CAREER: Underwater Power Distribution System for Continuous Operation

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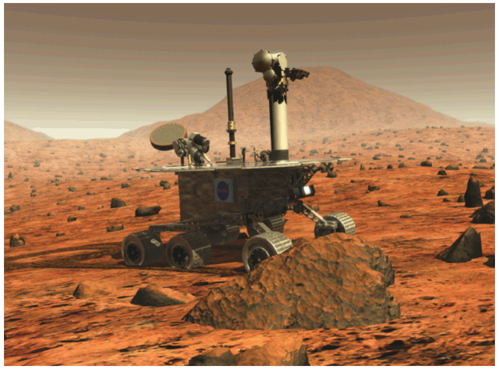

Mobile power distribution systems to increase efficiency and guarantee persistence of large robotic networks in diverse environments.

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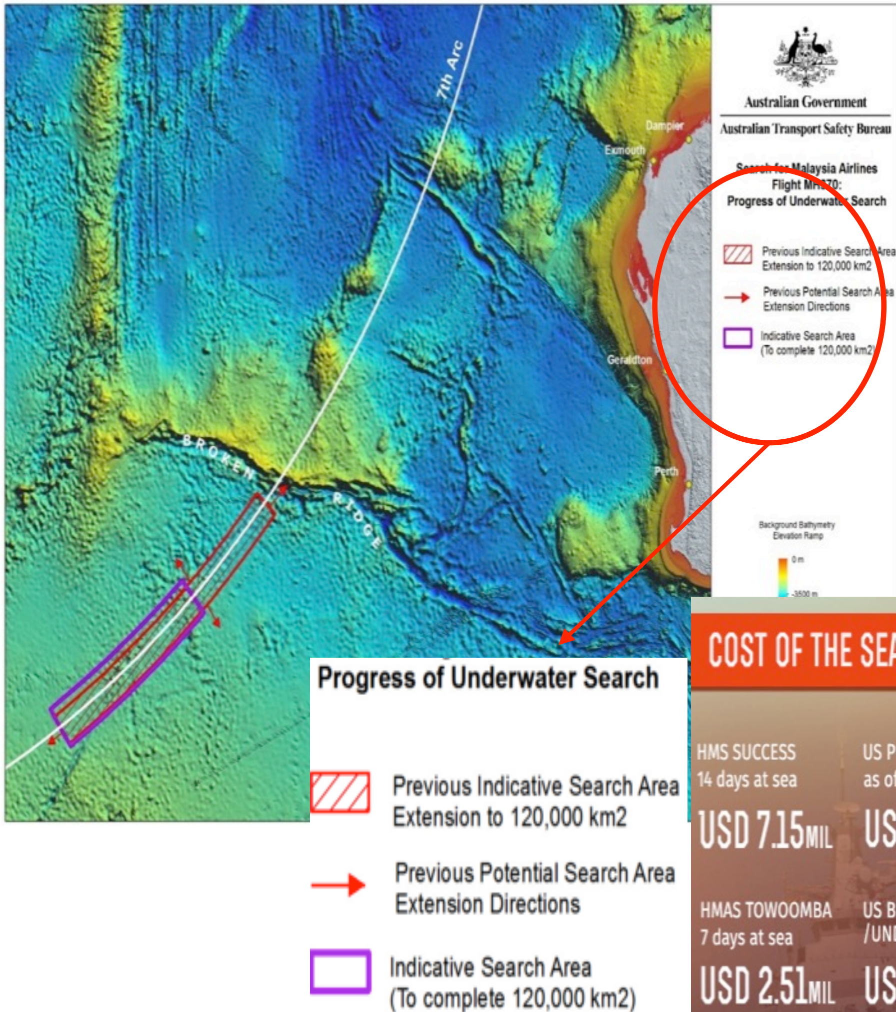
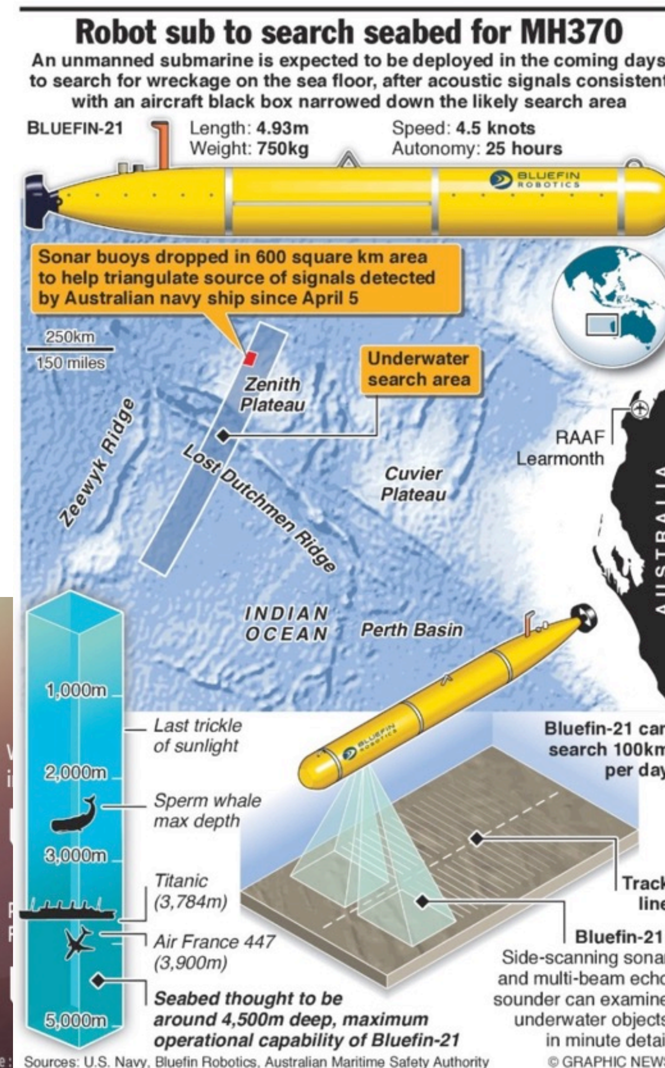
Search Mission for Missing MH370 Airplane





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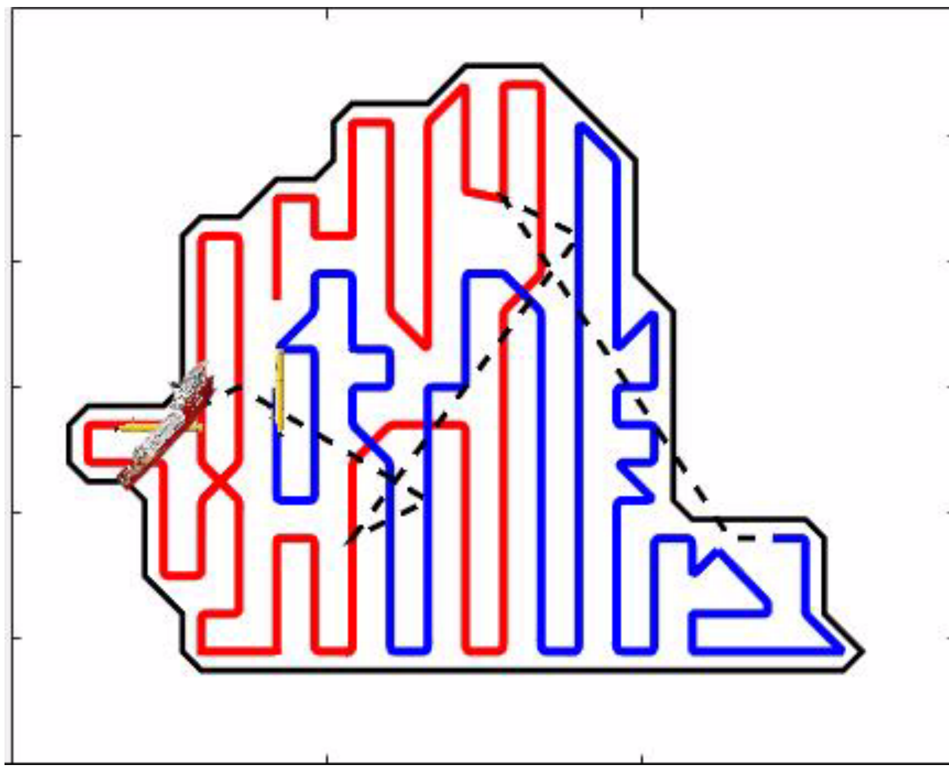
Australian Government https://www.atsb.gov.au/mh370-pages/updates/operational-update/

Autonomous Long-term Missions

The key is lowering deployment and operating costs, while also increasing efficiency, endurance and persistence.

The approach includes:

- task and energy routing scheduling,
- efficient path planning and coordination, and
- low-infrastructure platforms.



Resource Allocation and Scheduling

Mission planning architecture for persistent operation to

- place and uses static charging stations

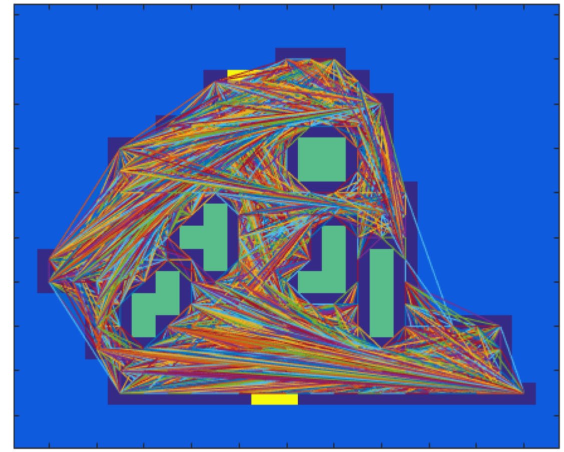
Or

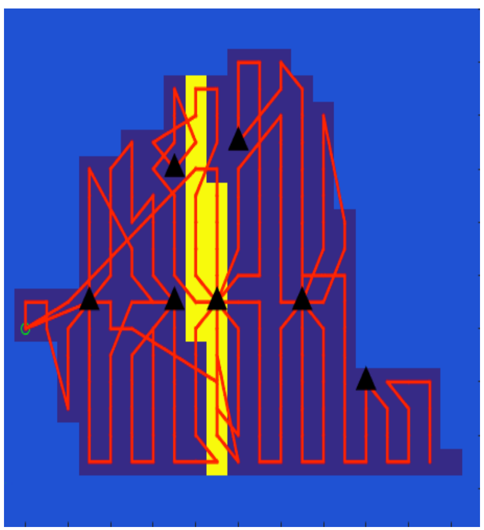
- find the rendezvous positions of mobile chargers

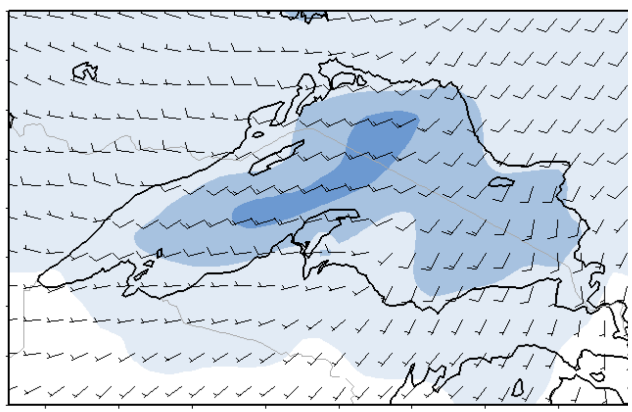
With primary constraints:
Full coverage of the mission area
limited battery life of the AUVs

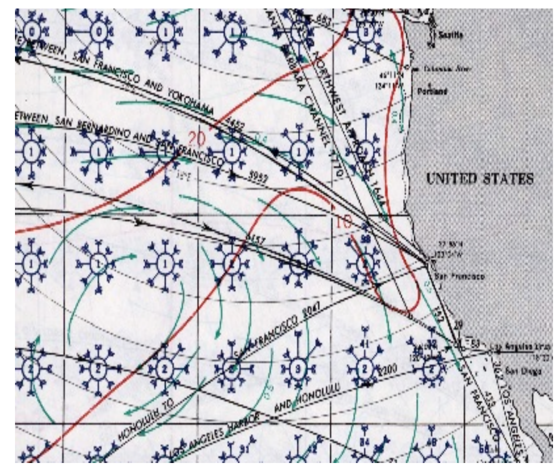
Capabilities of the architecture

- Mission type: surveillance, search and recovery, and mapping
- Mission area: non-convex, obstacles
- Uncertainties: current and wind disturbance in mission area









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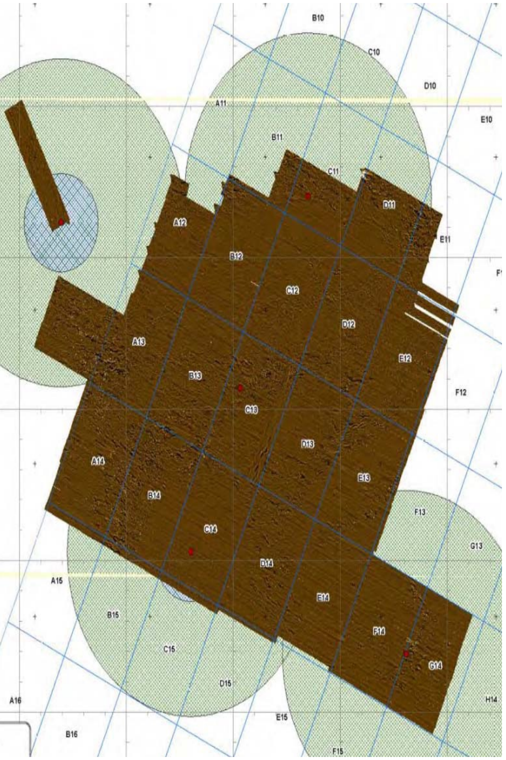
Problem Formulation



A graph based approach that discretizes the mission area $M = \{M_1, M_2, \ldots, M_N\}$

Trajectories of AUVs $W = \{W_1, W_2, \ldots, W_w\}$

Battery life of AUVs $t_b = \{t_{b1}, t_{b2}, \ldots, t_{bw}\}$

Mission completion time $T = \text{Max}\{T_1, T_2, \ldots, T_{N_w}\}$

Cost function $\min\ (D_w + \alpha D_c)$

Full coverage of mission area $M \subseteq W_1 \cup W_2 \ldots \cup W_{N_w}$

Battery life for traveling between charges

$$\text{Max}(\{D_{int\ m} = \sum_{i=1}^{N_{int}} disp_i | m \in 1, \ldots, N_t\}) \leq t_b v$$

Charging efficiency

$$\frac{\tau_{wi} - \tau_{w(i-1)}}{\Delta t_{wc,i}} \leq \beta$$

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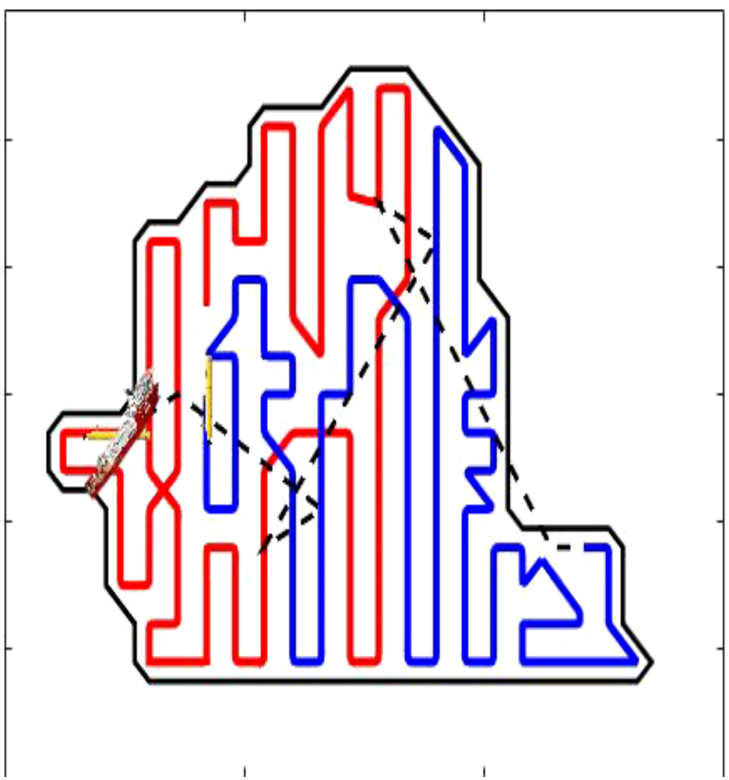
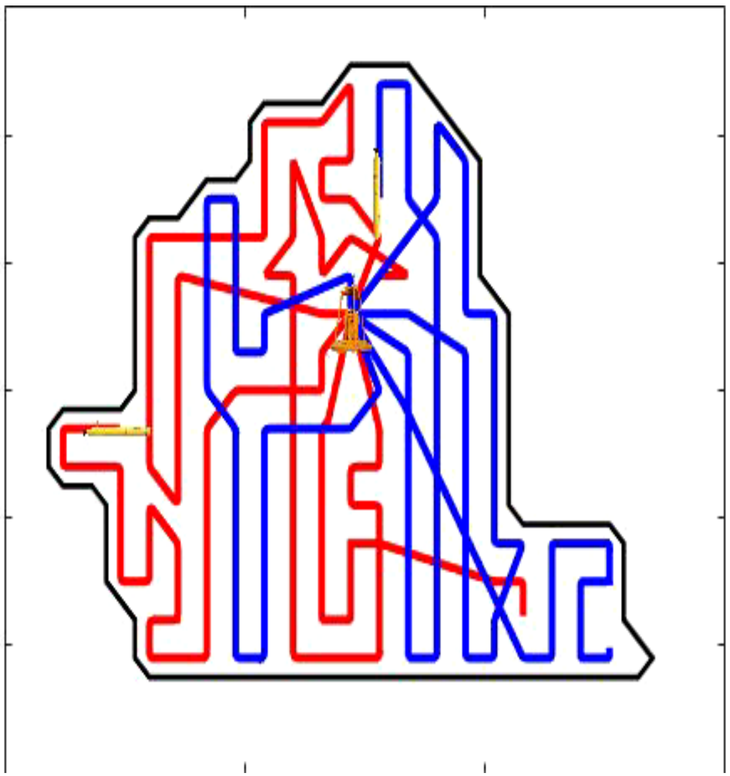
Static Charging Station VS Mobile Charger

Mobile Charger $$\left\|\vec{d}_{tp_{ki},tp_{kj}}\right\| \leq \left[t_{w2,j} - (t_{w1,i} + \Delta t_{w1,i})\right] v_{mc}$$

Static Charging Station $$\text{Max}(\{\left\|\vec{d}_{tp_{ki},tp_{kj}}\right\| | k \in 1,\ldots,N_c; i,j \in 1,\ldots,N_t/N_c\}) \leq \lambda t_b v$$





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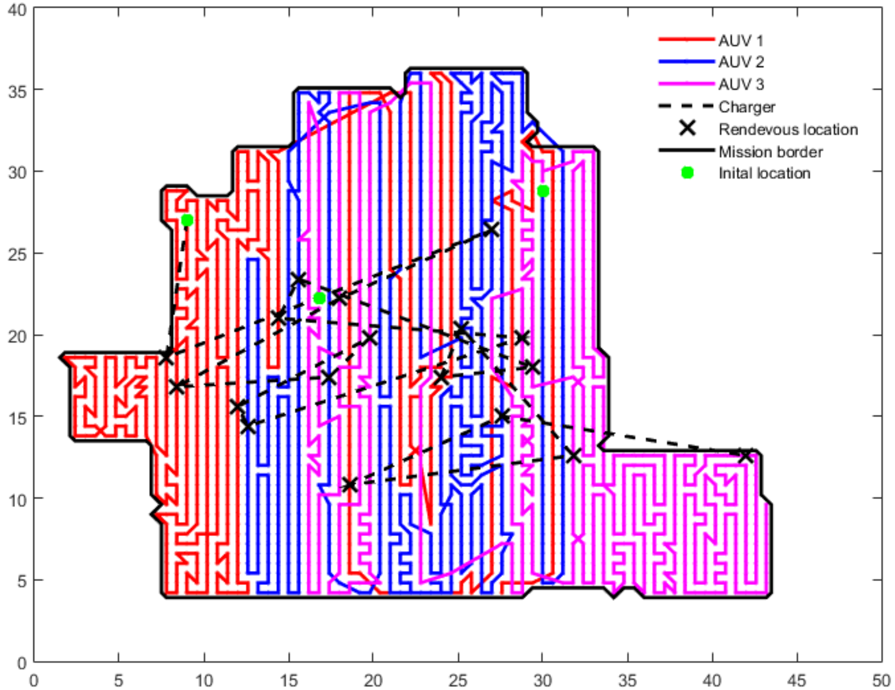
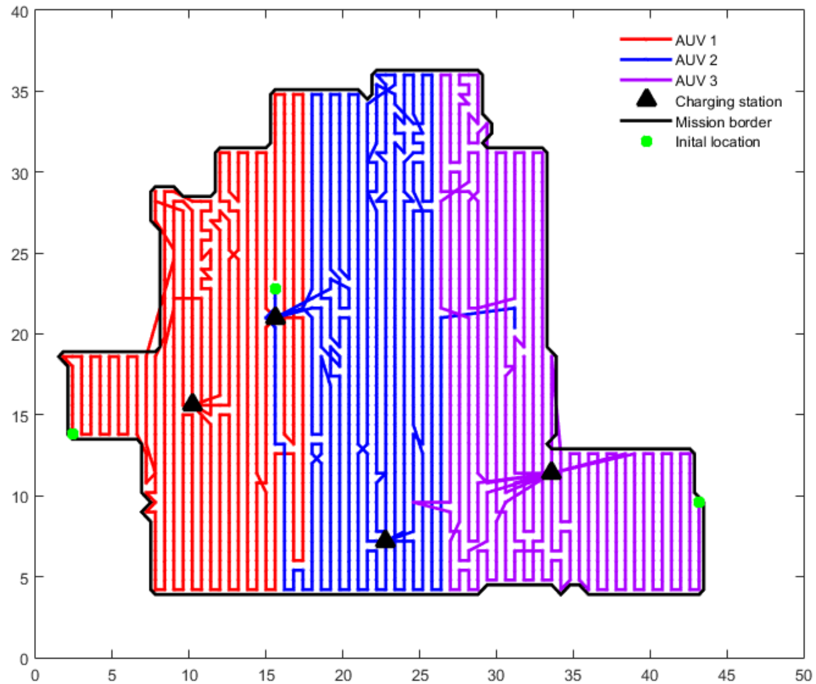
Simulation Results for MH370 Search

2400 mission points was used for the search area of 860 km^2. The Bluefin AUV travels with the speed of 4.3 km/h with side-scan sonar reach of 0.3 km. Ocean Shield max speed is 64 km/h.



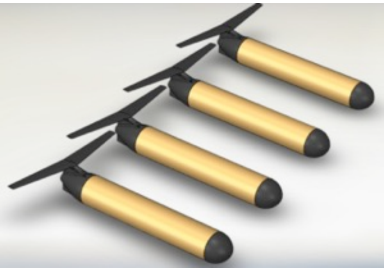
Trajectories of Nw = 3 and Nc = 1 with Dw = 1561.3 km, Dc = 170 km, and T = 124 hr. compared to:
Nw = 1,T = 384 hr and Nw = 2,T= 196 hr

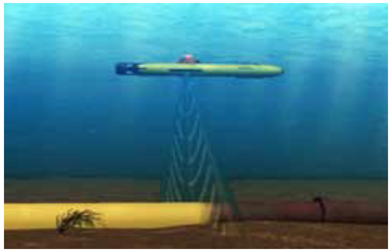


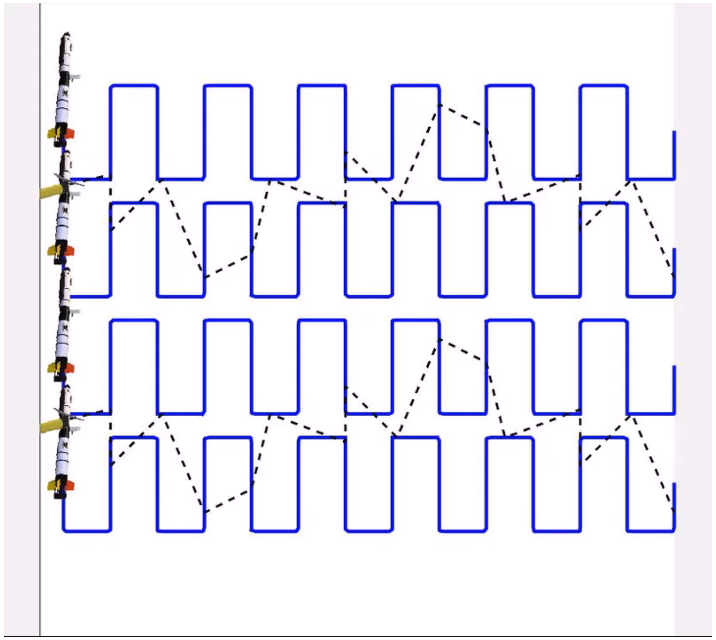
Trajectories for Nw = 3 with placement of Nc = 4, Dw = 1529 km, and T= 111 hr.

Mobile Power Delivery

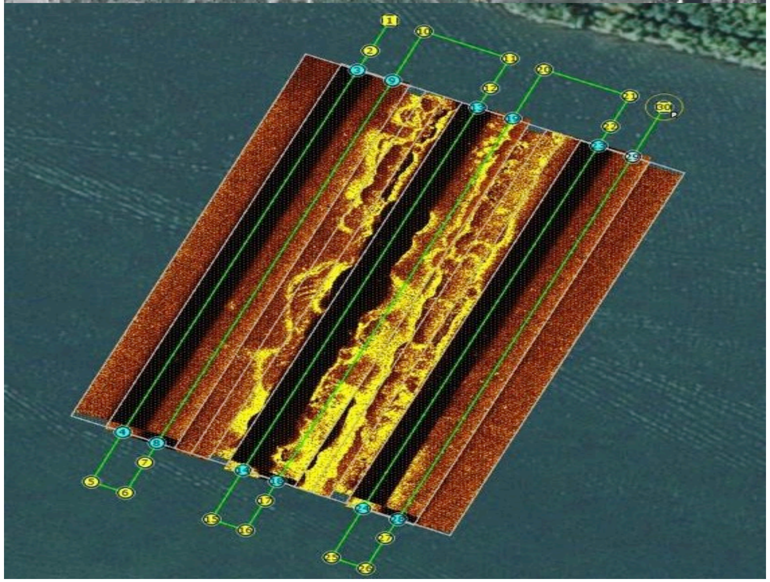
Develop experimental test-bed including a mobile charger capable of autonomous docking and wireless energy transfer for marine settings.

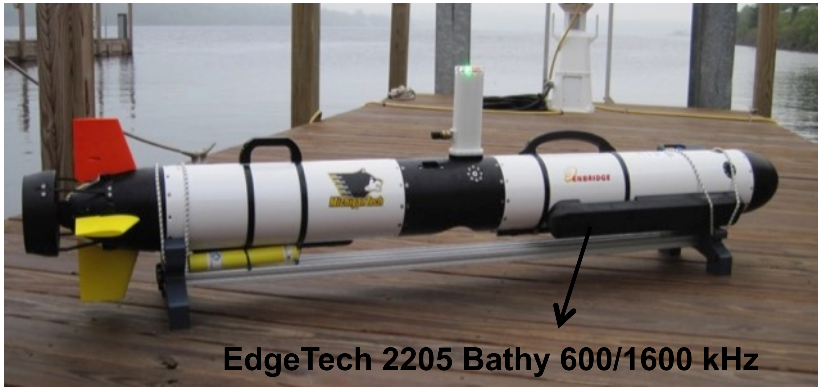






Working AUV: Ocean Sever IVER 3





UAV can provide high-quality external inspection of pipelines. It is a quick and inexpensive method.

Processor	Dual Core Intel Atom
Clock speed (GHz)	1.6
Hard drive (GB)	256 SSD
Operating System	Windows Embedded
Speed (knots)	2.5 (max 5)
Payload Mass (kg)	2
Sonar Frequency (kHz)	600-1600
Endurance (hr)	12
Maximum Depth (m)	100

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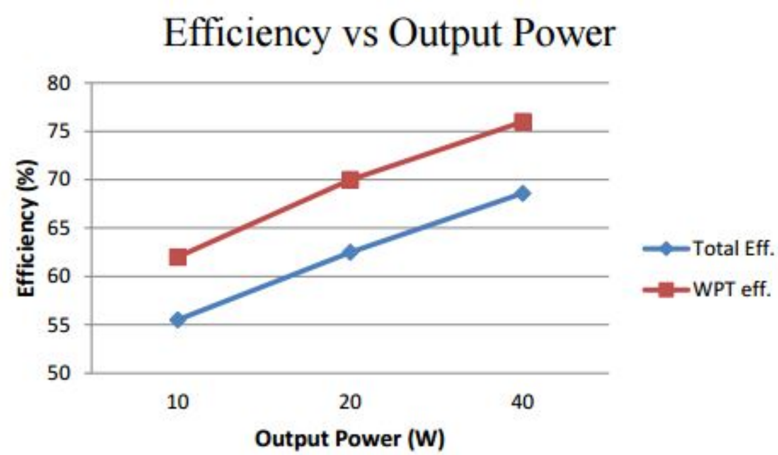
Coupling Mechanism Design Considerations

- Self contained coupling system
- Minimal modification required to working robot
- Minimal hydrodynamic drag for both working and charging robot
- Maximum docking envelope
- Integrate WFS inductive power transfer module

  Seatooth Connect 50W



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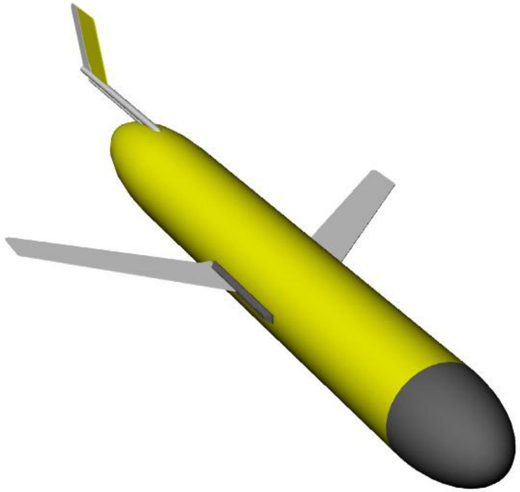
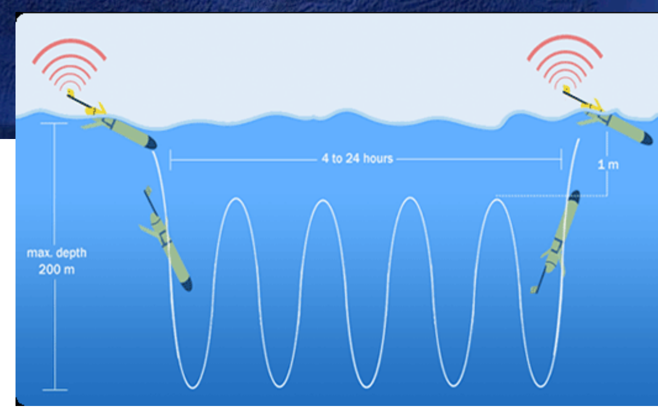
Utilizing Underwater Gliders



Slocum went to Spain

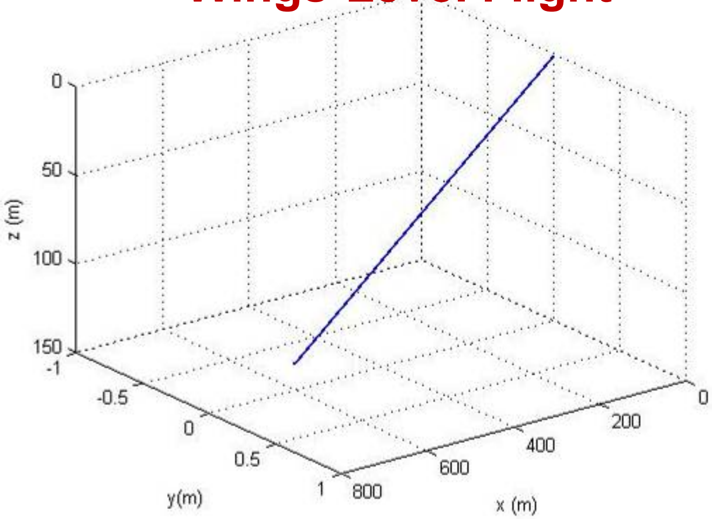


Latest Glider Data
As of: 12/04/09

Days at Sea	**221 days**
Distance	**7409.60 km**

Motion Control: Exploiting Stability

Wings-Level Flight

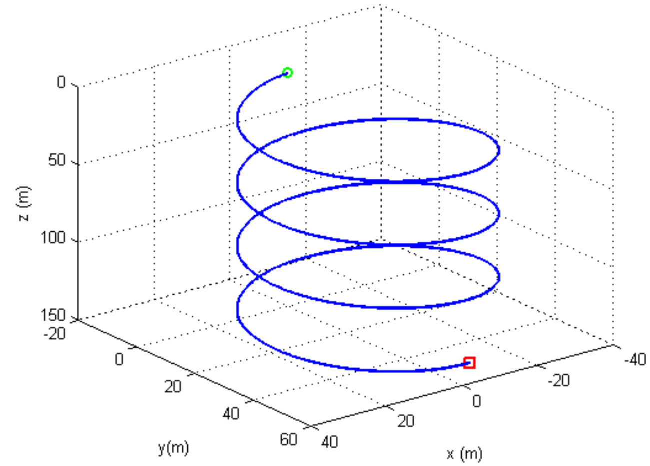


$$\boldsymbol{\omega} = \mathbf{0}$$

$$\boldsymbol{v} \cdot \boldsymbol{e}_2 = 0$$

$$\boldsymbol{\zeta} \cdot \boldsymbol{e}_2 = 0$$

Turning Flight



$$\boldsymbol{\omega} = \omega \boldsymbol{\zeta} \quad \text{where}$$

$$\omega = \epsilon \omega_n \quad \text{with} \quad \omega_n = \frac{V_0}{L}$$

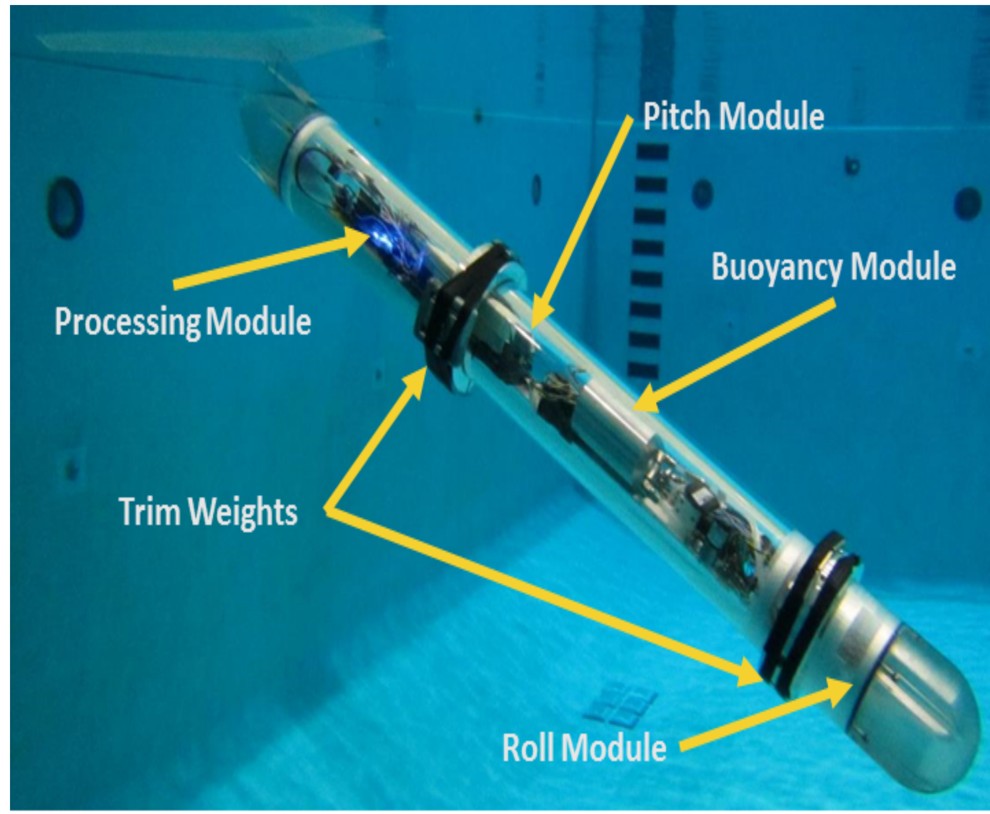
Underwater Gliders: Challenges

- Low speed and limited maneuverability
- Limited surface communication
- Inhospitable, uncertain environment for sensing and communication
- For endurance, require efficiency in use of power
- Affordability for fleet oriented deployment
- Hard to modify hardware and software design

Low-cost Glider for Autonomous Littoral Underwater Research, ROUGHIE

- **Low cost and Man portable**
- **Shallow water deployable**
- **Modular design**
- **Easy payload attachment**
- **Easy extension for larger payloads**

Metric	Value
Total Mass	12 Kg
Length	1.2 m
Payload Mass	4 Kg
Endurance	60 hr
Max Depth	30 m
Cost	$10,000



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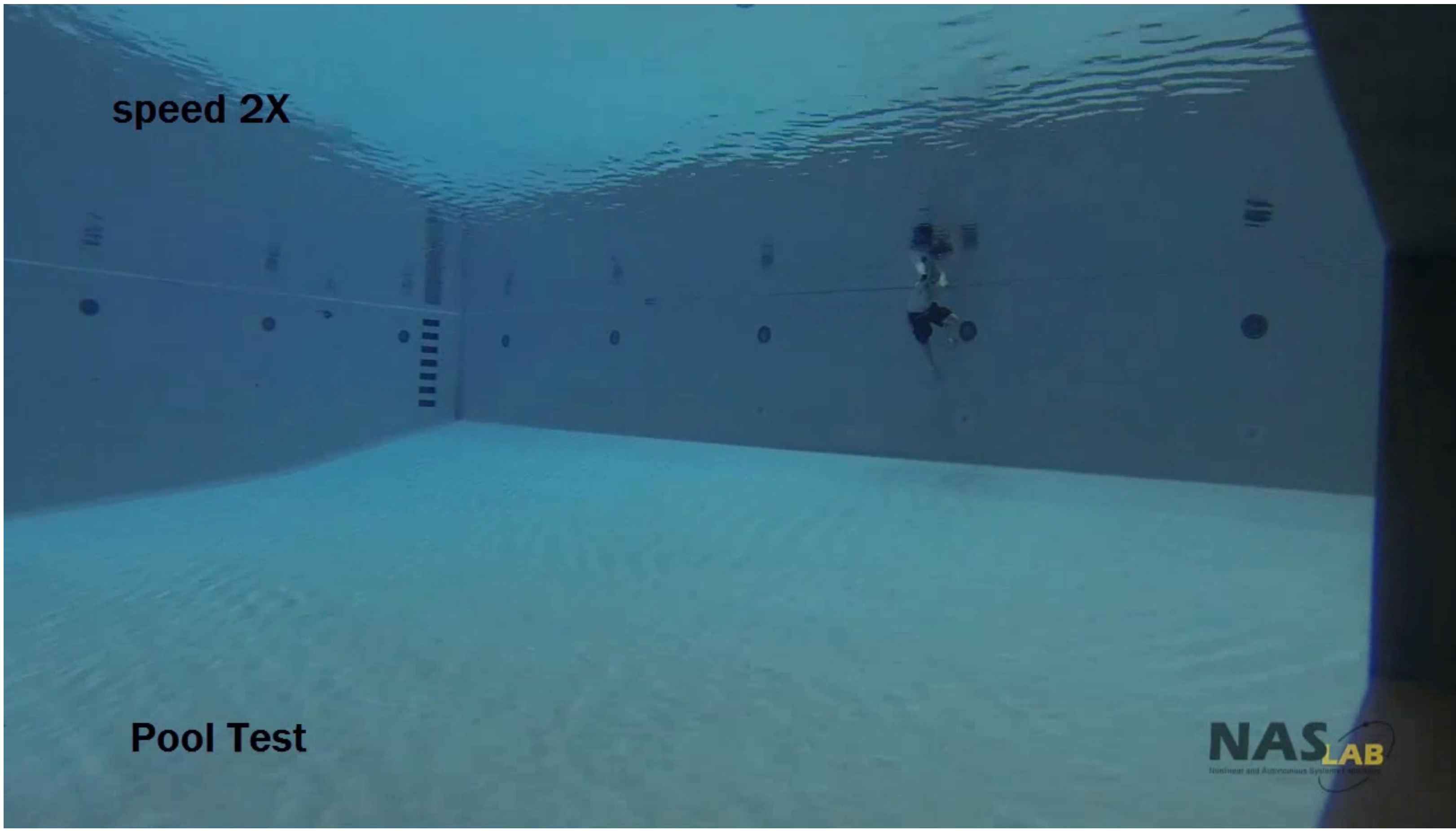
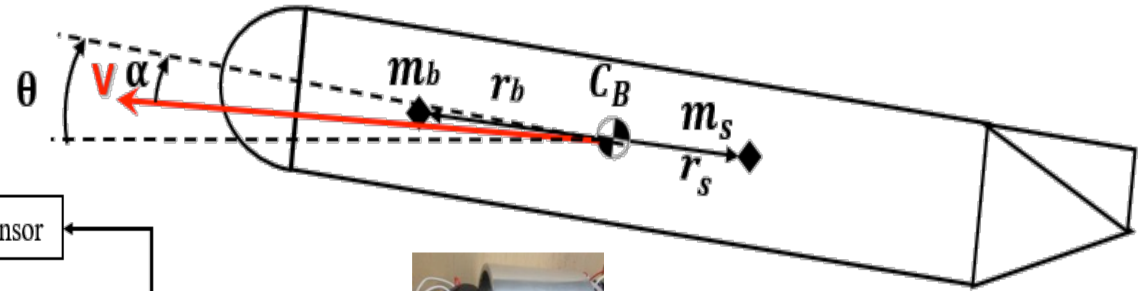
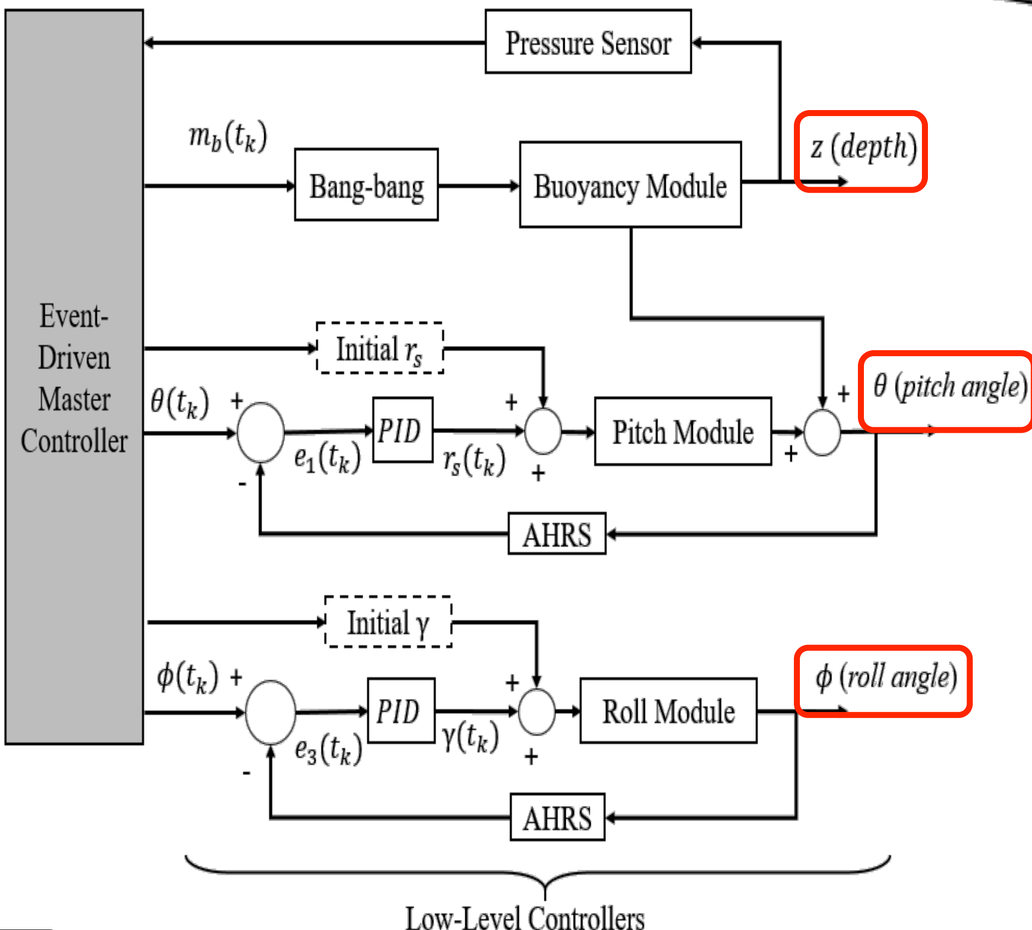
ROUGHIE

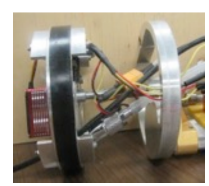
Research Oriented Underwater Glider for Hands-on Investigative Engineering

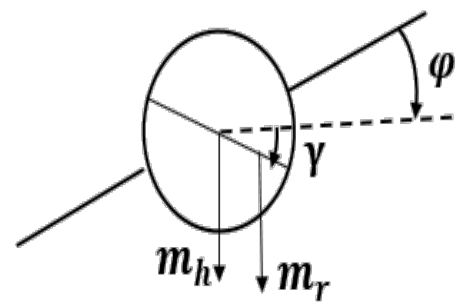


ROUGHIE Model and Controller









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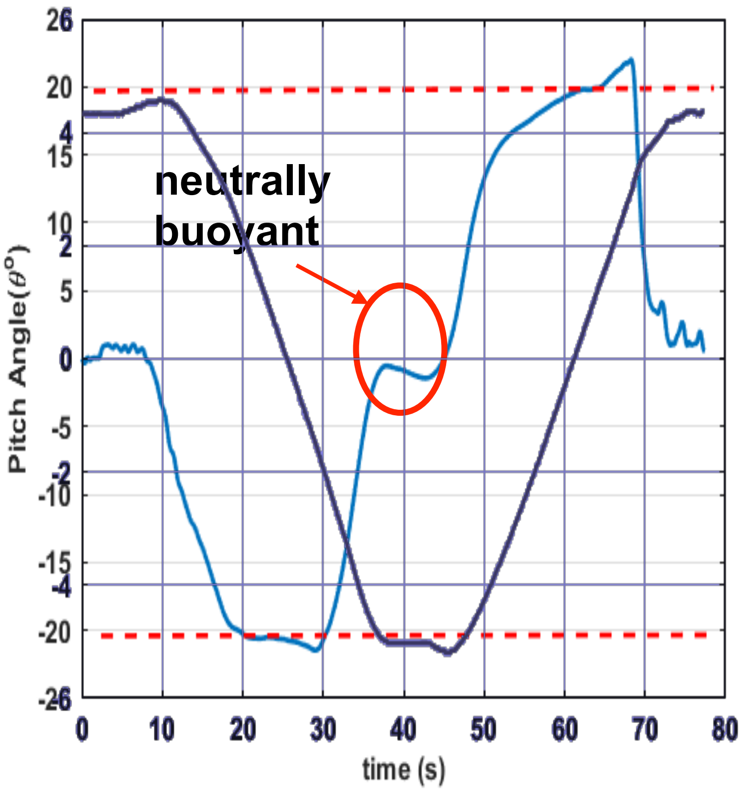
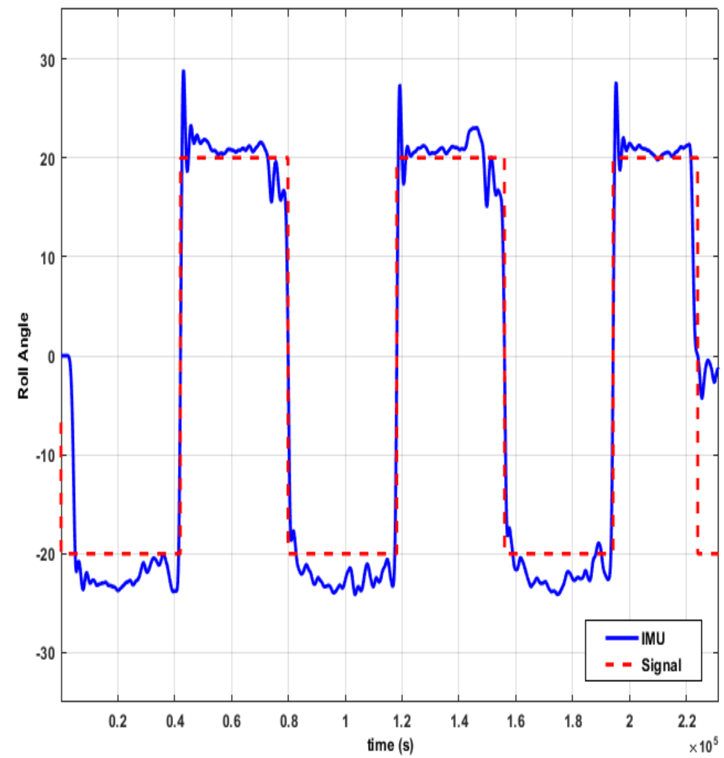
Pitch and Roll Controller

SAW-TOOTH



SPIRAL



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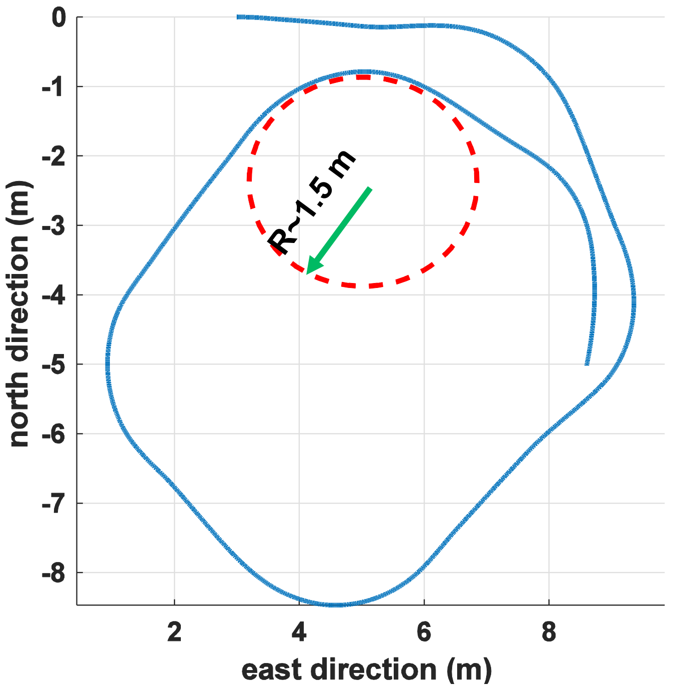
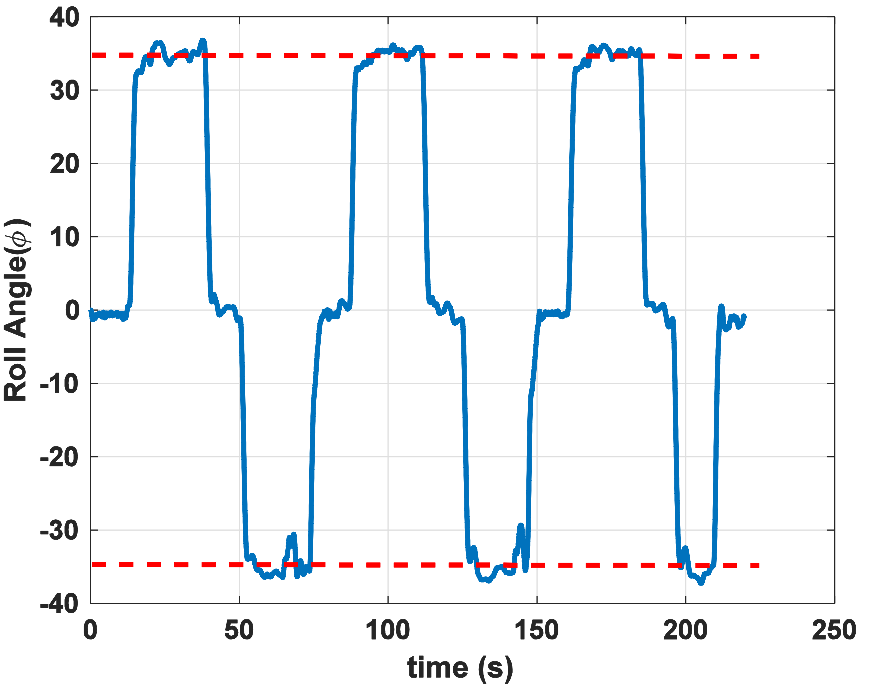
Circular Maneuver and Roll Behavior

Circular maneuver with straight flight delay in swimming pool

Vertical speed= 0.1 m/s Glide depth= 4 m Number of glides= 3
Pitch angle = 20 deg. Roll angle = 35 deg.





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ROUGHIE Achievements

- Fleet of 3 vehicles
- 200 hours of testing
- Performing internally actuated tight turns

A Rescue Story

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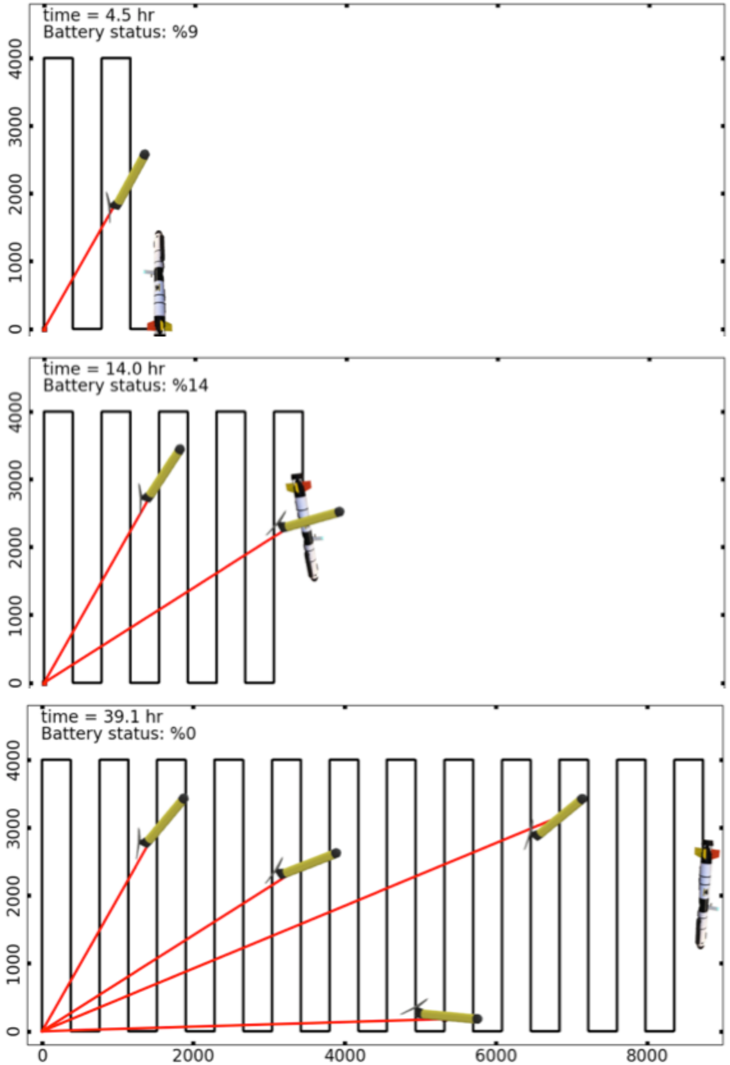
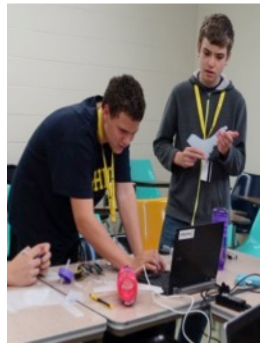
One Working AUV with Multiple Mobile Chargers

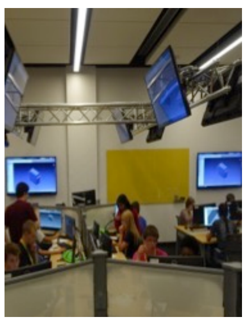


- IVER speed 2.2 knots and battery life is equal to 5 hours.
- The efficiencies of the wireless charger and power conversion systems will be considered 75% and 80% respectively. An overall efficiency 48% is considered for the whole system.
- IVER's battery can store 800 Wh and for each recharge of this battery 1670 Wh is needed.
- ROUGHIE should carry 16 battery cells with total mass of 6.94Kg.
- ROUGHIE speed .5 knots.

Research Integrated Education





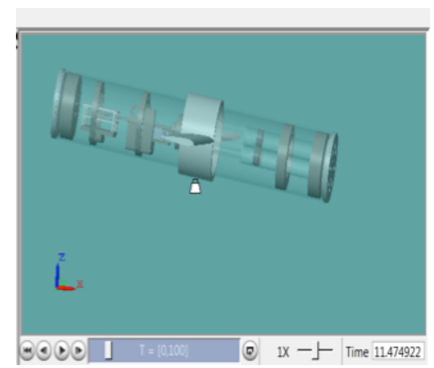


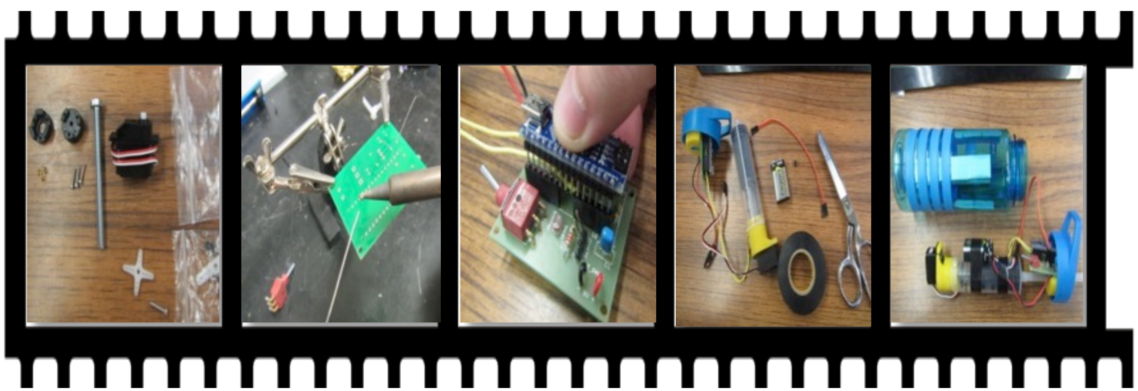

Scaffold learning from middle school to graduate school

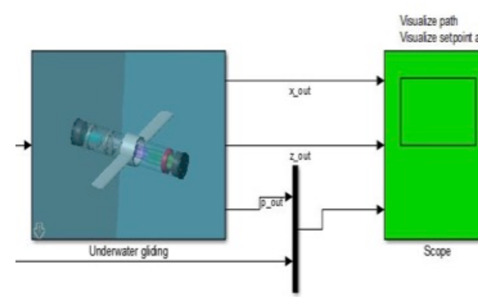
Micro glider : wood craft +paper clip

Mini GUPPIE: Water bottle +syringe

GUPPIE: Acrylic tube+ pinion rack + syringe + Modeling







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GUPPIE

Glider for Underwater Problem-solving and Promotion of Interest in Engineering

http://youtu.be/dlaiIqyl8MU

http://youtu.be/Z2jrbLKeJNQ

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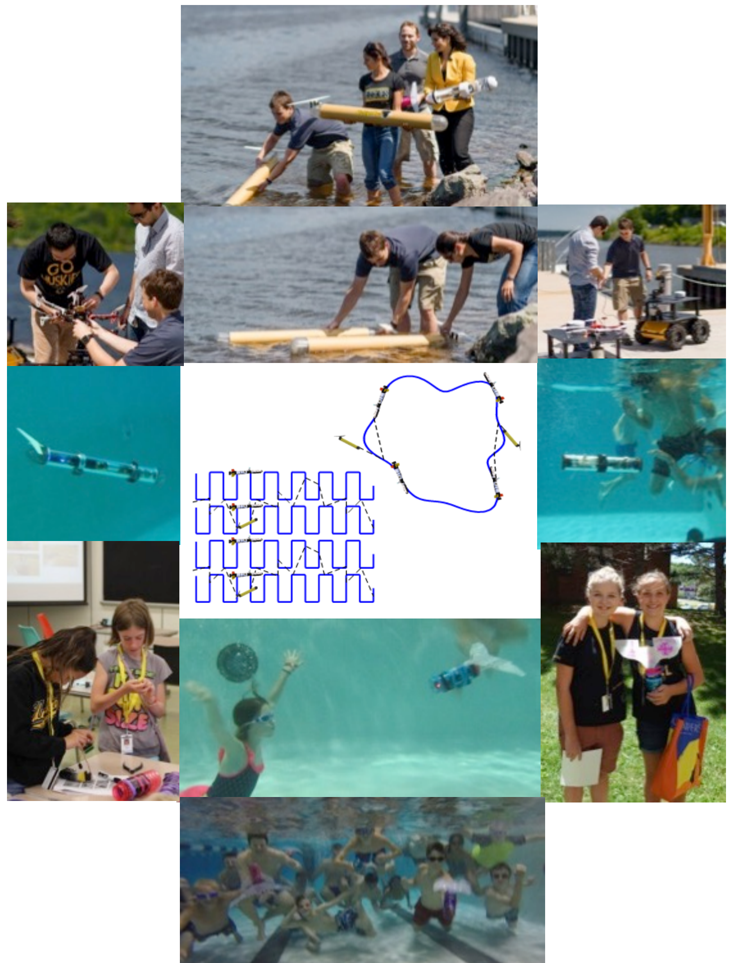
CAREER: Autonomous Power Distribution System for Continuous Operation

Challenge:

- Collective power management for long-term multi-robot operation.
- Effectively respond to energy needs in the presence of dynamic conditions and environmental uncertainty.

Solution:

- Task and resource allocation model for persistent mission planning.
- Scalable charging mechanism for mobile power delivery system for undersea.
- Efficient path planning and coordination strategy to accomplish persistent mission plan.



Scientific Impact:

- The theoretical, computational, and experimental tools for universal and scalable mobile power delivery and onsite recharging.

Broader Impact:

- Permanent deployment of large-scale network systems, extending the life from days to months.
- Engaged 126 high school and middle school students in week-long robotics summer youth program utilizing GUPPIE including 61 female students.
- Offered one-day activity to over 800 pre-college students through KSEF and Water Festival in Upper Peninsula Michigan.

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