Reference Architectures for (Aerial) Robotics

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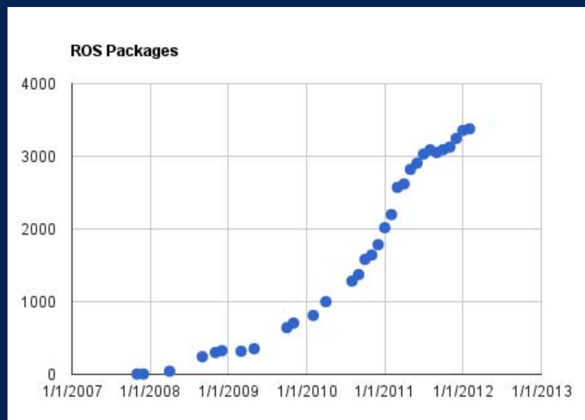
aerialrobots.org

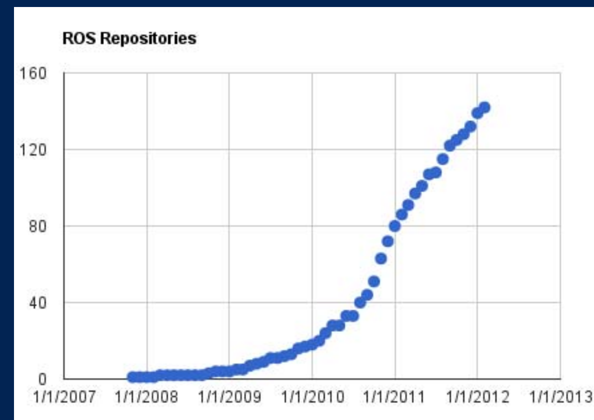
Penn Engineering

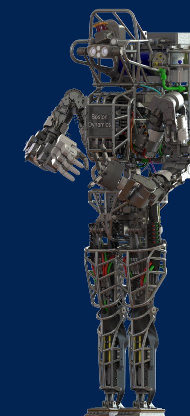
Open Testbeds and Reference Architectures

- Level of R&D maturity reaches a tipping point
- Need for extensive testing and validation
- Decrease design/development time
- Share and build on each others' results

Player/Stage, Gazebo, ROS, Willow PR2



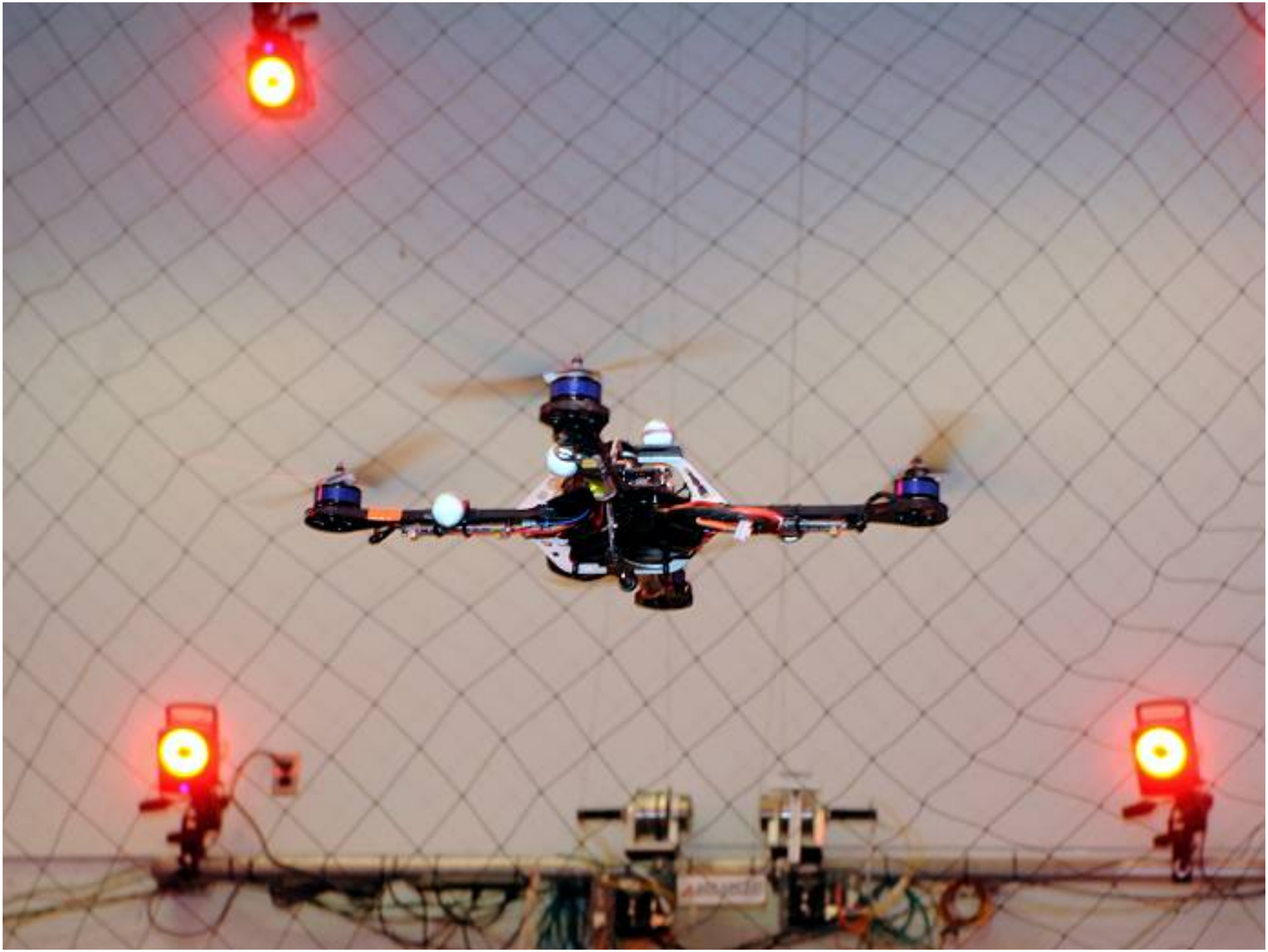




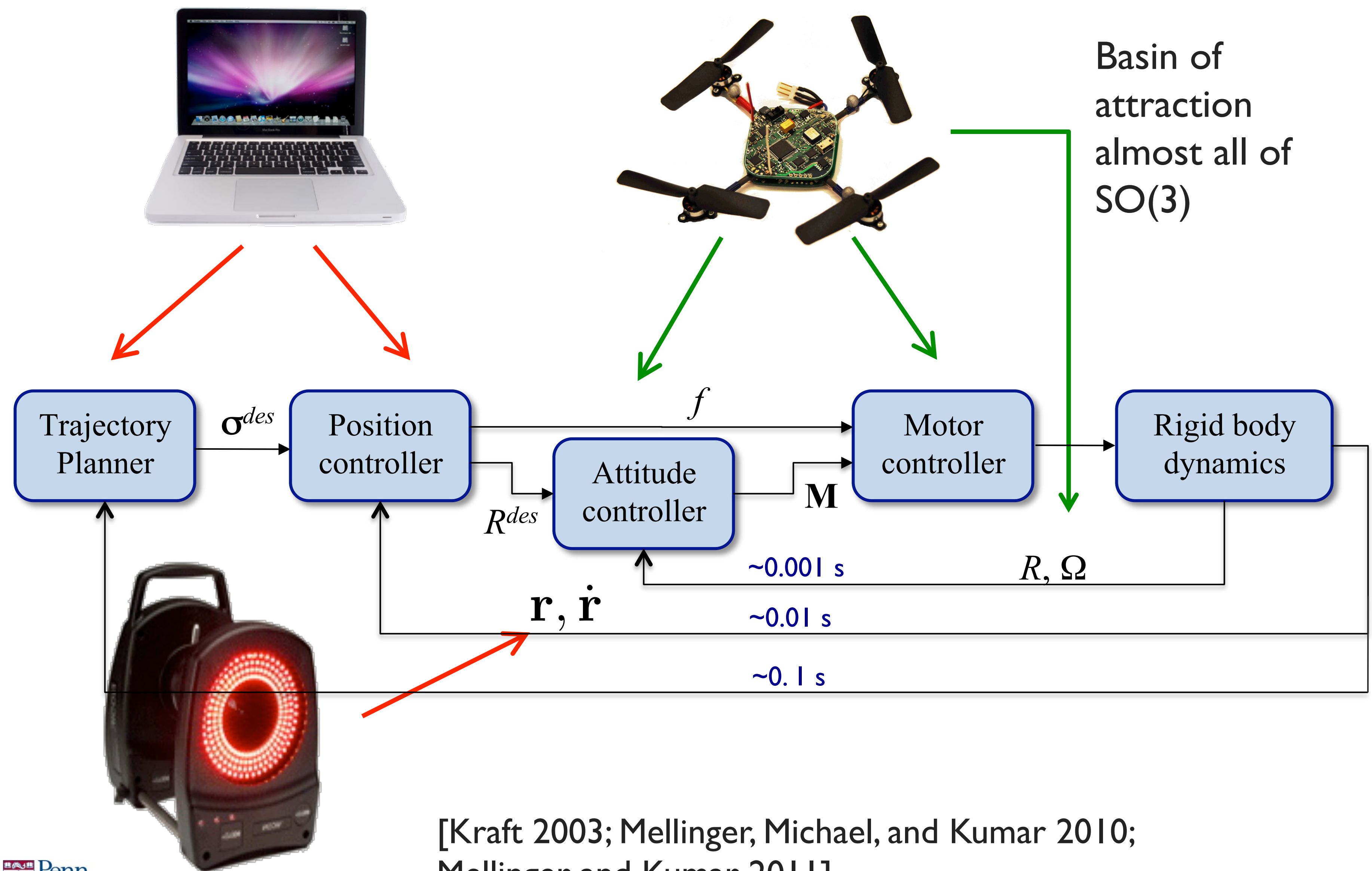
ROS

www.ros.org

- Middleware
- Standards for nodes and messages
- Formal descriptions of robots
- Abstractions for hardware
- Software libraries
    - rqt, rviz, pcl



Software Architecture



[Kraft 2003; Mellinger, Michael, and Kumar 2010; Mellinger and Kumar 2011]

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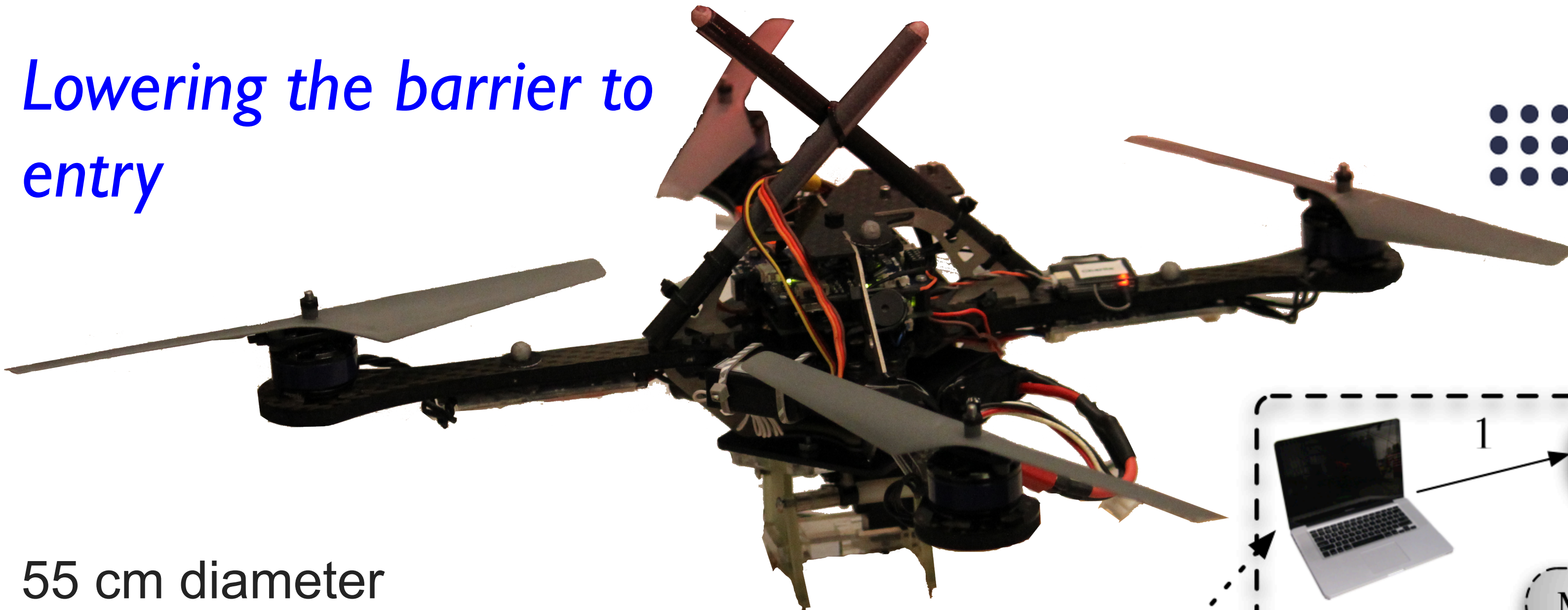
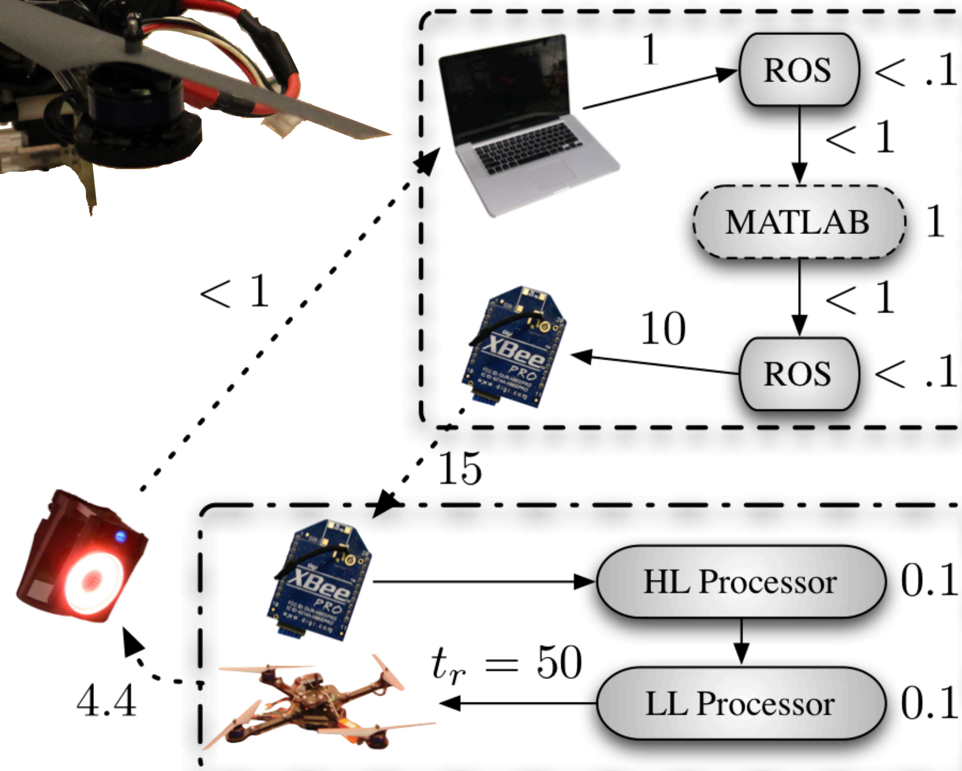
Open Testbed (2010)

Lowering the barrier to entry



55 cm diameter
8 cm height
Carbon fiber, Mg frame
500 gm (3 LiPo cells)
140 gm claws + camera



Planning/estimation run on MATLAB on a Macbook Pro

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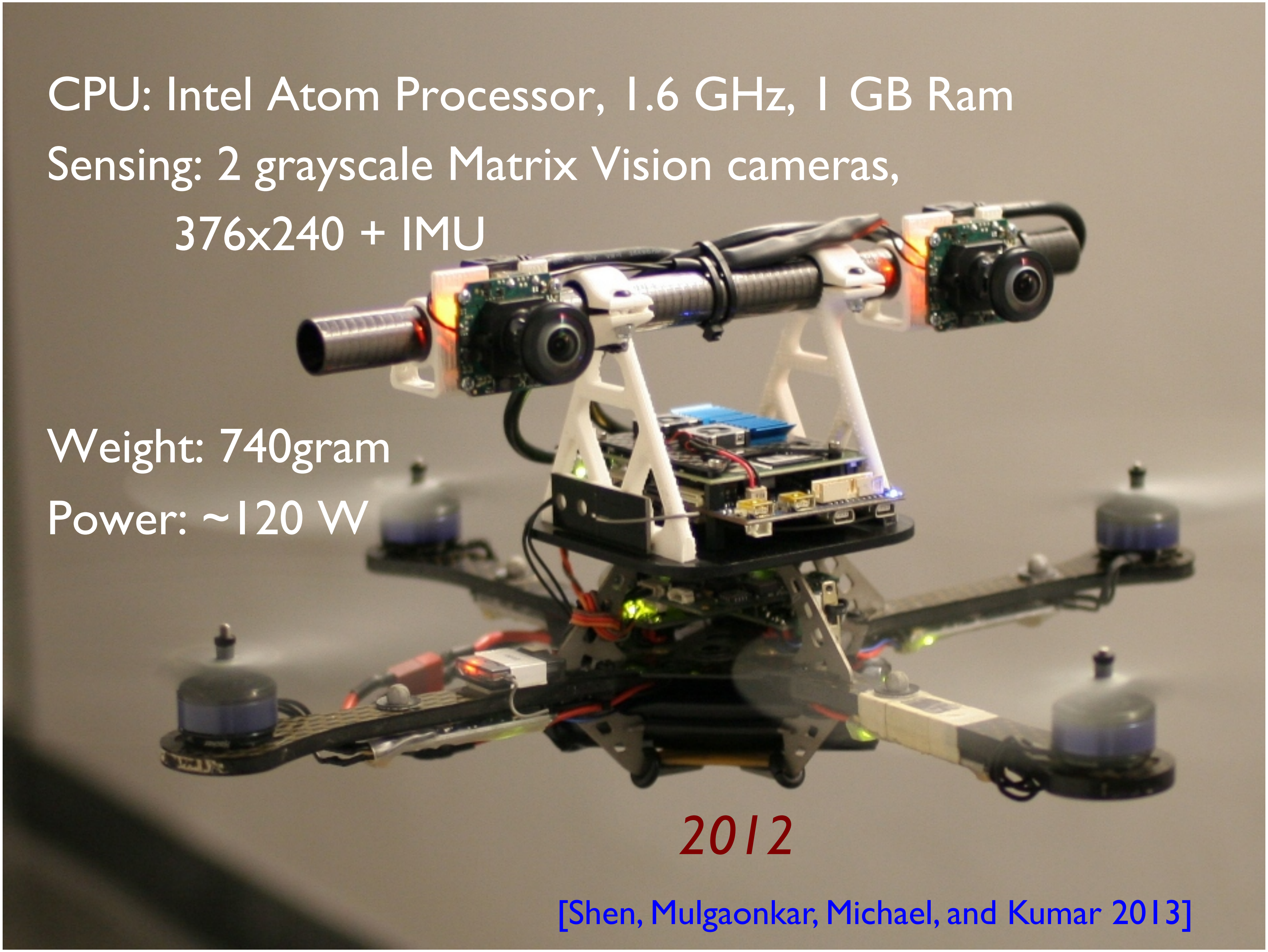
[Mellinger, Michael, and Kumar 2010]

Indoor/Outdoor Environment

- 1.8 GHz Core i3 processor, 8 GB RAM
- u- blox LEA-6T GPS module
- Hokuyo UTM-30LX LiDAR
- 2 mvBlueFOX-MLC200w grayscale HDR cameras
- (fisheye lenses, 752 × 480, 25 Hz)
- IMU 100 Hz

[Shen, Mulgaonkar, Michael, and Kumar 2013]



CPU: Intel Atom Processor, 1.6 GHz, 1 GB Ram

Sensing: 2 grayscale Matrix Vision cameras,
376x240 + IMU

Weight: 740gram

Power: ~120 W

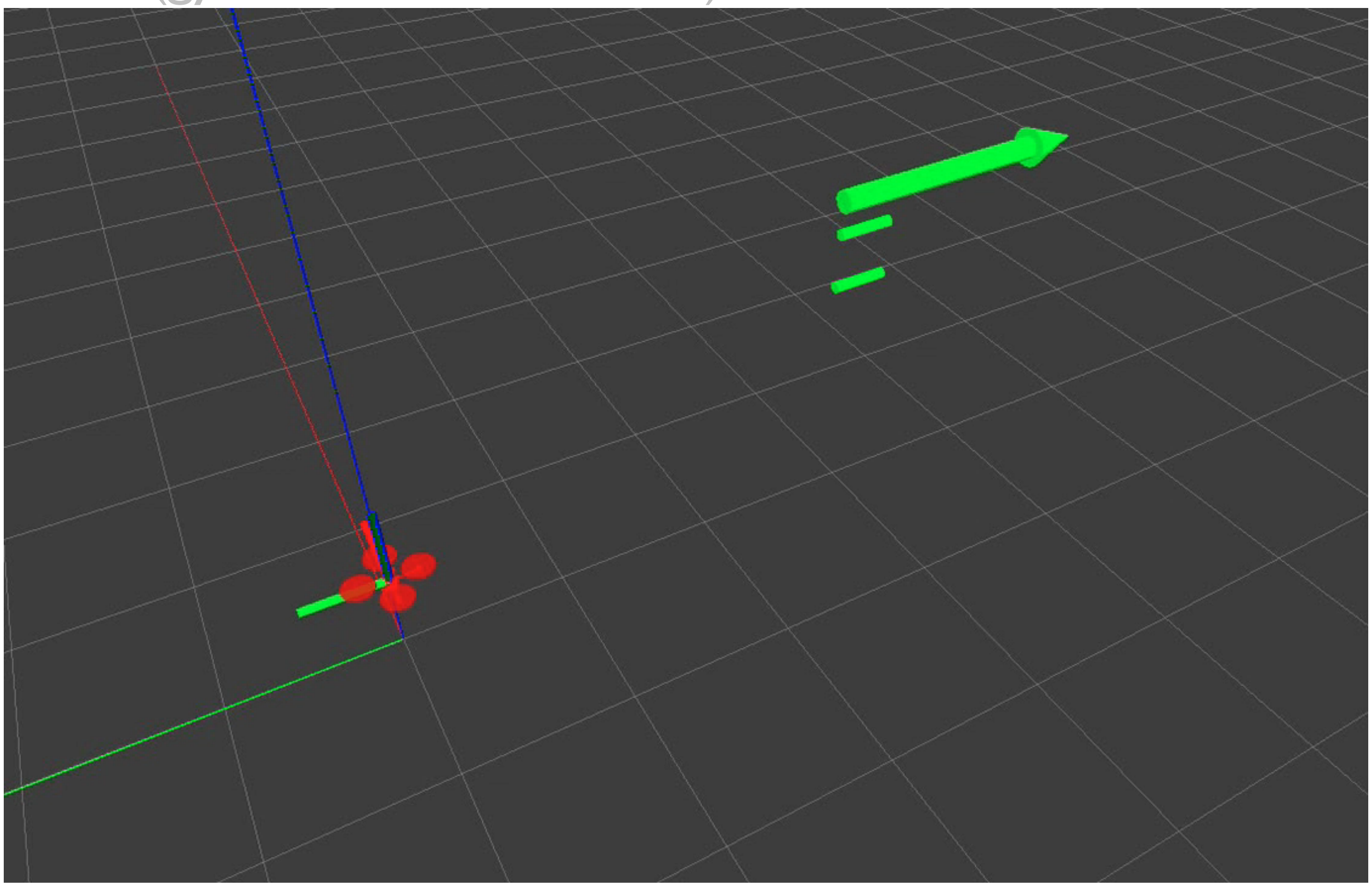
2012

[Shen, Mulgaonkar, Michael, and Kumar 2013]

ROS Simulator

Test controllers, estimators, planners

- Dynamics (rigid body, aerodynamics, motor dynamics)
- Sensors (gyros, accelerometers), laser scanner, cameras



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ROS Simulator

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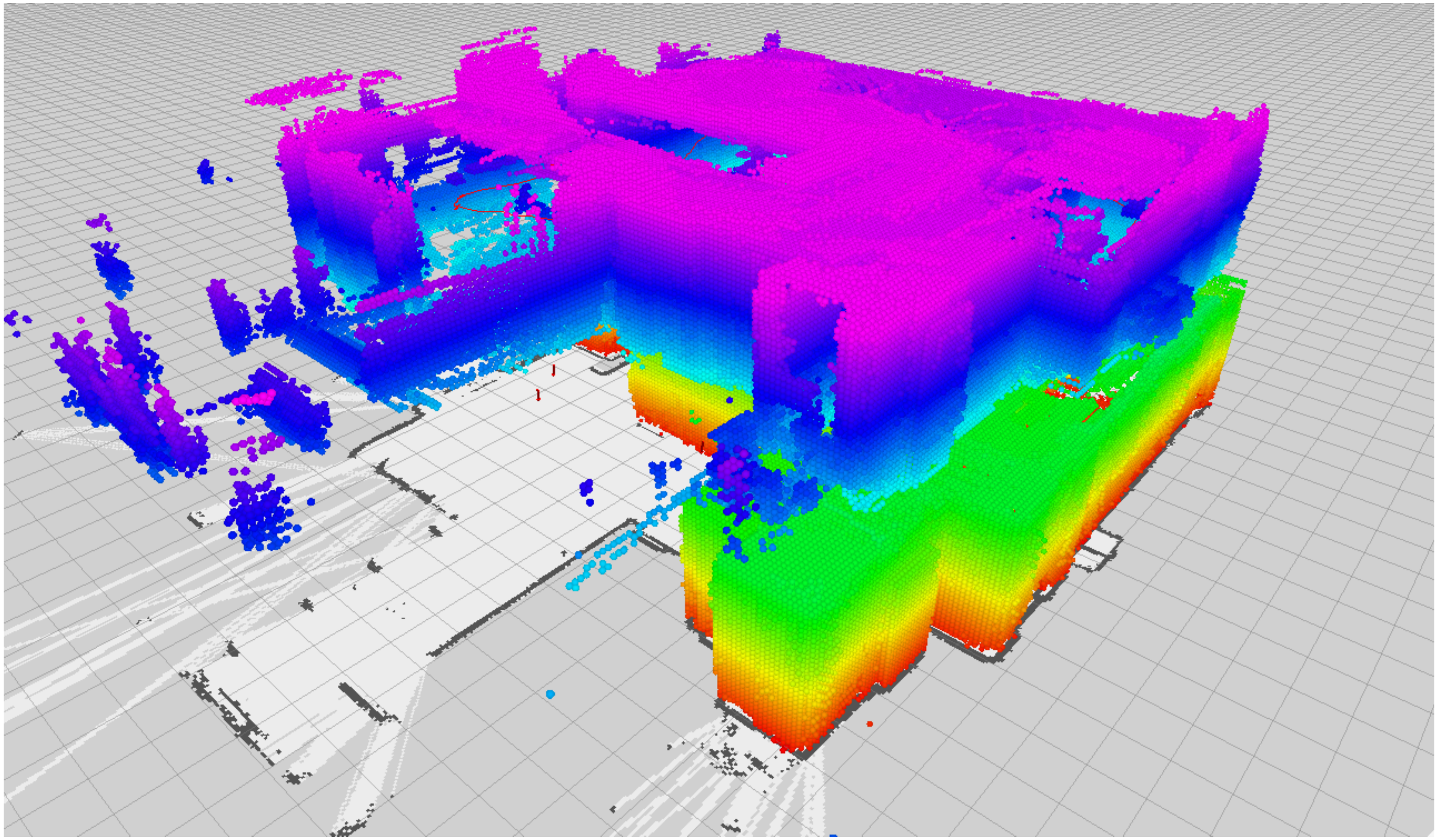

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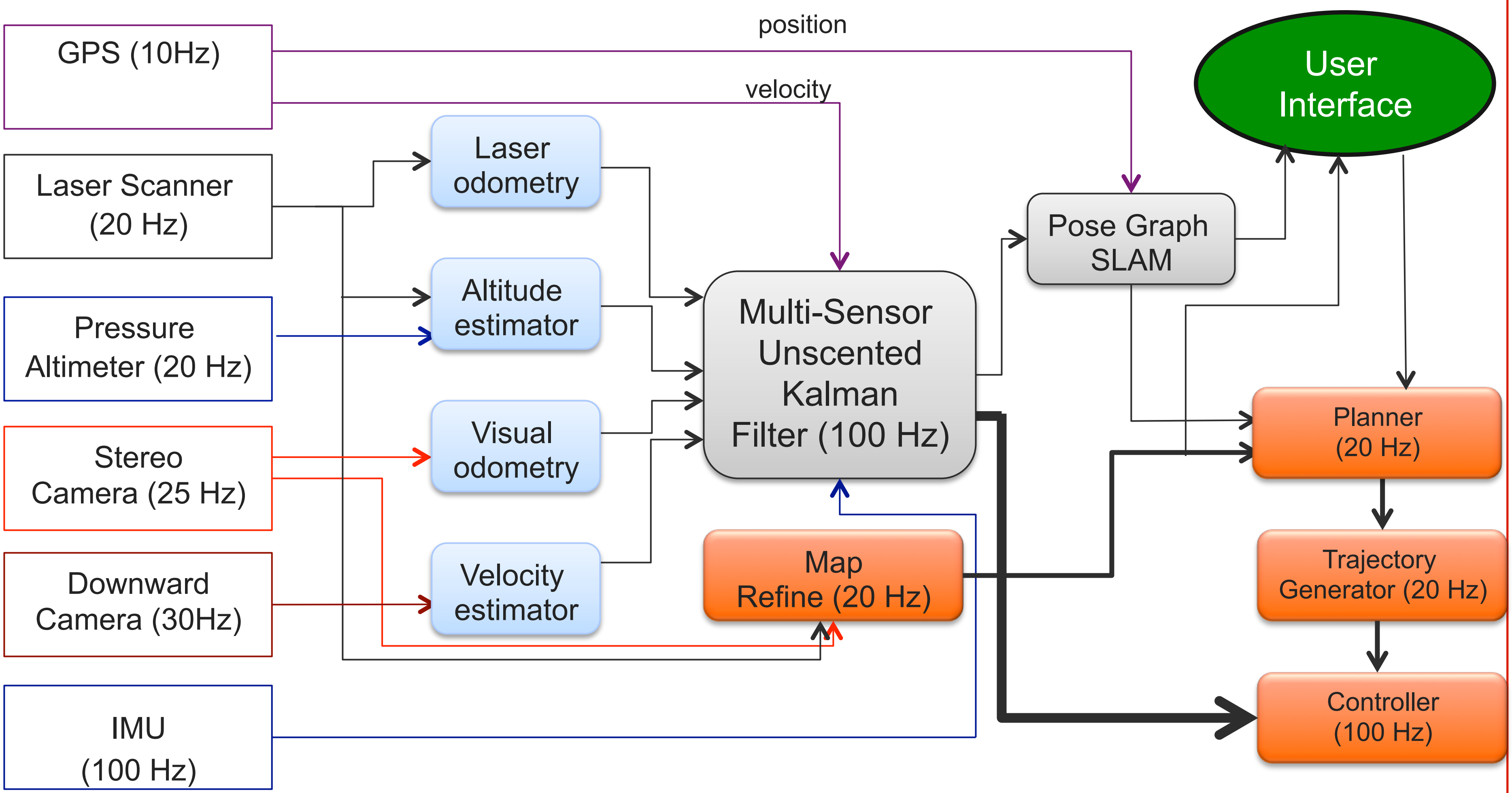
Estimation and Control Architecture



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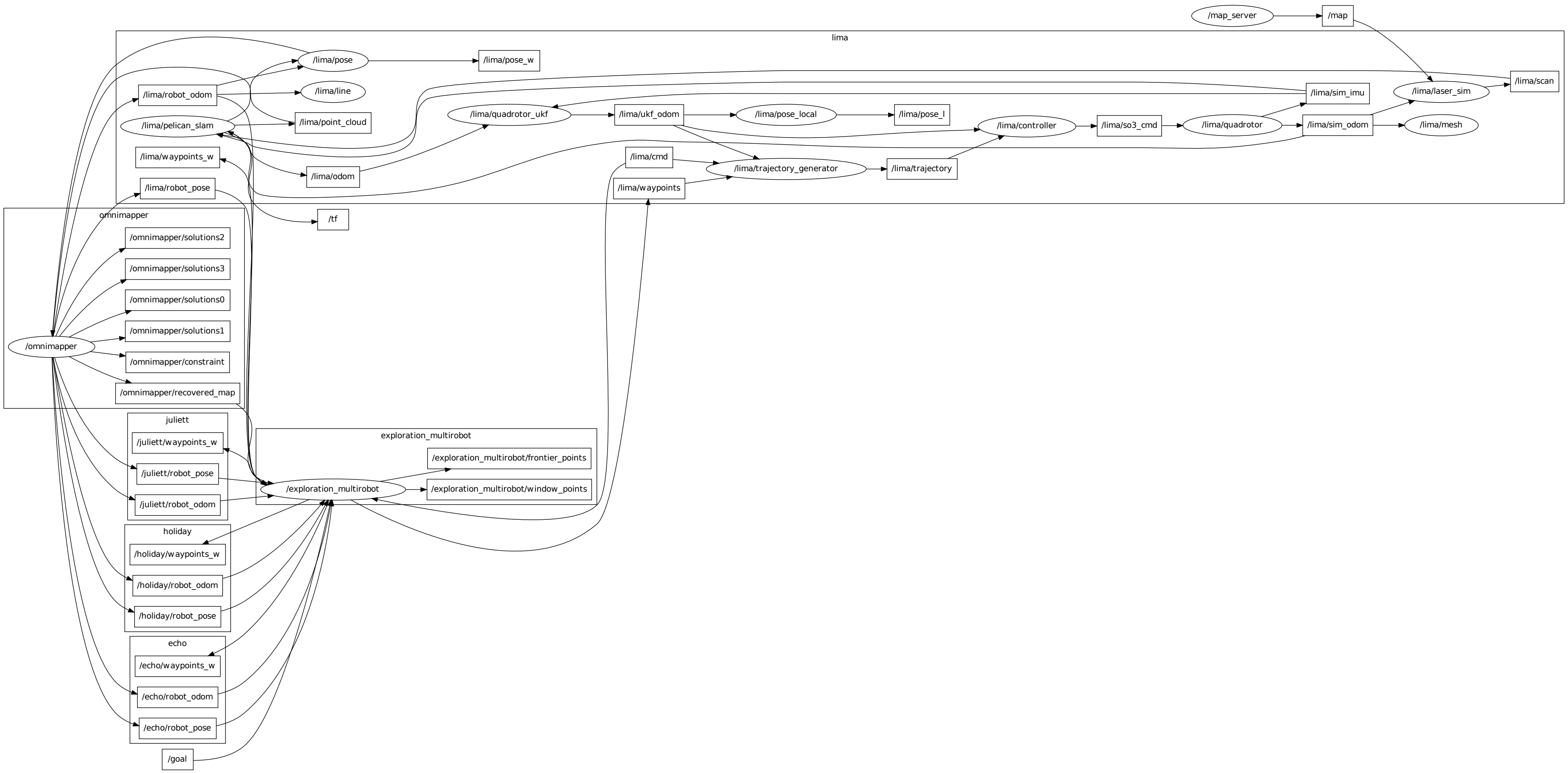
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/lima/waypoints_w
/lima/odom
/lima/robot_pose
/tf
/lima/quadrotor_ukf
/lima/ukf_odom
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/lima/pose_l
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/omnimapper/constraint
/omnimapper/recovered_map
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/juliett/robot_odom
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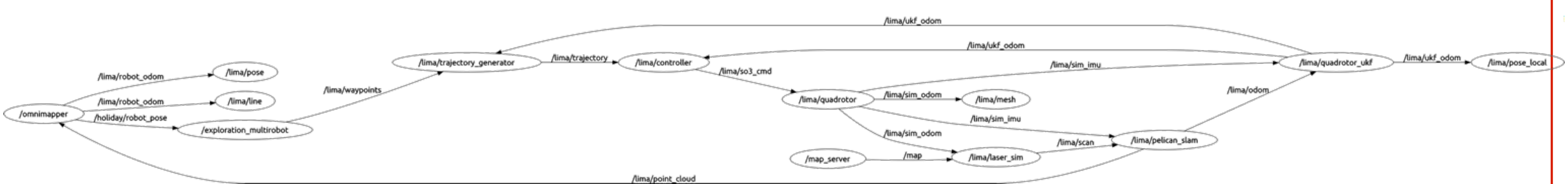
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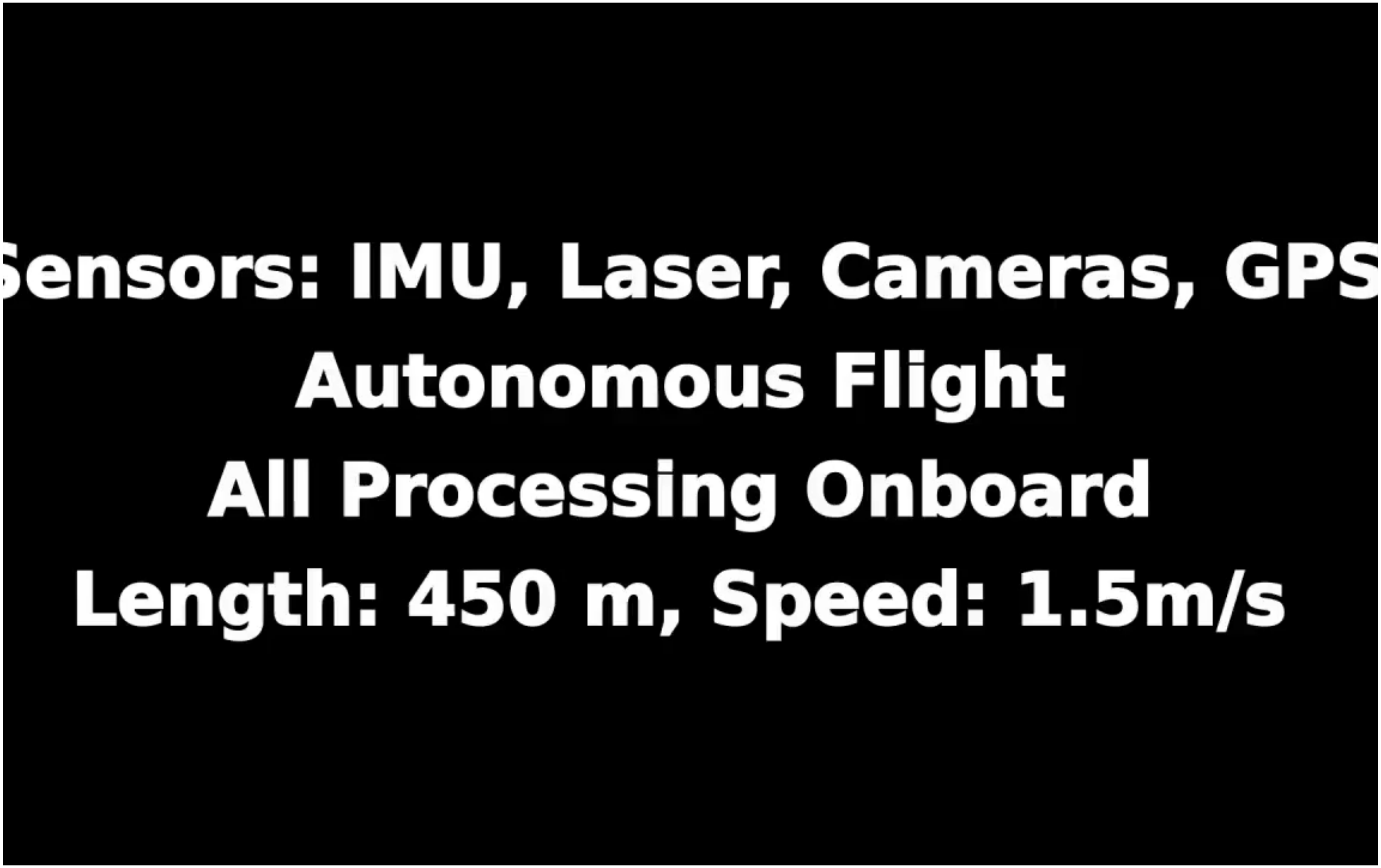


[Shen, Mulgaonkar, Michael, and Kumar 2013]

CPS for Autonomous Systems

ROS

State of the Art	Limitations
Software abstractions	Formal semantics
Perception-action loops	Real-time guarantees
Tools	Ease of use
Graph representation of architecture	Nested, hierarchical representations
	Support for co-design

Reference Architectures for Swarms of Robots

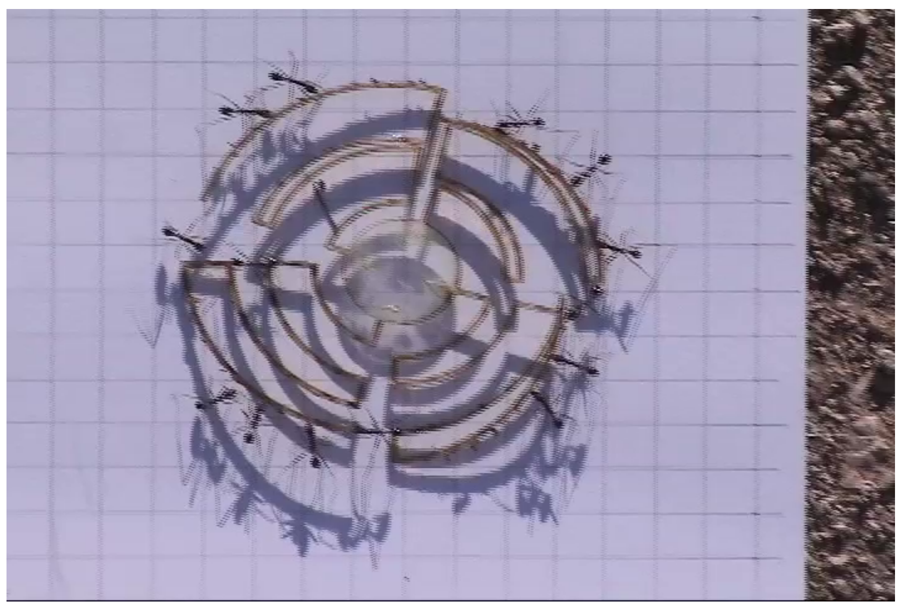
aerialrobots.org

Swarms of Aerial Robots

1 Act independently

2 Require only local information

3 Anonymous behavior


Leader-Follower Networks

PBS NOVA: Making Stuff Wilder (Hosted by David Pogue)

Anonymity (unlabeled robots)

PBS NOVA: Making Stuff Wilder (Hosted by David Pogue)

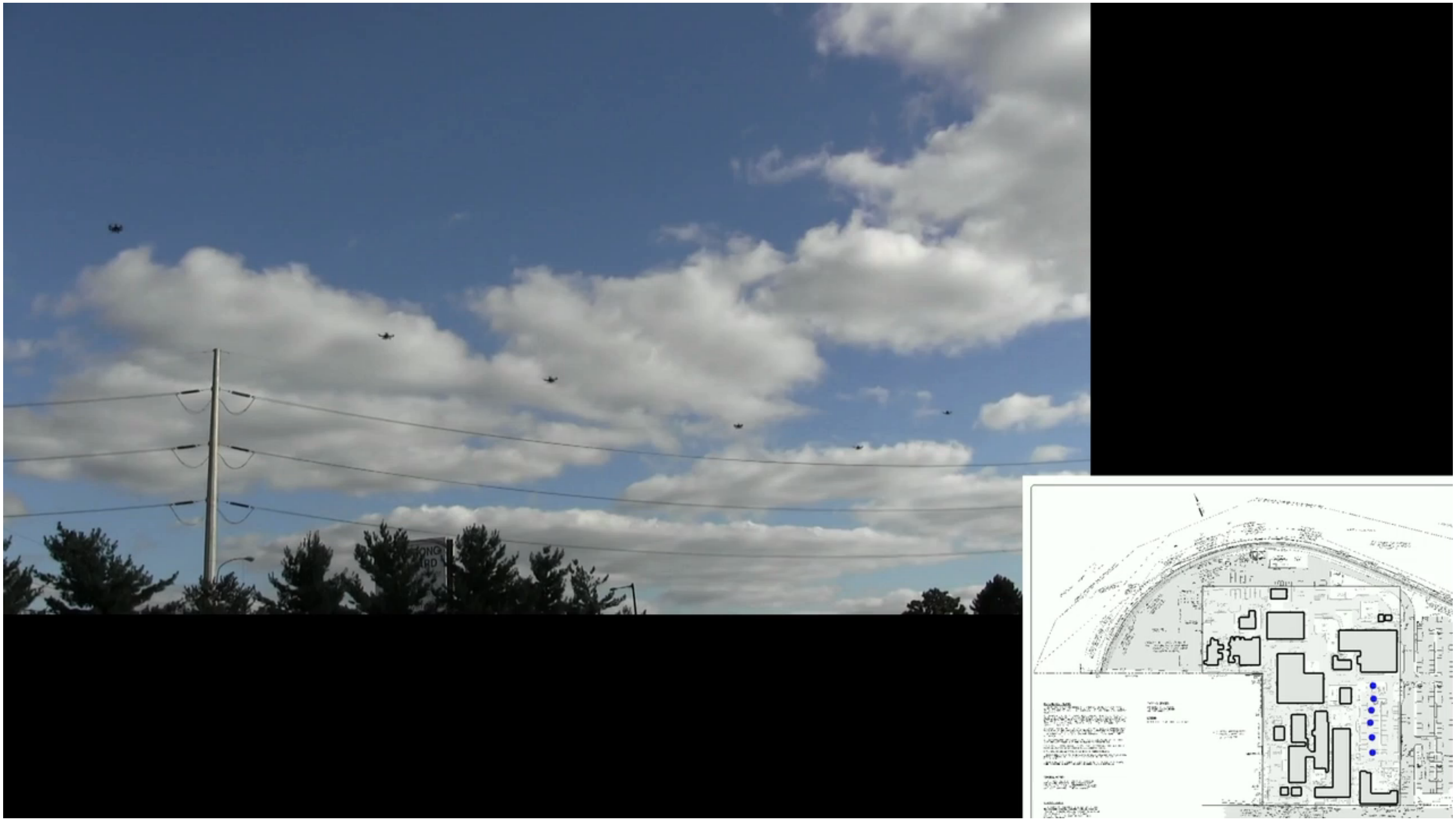
Control of Formation Shape and Group Motion

(Turpin, Michael, and Kumar, 2013)

Applications

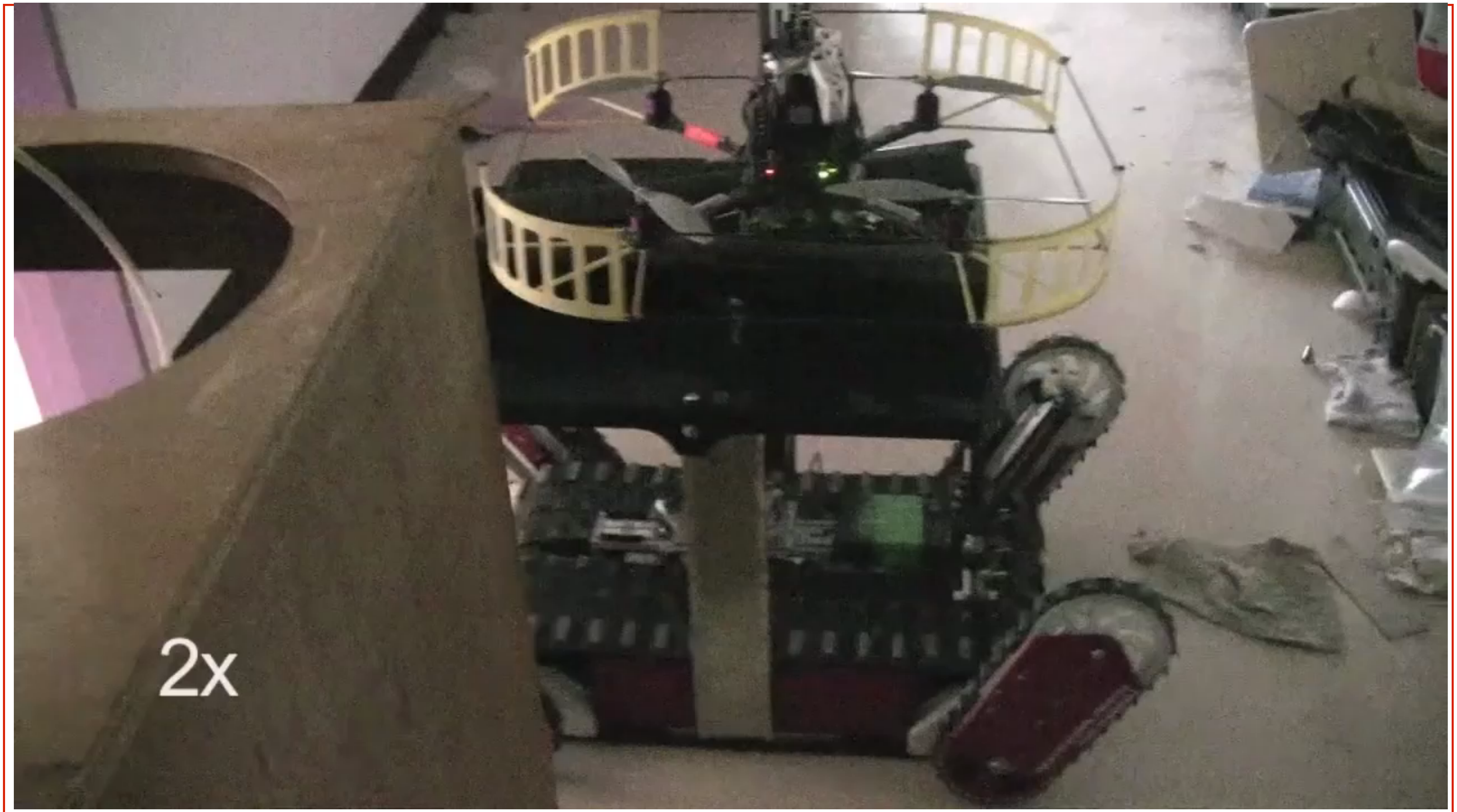
Outdoor Swarms

Outdoor Swarms



[Mohta *et al*, 2014]


PCMS
Emerson Quartet



Sendai, Japan, July 21, 2011

N. Michael, S. Shen, K. Mohta, Y. Mulgaonkar, V. Kumar, K. Nagatani, Y. Okada, S. Kiribayashi, K. Otake, K. Yoshida, K. Ohno, E. Takeuchi, and S. Tadokoro, "Collaborative mapping of an earthquake-damaged building via ground and aerial robots," J. Field Robotics, vol. 29, no. 5, pp. 832–841, 2012.

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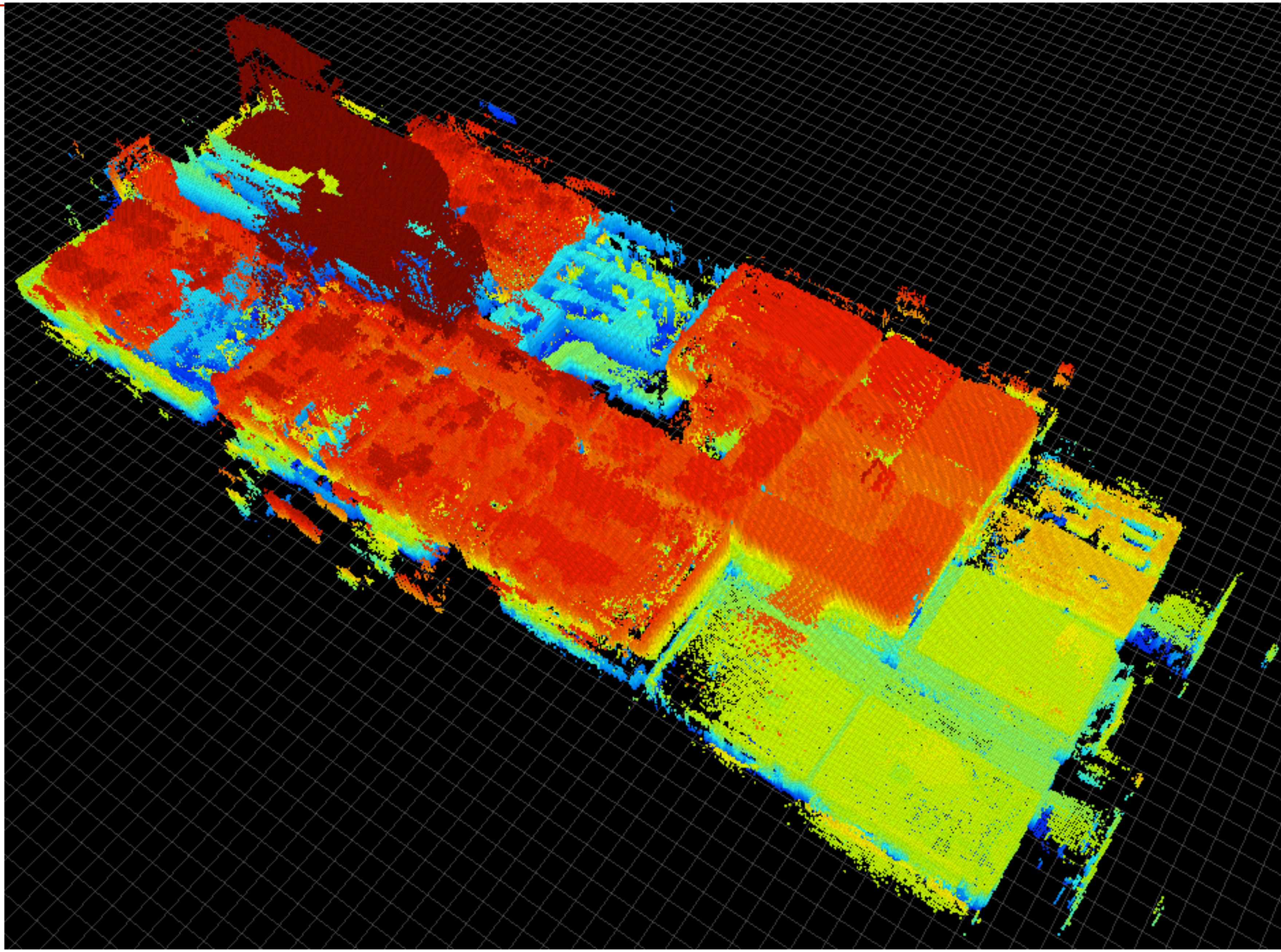
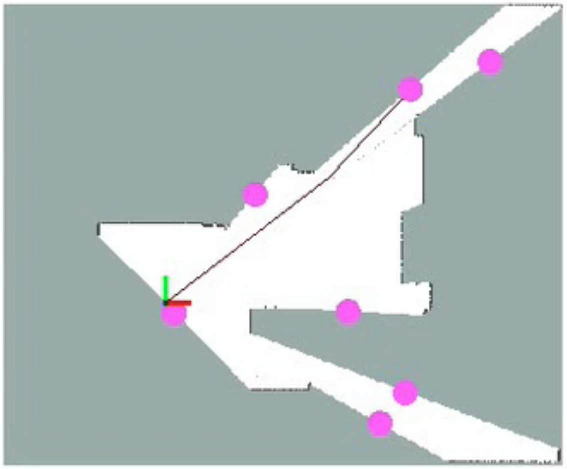
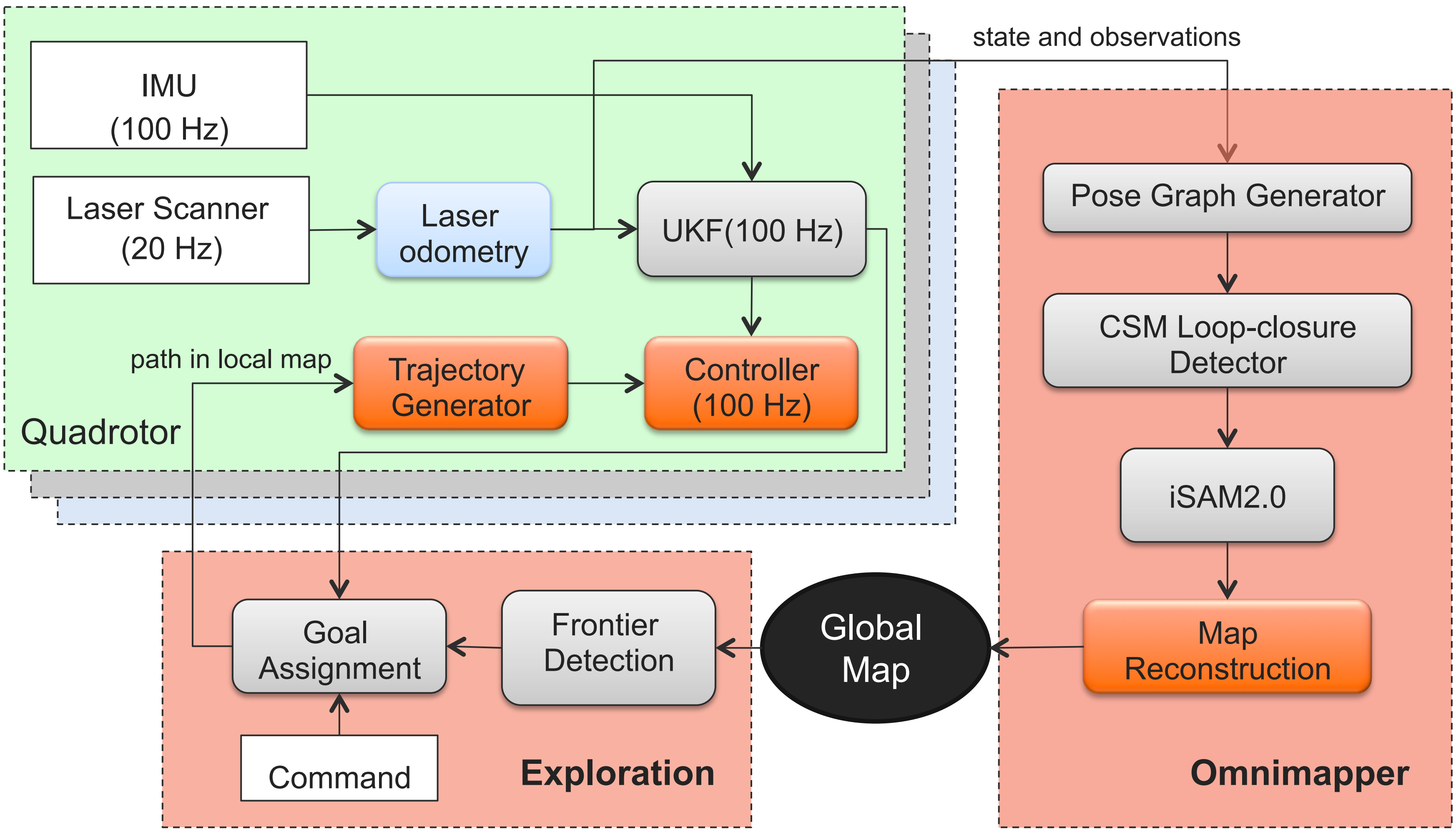


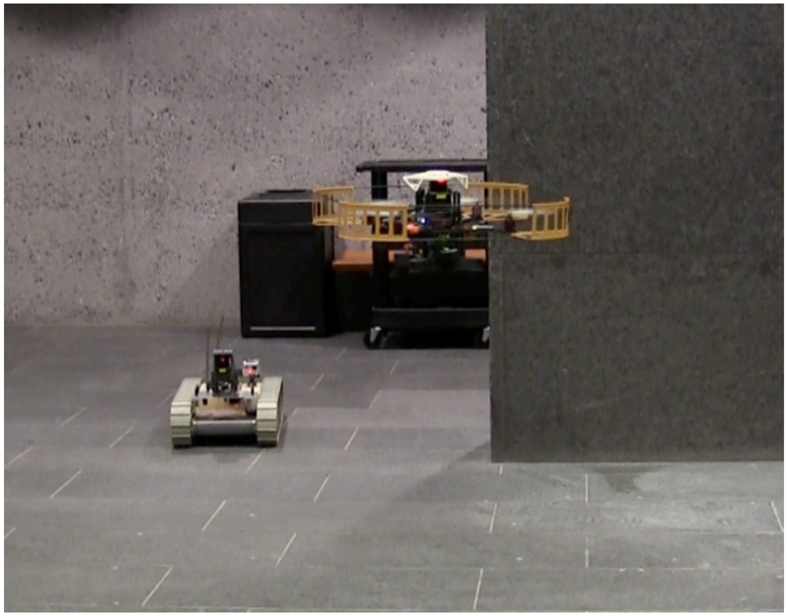
7th, 8th, and 9th floors

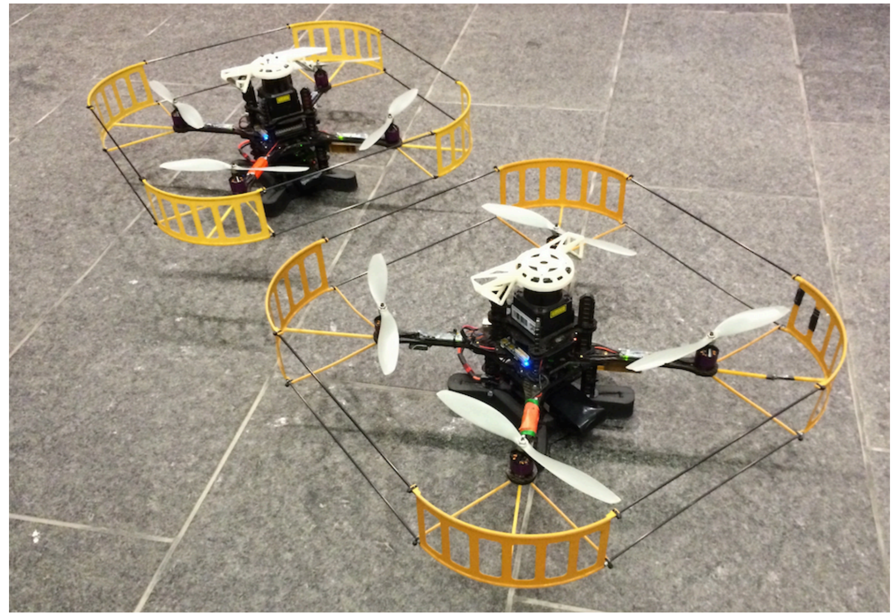
Collaborative Mapping and Exploration

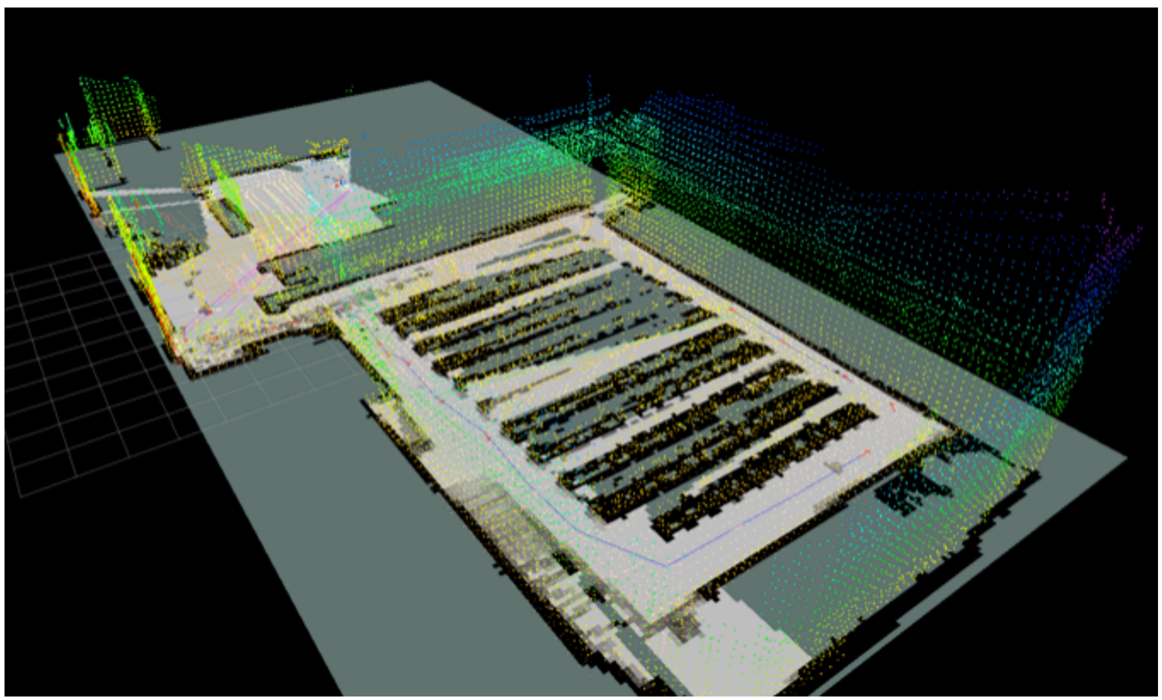


Collaborative Mapping and Exploration









Collaboration with H. Christensen (GT), J. Rogers (ARL)

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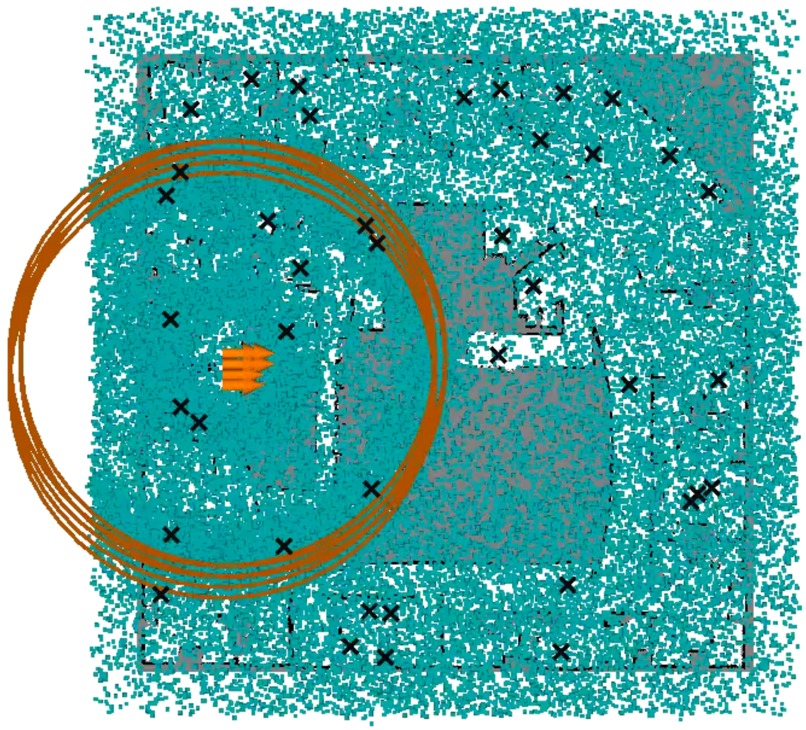
Information Based Control

Localizing Wireless Sensors in Buildings



[Charrow, Michael, and Kumar, 2014]

CPS for Swarms

ROS

Advantages	Limitations
Software abstractions	Formal semantics
Perception-action loops	Real-time guarantees
Tools	Ease of use
Graph representation of architecture	Nested, hierarchical representations
Distributed	Communication, no global clock