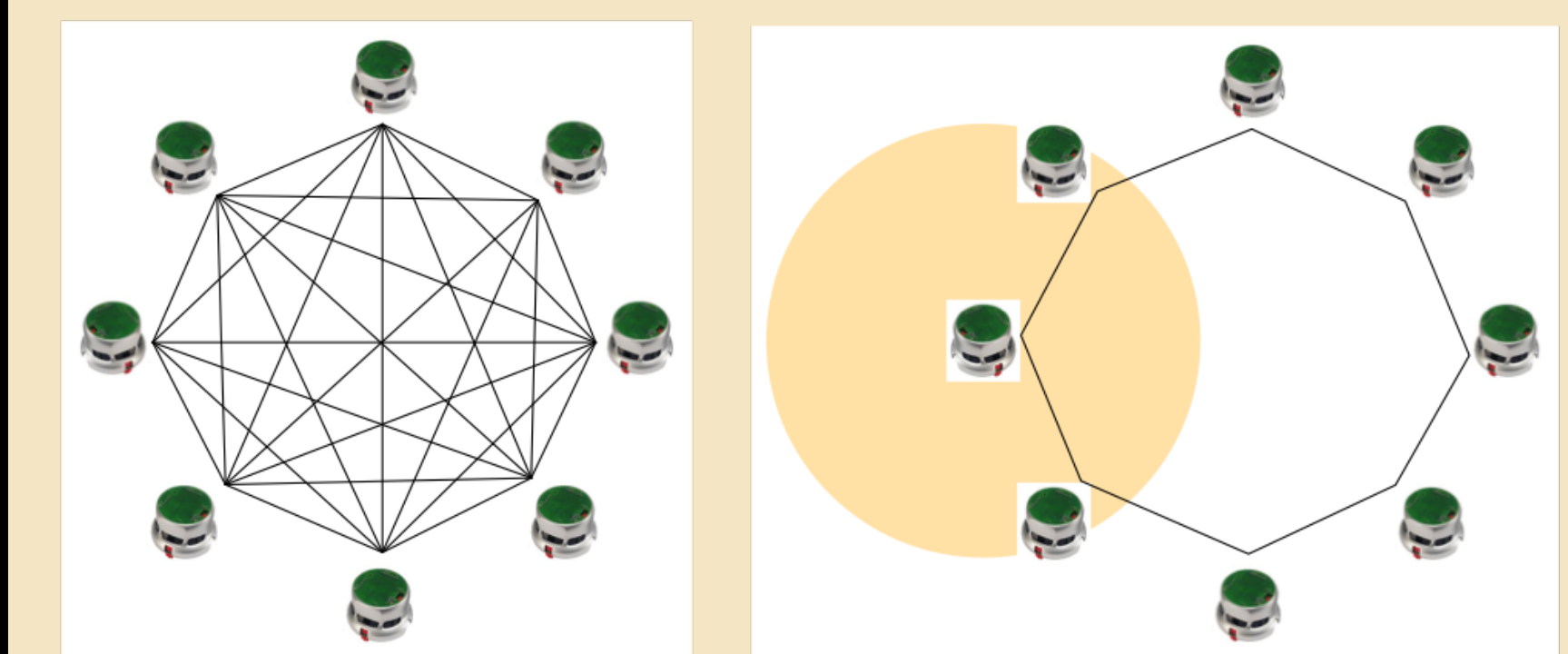
$$\min_{\mathbf{u}} \|\mathbf{u} - \mathbf{u}_n\|^2$$

subject to ZBCF

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

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.

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

## Acknowledgements

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