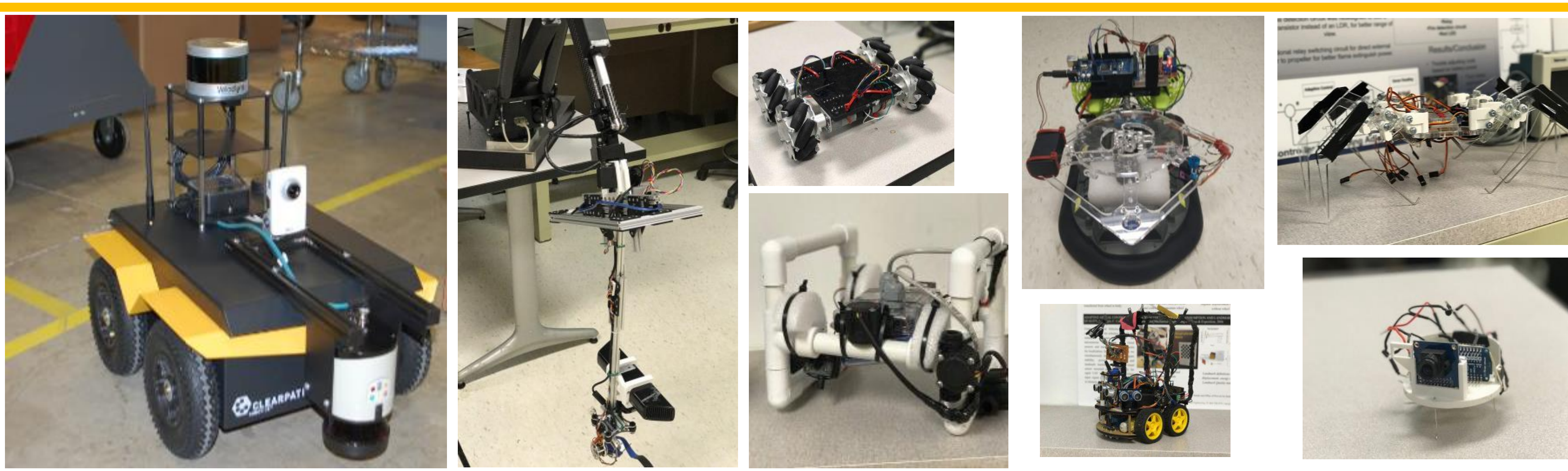
Probabilistic Methodologies for Autonomous Mobile Robot Localization

Speaker

Dr. Akin Tatoglu | tatoglu@hartford.edu
Assistant Professor, Mechanical Engineering



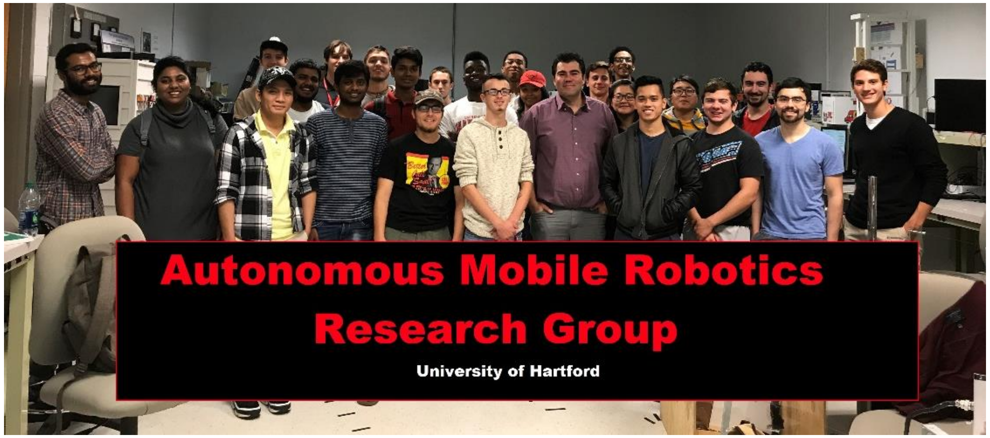
Autonomous Mobile Robotics Research Group | D-121

UNIVERSITY OF HARTFORD
COLLEGE OF ENGINEERING, TECHNOLOGY, AND ARCHITECTURE

December 7th , 2017

Autonomous Mobile Robotics Research Group

- **What do we do?** We are a research group focusing on design and development of robotics, industrial automation systems and advanced mechanisms.
- **Who are we?** We have 32 active members from all majors.



- **What do we offer?**

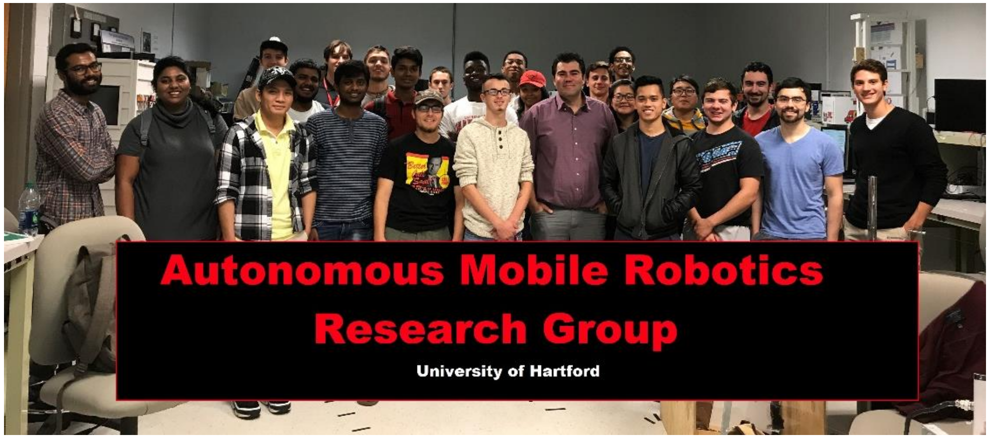
Our group offers free courses about:

- Robotics Design,
- Embedded Control,
- Software Development (Arduino, Raspberry Pi, Matlab)

which will be useful for your education and future scientific research.

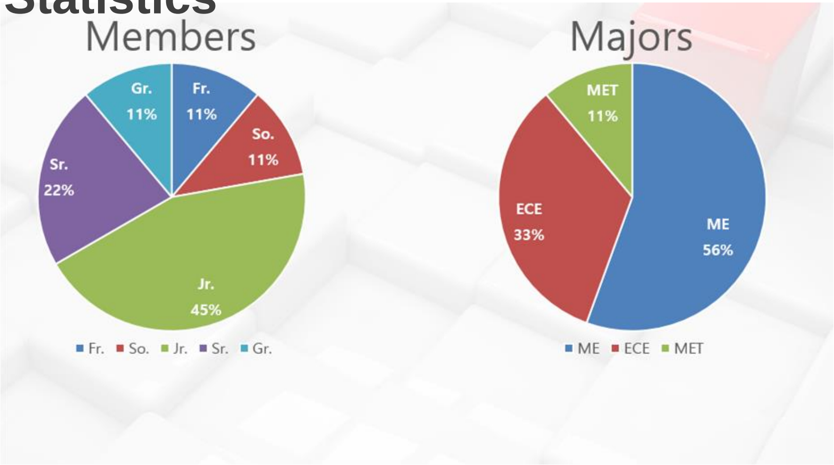
Autonomous Mobile Robotics Research Group

We have 32 active members from all majors.



		Solid Works	Electronics	Arduino IDE	Linux C++	Matlab	Java	TEAM-I	TEAM-II
1	Ackeifi, Ross		X	X	X		X	A	D
2	Bandarupalli, Gouthamsai	X		X		X		D) Robotic Arm	B
3	Bituin, AmielAndrew	X		X	X			B) Self Drving Golf Ca	D
4	Dai, Shuang	X	X					B	C
5	Darlington, HestonDavid	X			X			B	C
6	DeRosa, Stephen	X	X	X	X			B) Self Drving Golf Ca	E
7	DeVeau, Adam		x	x	x			A) OmniDirectional Ro	C or E
8	Ferrera, Amber	X	X		X	X		A) OmniDirectional Ro	B
9	Garcia, Josephine				X	X	X	A) OmniDirectional Ro	B
10	Jacobson, Eric	x	x	x	x	x	x		
11	Karuturi, JitendranathCh	X						B	C
12	Klesczewski, Peter		X	x	x		x	B) Self Drving Golf Ca	A
13	Kobos, Alexander							C) Hovering Robot	B
14	Kodali, Madhukanth	X	X					C) Hovering Robot	B)
15	Kral, Jacob								
16	Likhitha Mullapudi	X						B)	C)
17	Malempati, PoornaPruthvi	X						B	C)
18	Maynor, Kaelaan		x	x	x			B) Self Drving Golf Ca	D
19	Melecio, Javier	X						C) Hovering Robot	B
20	Merrikin, Ryan		X	X				A	E
21	Pagadala, SaiAditya	x						B	C
22	Severino, Jeffrey	X				X		B	C
23	Simko, Justin	X		X	X		X	A) OmniDirectional Ro	D
24	Tamboli, Parth								
25	Woodard, Matthew		X		,X	X	X	B) Self Drving Golf Ca	C
26	Dion, Scott	X	X	X	X	X	X		
27	Day Moo	x		x	x	x		B	
28	Nigel Otis							B) Self Drving Golf Cart	
29	Christopher Jaramillo							C) Hovering Robot	A)
30	Toby Poole	x	x			x		D) Robotic Arm	C

Statistics



- We welcome all experience levels.
- If you would like to join our meetings, please drop your name and email address.

Today, we will talk about

A) Our research projects,

B) Fundamental Robotics Concepts:

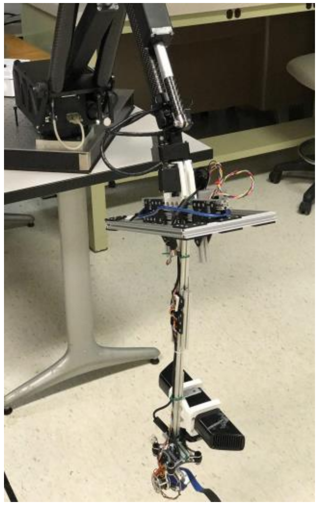
- Feedback
- Sensor Fusion
- Perception
- Platforms
- Advanced Locomotion
- Basic Localization

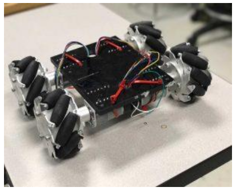
C) Probabilistic Localization and Mapping

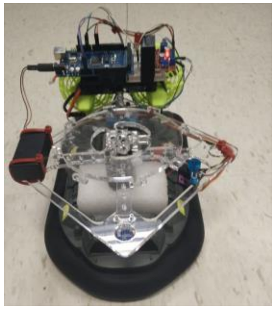
D) Future of Engineering Education

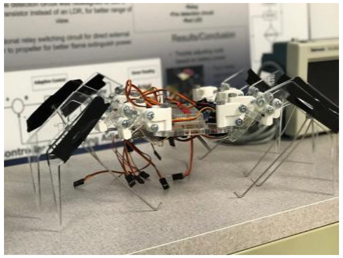
E) Q&A

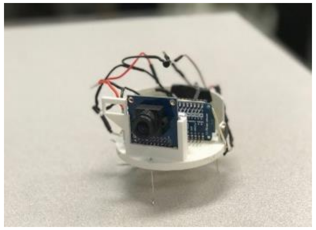
Our platforms: “We create!”











Mr. Jackal

All Terrain Mobility

Advanced Sensor Suit

Differential Drive

3D Mapping

Exploration Missions

Octopus

Aggressive UAV Maneuverability Study

Target Following

Automated 3D Scanner

OmniBot

Omni-directional Motion

UUV

Underwater Domain

HoverBot

All Terrain Advanced Dynamics

Bubble

Educational Platform

SpiderBot

Advanced Locomotion

Vibron

Swarm Robotics Study

How can I start ?
Let’s start with couple concepts…

Sensor Suite

Bionic Egg: Ruggedized Remote Sensor Suite for Impact and Ambient Conditions

Design Challenges:

a) 2 - 2.7inches in length

b) 1.5 - 2 inches’ wide

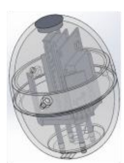
c) 5 inch average circumference

d) 114 grams of approximate weight

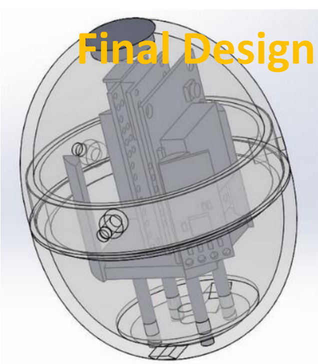
Iteration 1

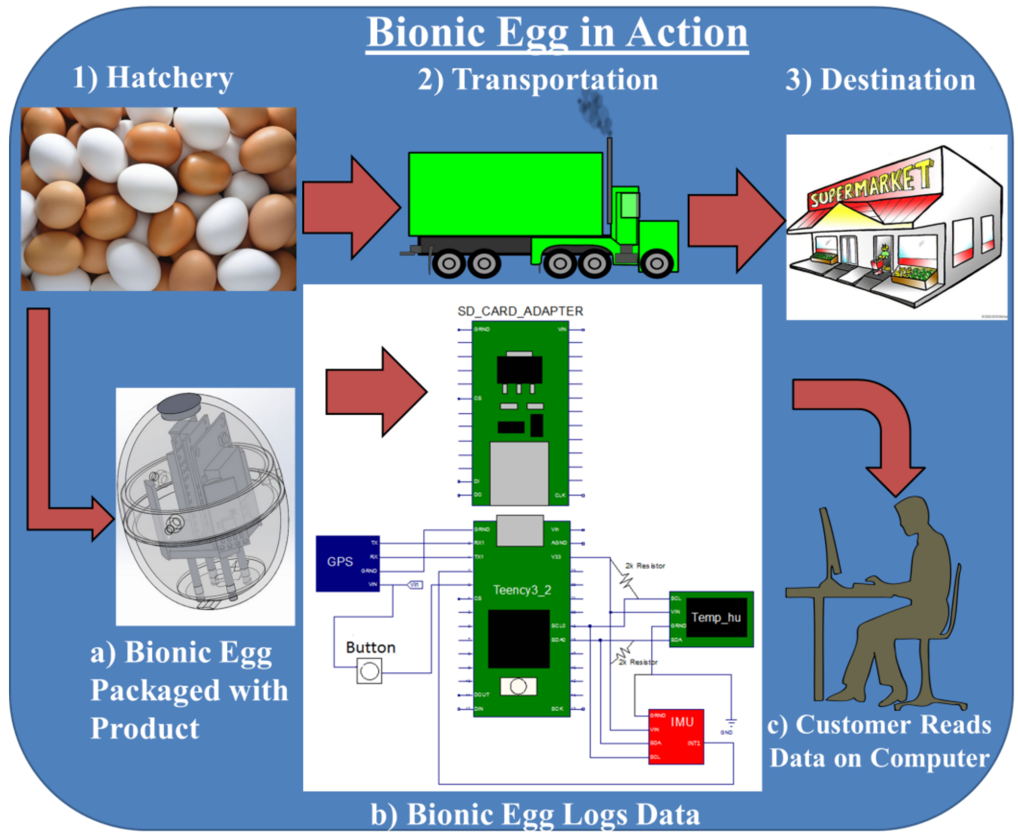
Iteration 2

Iteration 3



Iteration 4



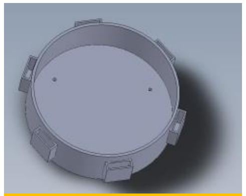


Students: Electrical Engineering: Simon Darius | Computer Engineering: Eric Jacobson, Mechanical Engineering: Theresa DeFreitas, Maegan Hall, Jerrod Sutcliffe

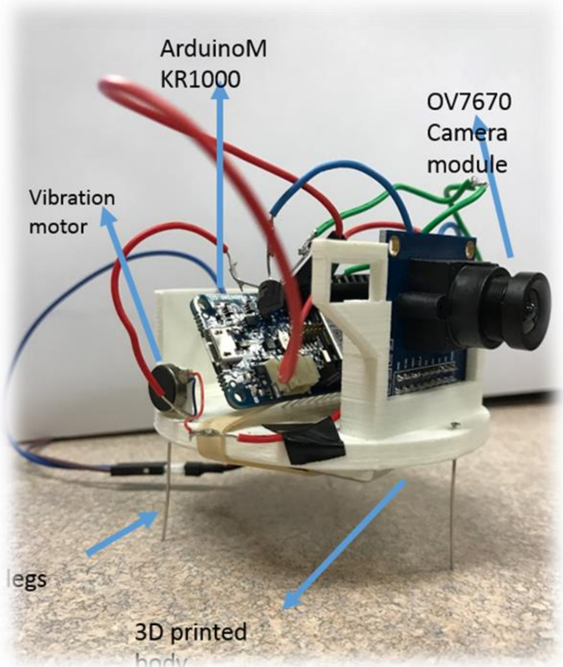
Paper: “Bionic Egg: Sealed mobile sensor packaging design with adaptive power consumption, E. Jacobson, S. Darius, A. Tatoglu and P. Mellodge, IEEE Long Island Systems, Applications and Technology Conference (LISAT), Farmingdale, NY, 2017, pp. 1-6. 2017”

Swarm Robotics

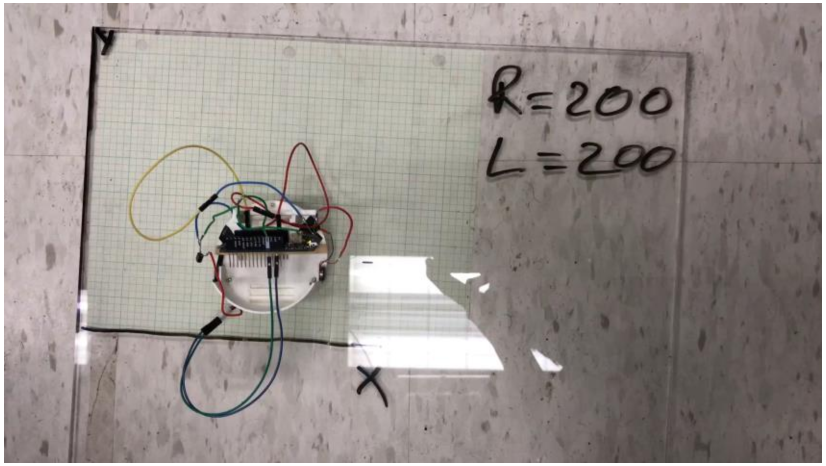
Vibron: A new approach to the coordination of multirobot systems which consist of many small physical robots. No moving parts!



New Design: 3D Printed Body

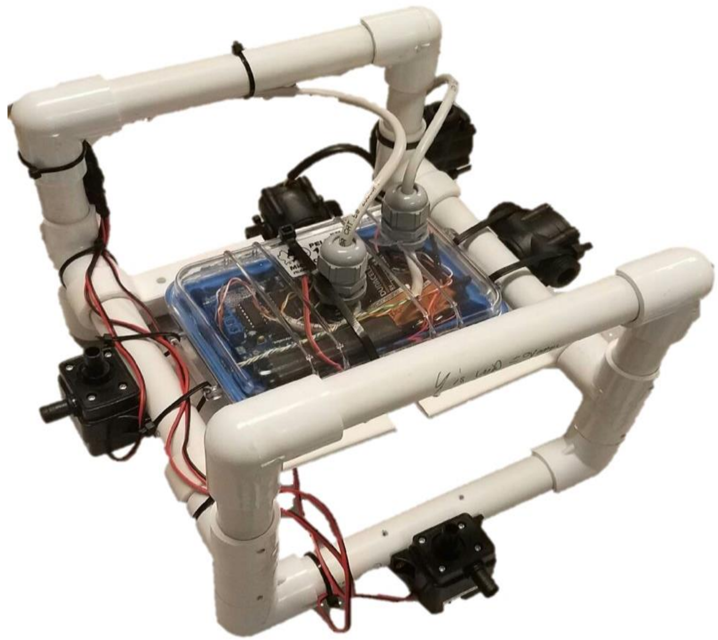


- They are designed to work collectively and in tune with each other.
- Primary focus is pointed at controlling the motion of the robots and possibly make them communicate with each other



Environmental Decisions: Harsh Environments

Unmanned Underwater Vehicle: Create a simple autonomous robot that travels underwater following predetermined cube like path.



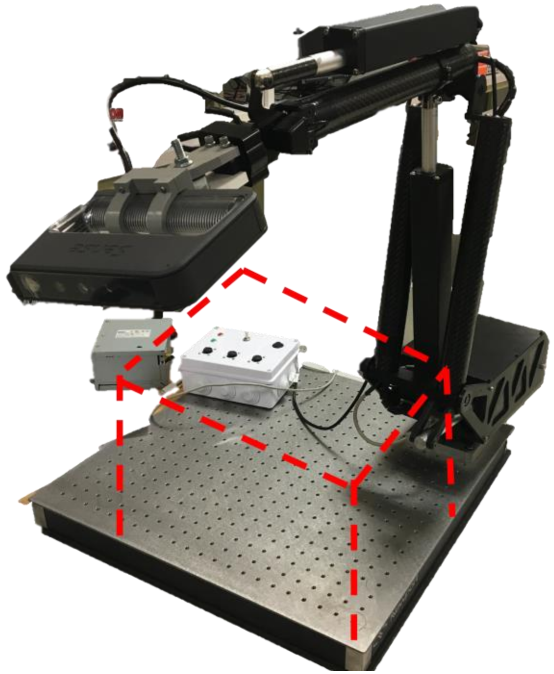
Bill-of-Materials

- Pelican 1020 Waterproof Micro Case, Arduino UNO, Motor Drive Shield, 12V Submersible Water Pumps
- Plastic Submersible Cord Grip, Adafruit Water Flow Sensors, Zip ties, Styrofoam

Students: Jason Carter, Jamie Dolan, Tiffany Pauley, Troy Solt, & Jeremy Stager

Perception

3D Robotic Arm Scanner: A device that uses a robotic arm along with a hand held scanner to make digital 3D model of objects.



Smart Scanner

3D Reconstructed Object

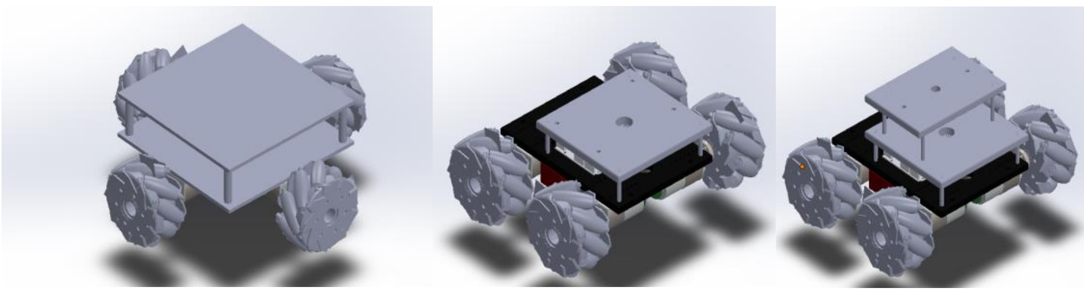
3D Reconstructed Face

Students: Mason Paul ME, Gabriel Valero ME, Hector Ortiz CET, Justin Simko ME

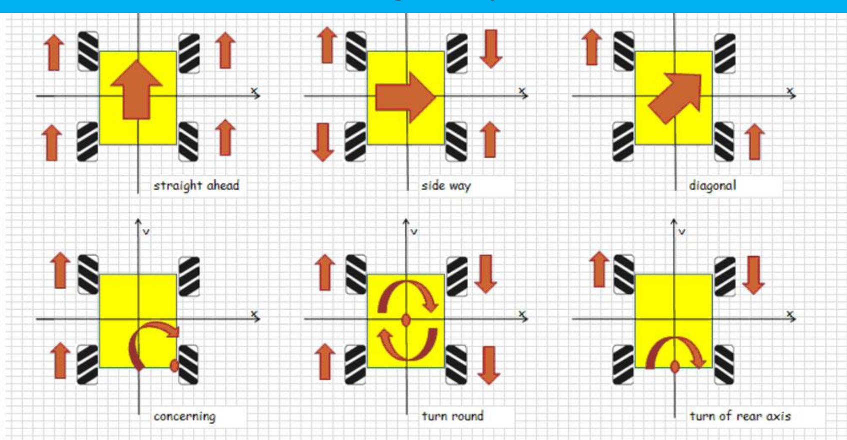
Locomotion: Alternate Mechanisms

OmniBot: SPARK: A ground vehicle with use of mecanum wheels that can move in all directions.

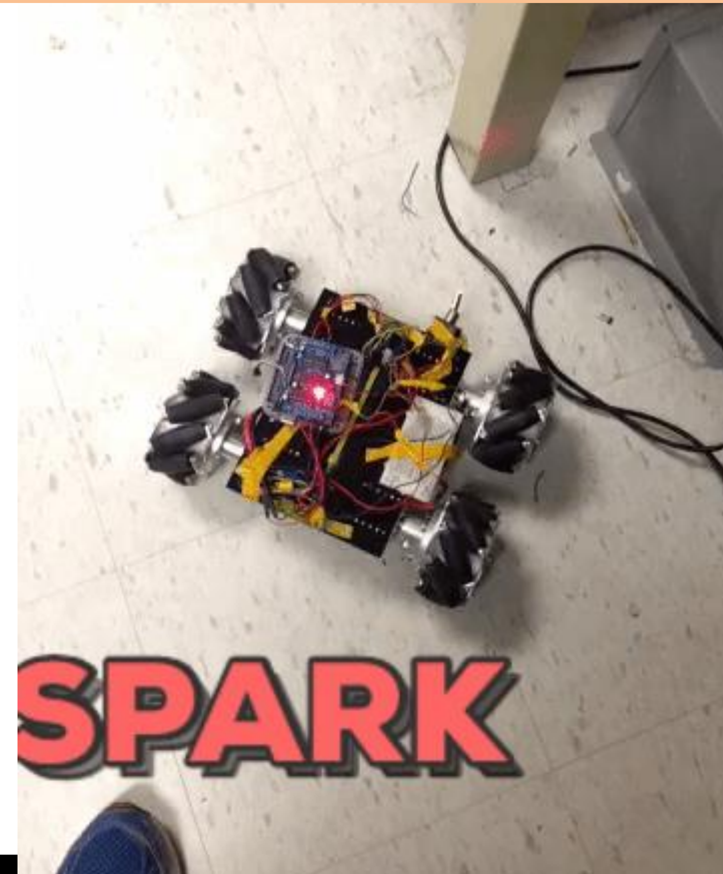
Design Iterations



Working Principle



Zero Radius Rotation



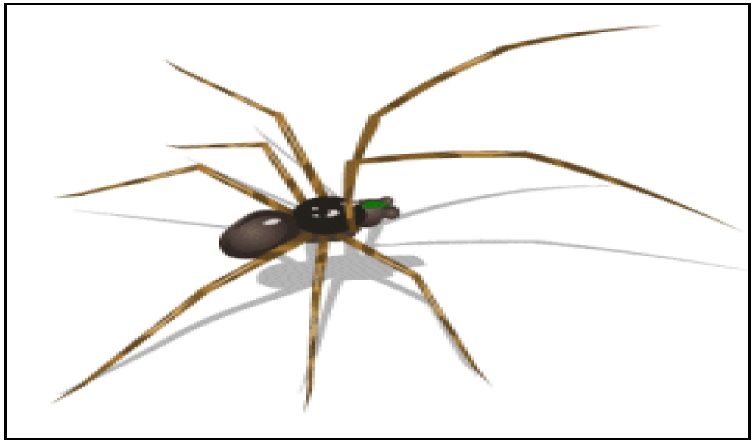
Can nature help me ?

Of course! Robotics and Biomimetic.

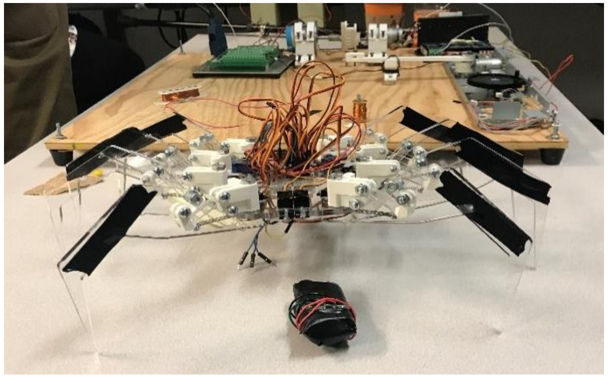
Locomotion: Mimicking Nature

SpiderBot: Locomotion of the robot imitating spider walk.

System Simulation



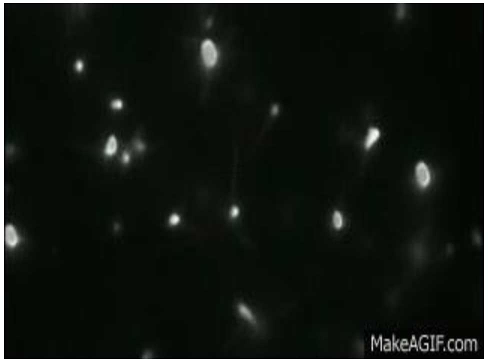
Manufactured System



Robotics and Biomimetic

MicroSwimmer: It has long been known that swimming at the microscale requires techniques that are very different from those used by macroscale swimmers, such as fish and humans [1].

- Can we use these techniques to develop a robot ? Locomotion of the robot imitating spider walk.



Robotics and Biomimetic

Microorganisms are able to swim at low Re using a variety of techniques[1], none of which look like those used by macroscale swimmers.

All of the swimming methods utilized by microorganisms are fairly inefficient, which is not a problem because microorganisms' source of energy (food) is so plentiful.

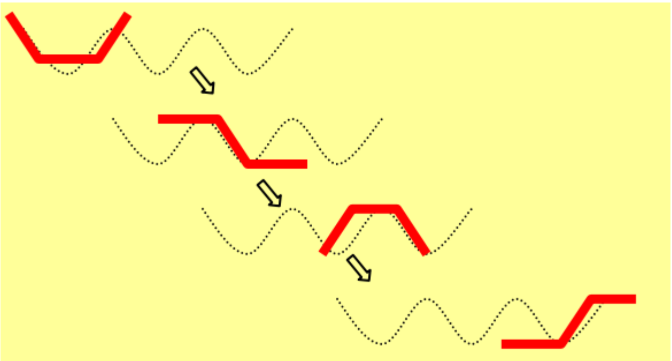
20 µm and have a diameter around 0.25 µm

Flagella

Cilia of an eukaryotic cells

Robotics and Biomimetic

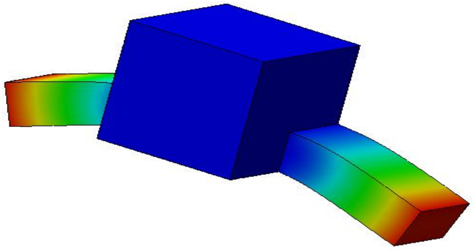
Structure

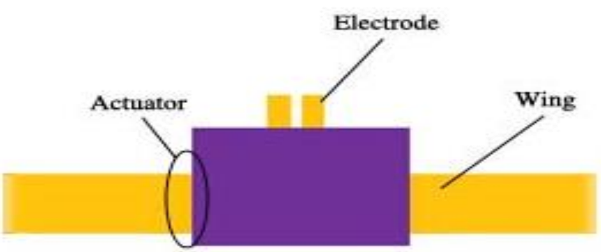


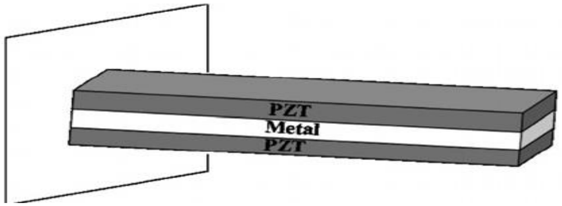
Trajectory

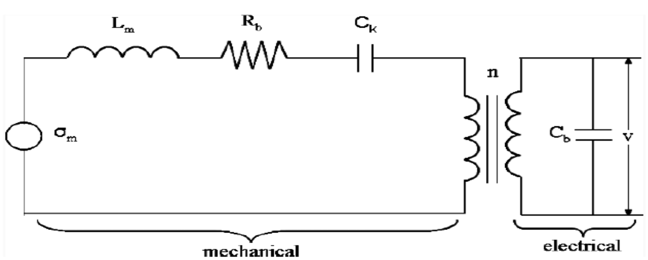
$$\sigma_{\text{in}} = L_m \varepsilon + R_b \dot{\varepsilon} + \frac{\ddot{\varepsilon}}{C_k} + nV$$

$$i = C_k \dot{V}.$$







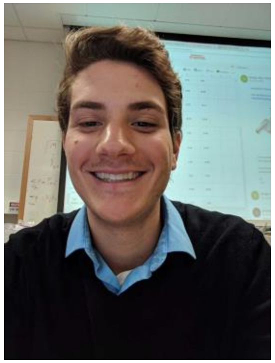
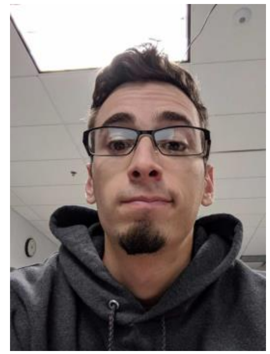
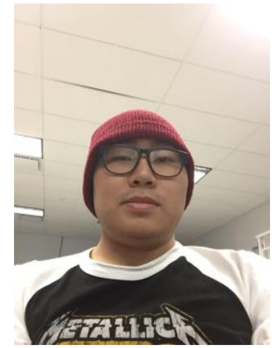
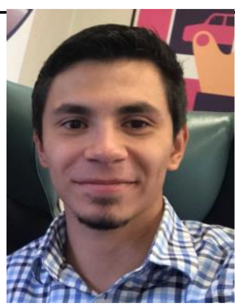
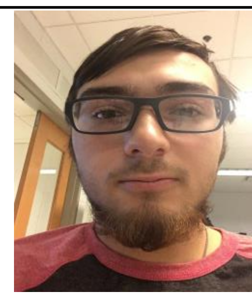
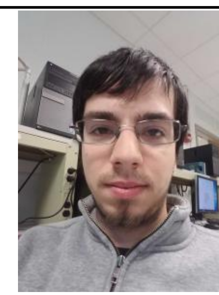


Chromium is used as an adhesive layer between the gold and the PZT. E-beam is used because it enables the deposition of a metal on top of another metal.

Tatoglu A., Propulsion System for Micro Underwater Robot, IEEE International Energy & Sustainability Conference, 2015

Can we build a self-driving car?
We are working on it!

Full Scale Self-Driving Car Project

				
Stephen DeRosa, ME, Jr	Matthew Woodard, ECE, Jr	Evan Gerard, MET, Sr	David Dai, ME, Sr	Peter Klesczewski, ECE, Fr
				
Digno Iglesias ME, Jr	Jeff Severino, ME, Jr	Nigel Otis, ME, So	Eric Jacobson, ECE, Gr	Day Moo ME, Sr

Fr. Freshman, So. Sophomore, Jr. Junior, Sr. Senior, Gr. Graduate

Autonomous Mobile Robotics Research Group

Full Scale Self-Driving Car Project

Phase 1: [Completed]

Brainstorming and designing the system that will be implemented with the cart. It also must take all safety measures into account. [Completed.]

Phase 2: [Mid-Spring Semester]

Is when the designed system will actually be implemented with the golf cart. At this point the golf cart will be made remote controlled. This this will allow for testing of the systems implemented in a safe and controlled manner.

Phase 3: [Summer and Fall Semesters]

sees the remote controls being handed off to the autonomous systems. Trials will be run under different circumstances the golf cart will encounter, to ensure proper and safe operation.

Cars are good, they can’t even swim ☹
Well, we have a solution for this!

Multi Terrain Vehicles

Hovercraft can travel over almost any non-porous surface:

- even or uneven terrain - sandy and icy grounds
- Ideal for disaster relief situations

Landing Craft Air Cushion (LCAC) is delivering supplies to the citizens of Meulaboh Indonesia after the 2004 Indian Ocean tsunami.

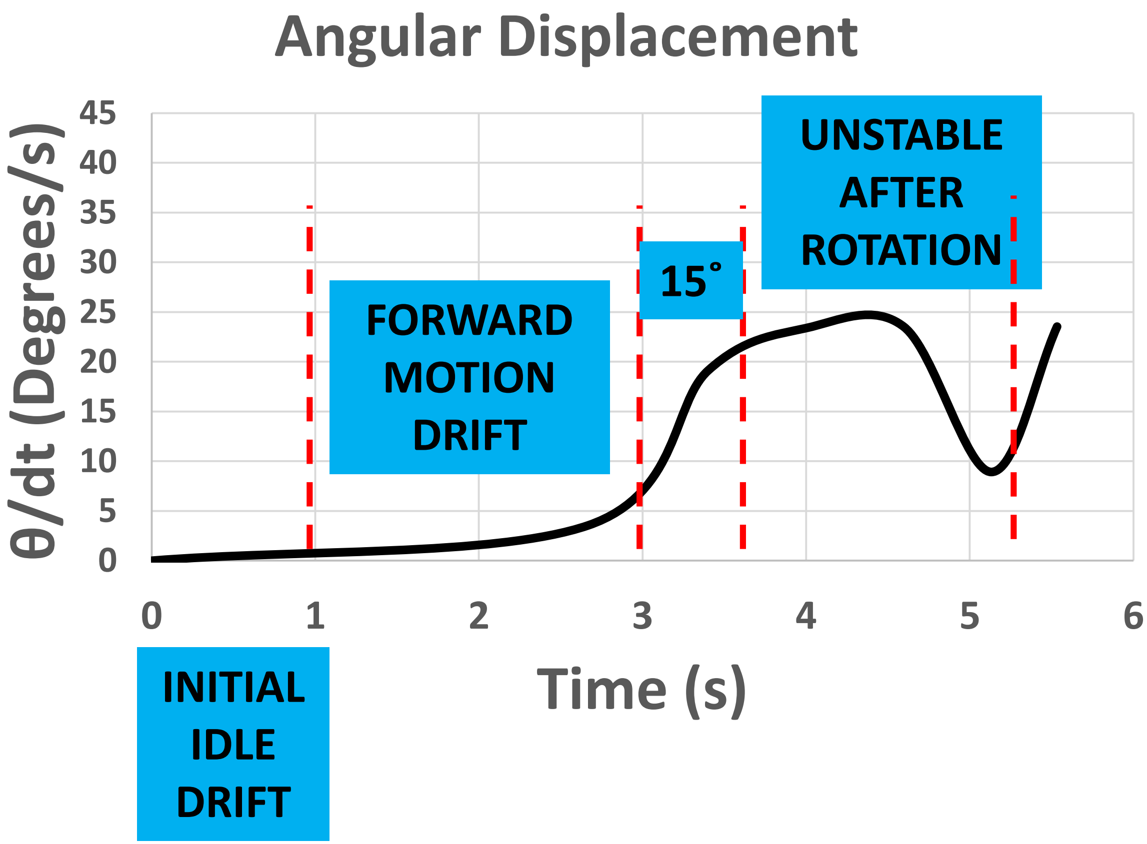
A hovercraft docking to a ship.

Alternate Locomotion: Hovering

- The hovercraft's ability to distribute its laden weight evenly across the surface below it makes it well suited to the role of amphibious landing craft.
- Hovercrafts can transport materials from ship to shore and can access more than 70% of the world's coastline, as opposed to conventional amphibious landing craft, which are only capable of landing along 17% of that coastline.

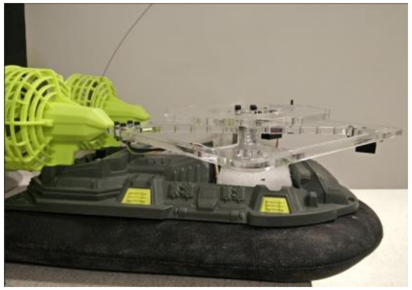
Control: Advanced Dynamics

- An Hovercraft is controlled by commands below.



MOTION COMMANDS:

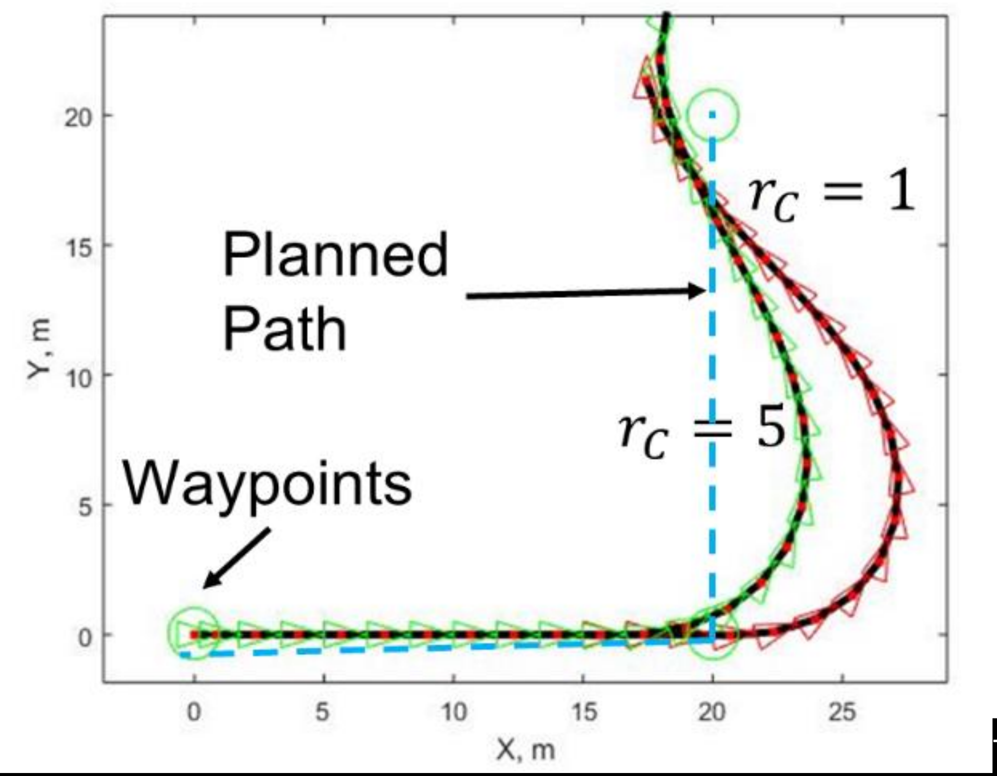
- STOP[1s]
- MOVE FORWARD [2 s]
- TURN LEFT [0.5 s]
- MOVE FORWARD [2 s]
- STOP[1s]



Utilizing Reaction Wheels to Increase Maneuverability and Localization Accuracy of a Hovering Robot, Tatoglu A, Greenhalge S, Windheuser K., ASME International Mechanical Engineering Congress and Exposition, Volume 4B: Dynamics, Vibration, and Control, 2016

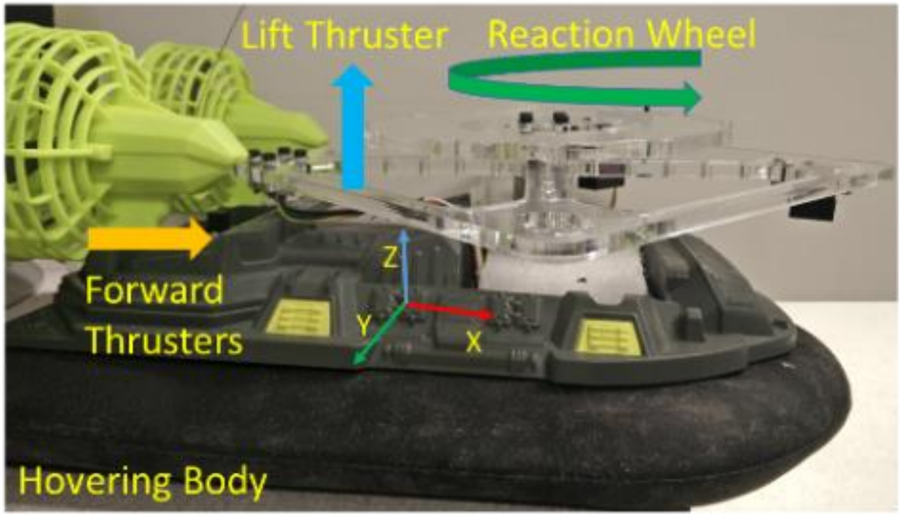
Control: Motion Planning

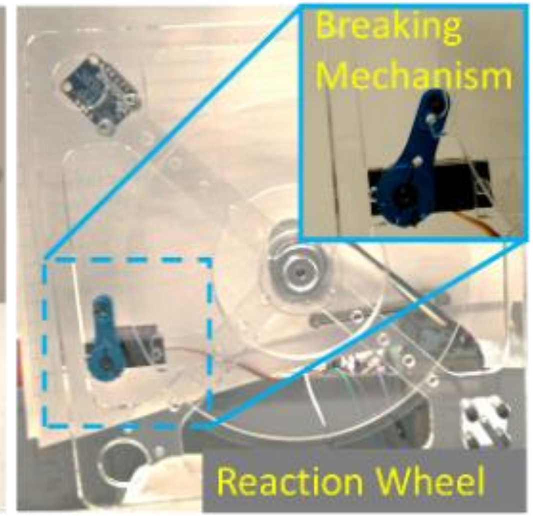
- Initial Simulations: Motion Planning and Execution
- Different capture radius values are tested.
- Rotation takes time and not accurate

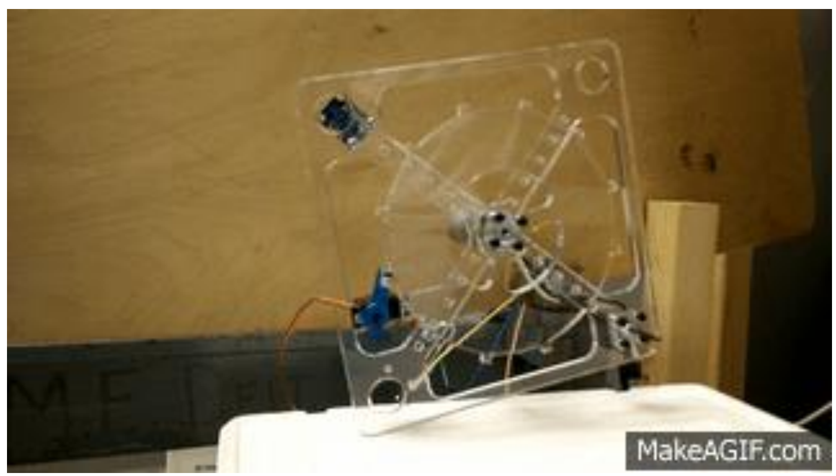


Utilizing Reaction Wheels to Incr… Tatoglu A, Greenhalge S, Windheuser K., ASME International Mechanical Engineering Congress and Exposition, Volume 4B: Dynamics, Vibration, and Control, 2016

Alternate Mechanisms

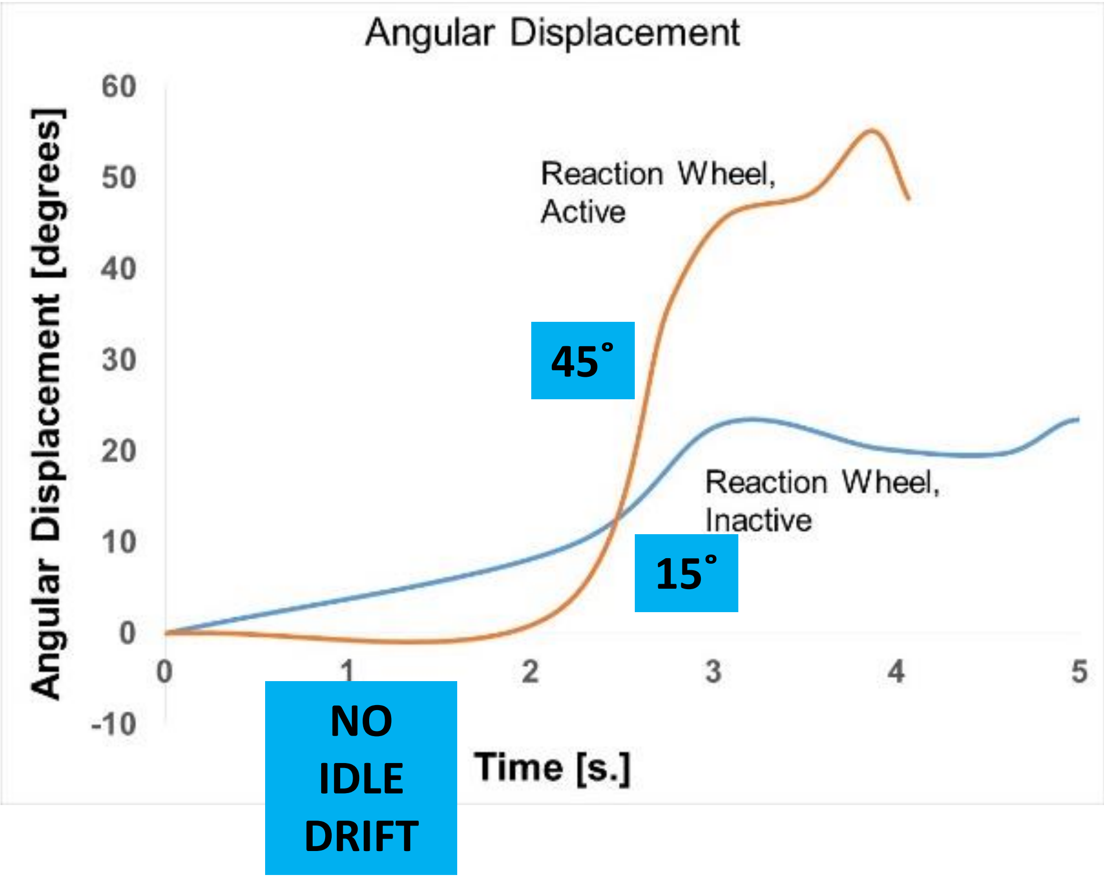


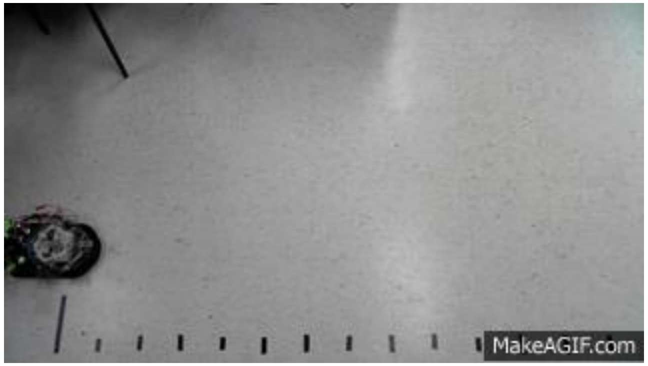




Utilizing Reaction Wheels to Increase Maneuverability and Localization Accuracy of a Hovering Robot, Tatoglu A, Greenhalge S, Windheuser K., ASME International Mechanical Engineering Congress and Exposition, Volume 4B: Dynamics, Vibration, and Control, 2016

Alternate Mechanisms





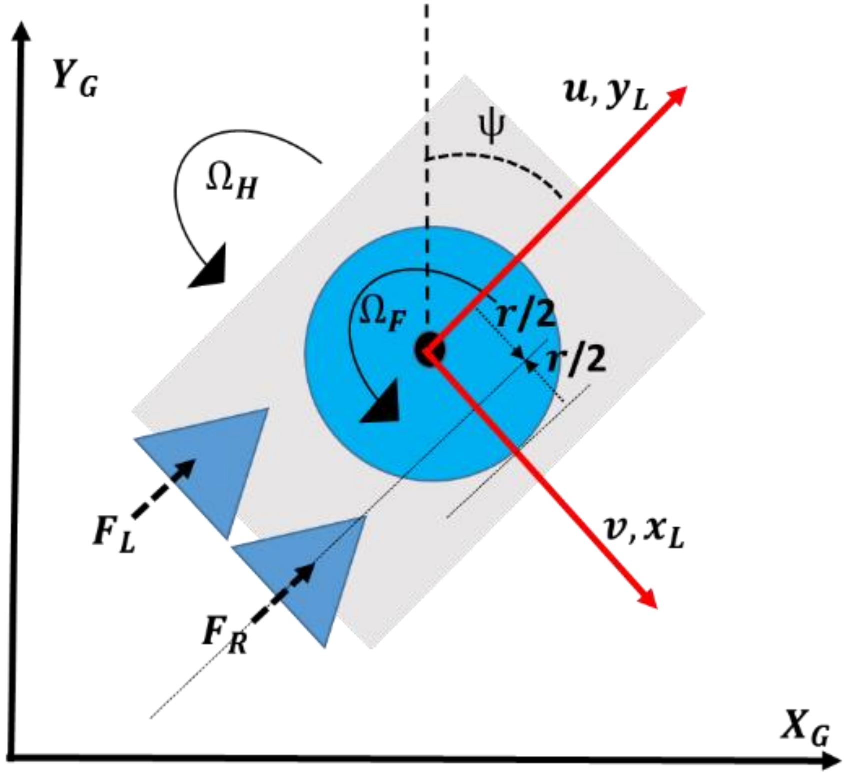
RESULTS:

- Momentum wheel substantially increased **rapid angular displacement** ability of hovering body.
- System is **less sensitive** to the terrain/ground shape.

Utilizing Reaction Wheels to Increase Maneuverability and Localization Accuracy of a Hovering Robot, Tatoglu A, Greenhalge S, Windheuser K., ASME International Mechanical Engineering Congress and Exposition, Volume 4B: Dynamics, Vibration, and Control, 2016

Controller Improvements with a more advanced system model

- Blows the air underneath the craft
- Rubber cushion–skirt—traps the air and inflates



The velocities on x and y axes are given by

$$\dot{x} = u\cos\psi - v\sin\psi \quad (1)$$

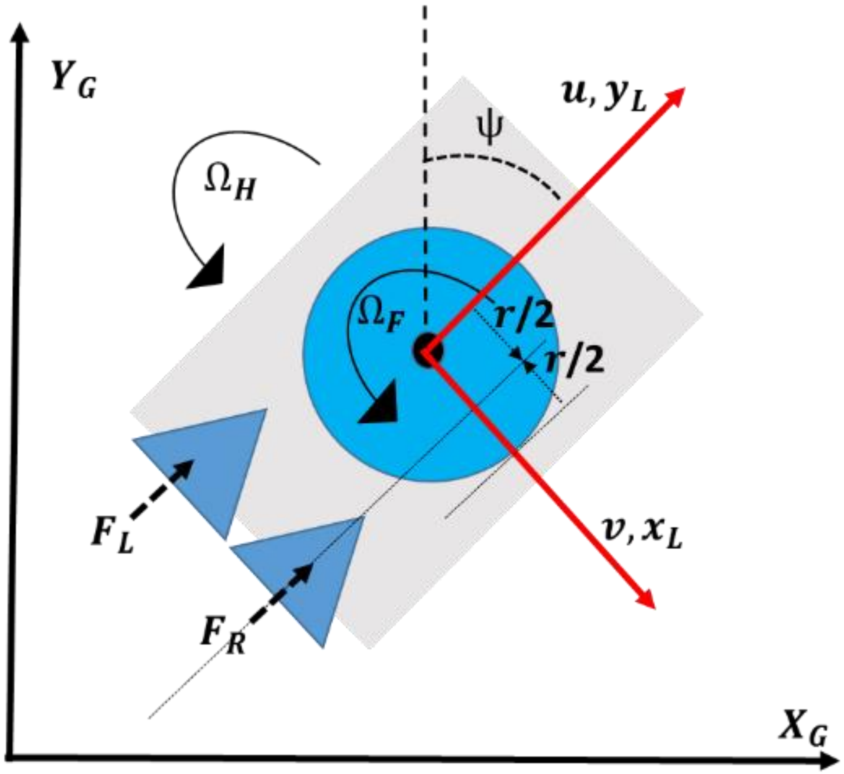
$$\dot{y} = u\sin\psi + v\cos\psi \quad (2)$$

ψ: is projection angle between frames.
u (surge speed) and v (sway speed) represent the velocities on x and y directions.
Ω_H: angular velocity of the overall body
Ω_H is equal to first derivative of vehicle orientation ψ given by

$$\dot{\psi} = \Omega_H$$

Parameter Identification and Closed Loop Control of a Flywheel Mounted Hovering Robot", Tatoglu A., ASME International Mechanical Engineering Congress and Exposition, 2017

Controller Improvements with a more advanced system model



The controller input u_1 is the sum of forward thruster fan forces which is given by

$$u_1 = F_L + F_R = m\dot{u} - mv\Omega_H + d_v u$$

This follows the second equation on the sway direction:

$$m\dot{v} + mu\Omega_H + d_v u = 0$$

d_v: the coefficient of viscous friction.
Second controller input u_2 is given by

$$u_2 = \frac{r}{2}(F_L - F_R) + M_w r = J\,\dot{\Omega}_H + d_r\Omega_H$$

J: is the overall vehicle inertia,
M_w: rotational torque released by the flywheel
d_r: the coefficient of rotational friction.

Controller Improvements with a more advanced system model

- Feedback Control system of the differential drive forward thrusters
- Flywheel break engages at the waypoint.

Fig.5 Waypoint following with feedback control system. Rotation is executed with flywheel and forward fans.

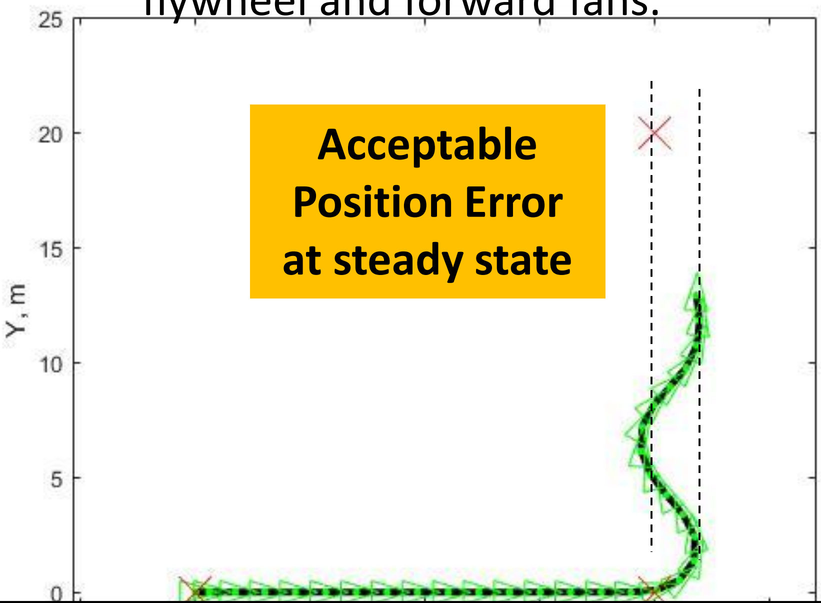
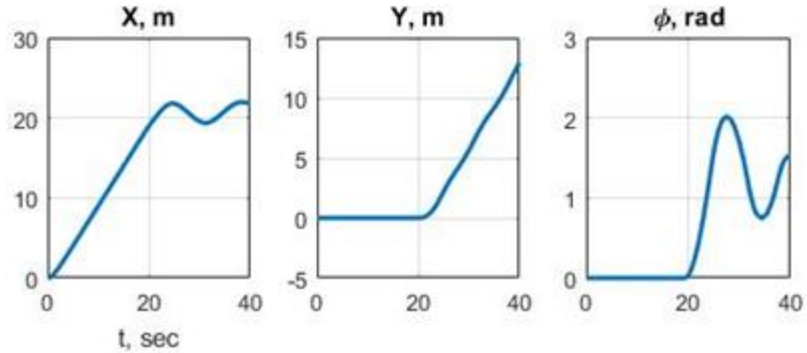


Fig.6 Global frames, individual axis linear and angular positions with feedback control system.



Parameter Identification and Closed Loop Control of a Flywheel Mounted Hovering Robot", Tatoglu A., ASME International Mechanical Engineering Congress and Exposition, 2017

Controller Improvements with a more advanced system model

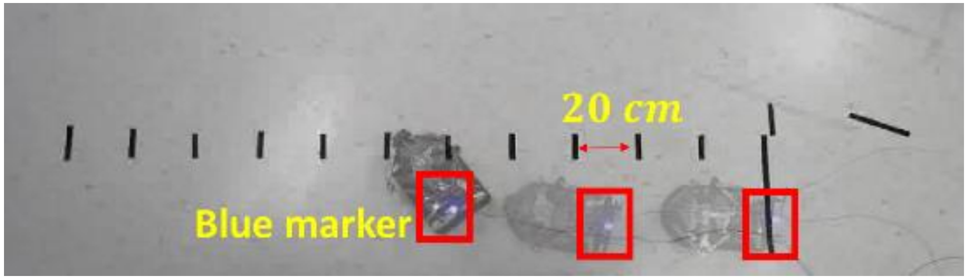


Fig.8 Object Tracking to Generate the Path followed

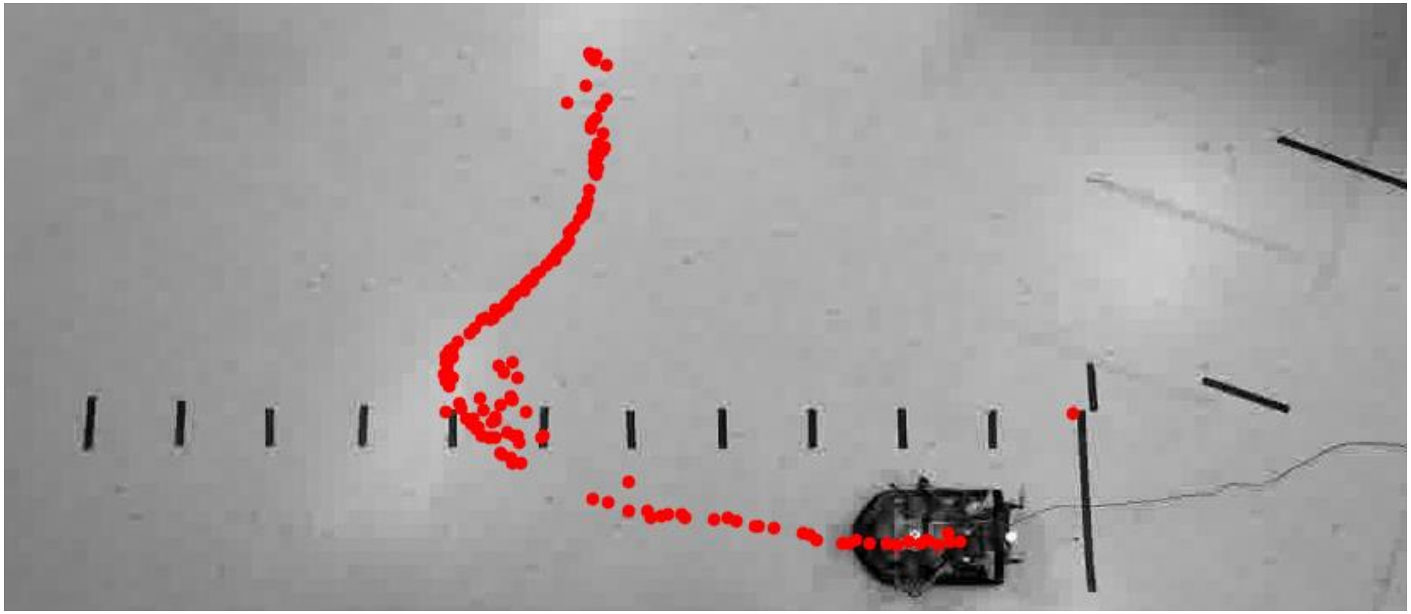


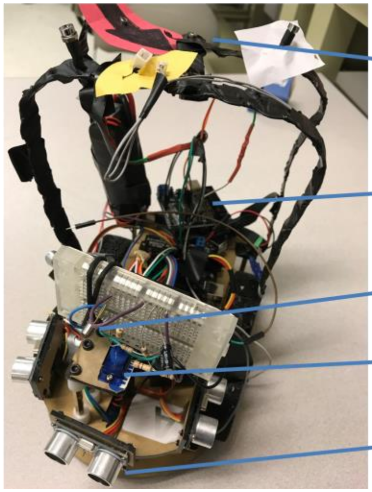
Fig.12 Rotation with flywheel and fans, feedback controller on after rotation

It looks complicated. Is there an easier way to learn the control logic?

Yes, of course! Pyro

Educational Platform: Pyro

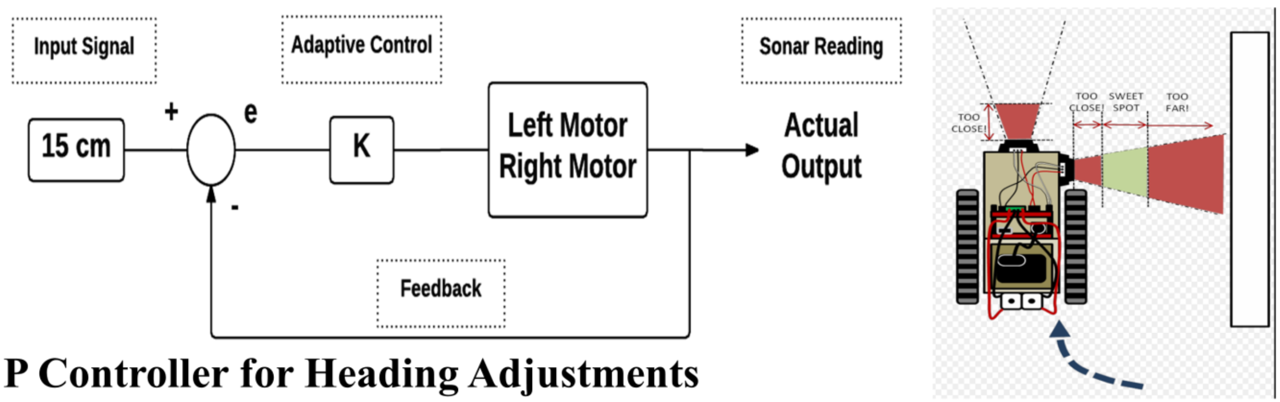
Electromechanical Design



Design, Prototyping & Testing

- Design & Testing Components
  - Microphone: detecting the start up frequency at 3.8KHz
  - Arduino Uno: Single-board microcontroller with Analogue and Digital Inputs/Outputs
  - Heat/IR Sensor: detects the fire at a certain distance and using an algorithm to be closer and extinguish it
  - Servo Motors: coding a rectangle shape to calculate the percentage error
  - Ultrasonic Sensors: Having 180 degree rotation to read obstacles and their distances

Robot Controller



P Controller for Heading Adjustments

Problem Statement

The tournament expects Pyro to avoid obstacle, solve the maze and extinguish a fire with fastest amount of time possible.

Solution

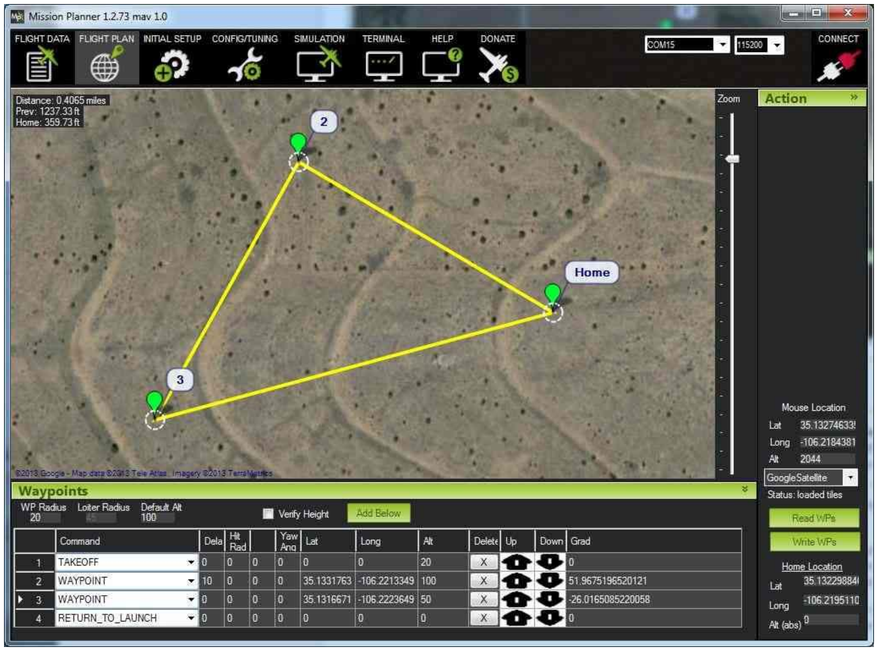
Using highly sensitive sensors like Ultrasonic sensors to avoid the obstacles and any walls present in Pyro's way, Left/Right hand rule so that Pyro follows the walls until it solves the maze and Heat/IR sensor to detect the fire and use a blowing fan to extinguish it.

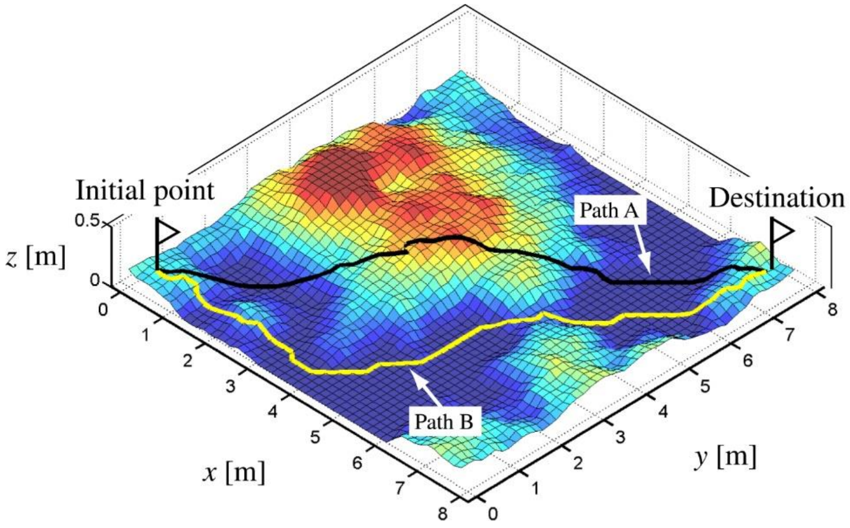
Trinity College, Firefighting Robot Competition 2017.
Students: Electrical Engineering: Heather Volkens, Mechanical Engineering : Yousef Bahman Ali Alsulaiman Bryant Miranda

How about UAVs?
Yup!! It is time!

UAV Path Planning

Localization algorithms are also used to follow a pre-determined path.





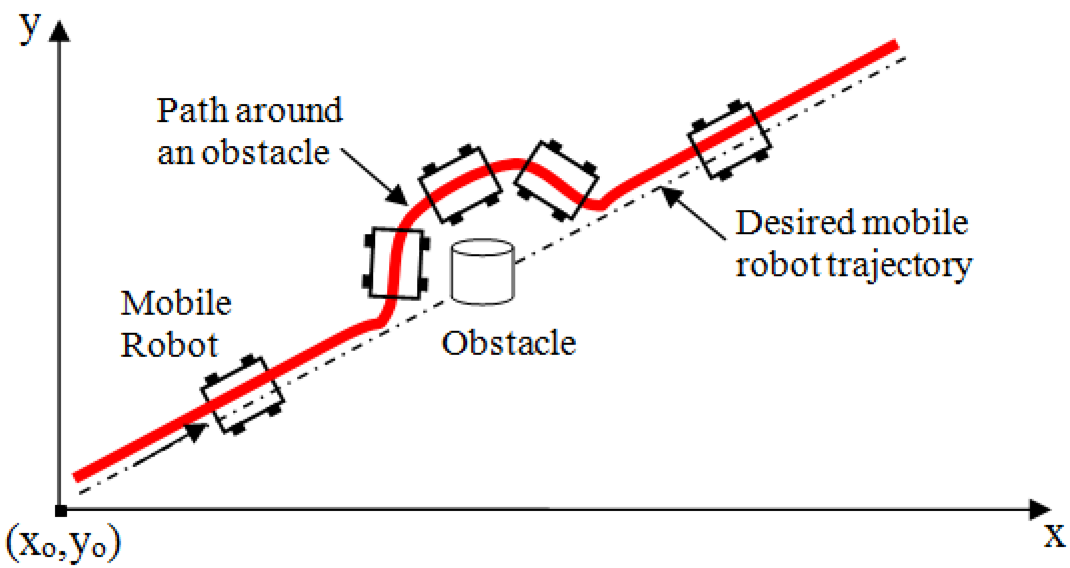
High Altitude:
Mostly Linear Path Plan
(This problem is kind of solved.)

Continuously Varying Path Plan:
Fixed distance from ground

Adaptive Gimbal Control Approach to Account for Power Consumption and Landmark Tracking Quality, Tatoglu A, Campana C. ASME International Mechanical Engineering Congress and Exposition, Volume 4A: Dynamics, Vibration, and Control, 2016

Obstacle Avoidance

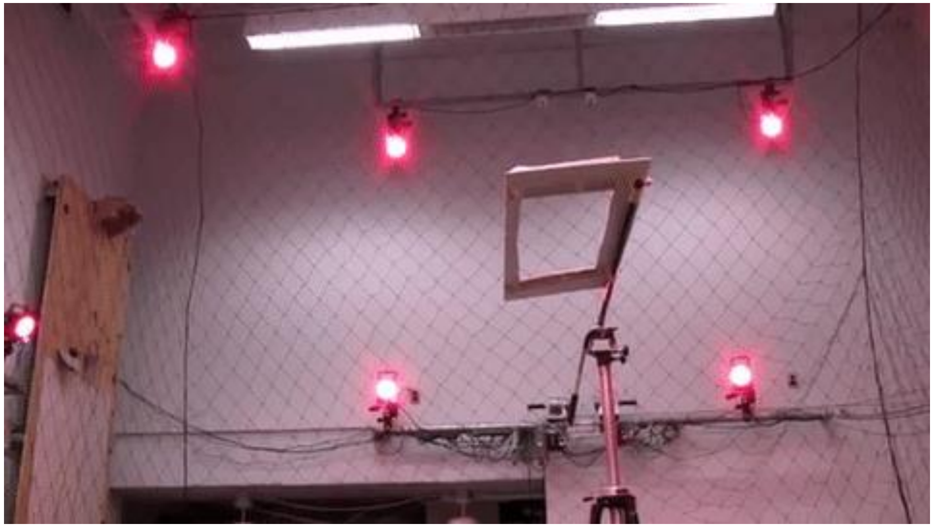
During the mission, path plan needs to be updated locally once an obstacle is met.



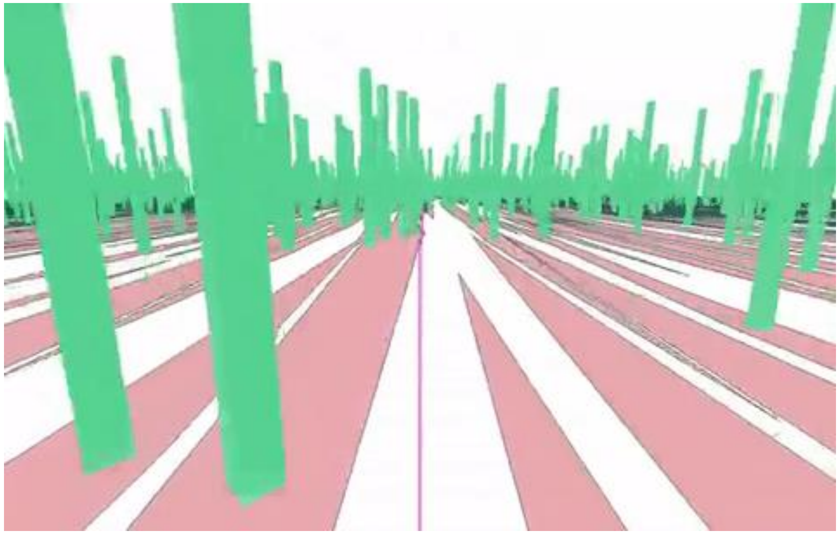
Mission Types

Constant vs Variable input signal

- Linear Path Plan vs Continuously Varying Path Plan
- Obstacle avoidance, Rapid Moving Object tracking
- Little Disturbance vs High Disturbance (i.e. wind)



[1] Aggressive Maneuvers for UAV Flight, GRASP Lab, UPenn, Mellinger, IJRR 2012

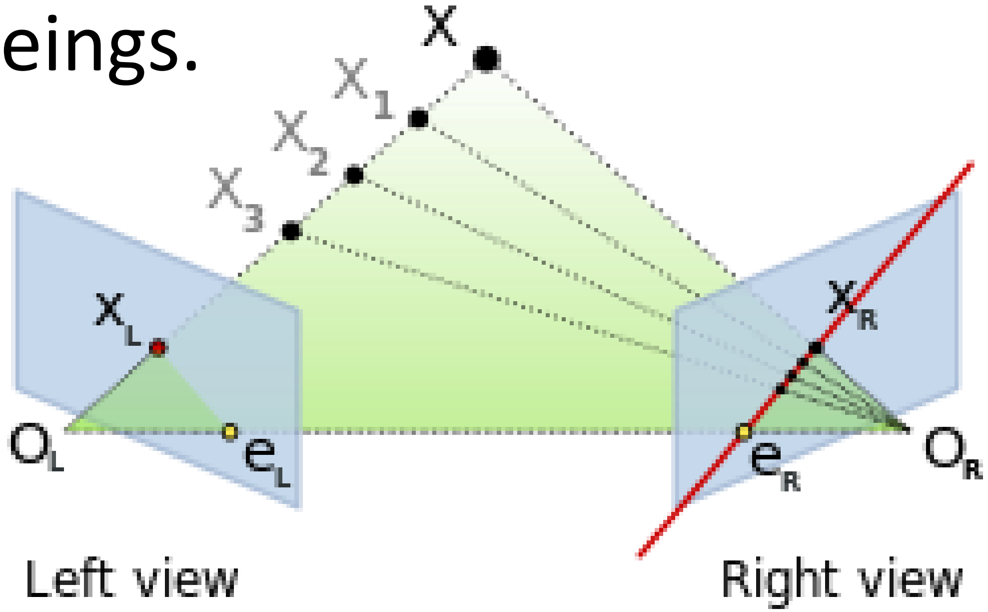


[2] High-speed Flight in an Ergodic Forest, MIT, Karaman , ICRA 2012

Stereo Imaging: Mimicking Human Vision System

How can a UAV/robot perceive the environment ?

Visual Navigation: It can perceive the environment including depth with a stereo camera system, same as human beings.



Adaptive Gimbal Control Approach to Account for Power Consumption and Landmark Tracking Quality, Tatoglu A, Campana C. ASME International Mechanical Engineering Congress and Exposition, Volume 4A: Dynamics, Vibration, and Control, 2016

Visual Navigation

<u>For a UAV and its visual navigation system:</u>

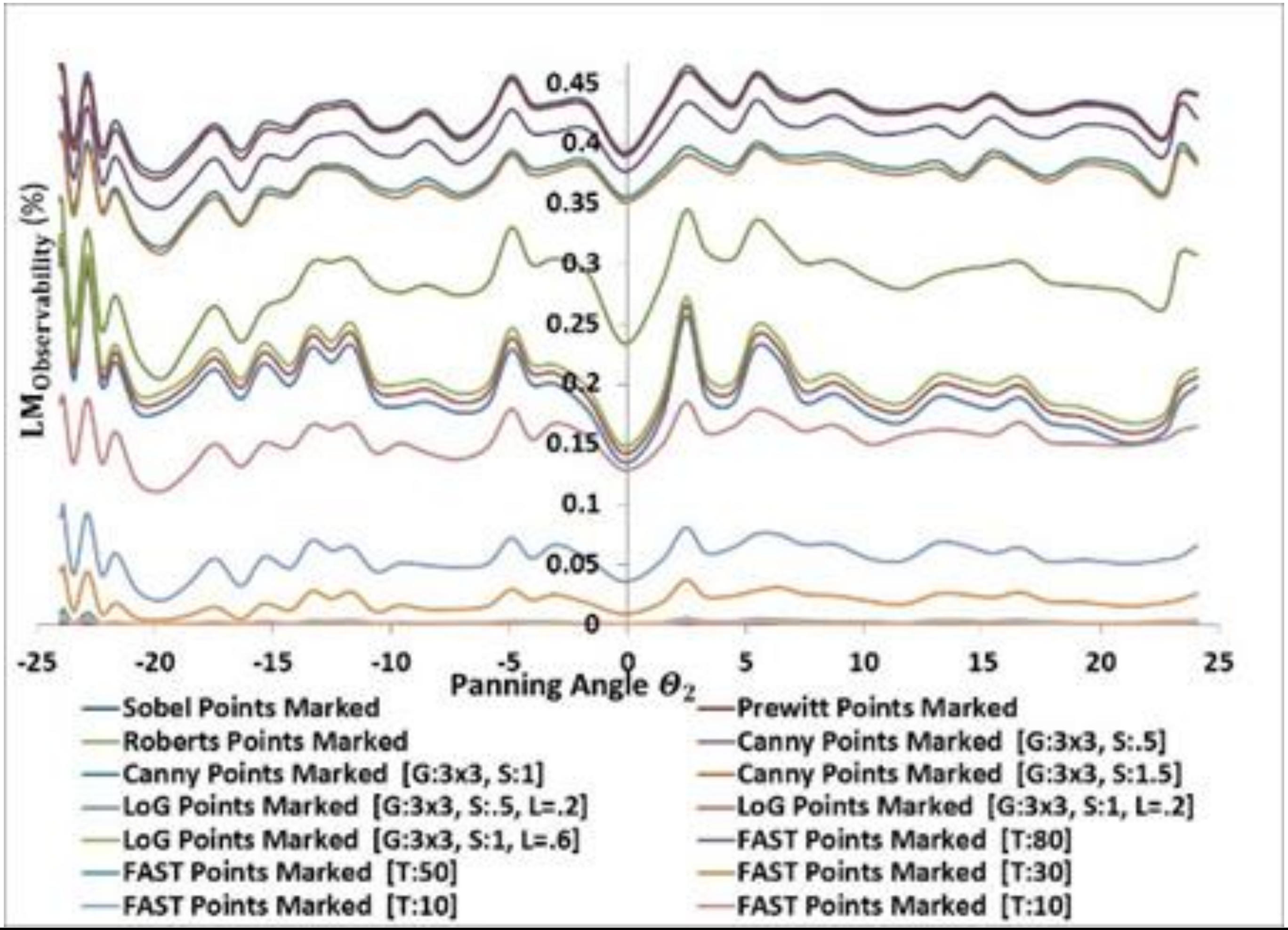
We want to develop a 2 DOF gimbal controller for continuously variable controller input for mission types discussed.

HOW CAN WE DECIDE GIMBAL CONTROLLER PARAMETERS IF WE ACCOUNT FOR:

Landmark Tracking Quality	LQM(Landmark Quality Metric)
Steady State Error	e_{ss} (error, steady state)
Energy Consumption	$Watt - second$

Landmark Detection Algorithms

Sobel, Roberts, Canny, LoG, Prewitt, FAST(Features from Accelerated Segment Test)



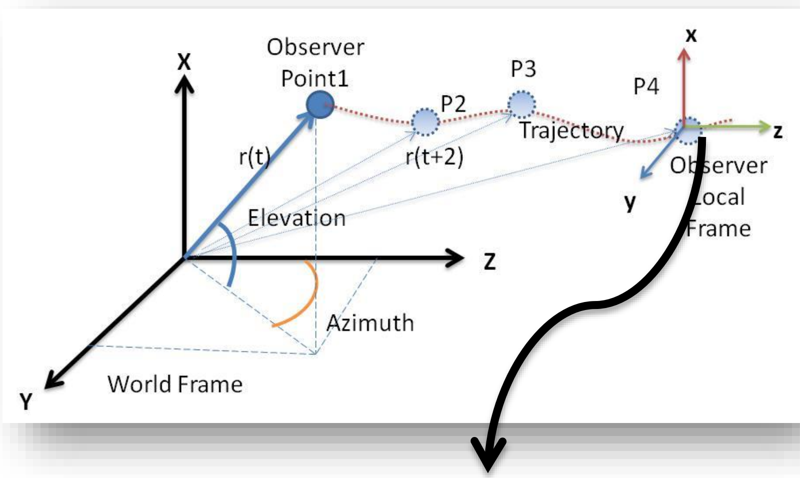
Adaptive Gimbal Control Approach to Account for Power Consumption and Landmark Tracking Quality, Tatoglu A, Campana C. ASME International Mechanical Engineering Congress and Exposition, Volume 4A: Dynamics, Vibration, and Control, 2016

Wait!!! I am lost! What is a landmark ?
OK, let’s start again, from the beginning.

What is the common task for all the robots discussed ?
If we ask them to go to the nearest Starbucks and get a coffee…

Why is Localization important?

- The first question required to be answered for all these robotic systems is “Where am I? “



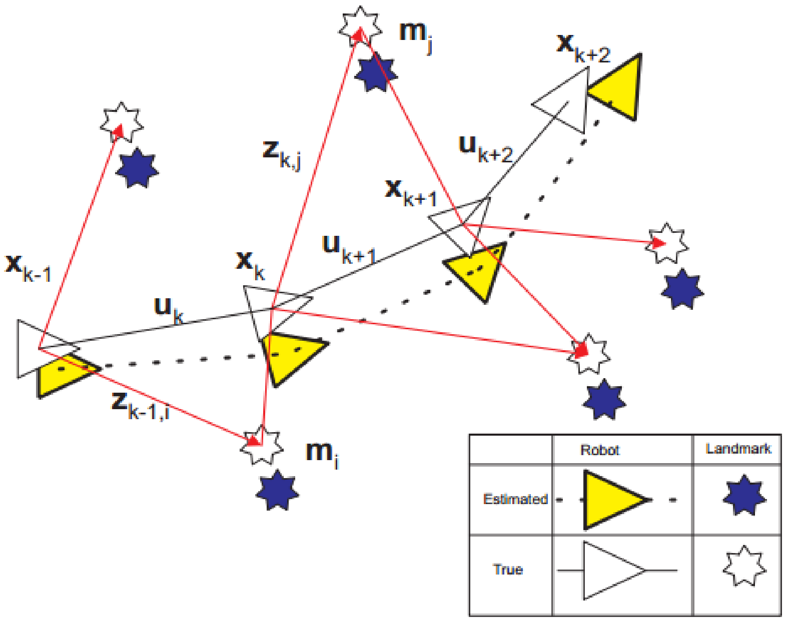
Where am I

Current State of Research Efforts

- SLAM(Simultaneous Localization and Mapping) is a stochastic(probabilistic localization algorithm.
- It is defined as a chicken and egg problem:
  - Robot moves, generates a map.
  - Then try to localize itself within this map.
  - By using this new location, it decides where to go.
  - And again generates a map to localize itself in it.
- It corrects itself and reduces uncertainty.
- Currently, SLAM is the most advanced localization algorithm.

Current State of Research Efforts

- SLAM(Simultaneous Localization and Mapping) methodology offers a probabilistic solution as an answer to the localization problem [Durrant-Whyte, 2006].



Localisation problem may be formulated as computing the probability distribution

$$P(x_k|z_{0..k}, \mathbf{u}_{0..k}, \mathbf{m})$$

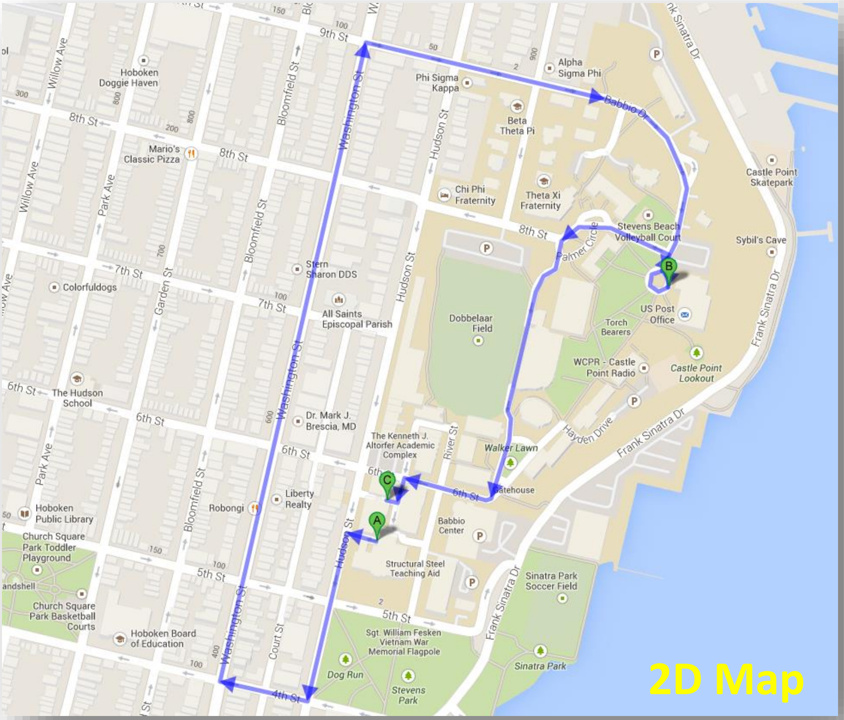
Current State of Research Efforts

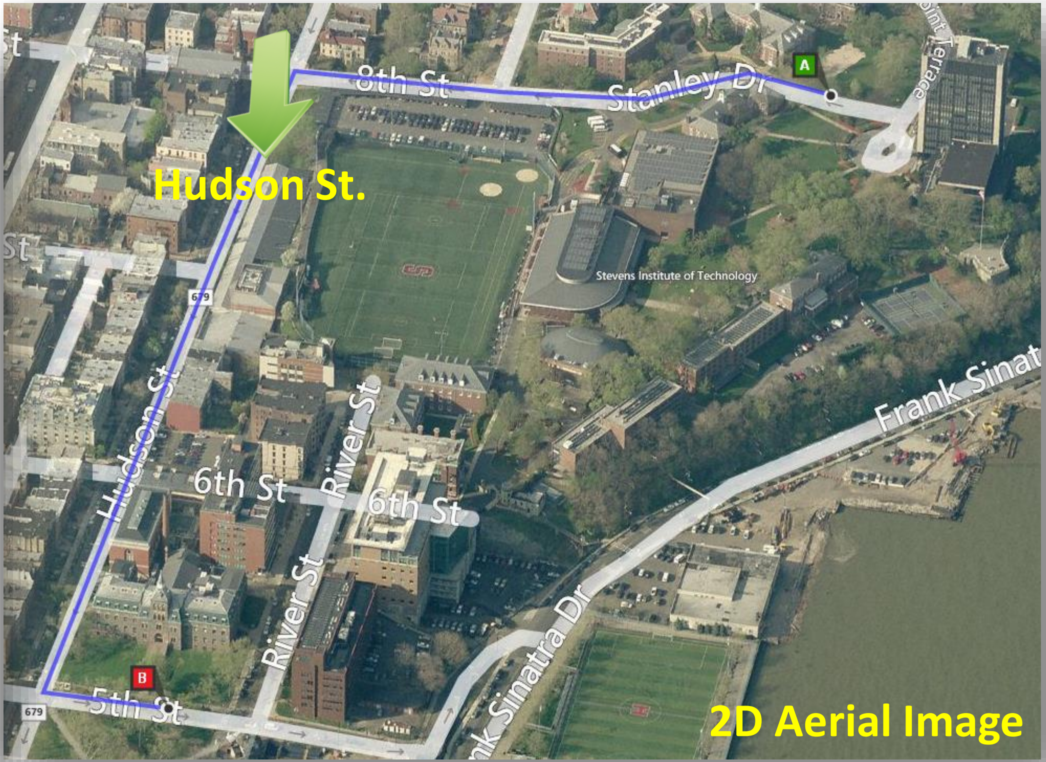
- There are various solution approaches
  - Stereo SLAM
  - RGBD SLAM [Kinect Like Sensors]
  - tinySLAM
  - SLAM with RBPF [Non-linear Solutions]
  - Visual Odometry [Camera + Odometry]
  - MonoSLAM [Single Camera Solutions]

What are the applications ?
OK, let's see the applications and finalize with a simple example.

Mapping and Localization

When there is a GPS and a map, localizing a robot is easy.





Courtesy of Google and Bing

Accuracy of GPS

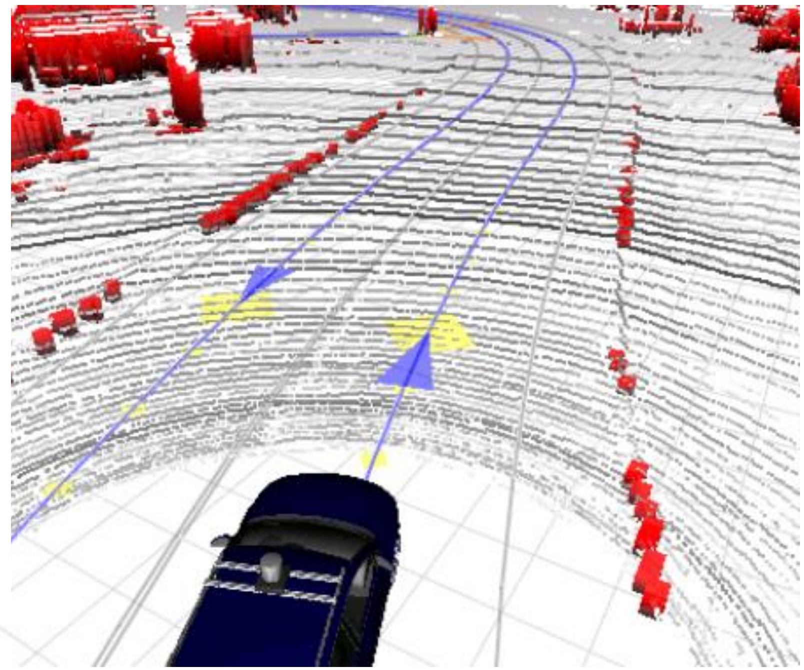
- Junior, DARPA Challenge: 3D Point Clo

GPS, Known map
And multi sensors

Junior Sensor Suite

Laser typical accuracy: +/- 2cm

GPS Error: ~2-20 meters

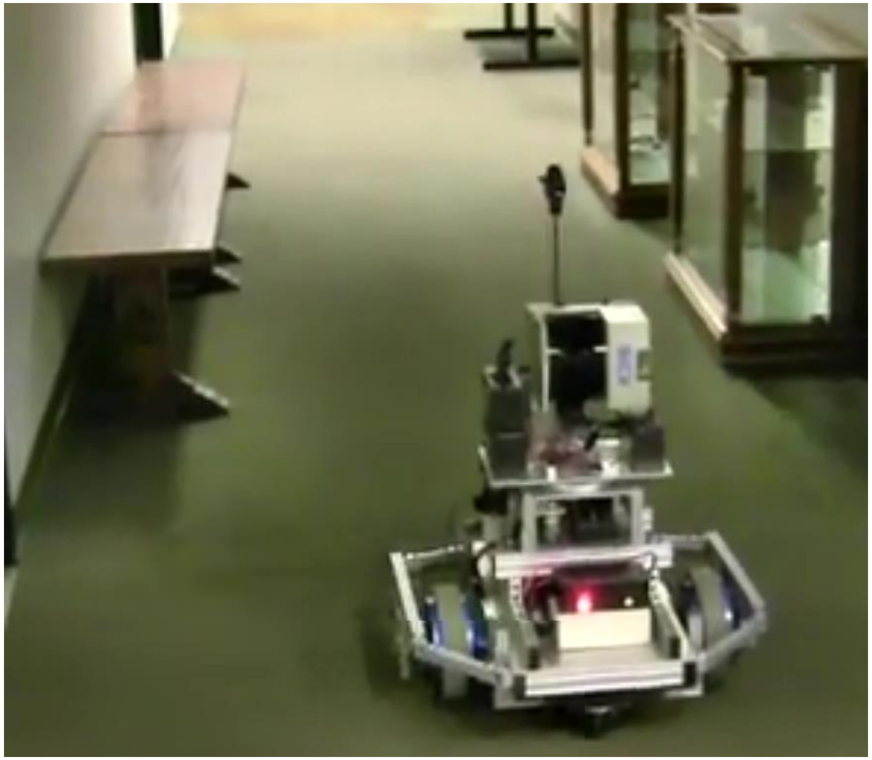


Localization

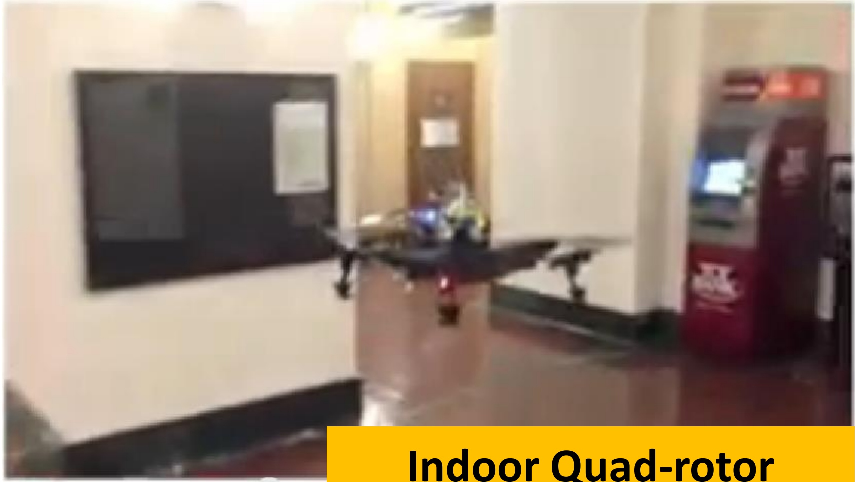
Indoor robot: No GPS

*No GPS,
Known map
And multi
sensors*

- Indoor Localization



Indoor Ground Robot
JAMES: SIT



No or Obsolete Map

No GPS,
No MAP,
Known
controller
input

- Mine and disaster area search missions

Mining Area

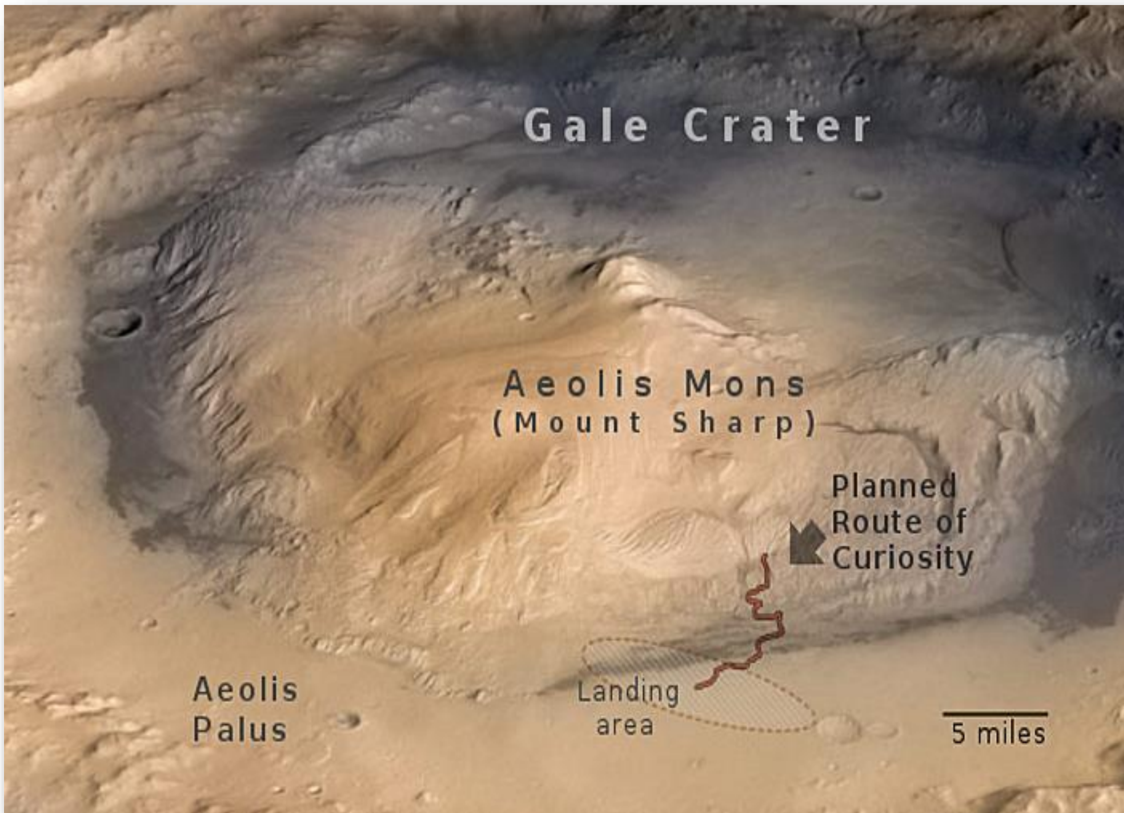
Rescue Robot: Gemini-Scout

**Snake like Search Robot
Tohoku University**

Unexplored areas

No GPS,
No MAP,
Known
controller
input

- Rover's planned path and navigation camera image



Navigation Cam

Planned Route

Localization at extraterrestrial planets (Courtesy of NASA)

Sooo, is it possible to localize a robot without GPS?
Let’s discuss a case study.

How do robots navigate?

- If we have a map and if we know velocity of a robot, can we find where it is ?

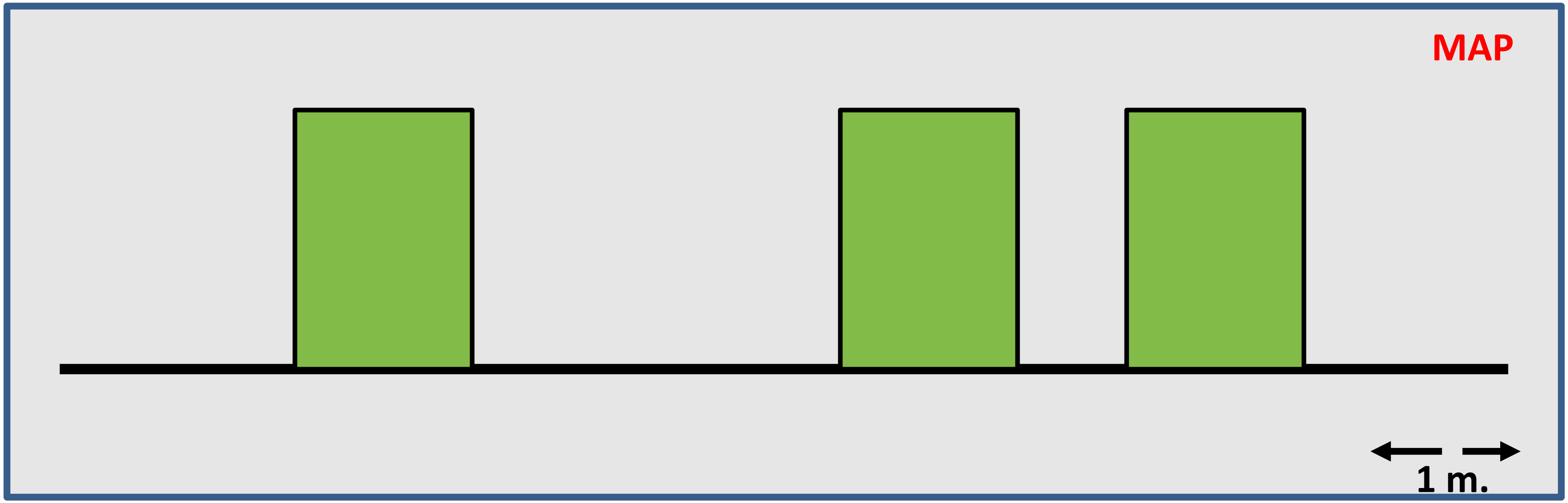
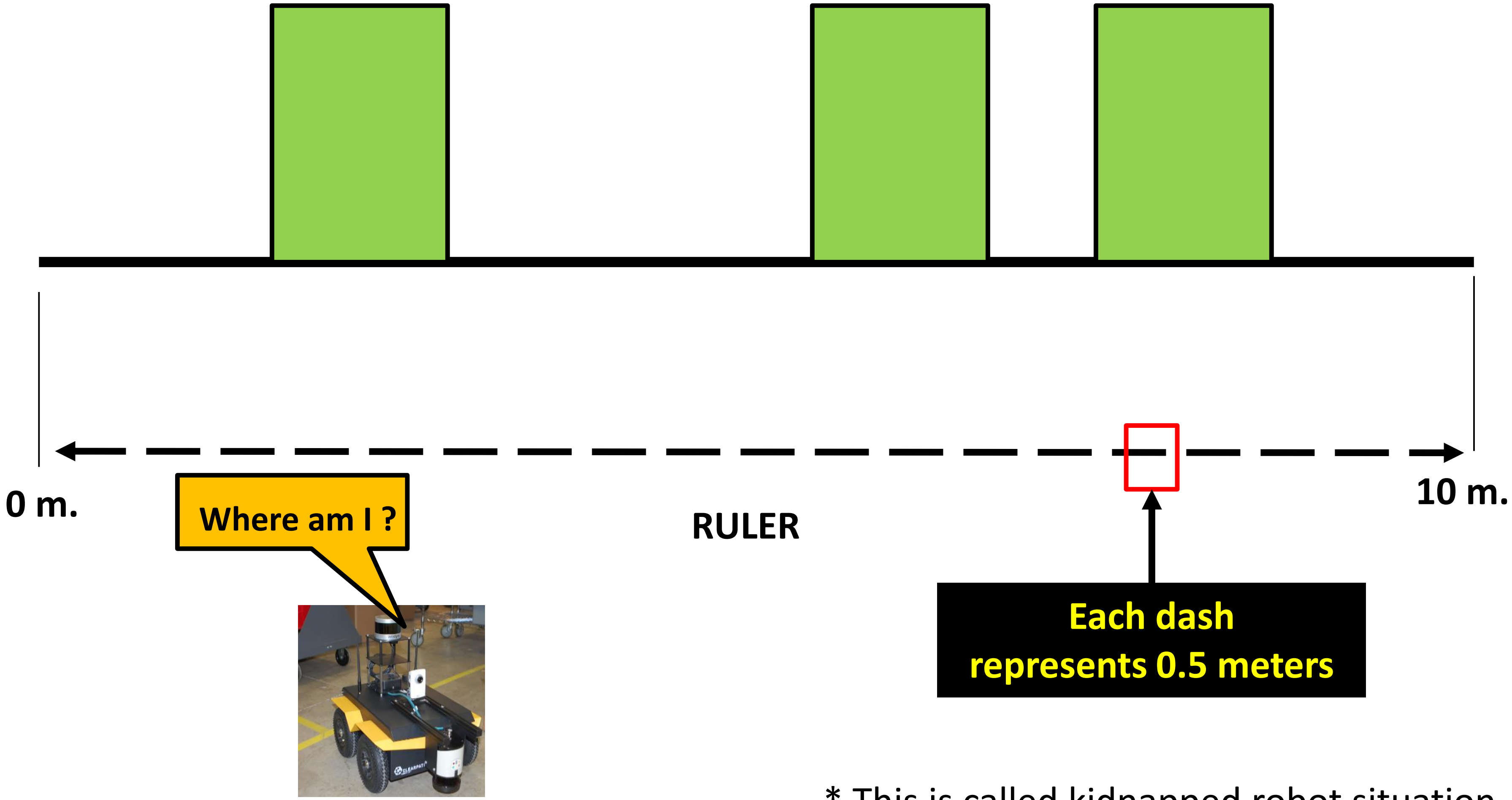


Illustration of a map with three doors A, B and C from left to right. Distances in between them is known(because we have a map).

How do robots navigate?

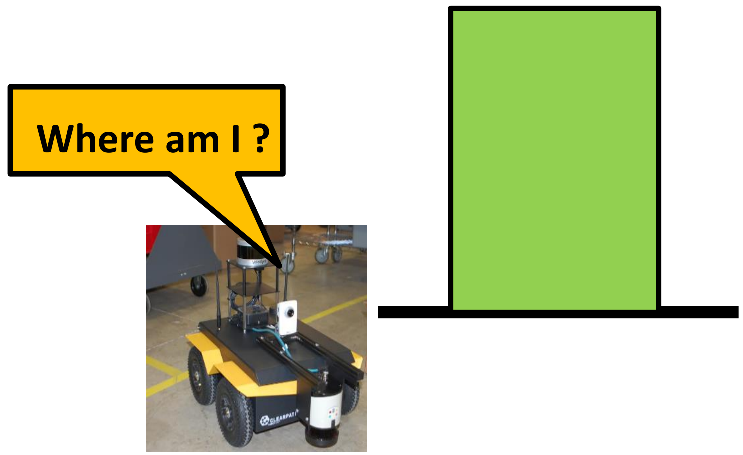
- Robot's current position is unknown. It is lost!*

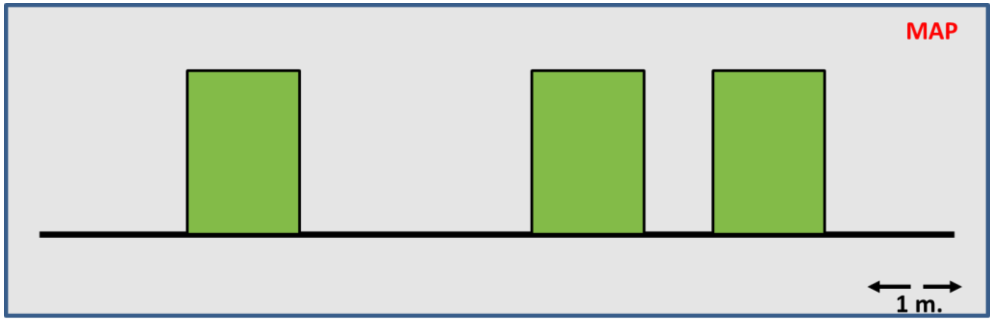


* This is called kidnapped robot situation.

How do robots navigate?

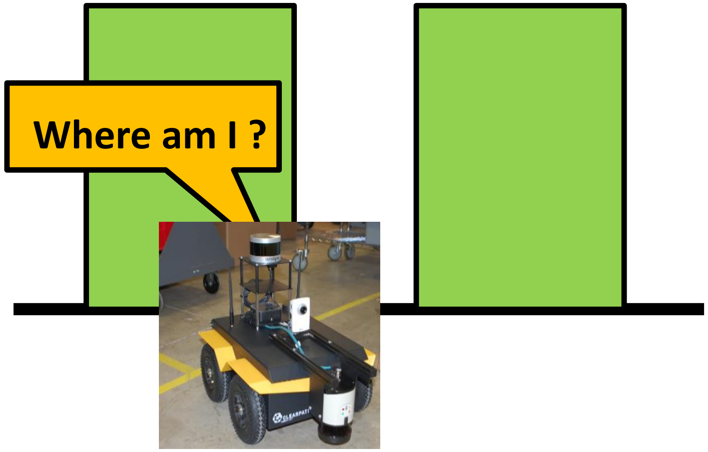
- Robot’s camera sees a door.
- Where can it be ?

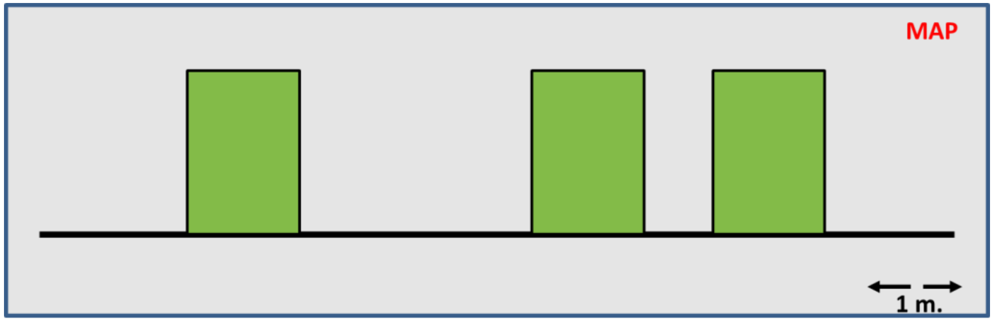




How do robots navigate?

- Robot keeps moving. Couple seconds later….
- It see another door.
- Now, where can it be?





How do robots navigate?

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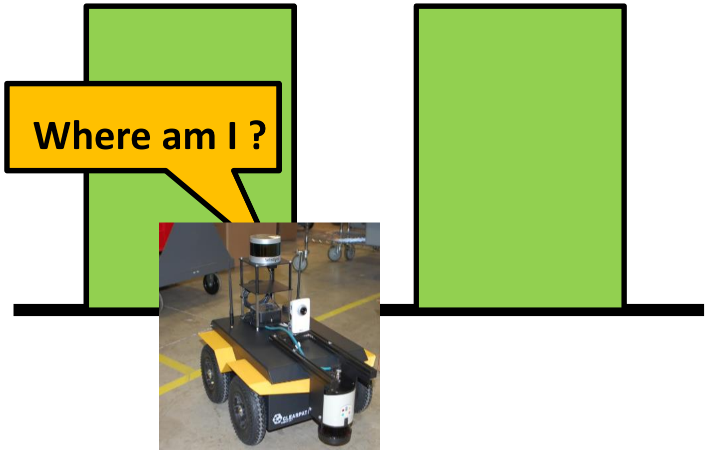
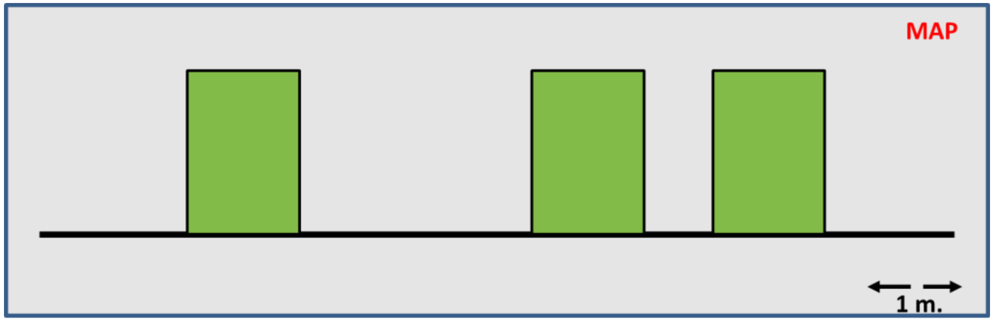
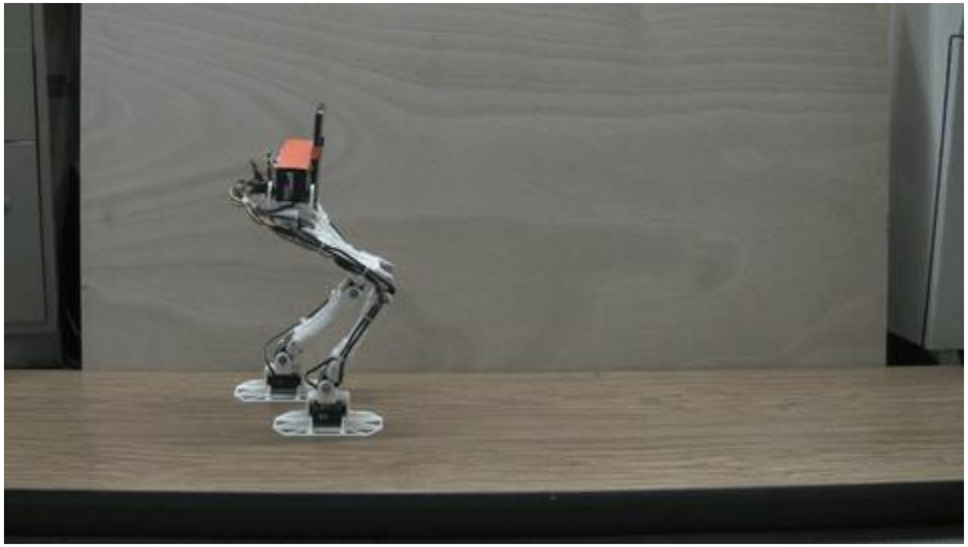




Are images sufficient?



3D Printed BiPad Robot

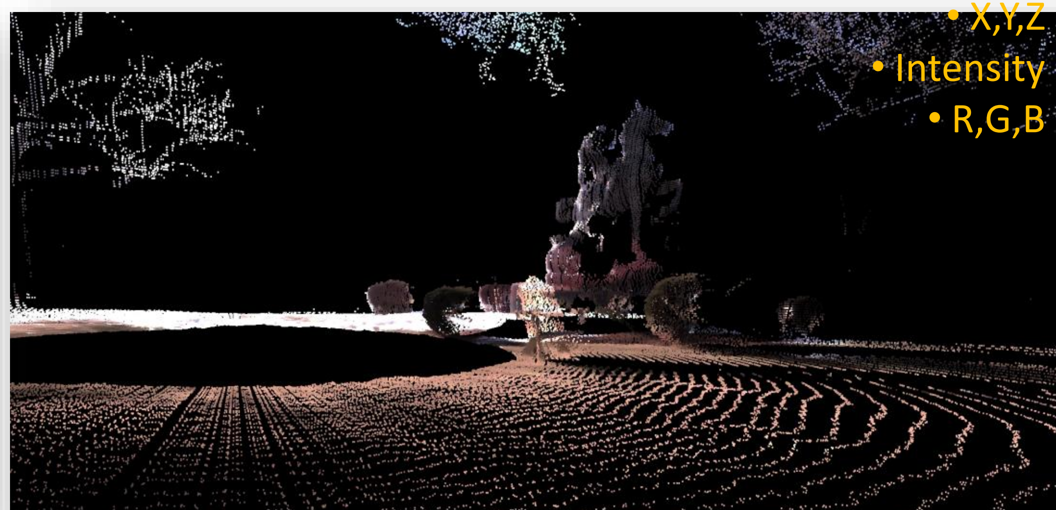
Blurred Image

Are images sufficient ?

- Images might not be sufficient for an accurate localization. Especially for self driving cars.

3D Point Cloud Attributes:
- X,Y,Z
- Intensity
- R,G,B

Original Image: 2D



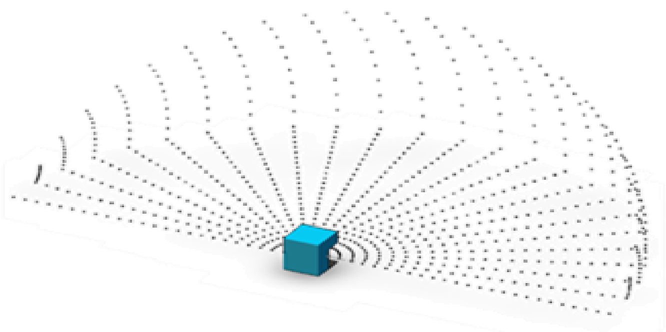
7 DOF 3D Map :
RGB: Color Space, XYZ: Position of each point, I: Intensity

3D Point Clouds

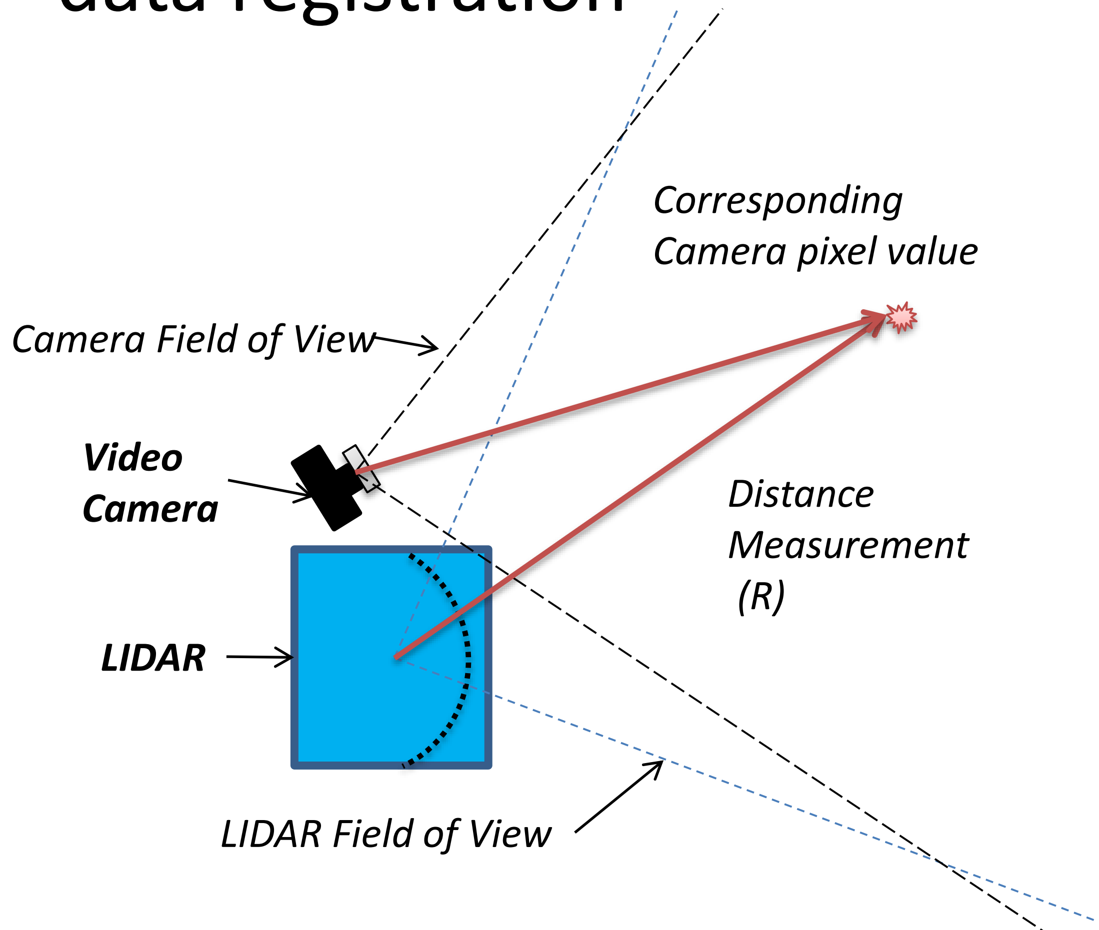
- Image and Lidar* data registration

SICK LMS 200
2D LIDAR

2D LIDAR Scan

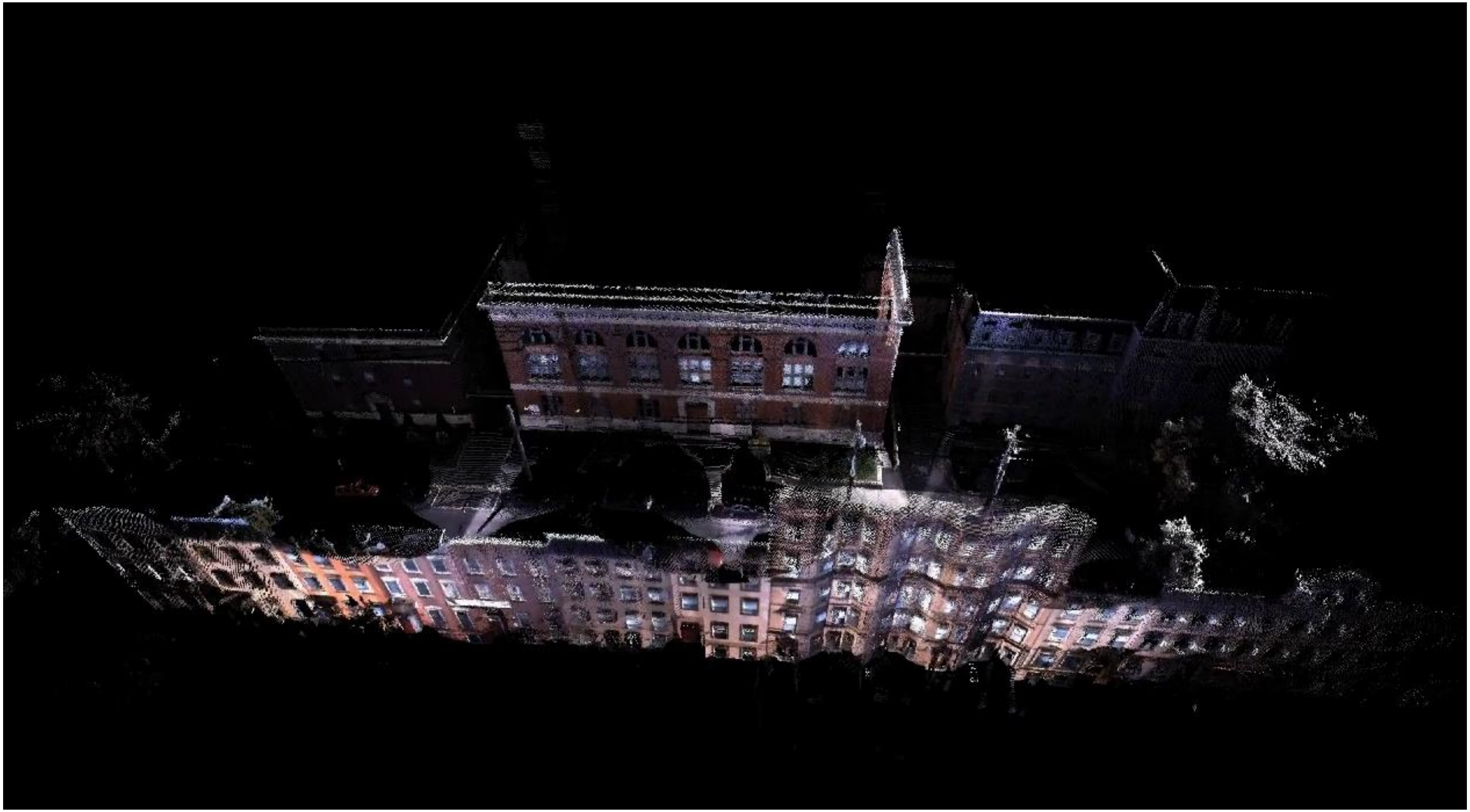


3D LIDAR scan using external rotary actuator



* Light Detection And Ranging (Lidar) sensor

3D Point Clouds



Point Clouds and Intensity

[VIDEO-1, Fly Through]

Other Applications

Embedded Virtual CAD Models

[VIDEO-2, Elm Street]

Robotics Research and Education

1) One of the most funded topic:
- National Robotics Initiative (NRI)
  The realization of co-robots acting in direct support of individuals and groups

2) Future of Engineering and Science
- A Roadmap for US Robotics- From Internet to Robotics
- New multidisciplinary departments

3) Self-Directed Learning will be the key of future education since most of the text books will be obsolete in couple years.

4) Gap between science and branches of engineering is closing.

Thanks!

Acknowledgements:
I would like to thank you ASME team, especially Mr. Ziair Deleon, for inviting me.

I also would like to thank ME Department and all students who were part of the projects.

Thanks!

If you would like to learn more about autonomous mobile robots, please join our email list.

Dr. Akin Tatoglu
tatoglu@hartford.edu

Autonomous Mobile Robotics Research Group | D-121

“We create!”

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