UNIVERSITY OF SOUTH CAROLINA

CSCE 574 ROBOTICS

Marine Robotics

Ioannis Rekleitis

What are robots best suited for?

- Environments that are dangerous.
- Environments that are inaccessible.
- Environments that are taxing.
- Environments are expensive to access.
- Environments that are inhospitable.

- **Marine Environment: inaccessible, dangerous, costly, demanding.**

As we all know, most of the world is undersea, yet it's the environment on earth we understand the least well!

Coral Reefs

Oceans: 70% of earth's surface.

Reefs: Greatest diversity / area of any marine ecosystem

- 4-5% of all species (91 000) found on coral reefs

Significant to the health of the planet:

- 1/2 of the calcium that enters the world's oceans / year is taken up and bound into Coral Reefs as Calcium Bicarbonate

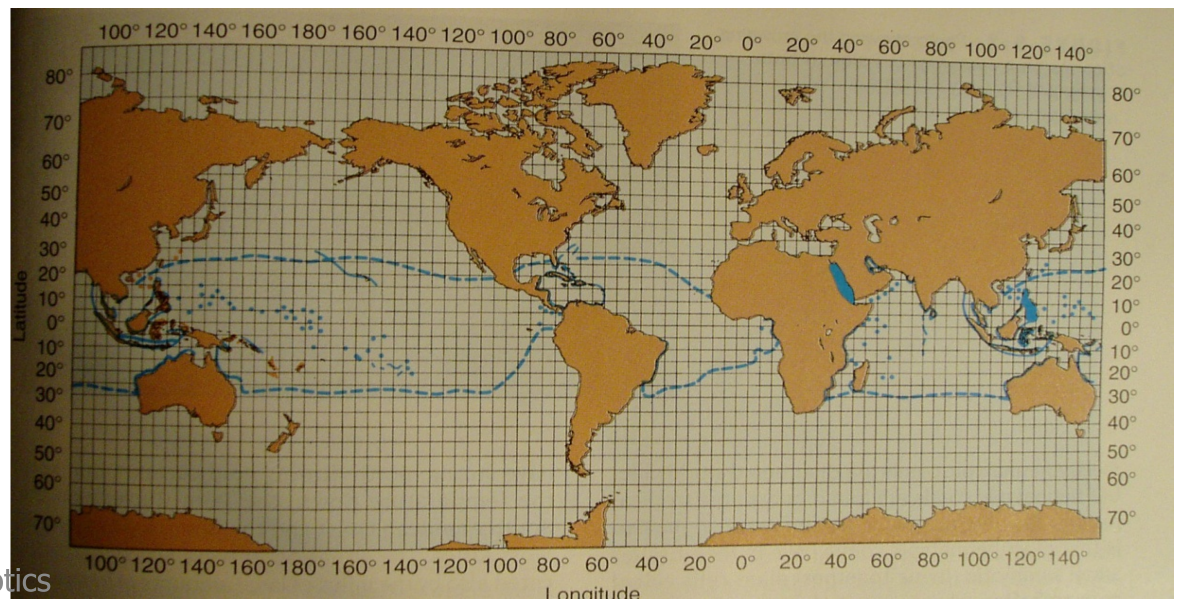
World Distribution

Coral reefs are found in polar, temperate and tropical waters

Highest diversity of species in tropics

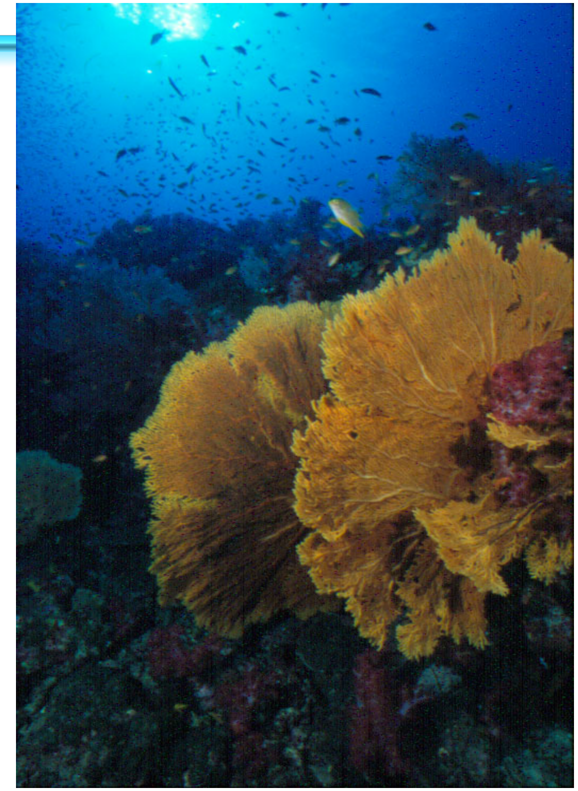
Found in 20 degree C surface isotherm

Optimal temperature for coral is 23-25 degrees C.

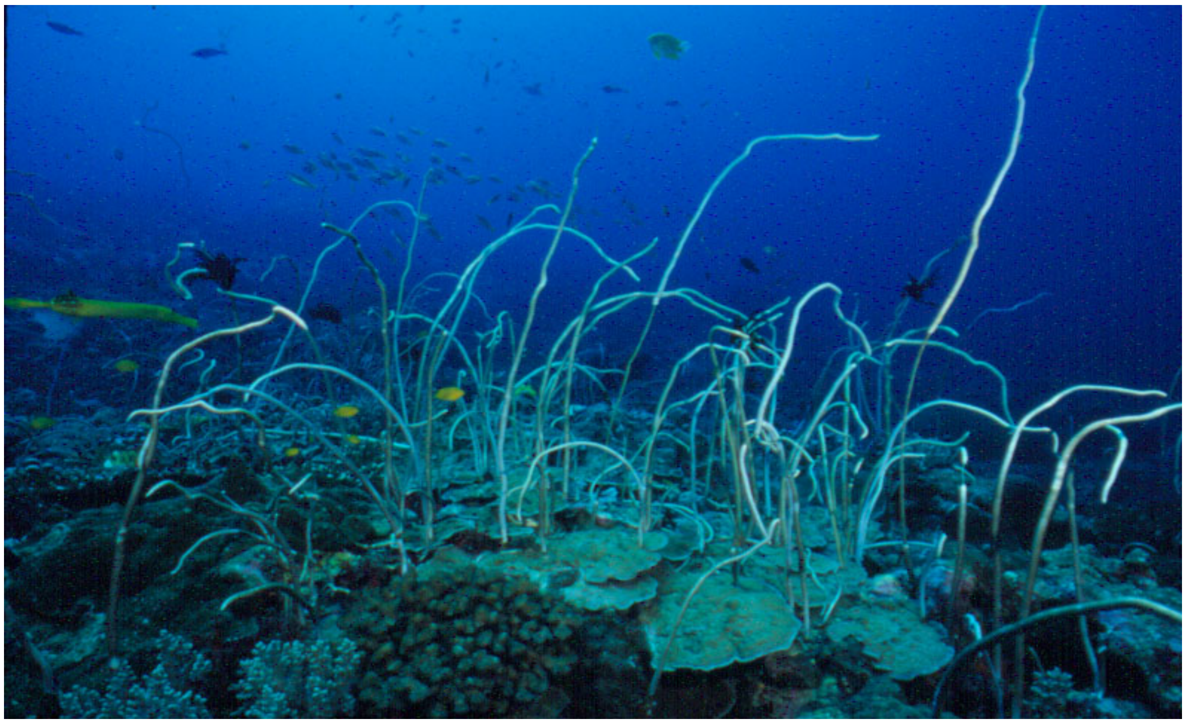


Atlantic

Sea fan



More common in Atlantic:



Sea Whip

Dominant coral types:
- Branching coral (3 sp)
- Fire Coral

Why Study Coral Reefs?

- Most biologically diverse and sensitive marine ecosystem
- Dramatically altered by humans
- By 1998, 27% of reefs were destroyed
  - 16% was from coral bleaching event (El Nino)

Coral Reefs

- Reefs are regions of *exceptional* biodiversity.
- 20% of the world's reefs have been destroyed.
- 24% of reefs are under imminent threat of collapse due to human pressure, 26% under longer term threat of collapse!

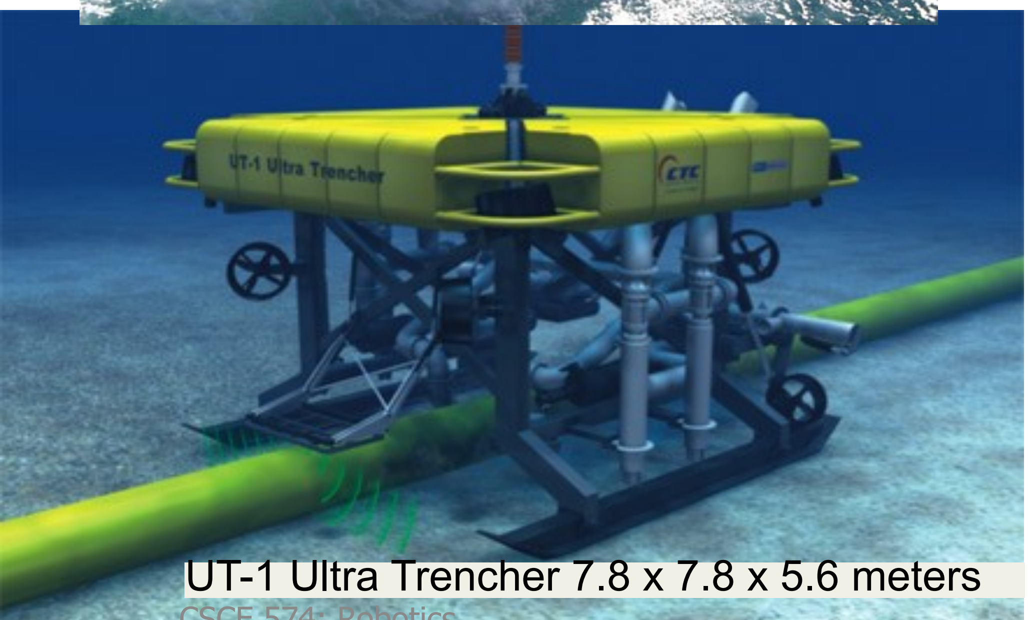
  Dec. 2005 there was a terrible coral bleaching (and destruction) in the Caribbean.

  95% of Jamaica's reefs are dead or dying.
- If we want to make things better, we need to be able to measure the changes!
- This is taxing, error-prone, tiring and dangerous.

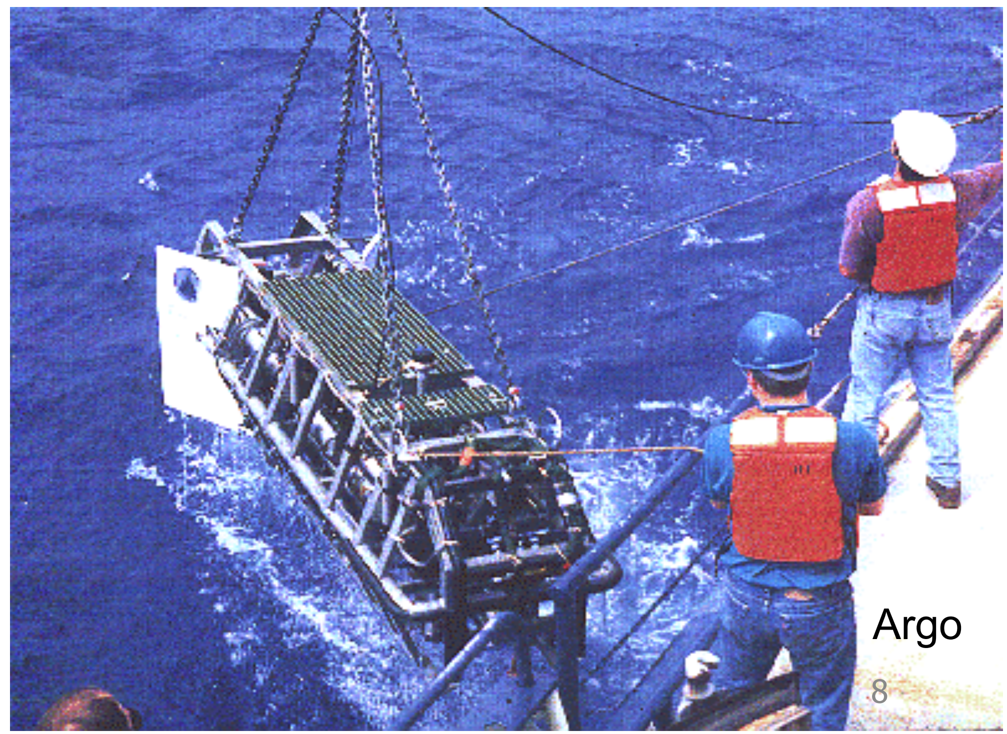
Underwater vehicles

Autonomous Benthic Explorer (ABE)

1200 pounds and a little over 2 meters long.

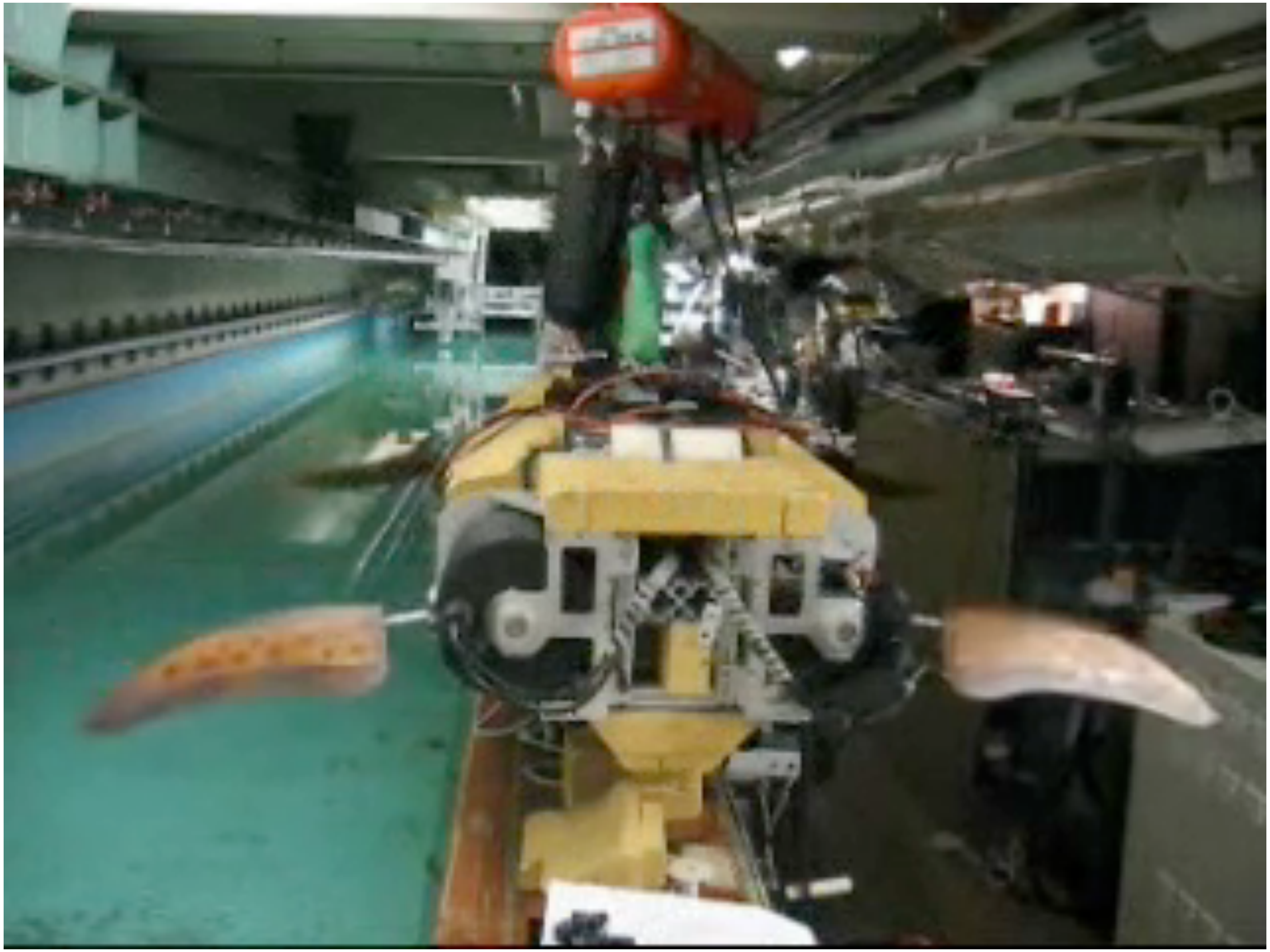


UT-1 Ultra Trencher 7.8 x 7.8 x 5.6 meters

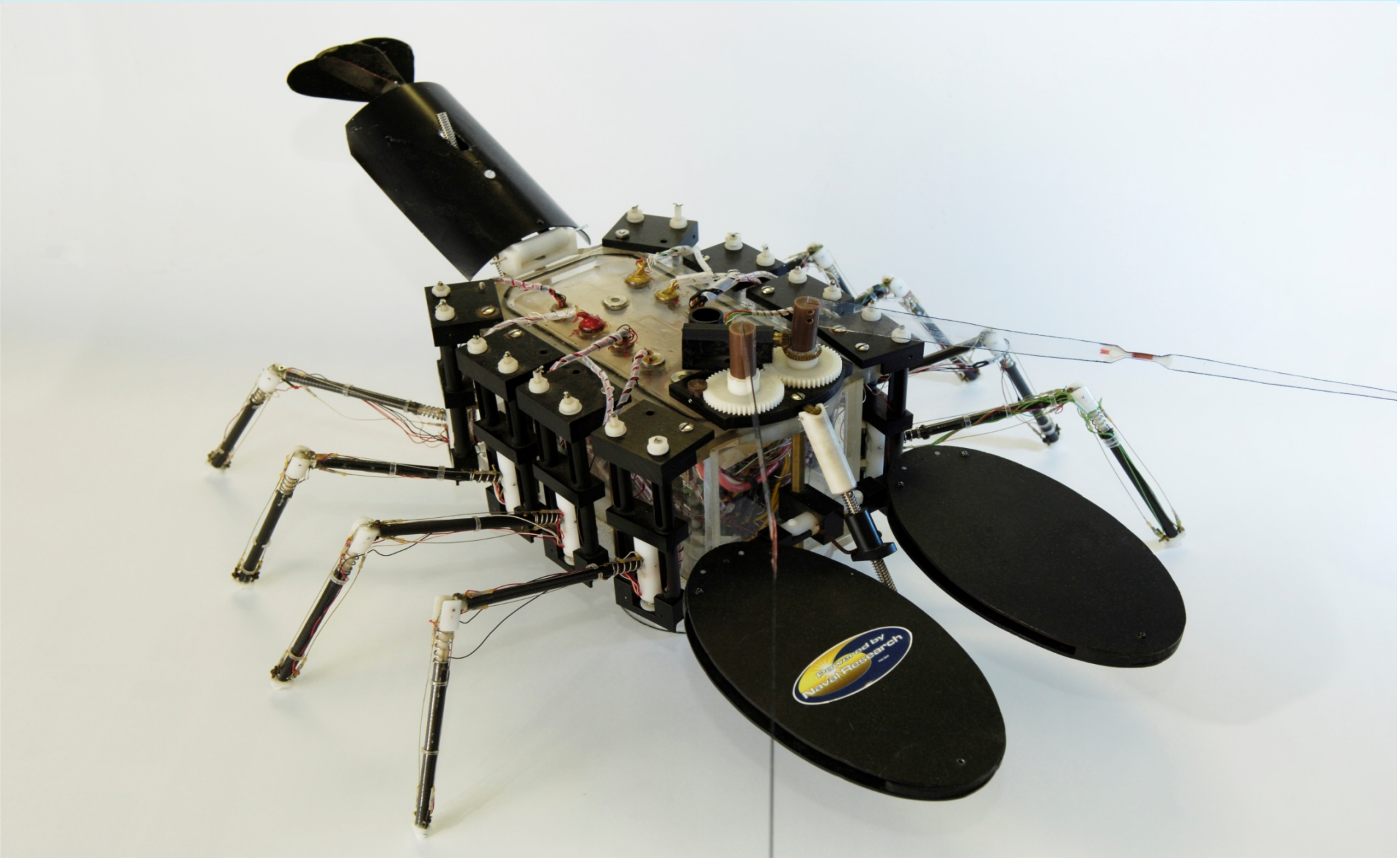


Argo

Turtle like Robot

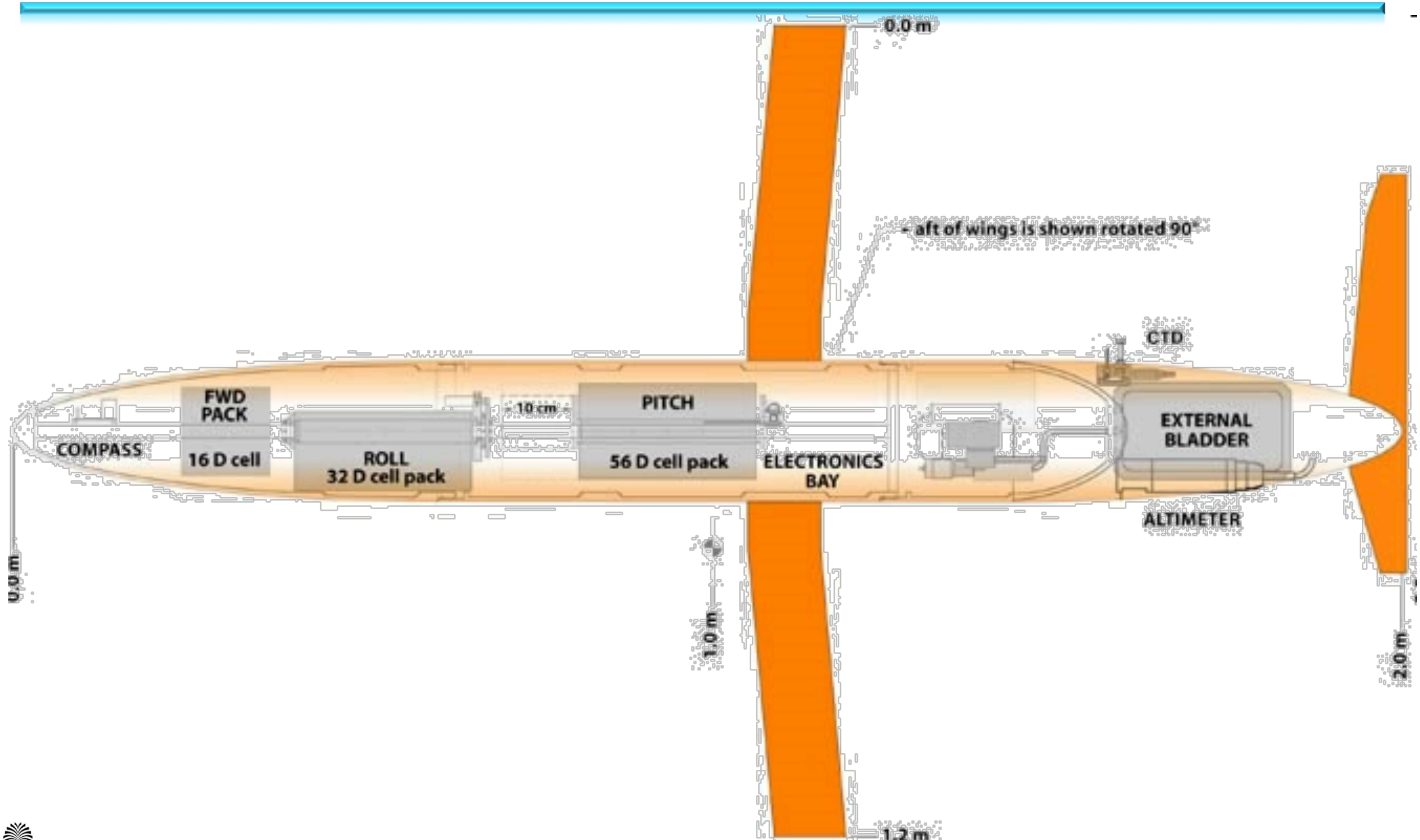


Lobster like Robot

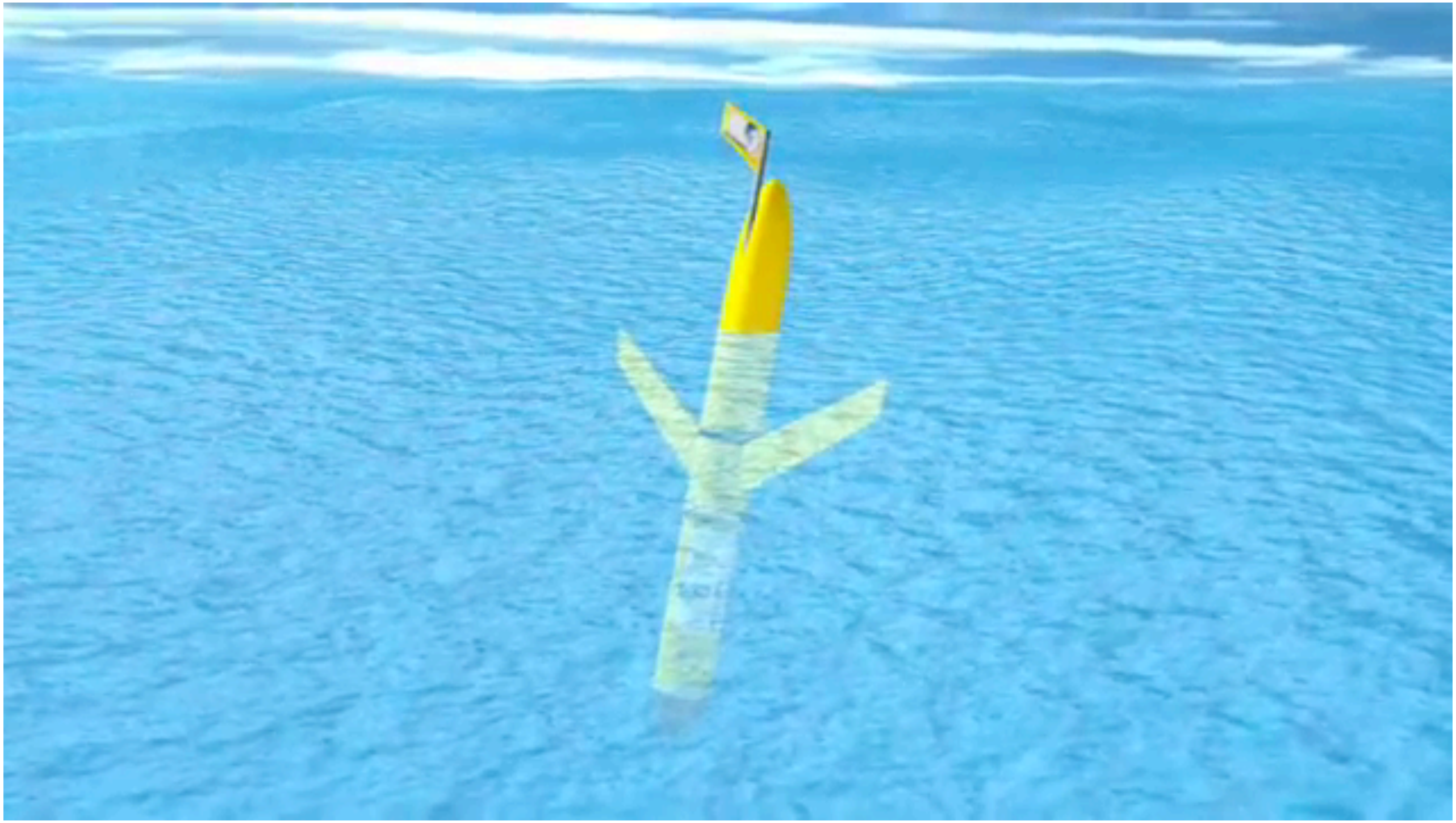


Glider UW Robot

Glider UW Robot

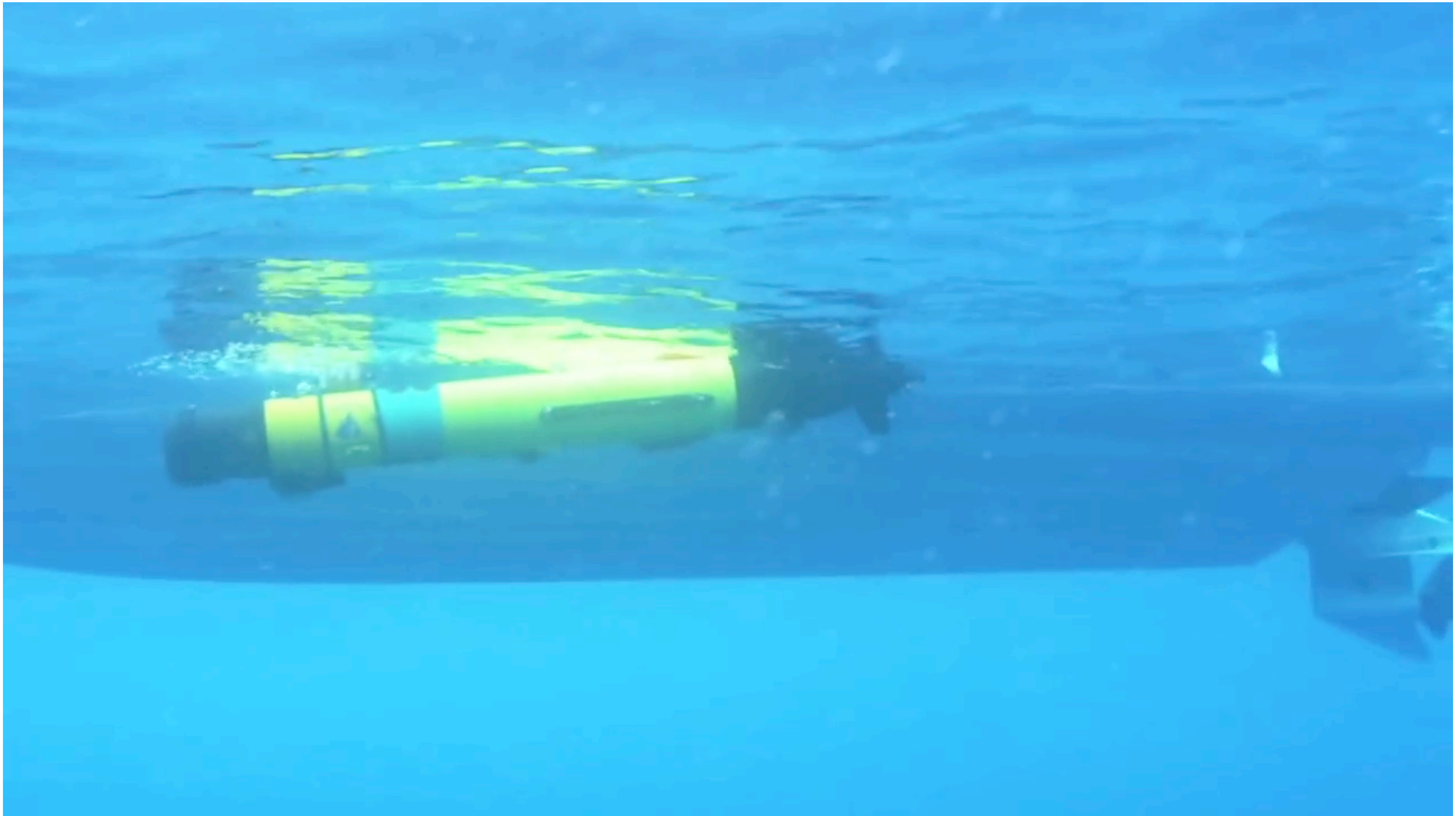


Glider UW Robot



Autonomous Underwater Vehicles (AUV) Hugin

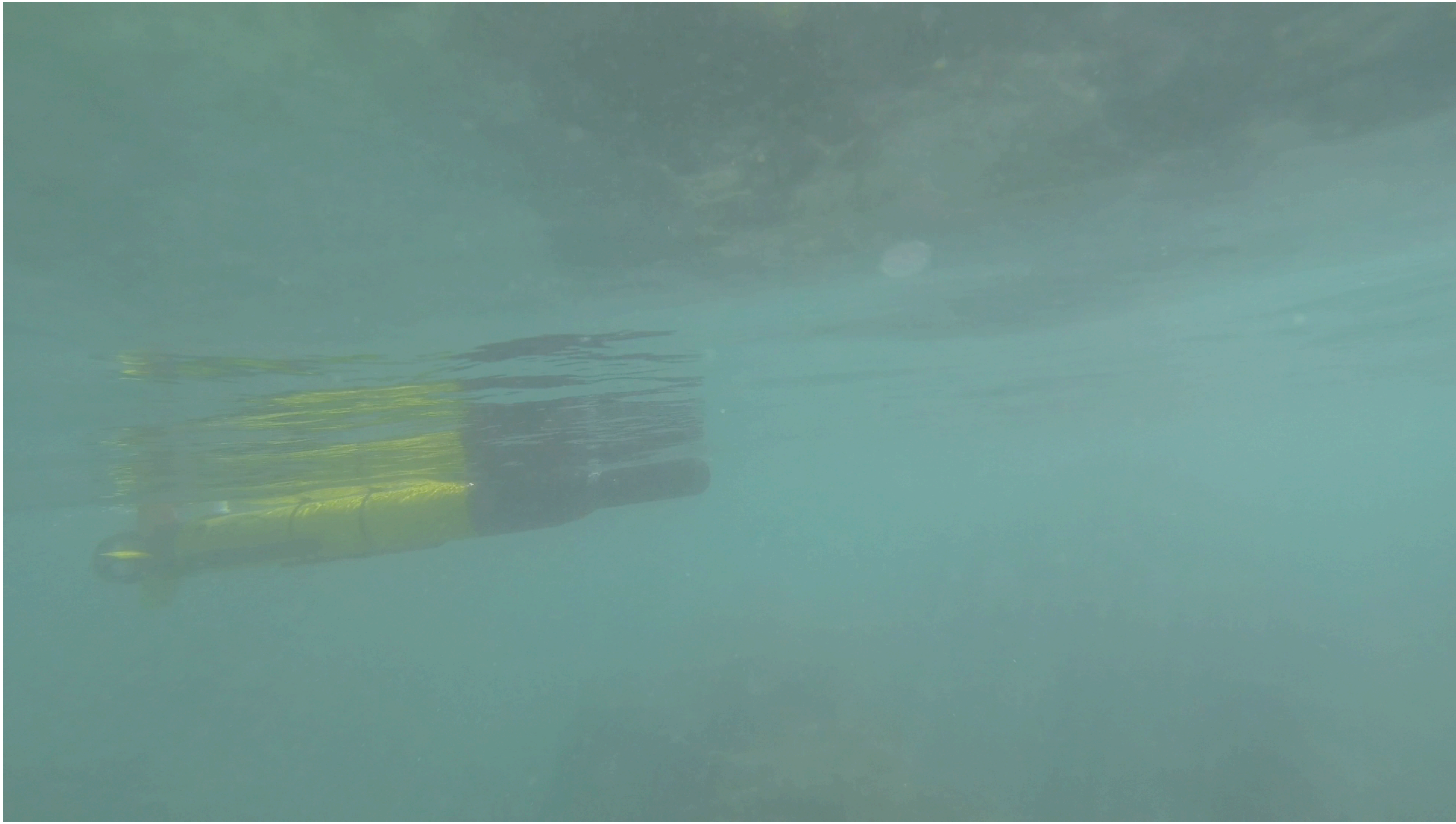
UAV: Remus



UAV: IVER

UAV: IVER

UAV: IVER



Sensors

- Vision
- IMU
- Acoustic Doppler current Profiler (ADCP)
- Doppler Velocity Log: (DVL)
- Echosounder (single beam sonar)
- Scanning Sonar
- Sidescan Sonar
- Multibeam Sonar
- Ultra-Short Baseline Positioning (USBL)
- Long Baseline Positioning (LBL)
- Conductivity Depth Temperature (CDT)
- Salinity, PH, Turbidity

Echo-sounding principle

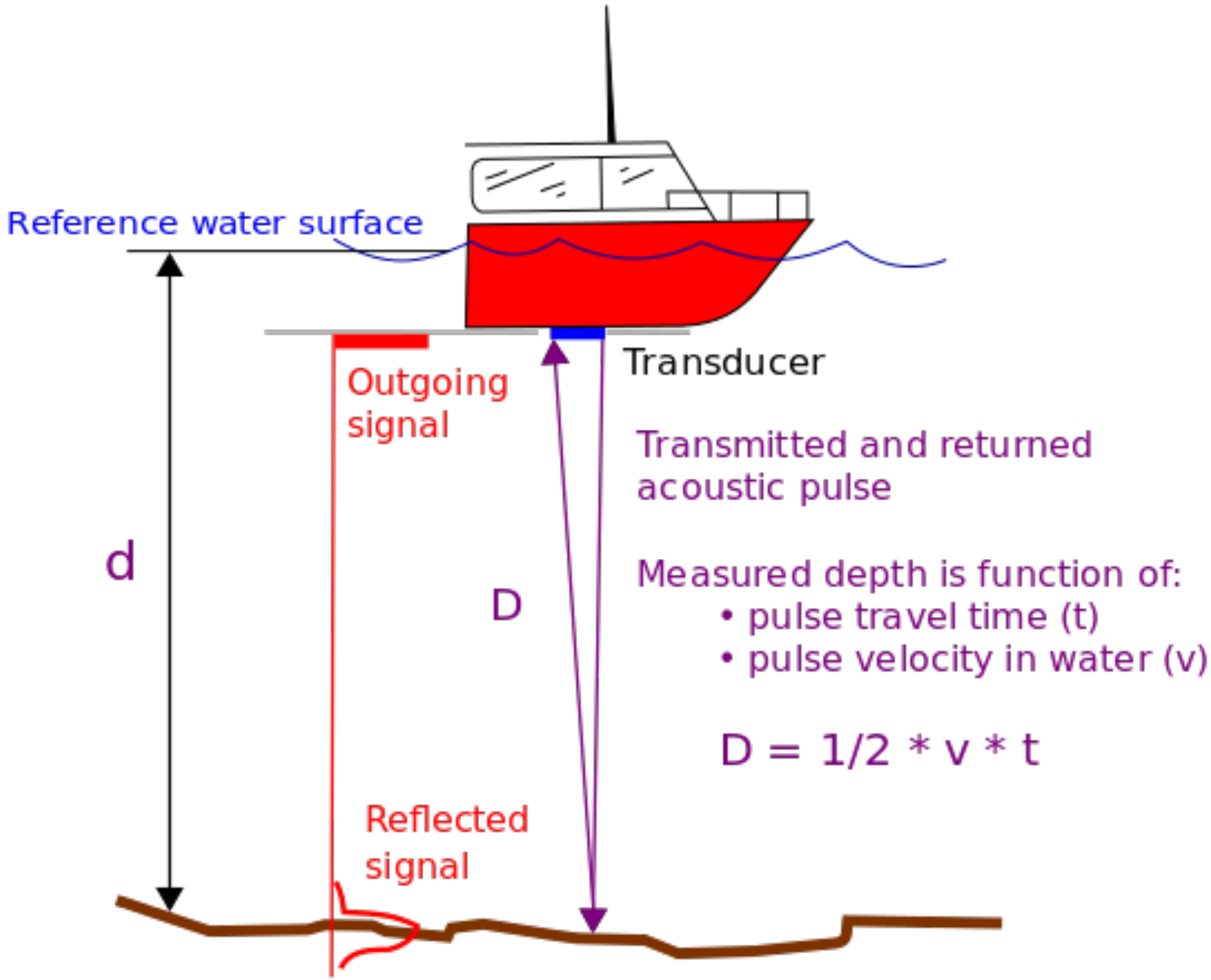
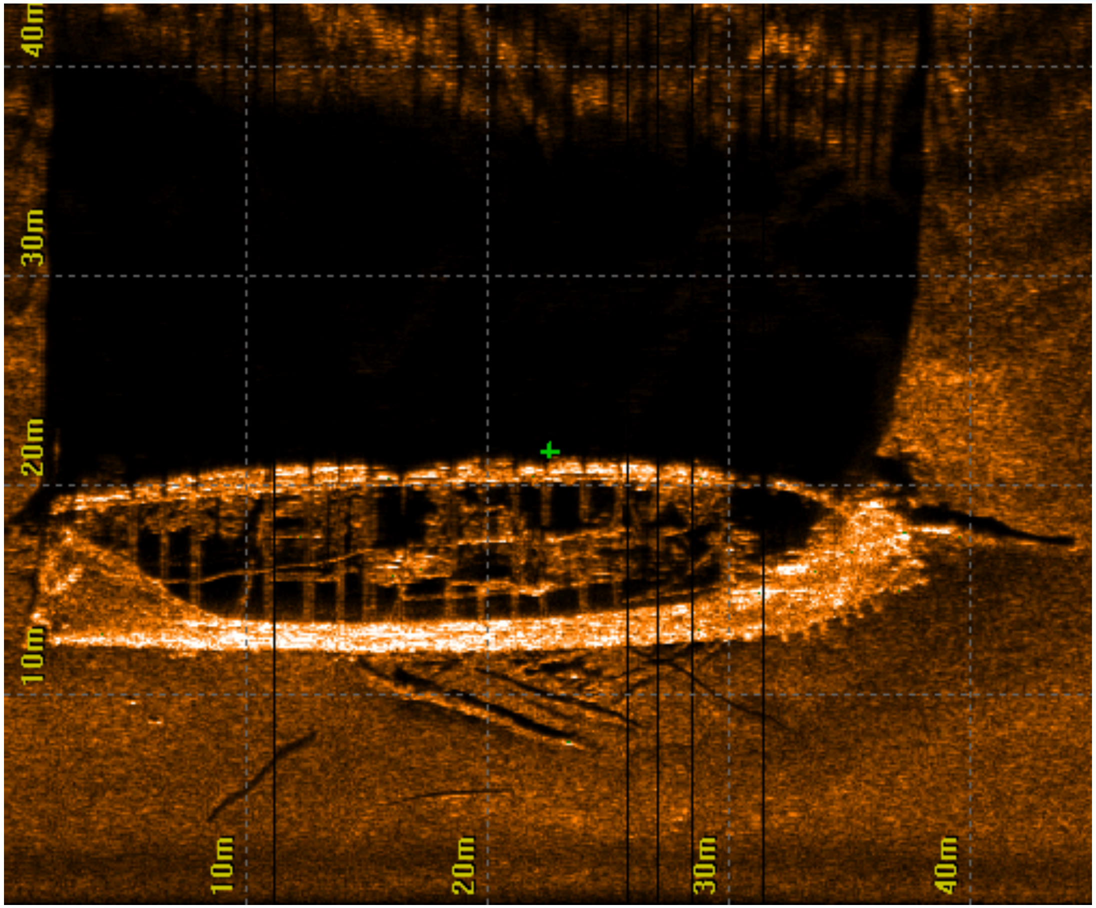


Figure 9-1. Acoustic depth measurement

By Brandon T. Fields (cdated) via the US Army Corps of Engineers - EM 1110-2-1003, Manual of Hydrographic Surveying, based upon Principle_of_SBES.jpg by en:User:Mredmayne.This vector image was created with Inkscape., Public Domain, https://commons.wikimedia.org/w/index.php?curid=23357601

Side-scan Sonar



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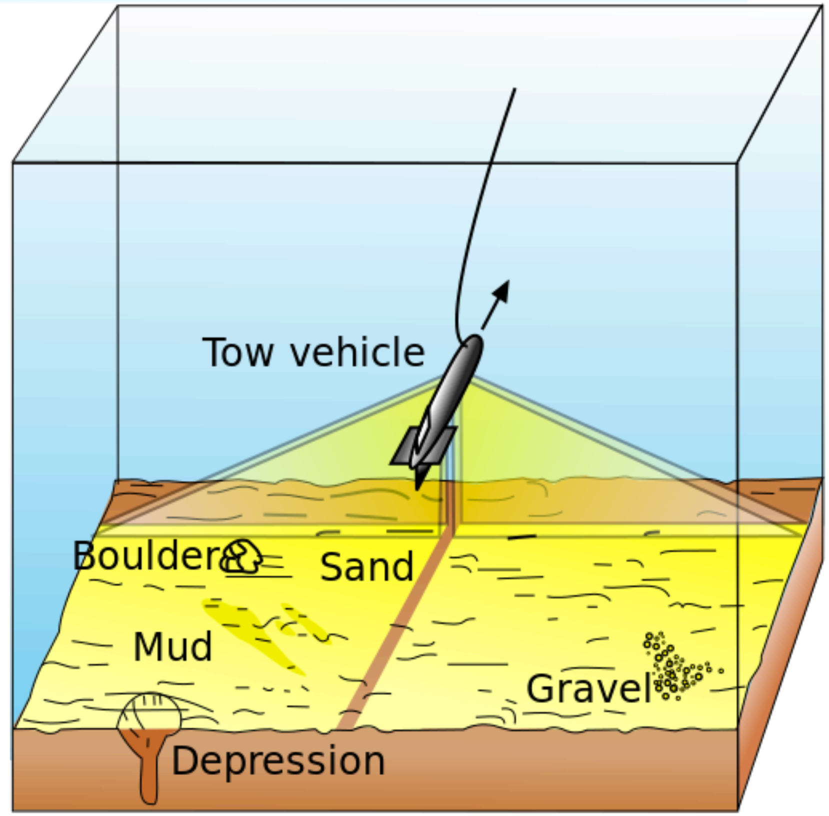

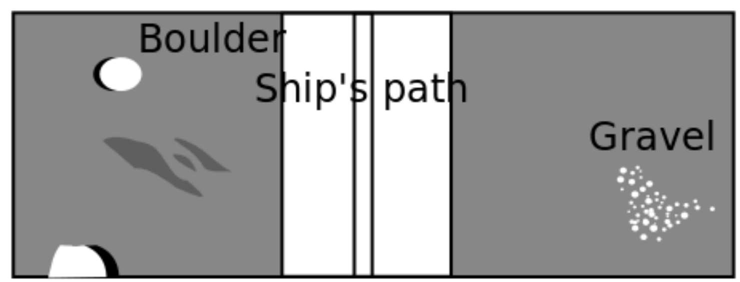

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Multibeam Sonar

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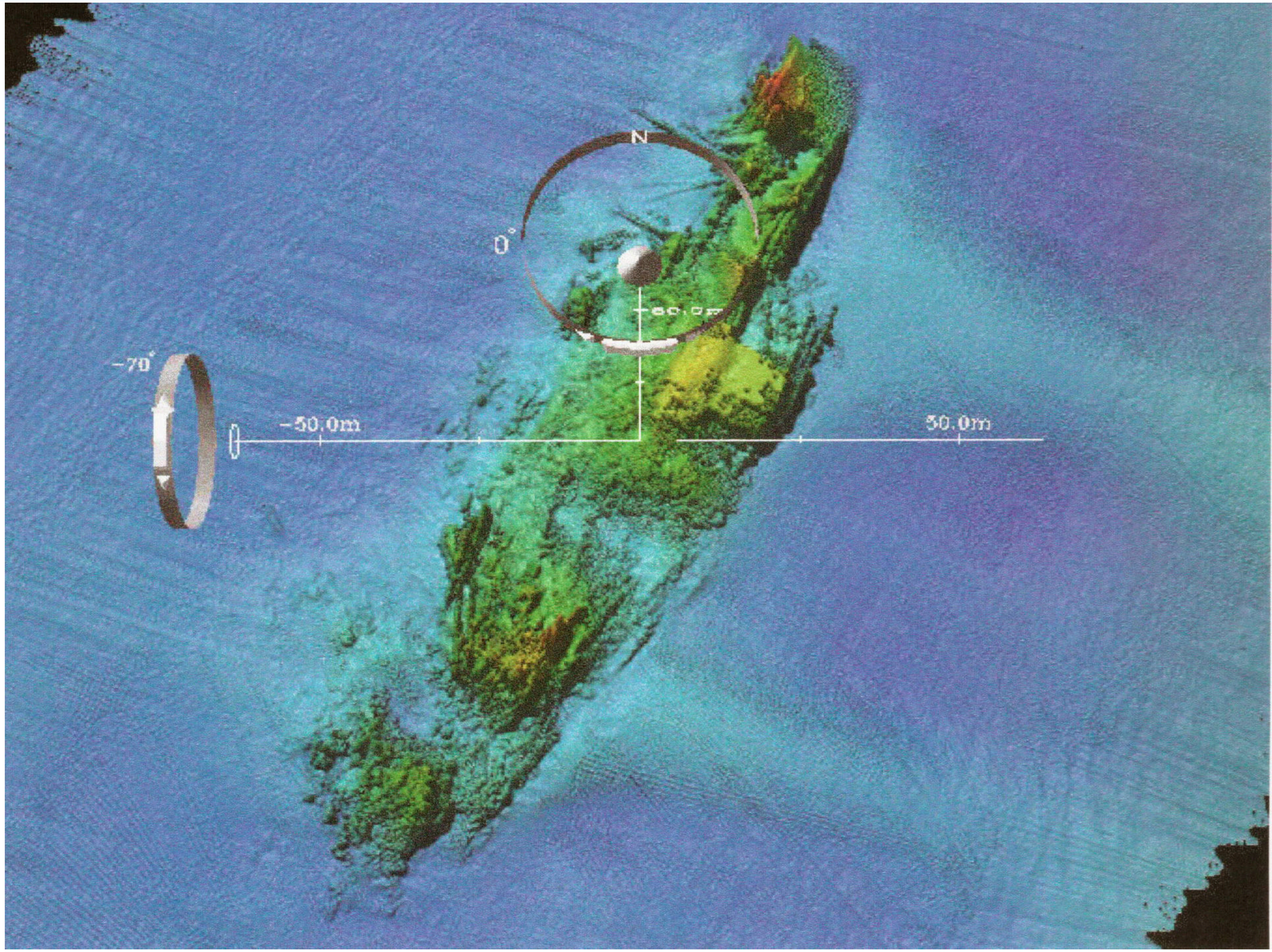
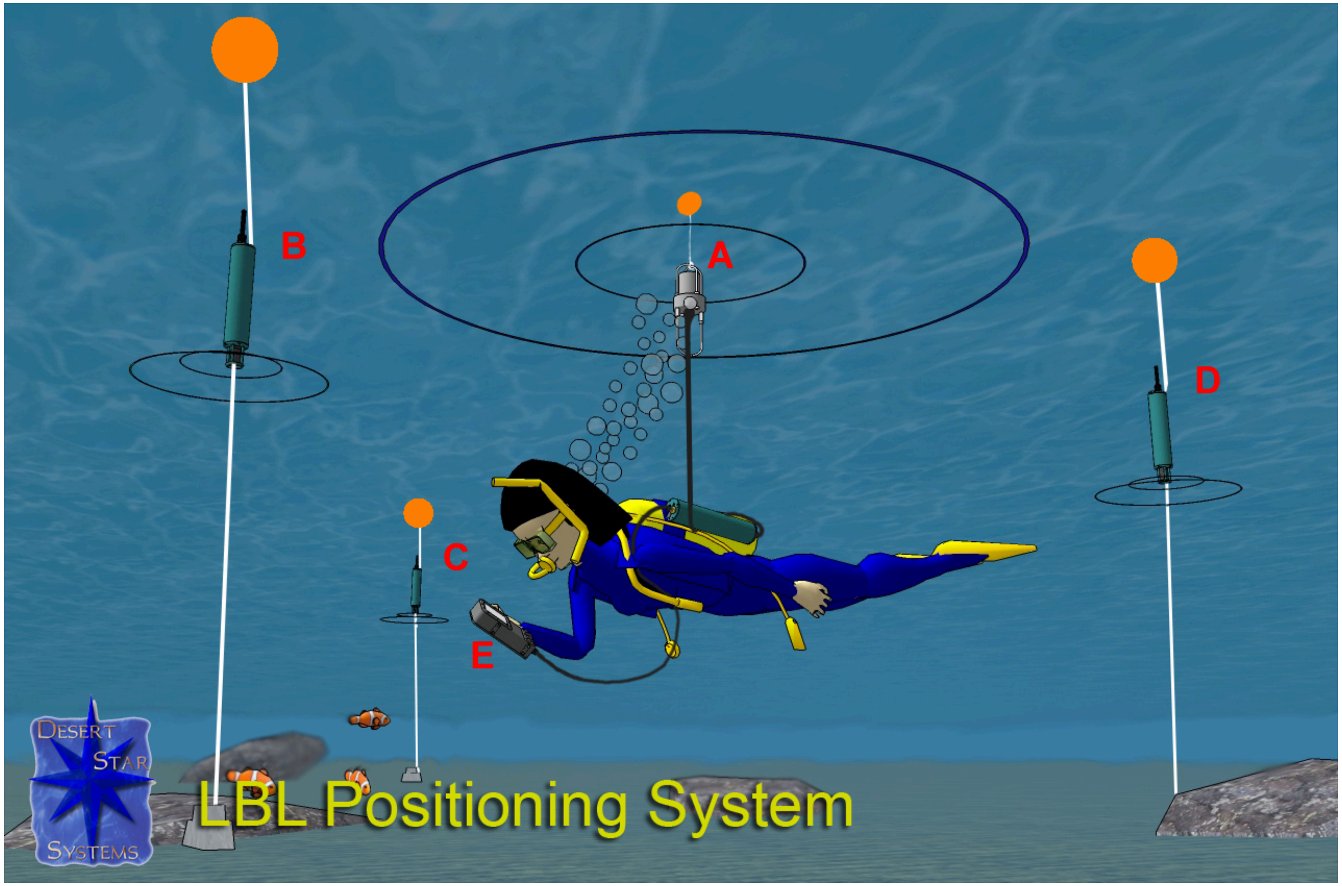


Long Baseline Positioning



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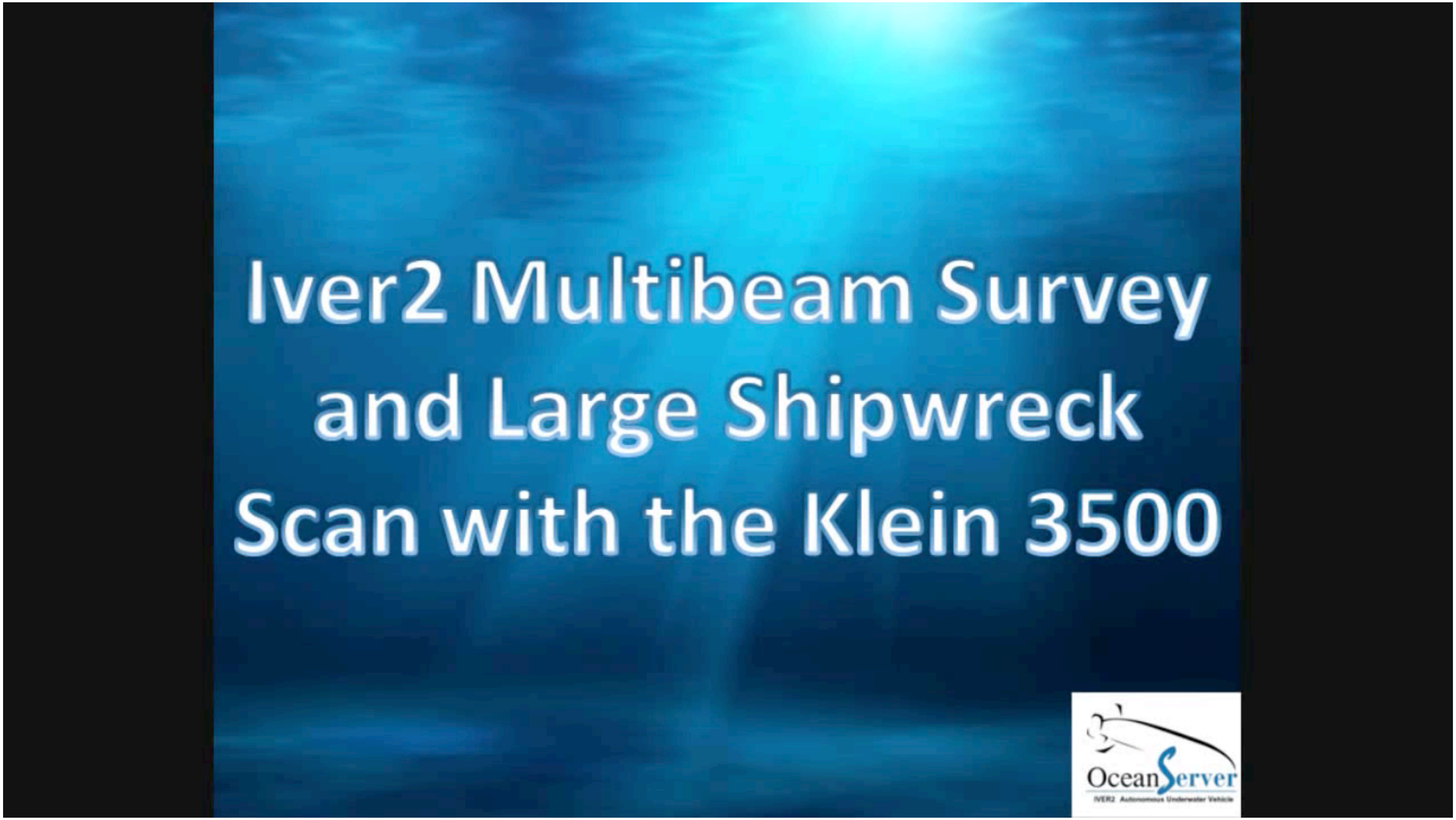
ADCP-DVL

Sensors: Multi-beam Sonar



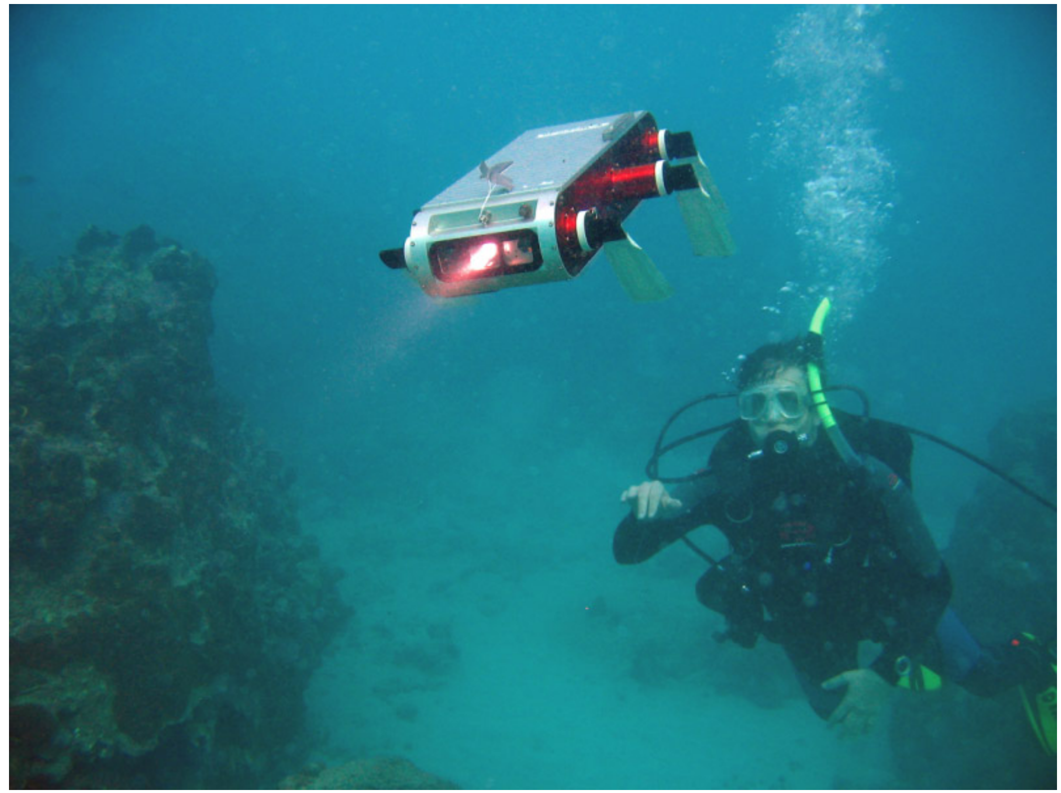
Enabling Autonomous Capabilities in Underwater Robotics

- This work was presented at the International Conference on Intelligent Robots and Systems (IROS), 2008, at Nice, France

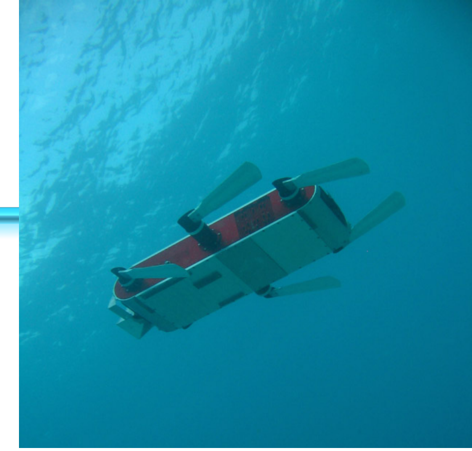
Overview

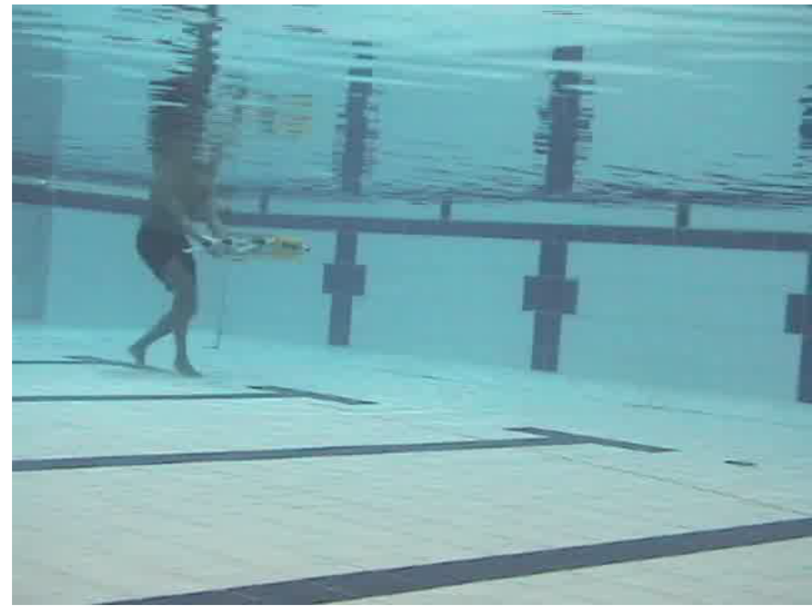
Technologies to increase the level of autonomy

- AQUA description
- Guidance and Control
  - Hovering
- Terrain Classification
- HRI
- Underwater Sensor Nodes
  - Video Mosaics



About Aqua



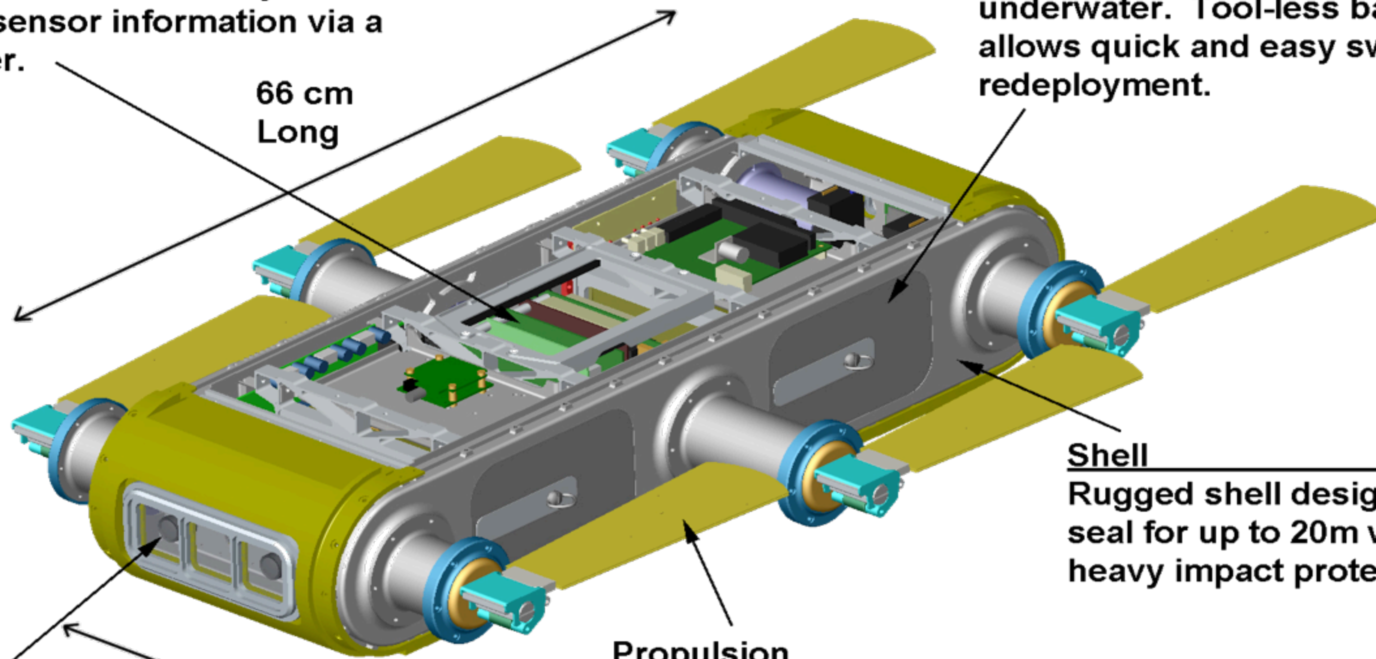


- Legged swimming vehicle
  - Hexapod with flippers, descendant of RHex
  - High mobility (can also walk, hover, etc)
- On-board cameras, IMU, computers
- Power autonomous for ~5+ hours
- Application: surveillance and monitoring of coral reefs, working in conjunction with marine biologists(s).

AQUA Components

Computation
AQUA operates with a Pentium CPU on a PC/104 stack and relays command and sensor information via a fiber optic tether.

Power
Two MIL-spec NiMH batteries allow AQUA to operate for over 5 hours underwater. Tool-less battery replacement allows quick and easy swaps for rapid redeployment.



Shell
Rugged shell design provides ample seal for up to 20m water depth and heavy impact protection.

Propulsion
Multiple iterations and tests have brought the biologically inspired flippers to generate optimal thrust. Experimentation with new swimming gaits has allowed for further improvement of AQUA's underwater performance.

Vision
2 front board cameras and 1 rear allow for remote operation of the robot. Future work will allow for visual servoing and stereoscopic 3D terrain mapping

(AQUA version 1)

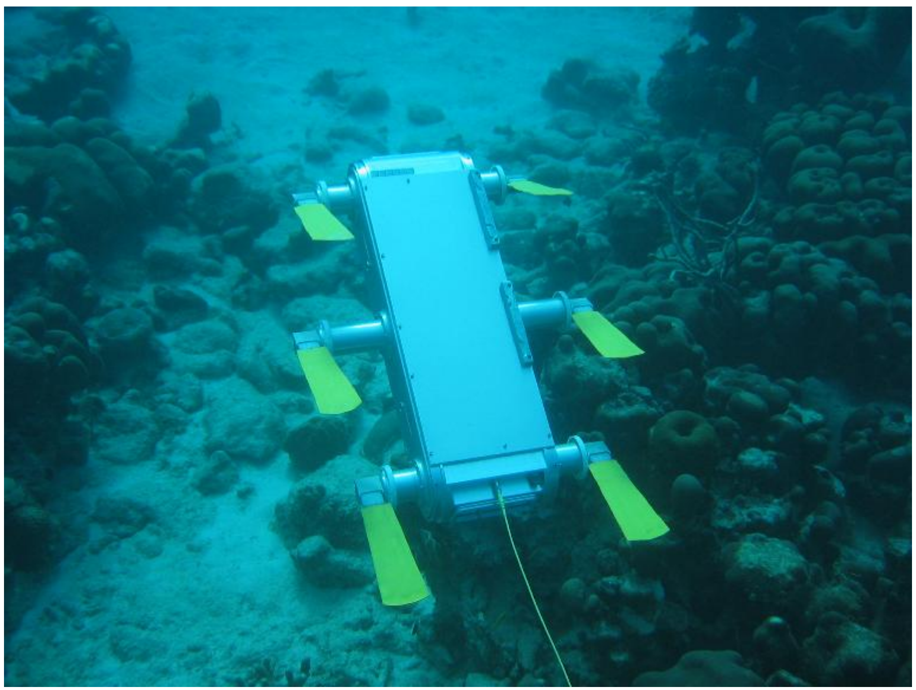
mass = 18.5kg (ballasted for salt water)

AQUA objectives

- AQUA is about developing a portable robot that can walk **and** swim, and which exhibits the ability to use vision and/or sound to know where it is and what is near it.
- The robot could be used, for example, to survey and monitor the conditions on a coral reef. By being able to land on the bottom and move around, the robot can make regular observations without disturbing the natural organisms.
- The ability to walk, swim and use vision underwater is unique to AQUA (derived from RHex [Buehler et al.])
- Allows for efficient station-keeping and surveillance.

Original Project objectives

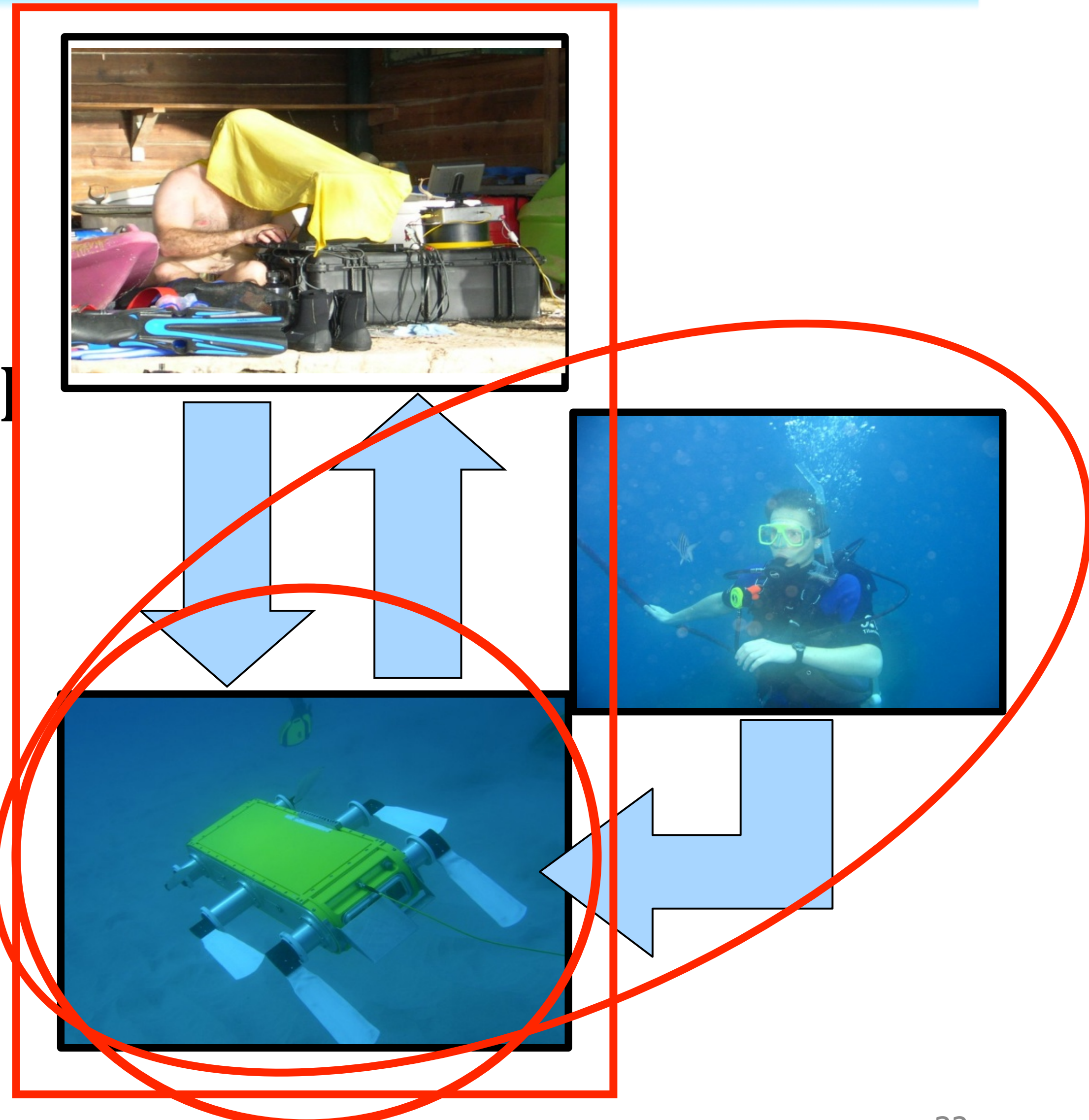
- Survey and monitor the conditions on coral reefs
- Ability to walk on land, swim, and use vision underwater
- Ability to land on the sea floor



Autonomy

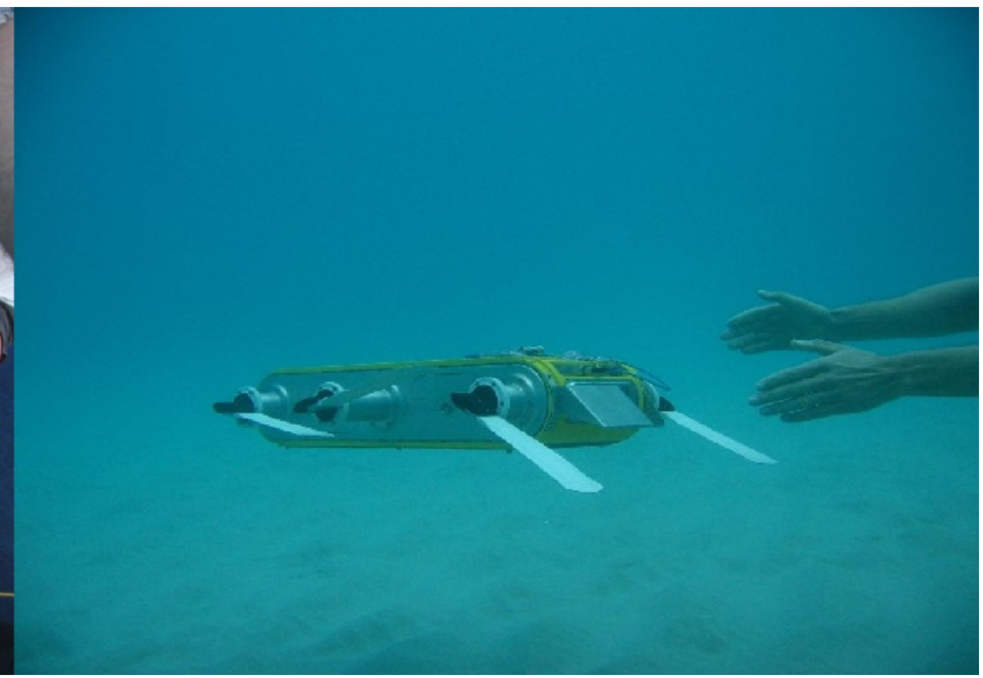
Operation Methods

- Tele-operation
- Partial Autonomy-HRI
- Full Autonomy

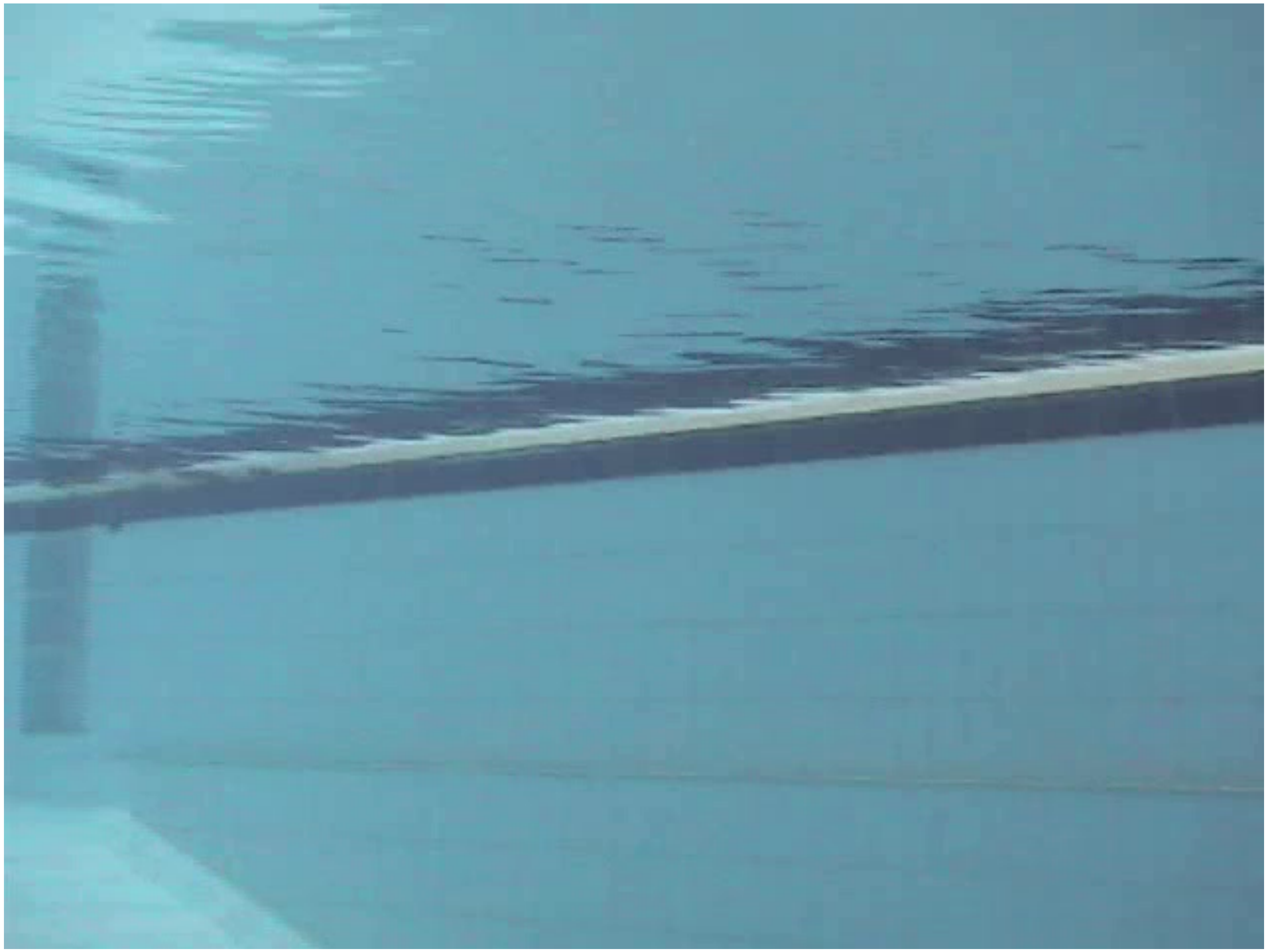


Guidance

- Small, light, moderate-cost robot
- Learn trajectories by (initially) following a diver
- Diver specifies specific actions as desired
- Diver specifies where and how data is collected

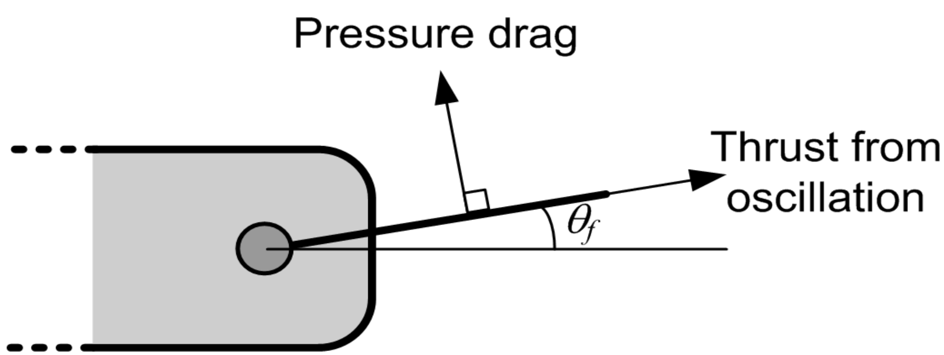



Alternative Entry Technique



Hovering illustration

- Hovering combines two distinct leg motions.
- Can also selectively tune thrust direction to minimize disturbances
- Combining hovering with motion can lead to interesting planning issues



Controllers: Objectives

- Provide trajectory tracking capabilities to the vehicle
  – Determine the required paddle force
  – Determine the appropriate paddle motion
- Stabilize the vehicle in the presence of disturbances

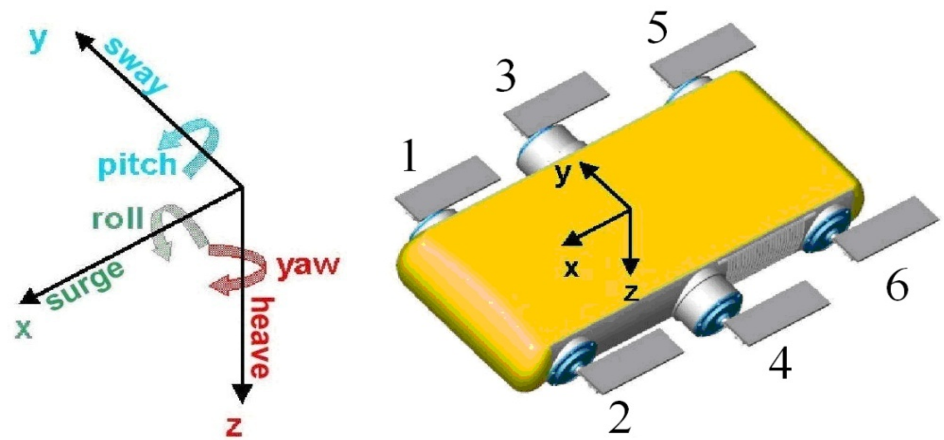
Linear Model

- Nonlinear model is linearized to allow use of linear systems theory

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}, \boldsymbol{\tau})$$

$$\downarrow$$

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\boldsymbol{\tau}$$



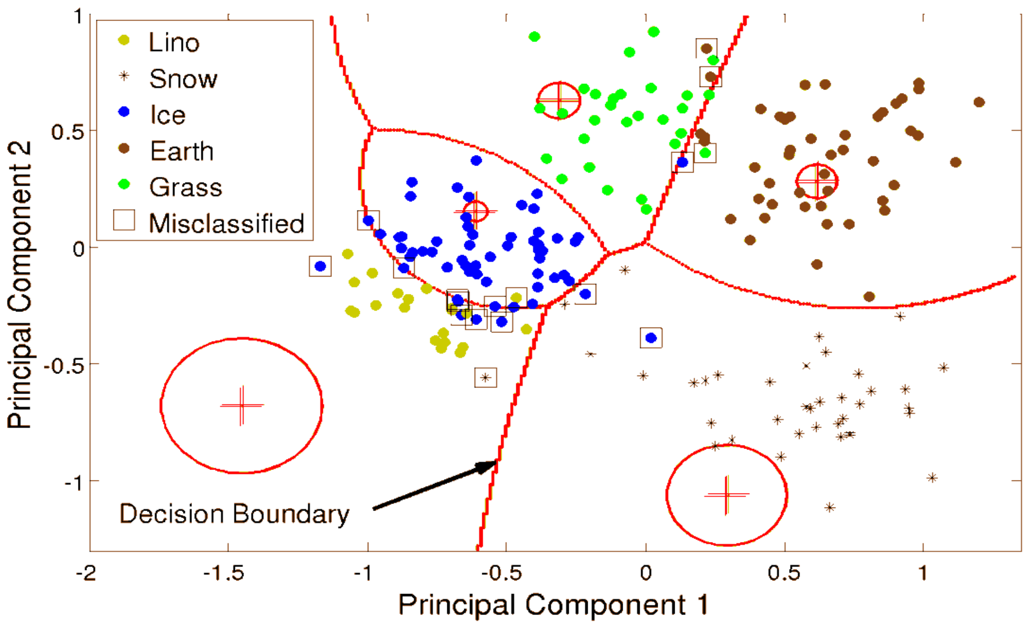
- State vector $\mathbf{x} = [u \quad v \quad w \quad p \quad q \quad r \quad x \quad y \quad z \quad \varphi \quad \theta \quad \psi]^T$
- Force vector $\boldsymbol{\tau} = [f_{x1} \quad \dots \quad f_{x6} \quad f_{z1} \quad \dots \quad f_{z6}]^T$

Model Based Control

- PID controllers used
- Both Linear and Non-Linear models used to augment the PID controller

Terrain identification

- Vehicle is capable of using contact forces to identify terrains
- This allows gaits to be selected or adapted as a function of terrain type



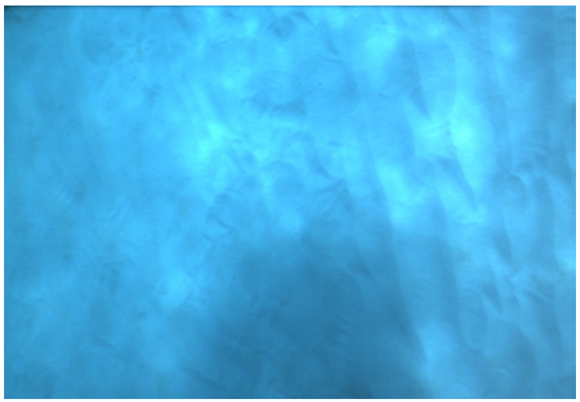
Aqua Sensing: Vision, IMU, Depth

Potential Issues in Underwater Vision

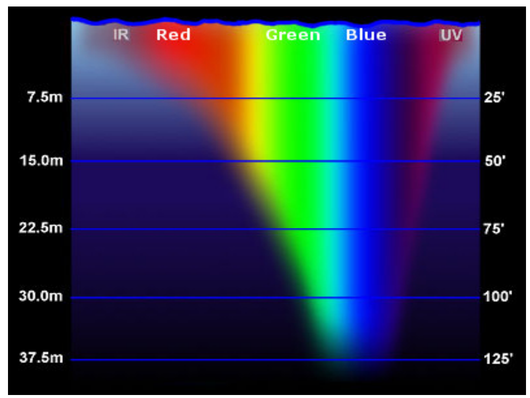
Limited visibility

Lighting variations

Backscatter



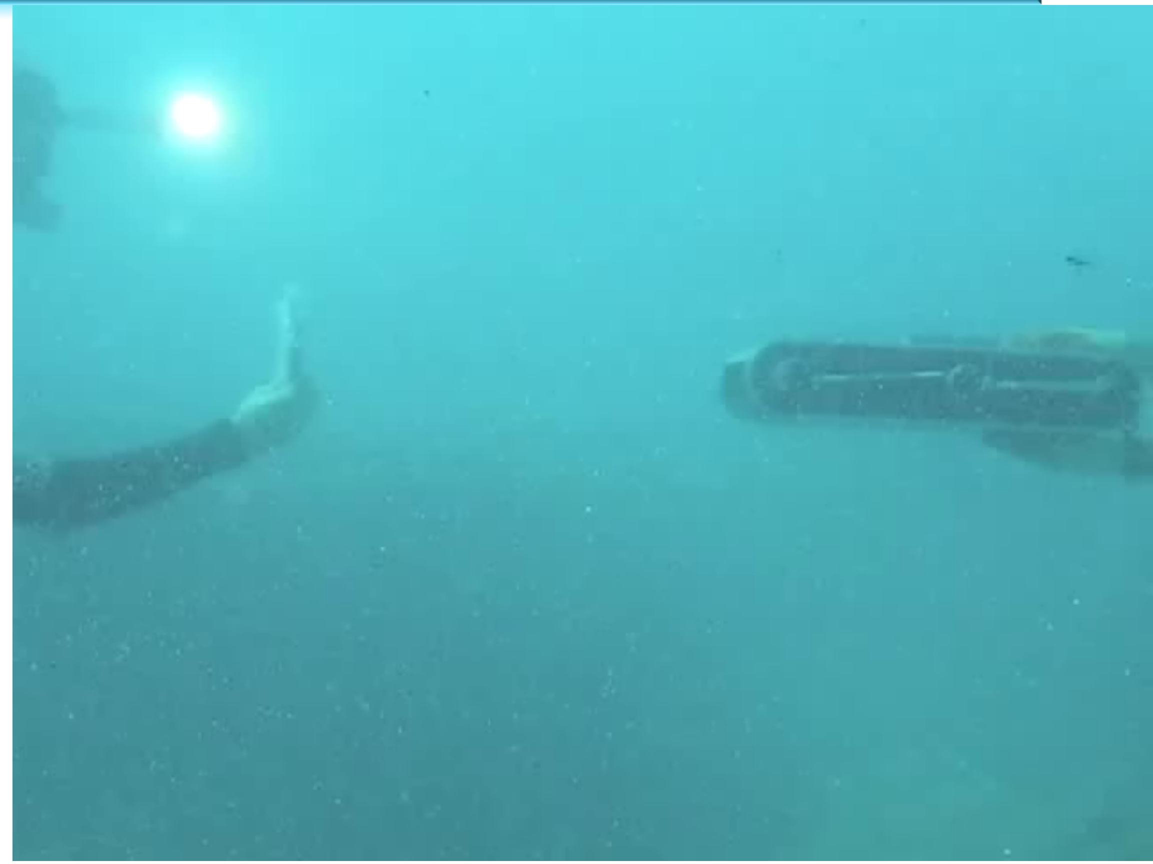
Lack of features



Light absorption

Vision-Based HRI

- Easier than conventional methods (e.g. type, touch screens)
- Requires no extra input mechanisms or sensors other than a camera
- Advantages of machine vision
  - Problems lie in interpreting 'gestures'
  - Fiducials as tokens

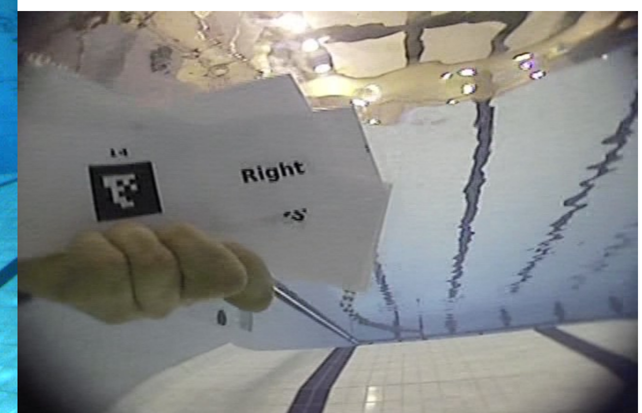


Corrected Image Content

Noisy data collected from an underwater node

Visual Language

- Gestural robot programming language
- Real-time interpreter
- Low-level constructs: robot action commands (e.g. MOVE_FORWARD)
- High-level constructs: loops, iterators, functions
- Commands coded in scripting language (Lua)



Features

```
for (i = 0; i < 4; i++) {
    angle = 90;
    duration = 2;
    Turn_Left(angle, duration);
    Move_Forward(duration);
}
```

C-like Pseudocode
(38 input tokens)

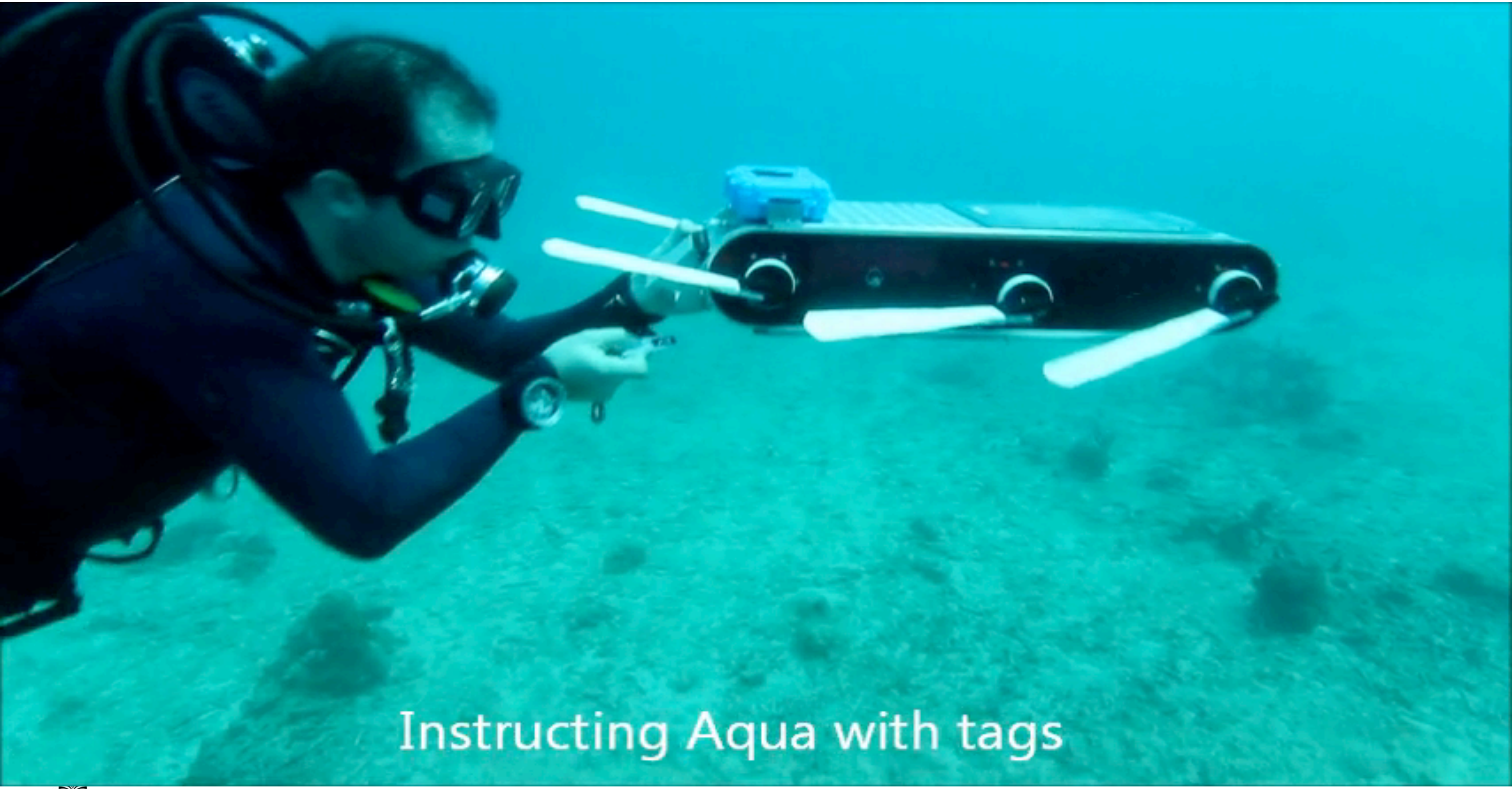
```
4 REPEAT
    9 0 ANGLE
    2 DURATION
    TURN_LEFT
    MOVE_FORWARD
END

EXECUTE
```

RoboChat snippet
(11 input tokens)

- Use of Reverse Polish notation to minimize unnecessary syntax artefacts (e.g. then, {...} *etc*)

Current Mode: HRI using Tags



Aqua – Lobster Interaction

Autonomous Surface Vehicles

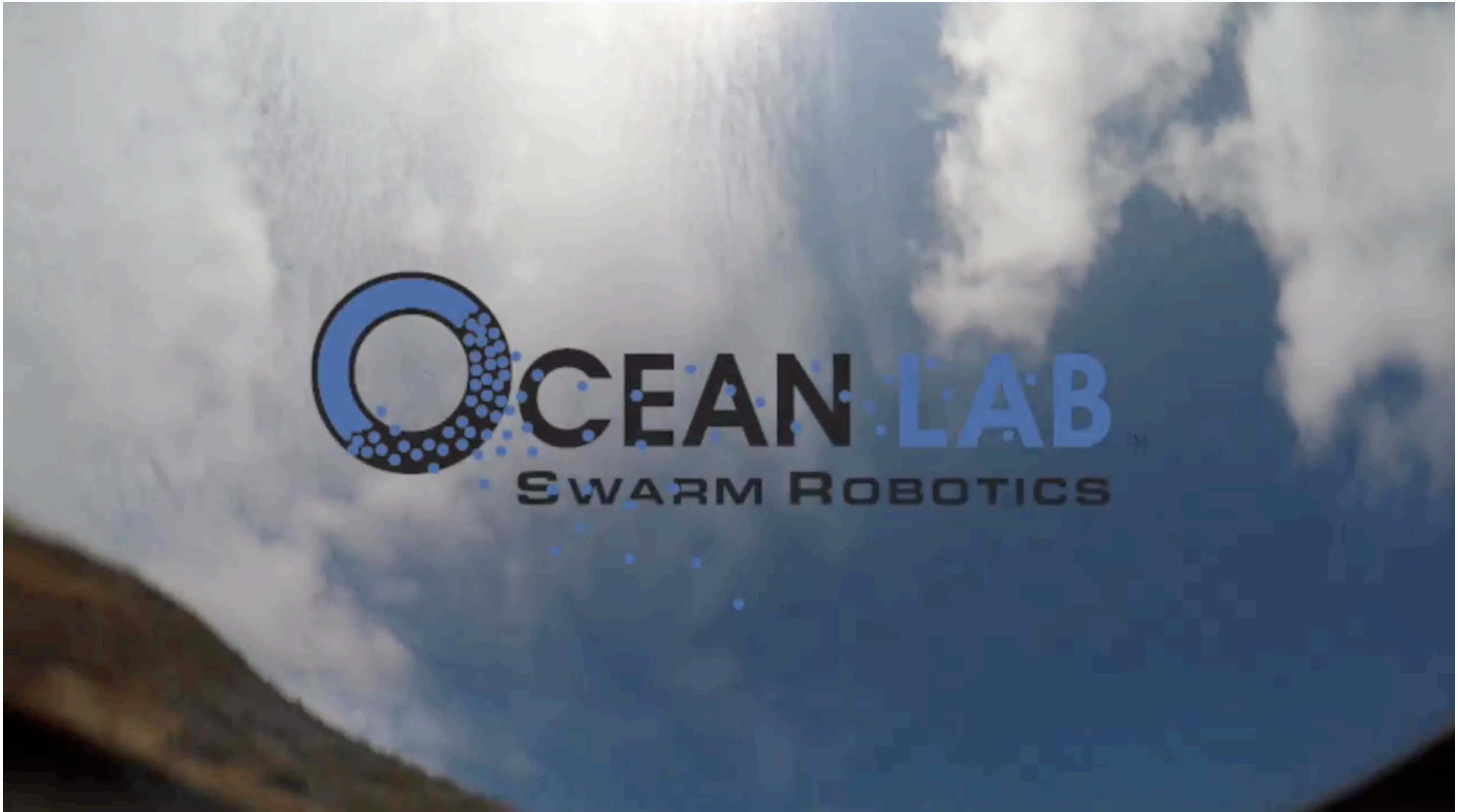
LIQUID ROBOTICS®

- **Wave Glider**

ASV: Autonomous Mokai (WHOI)

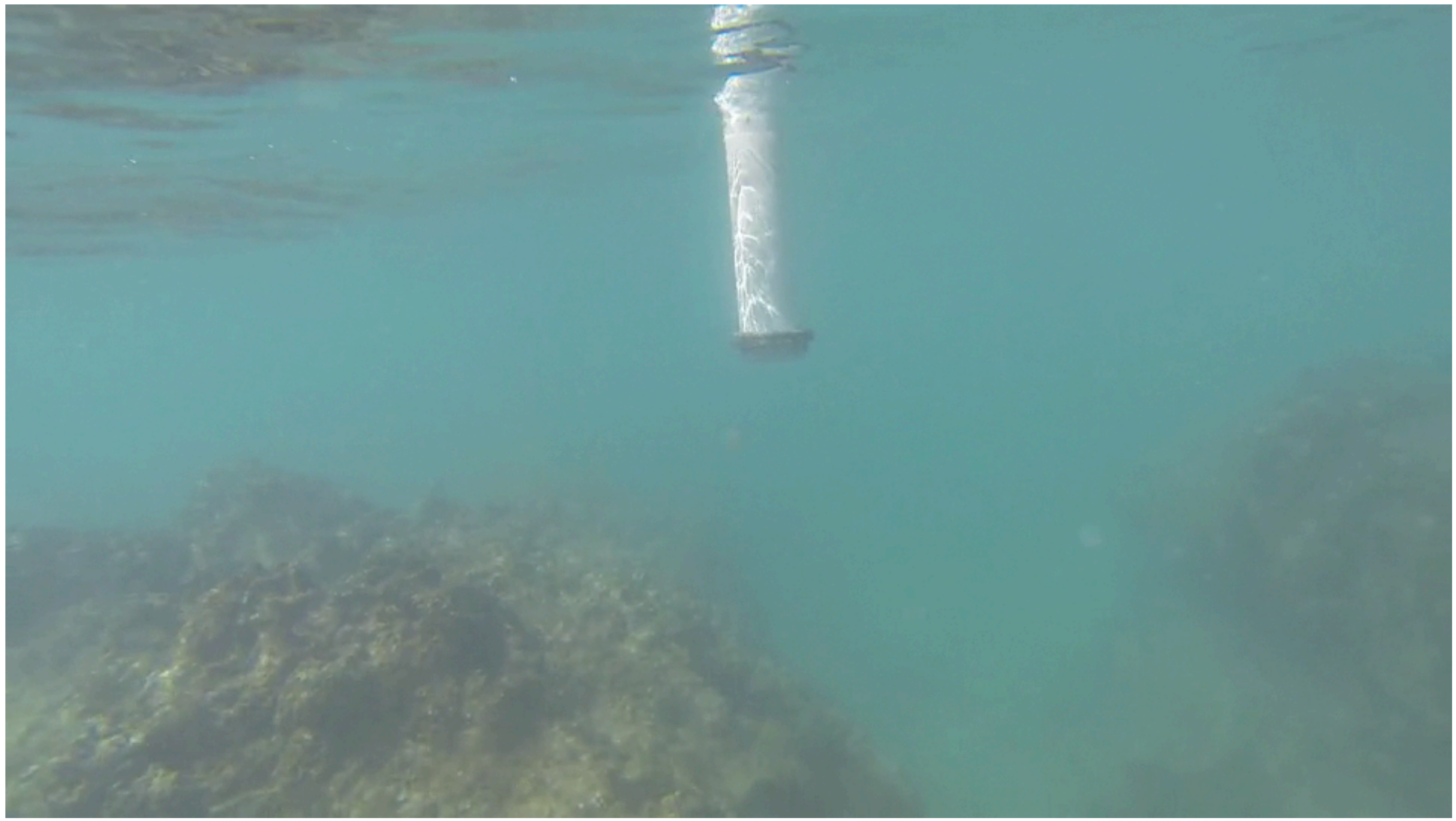
ASV: Autonomous Mokai (SC)

OCEAN LAB: Data Diver Swarm



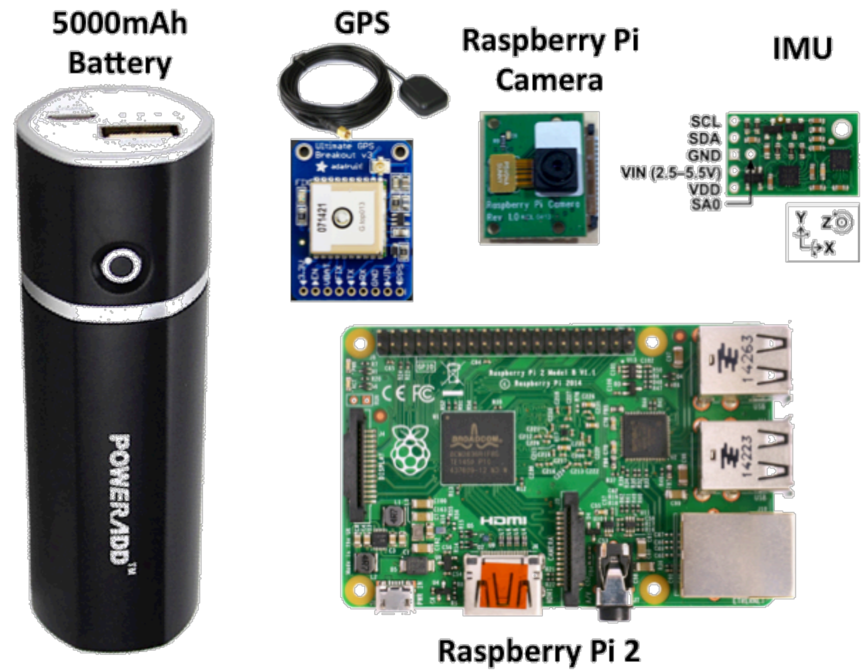
Drift Nodes

- Monitor, shallow coral reefs.
- Improve estimation accuracy



Hardware Implementation

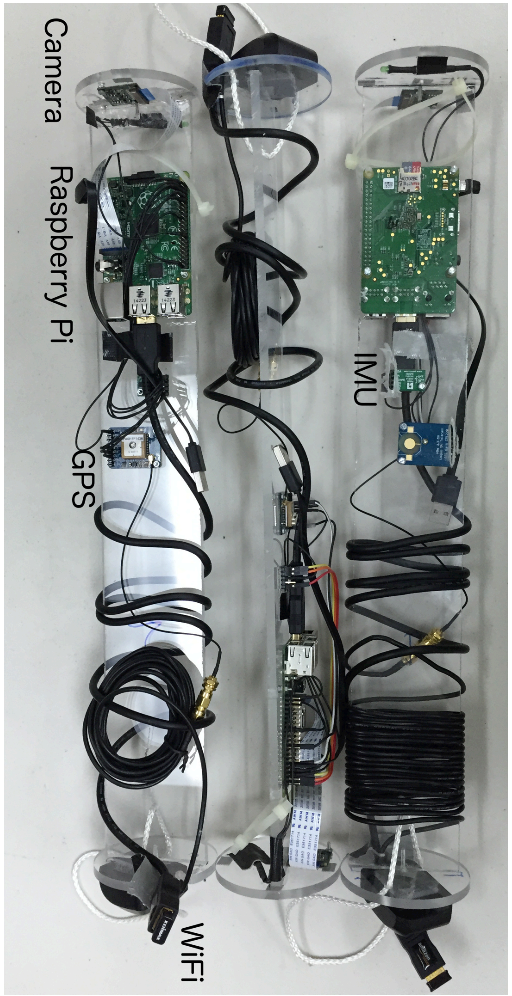
- Hardware
  - Computing Unit - Raspberry Pi 2
  - IMU - Pololu MinIMU-9 V3
  - GPS - Adafruit Ultimate Breakout
  - WiFi - Edimax USB Adapter
  - Camera - Raspberry Pi Camera
- Software
  - OS – Raspbian Wheezy
  - ROS – Standardized data and communications transmitting
  - GPSD – Communication with GPS
  - minimu9-ahrs - Communicate with IMU
  - Various shell and Python scripts to manage node operation



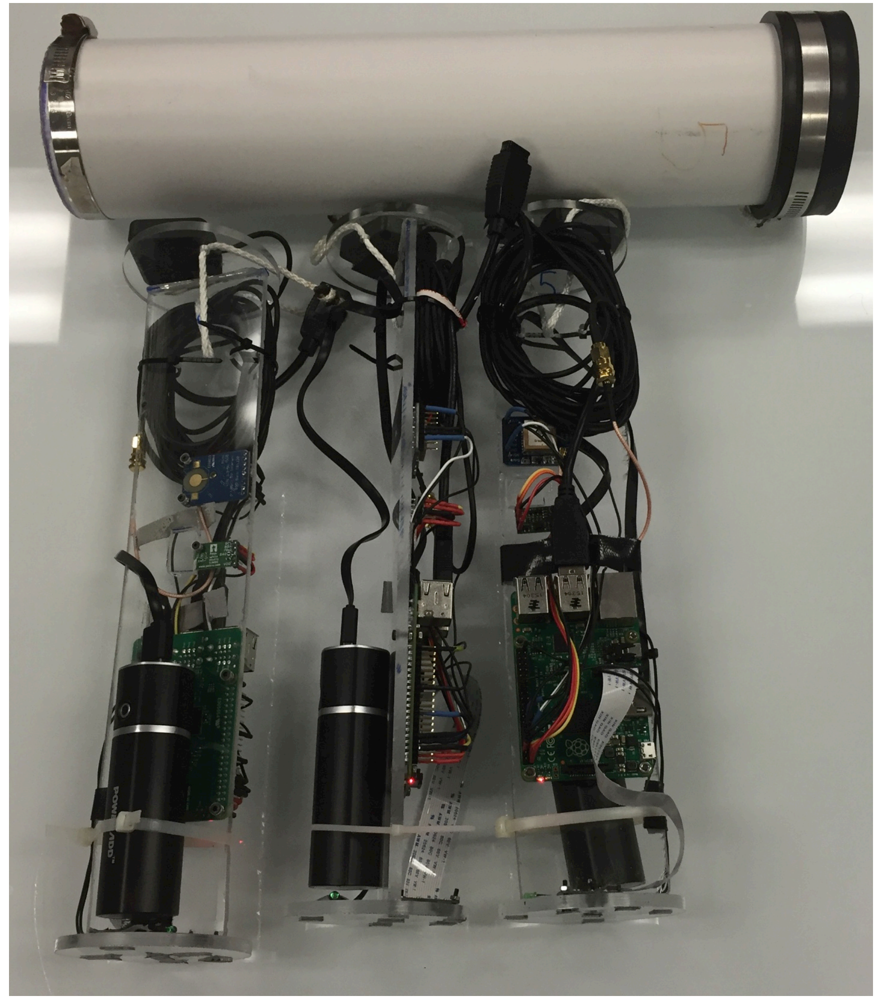
Total cost ~ $250

Drifter GPS Trajectories

Hardware Implementation



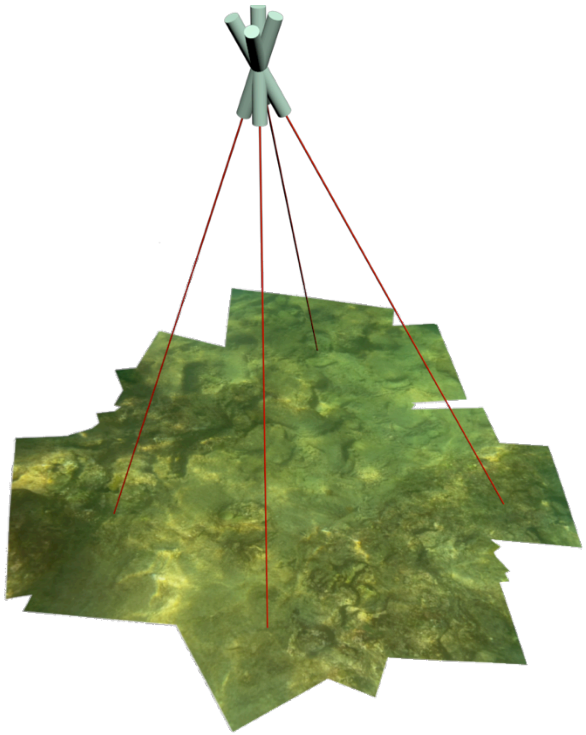
2015

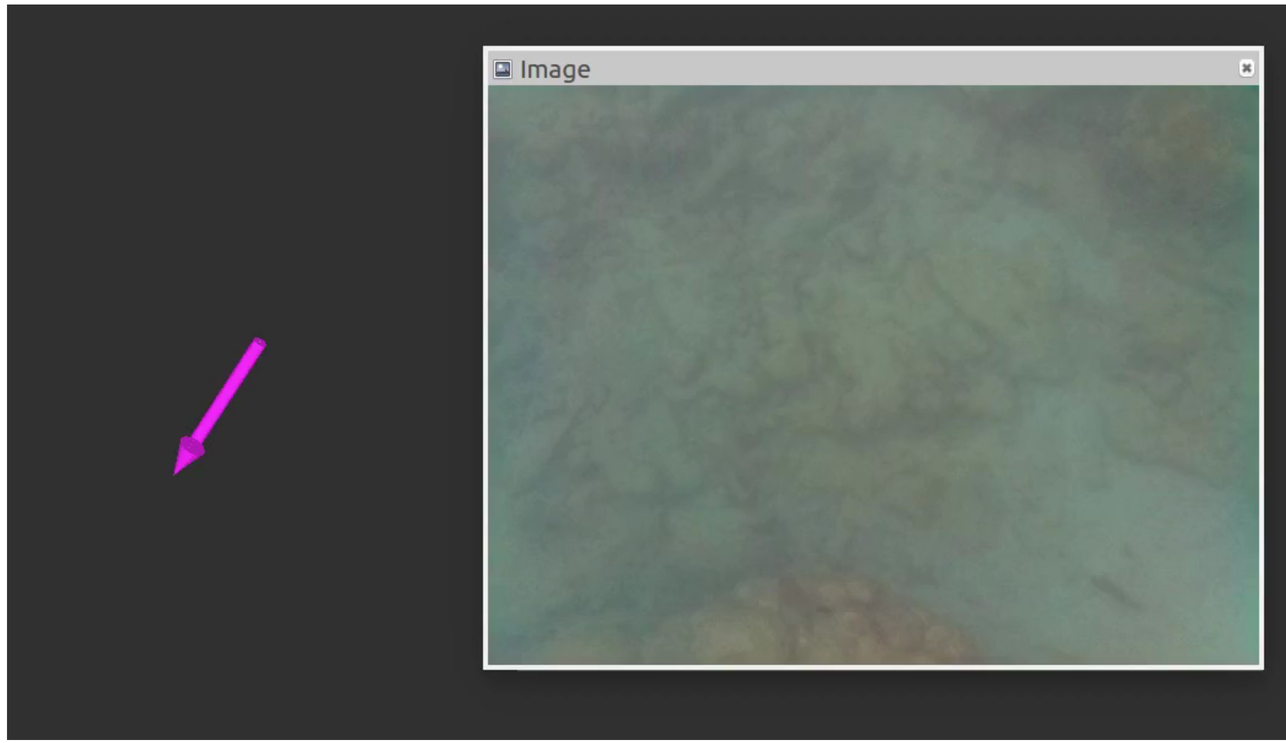


2016

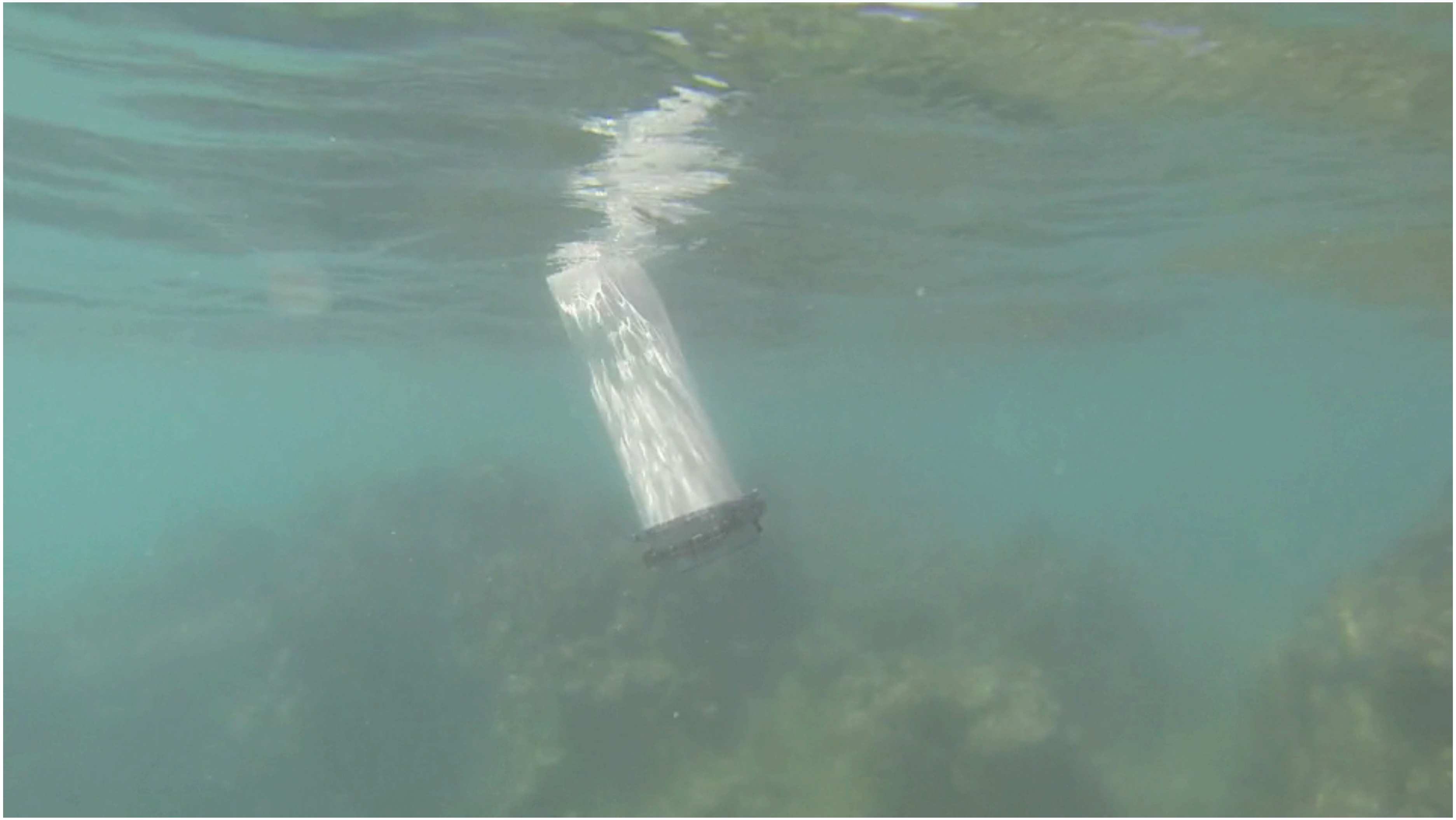
Wide Field of View

- Wave action results in wider field of view coverage

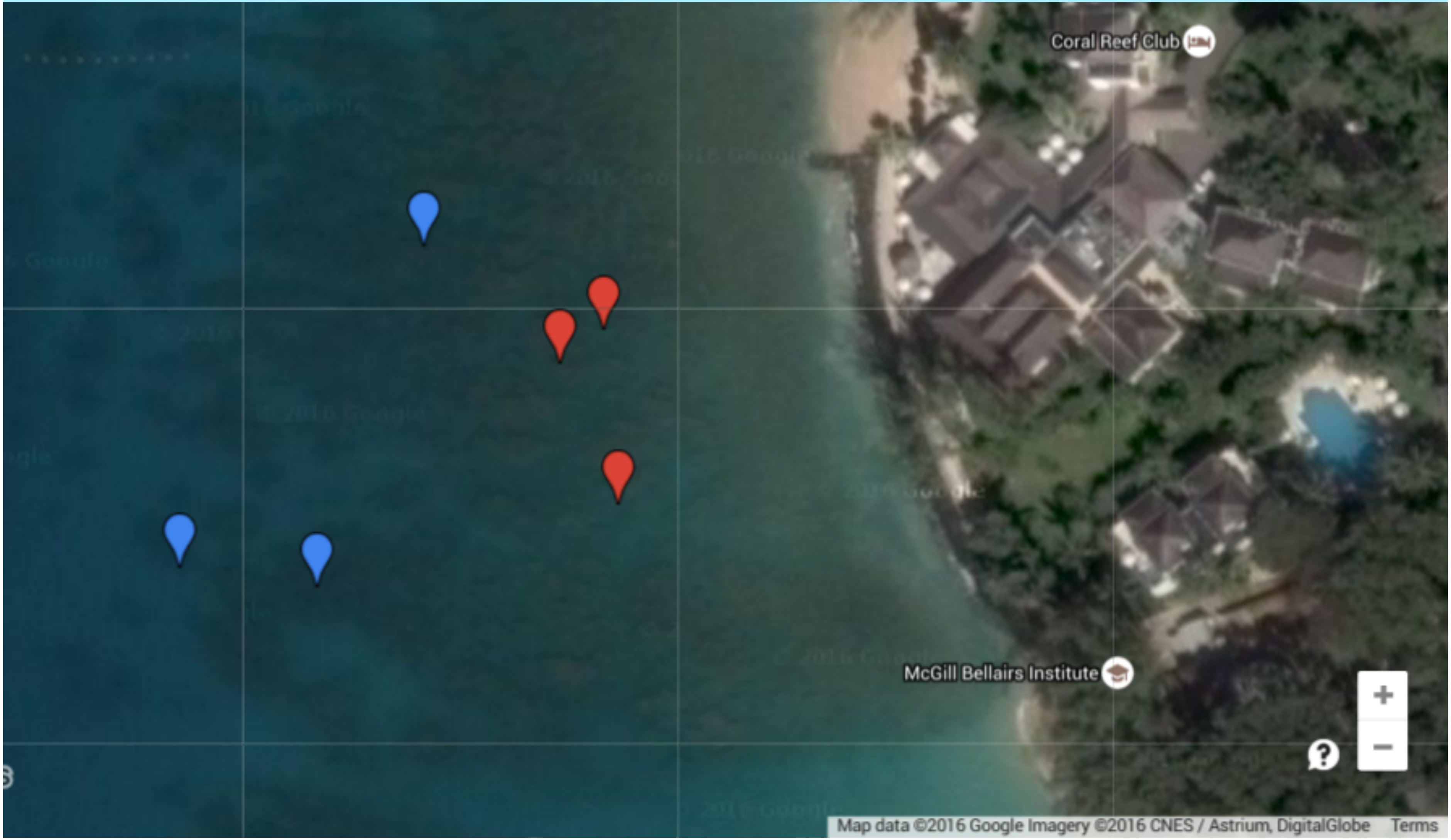




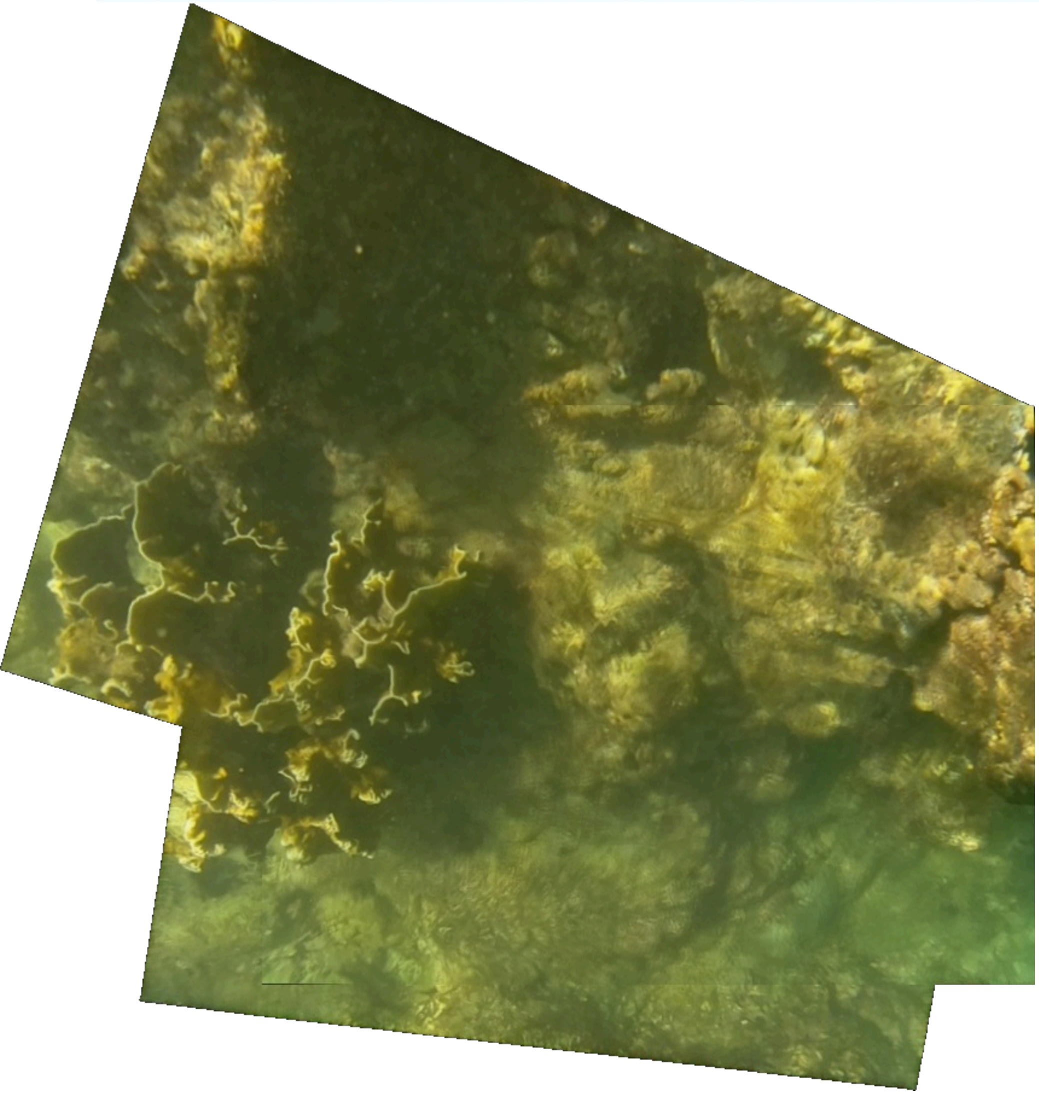
Surge

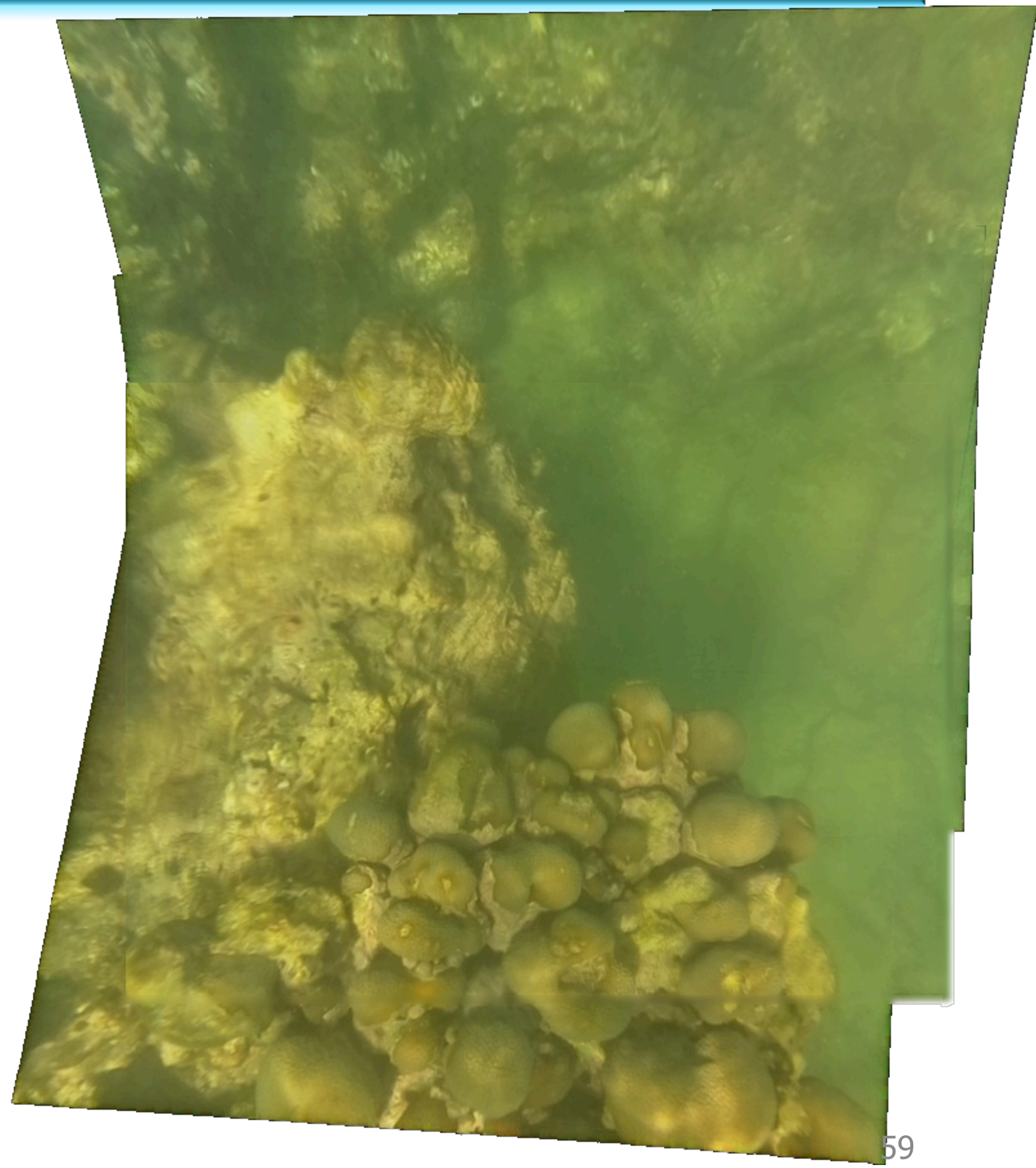


Sample GPS Location

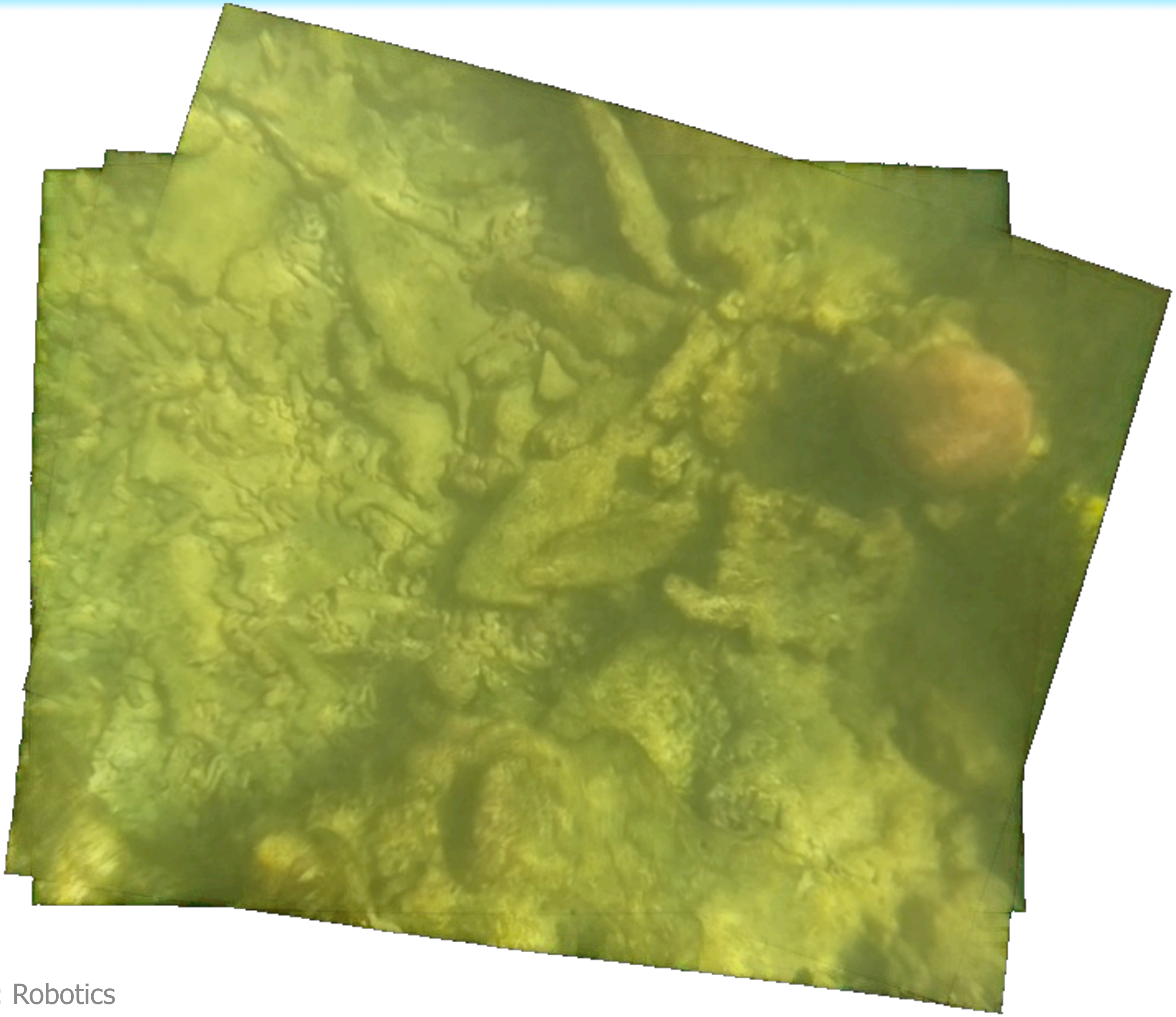


Shallow Areas

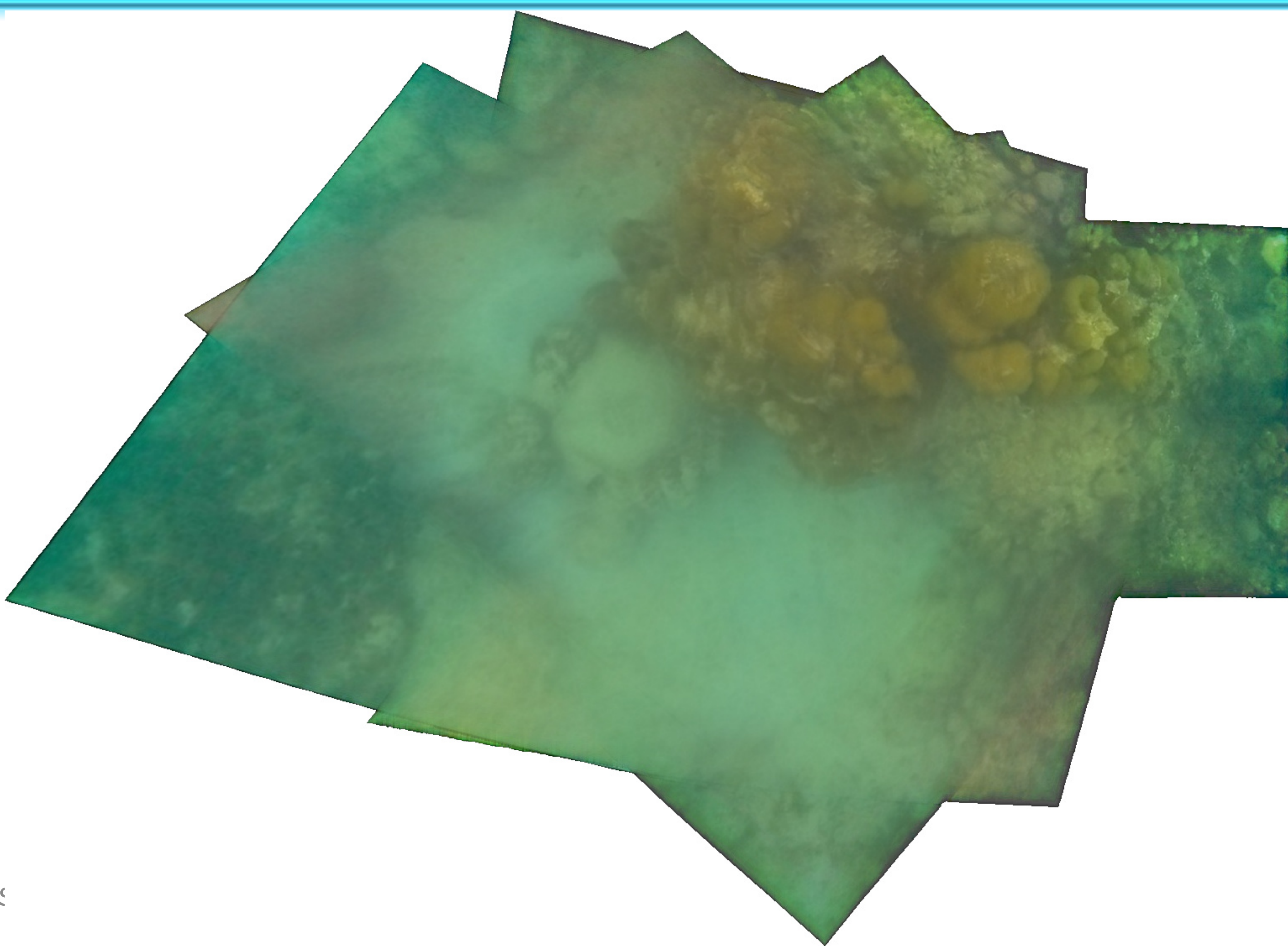




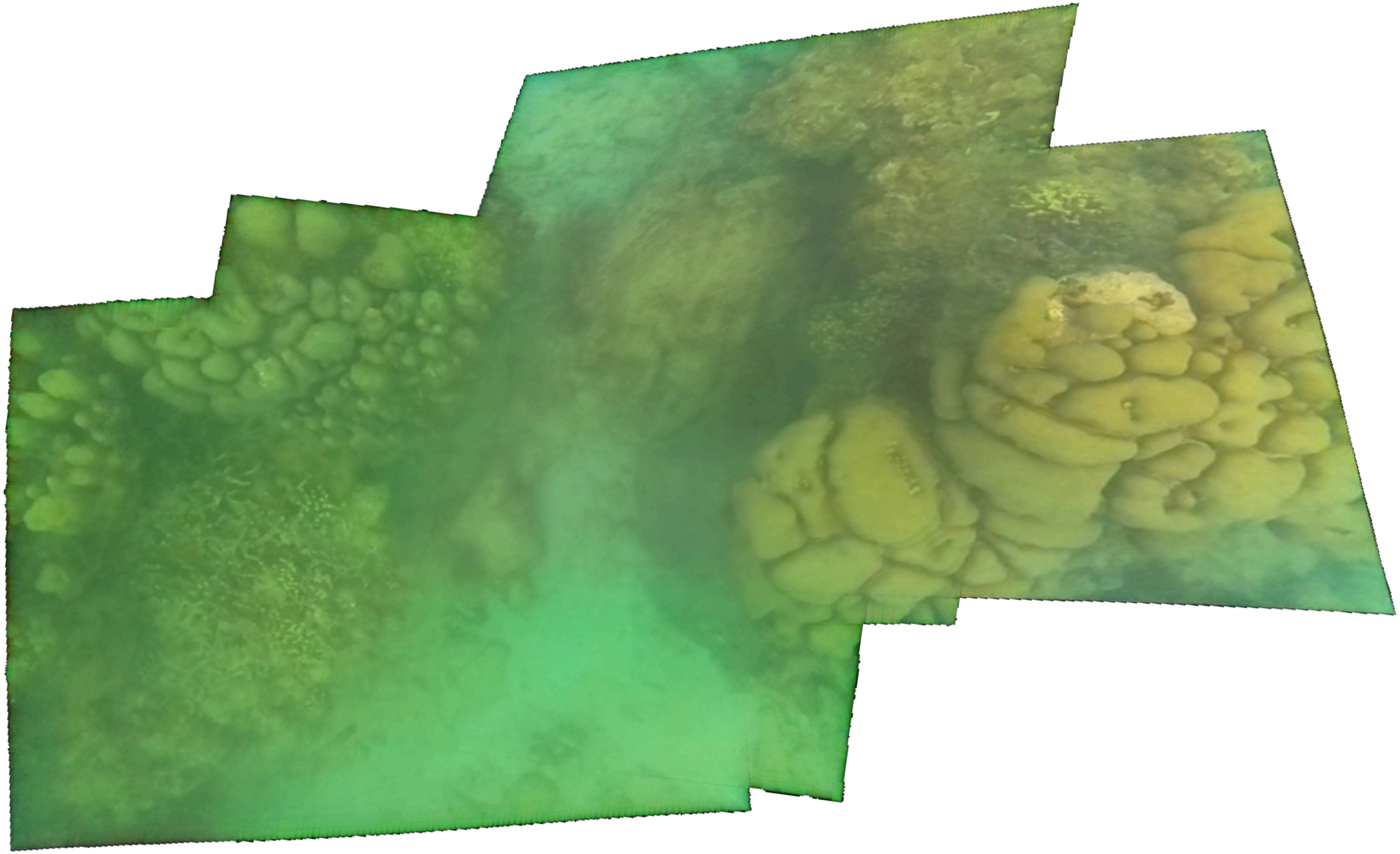
Shallow Areas



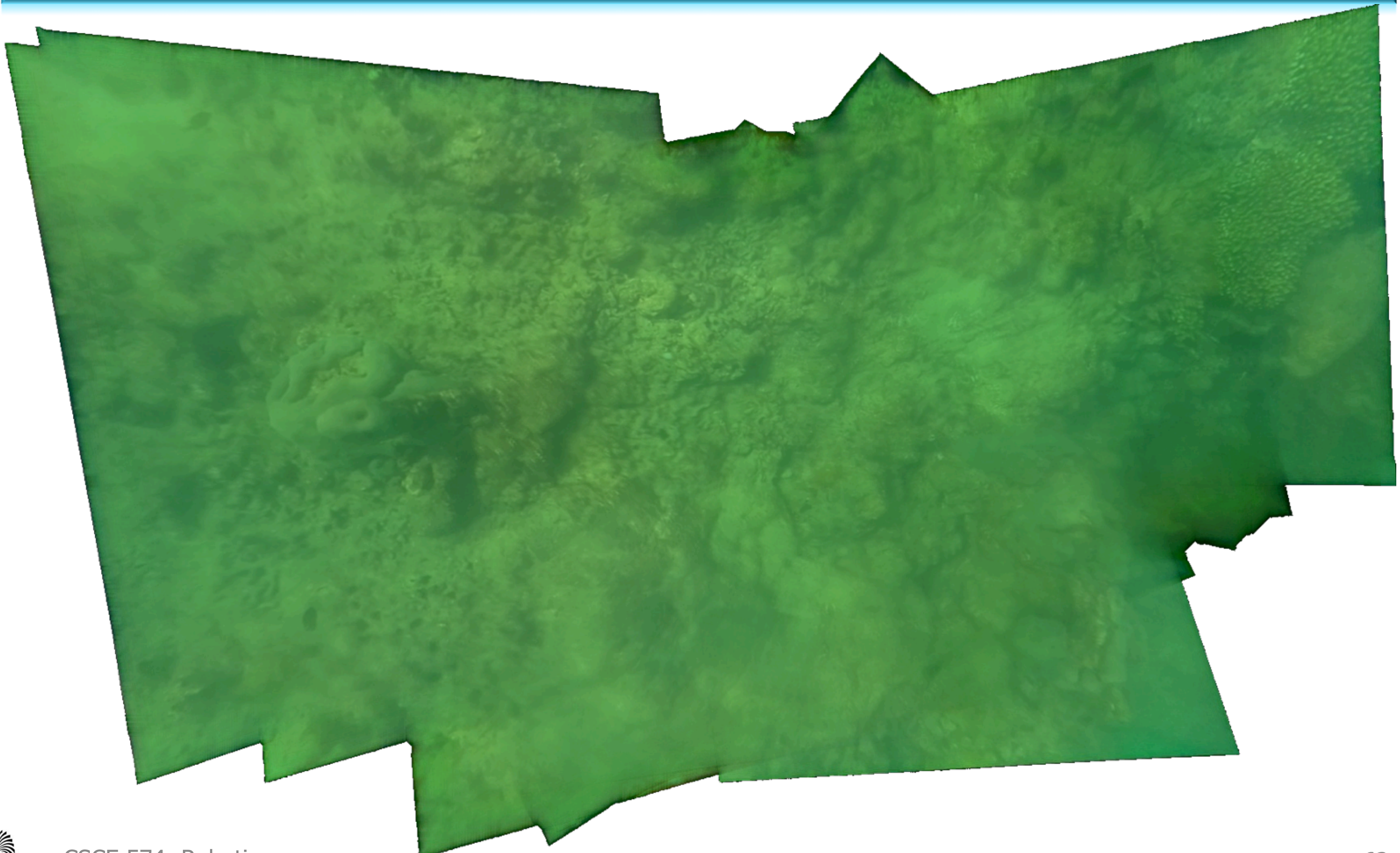
Deeper Area



Deeper Area

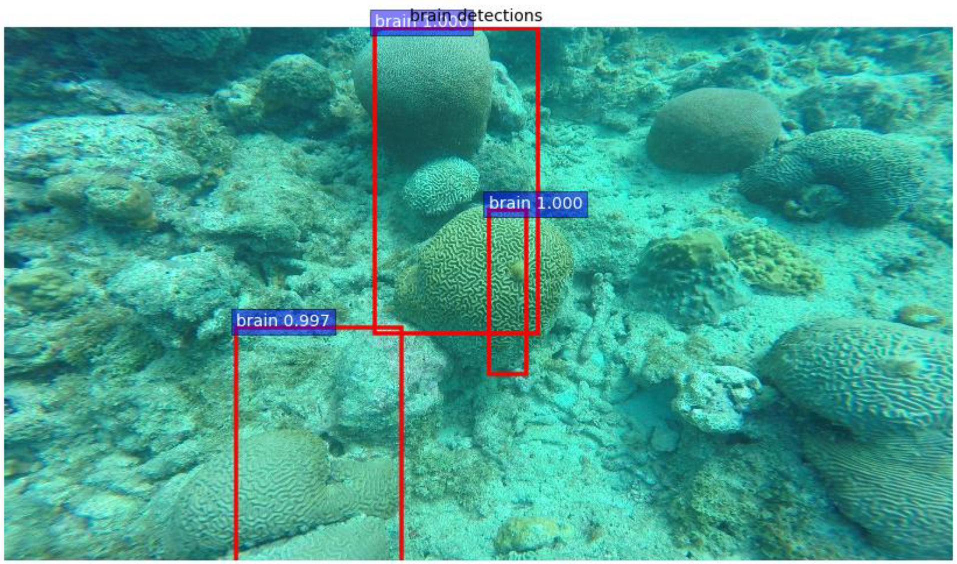


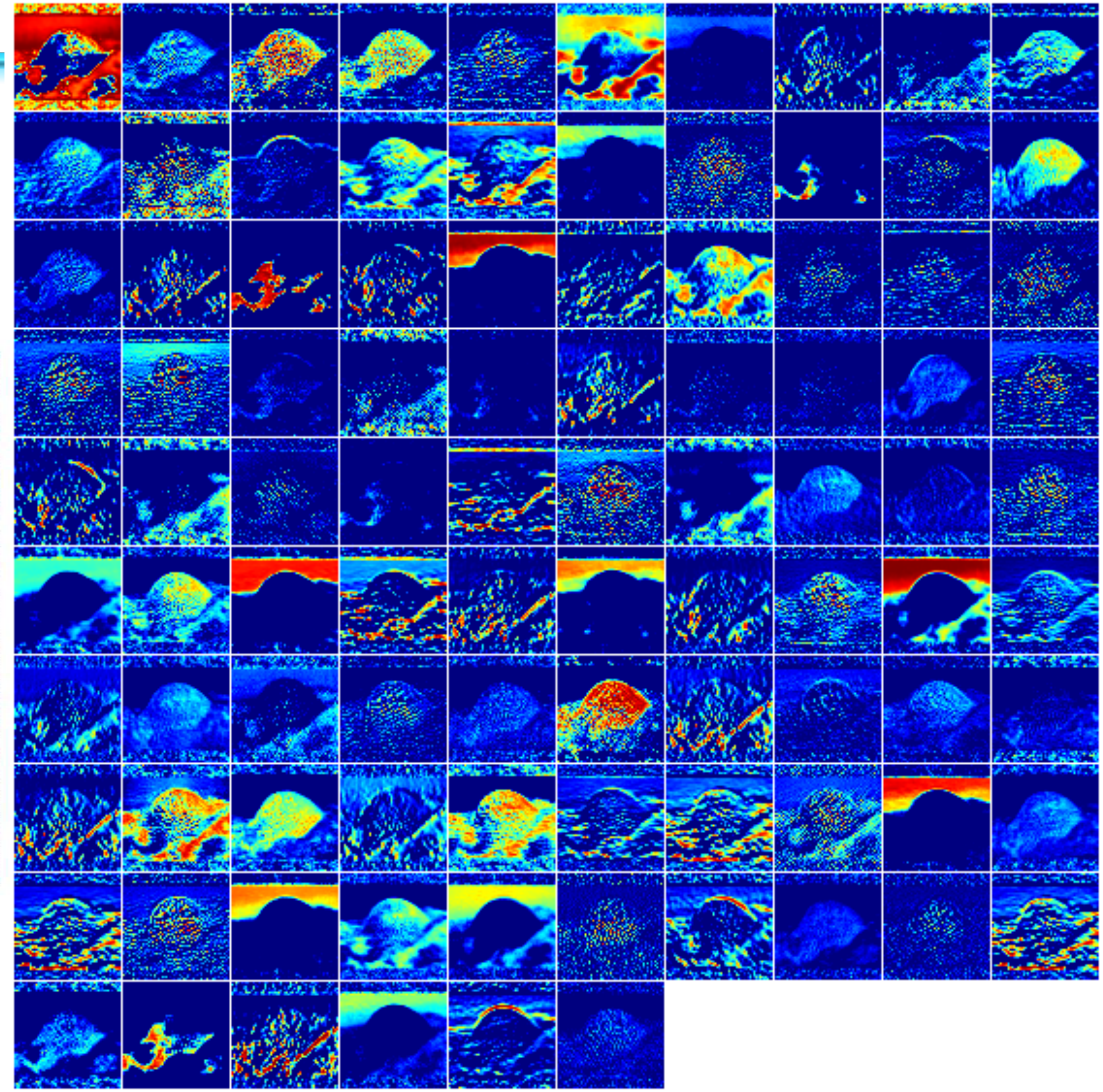
Deeper Area



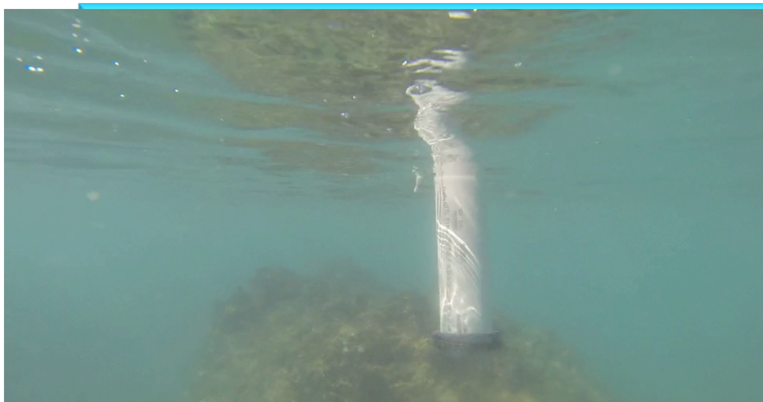
Shallow Coral Classification using Deep Learning

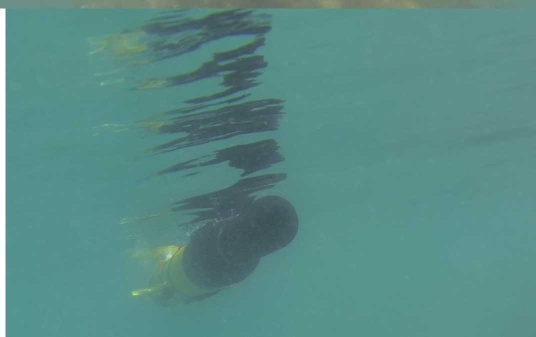
- Using a CNN

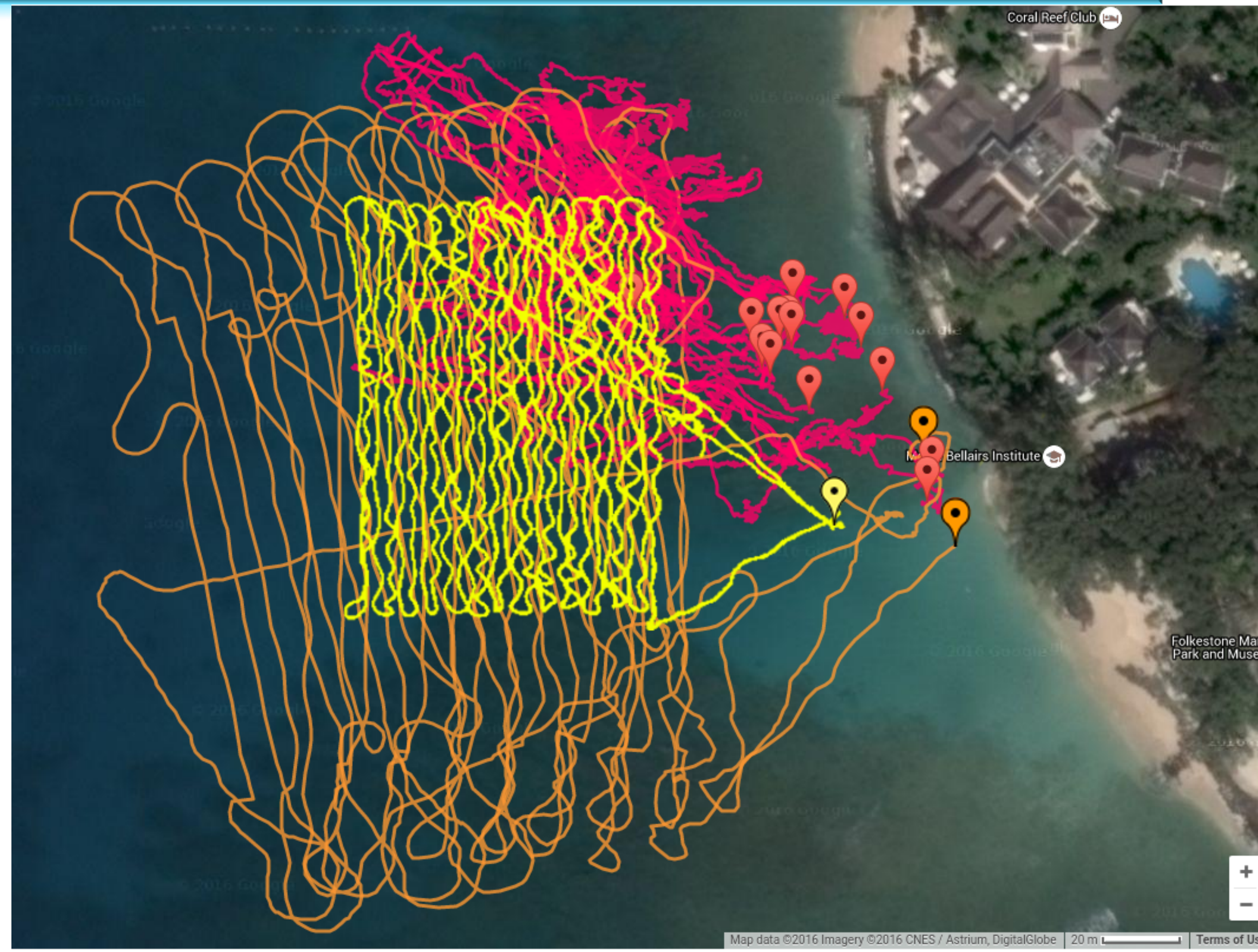




Coral Reef Monitoring by Heterogeneous Robots





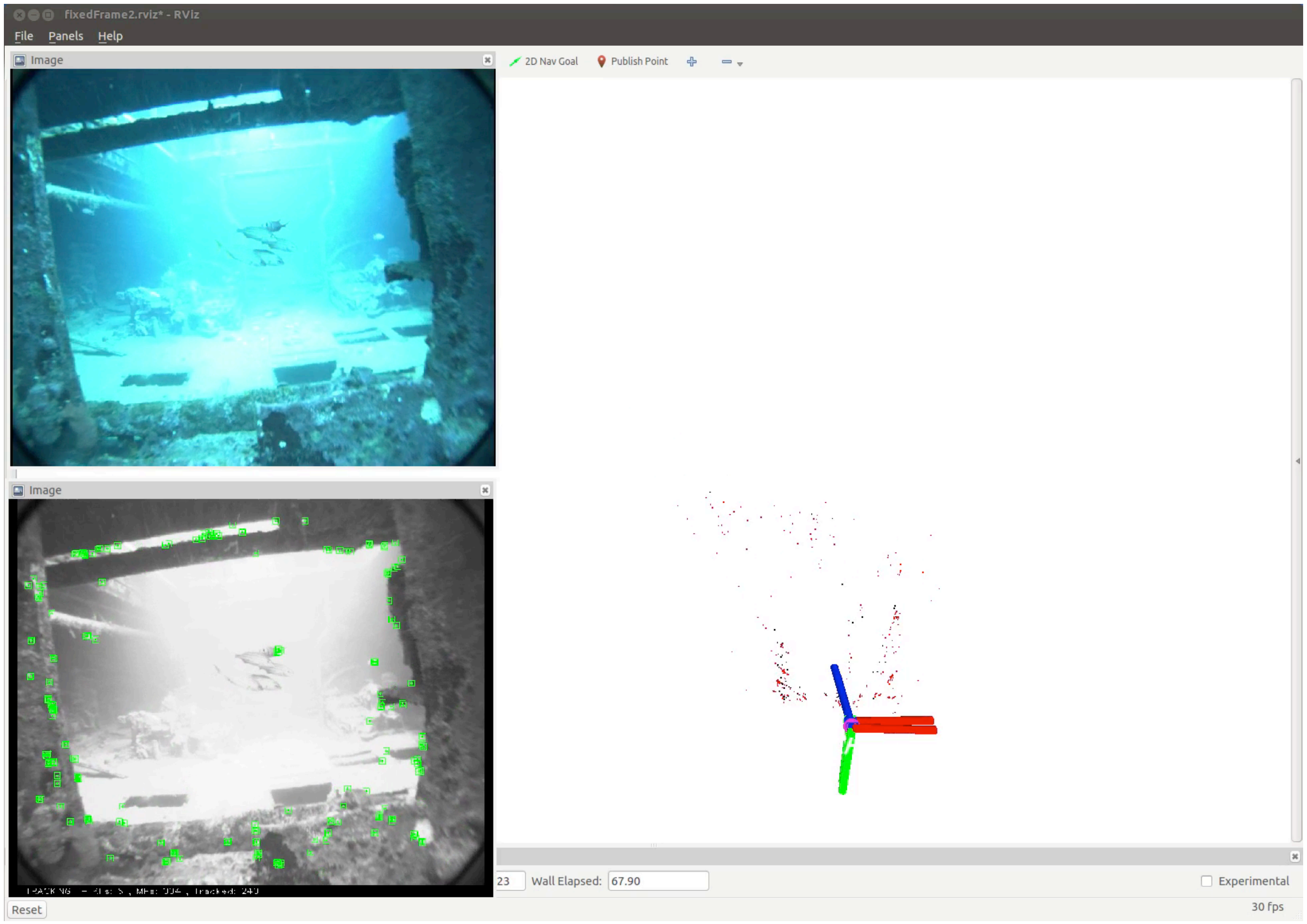


Shipwreck Mapping

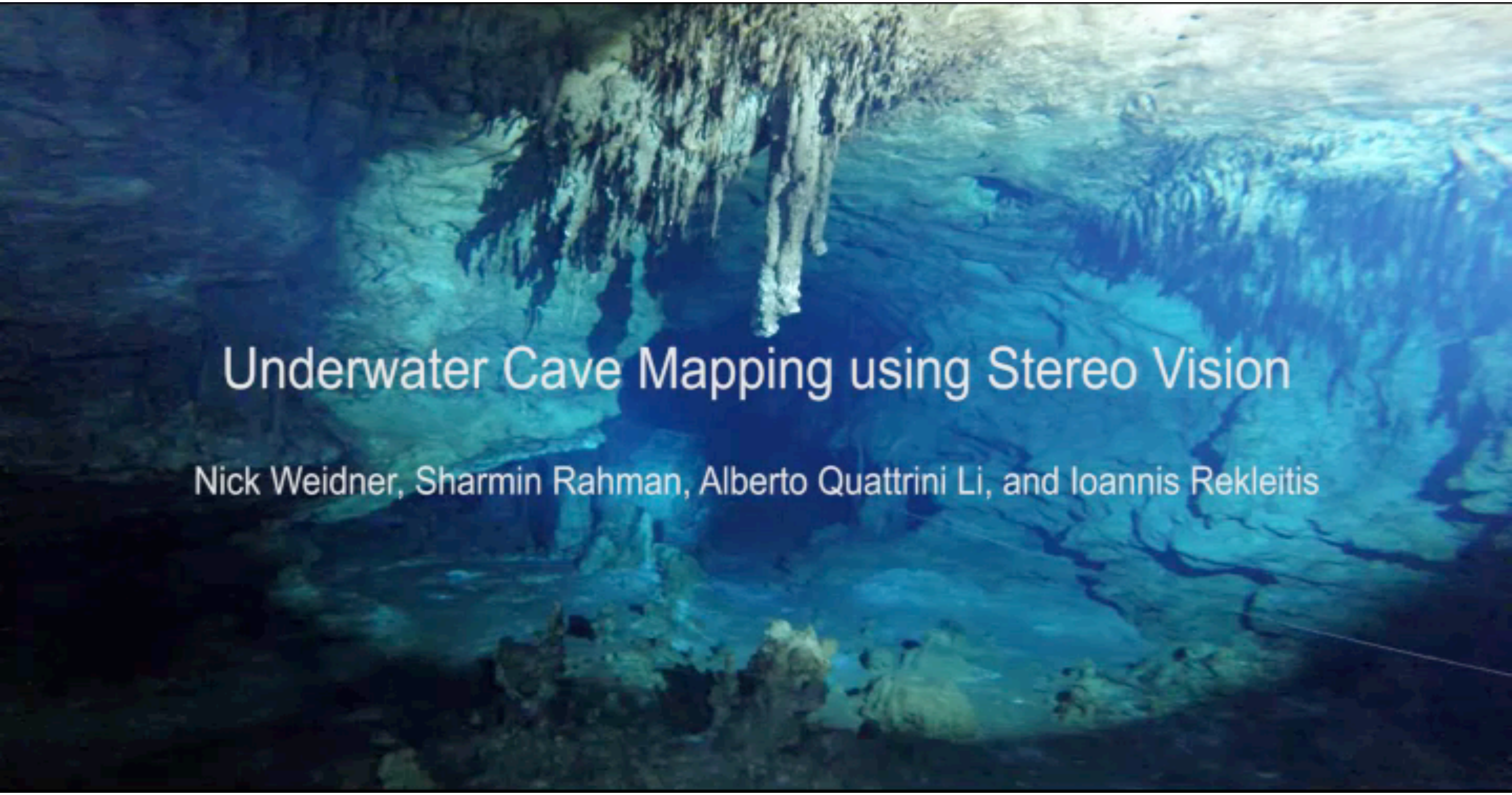
Shipwreck Mapping

Robot's Eye View

Shipwreck Mapping



Cave Mapping



Questions