A Short Summary of SeaBED and Some Data Highlights

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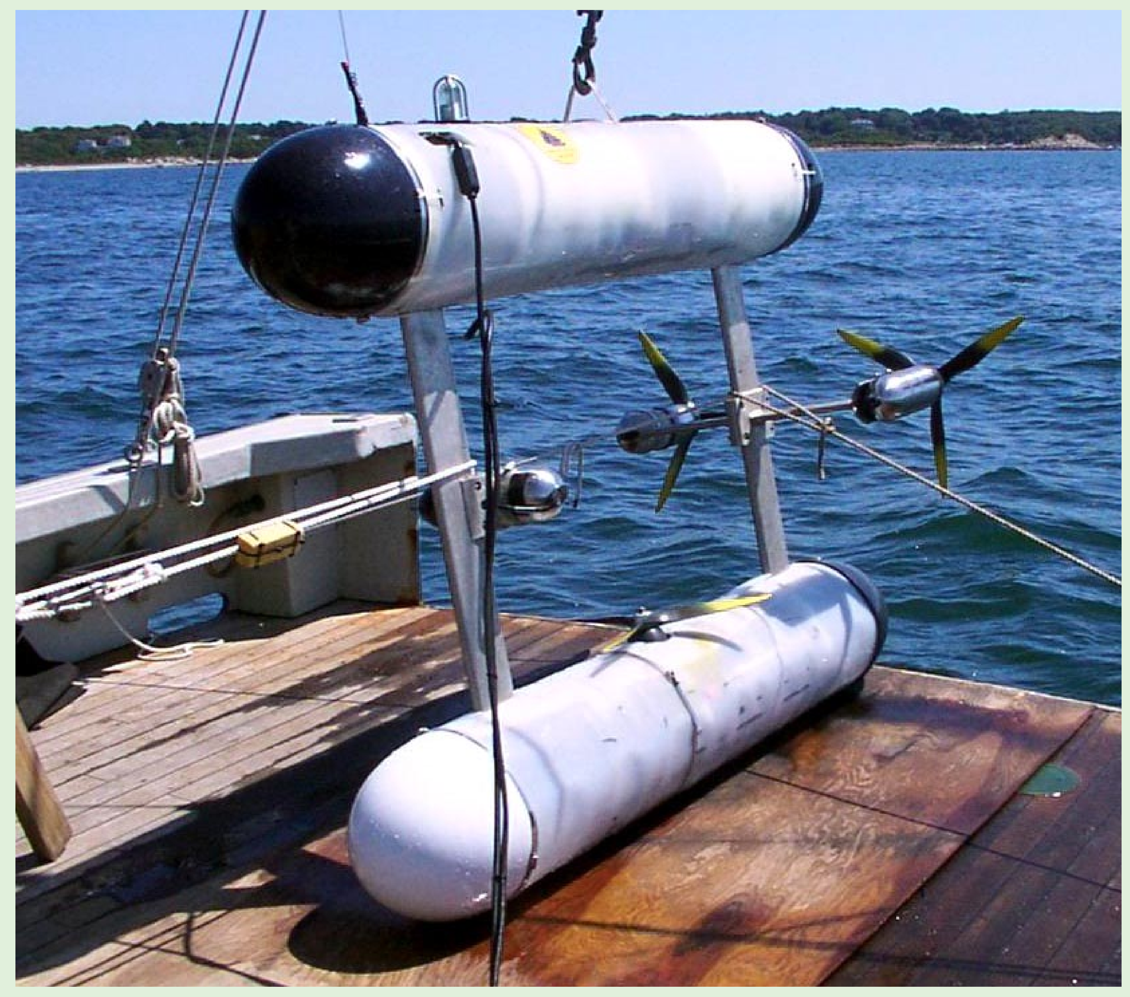
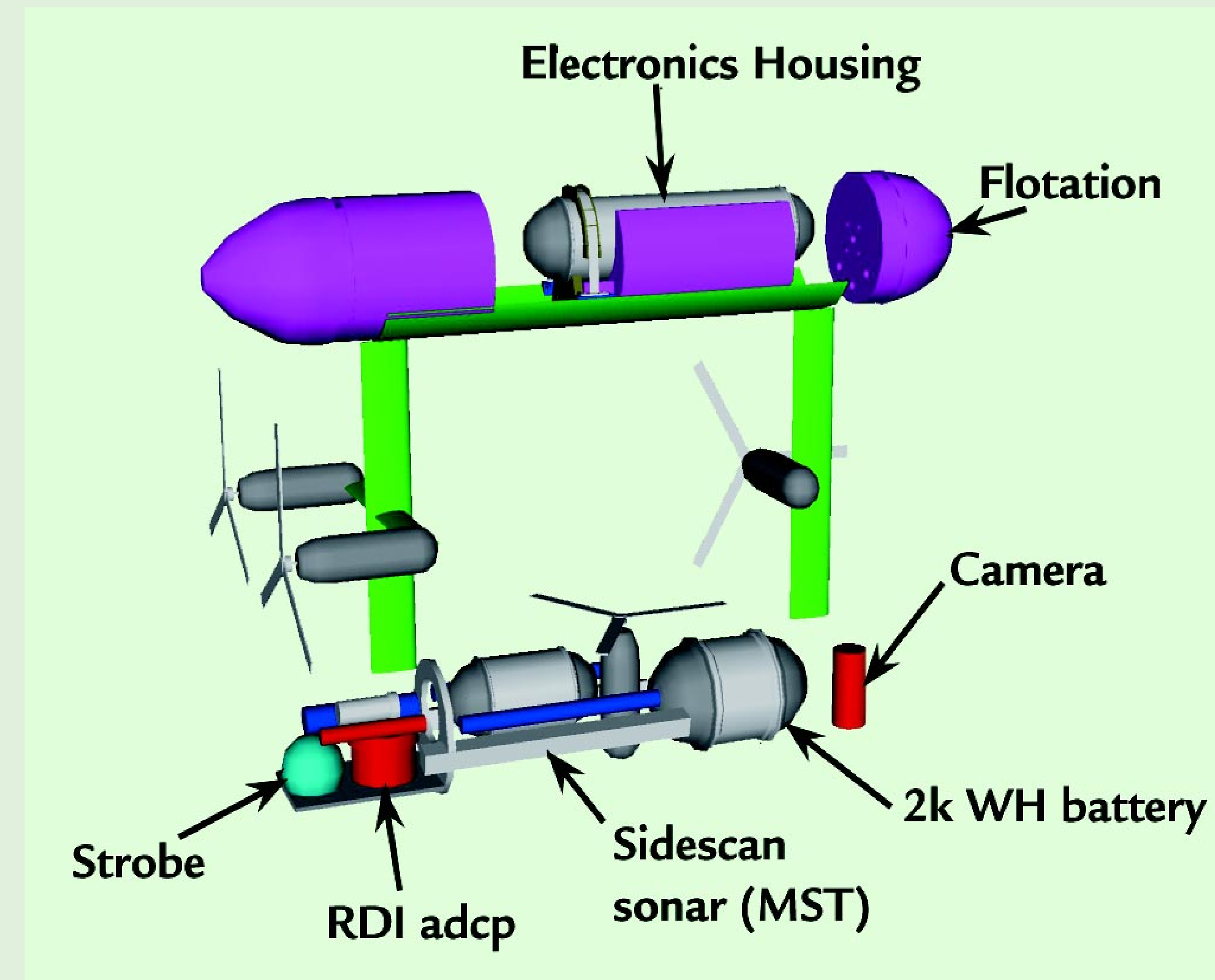
What is it?

SeaBED is an Autonomous Underwater Vehicle (AUV) built under the sponsorship of the Office of Naval Research, and the National Science Foundation's Censsis Engineering Research Center.





The SeaBED AUV

The objective of the Seabed AUV is to serve as a readily available and operationally simple tool that allows rapid testing of docking methodologies and imaging algorithms. We expect to actively pursue repeat surveys for change detection and quantification in areas such as: sidescan sonar survey, photomosaicking, 3D image reconstruction from a single camera, image based navigation, and multi-sensor fusion of acoustic and optical data.

Seabed is a hover-capable vehicle that performs optical sensing with a 12bit 1280x1024 monochrome CCD camera. Acoustic high resolution mapping is achieved using an MST 300 kHz sidescan sonar with a swath width of 400 m. A Seabird conductivity and temperature sensor, RDI ADCP and Acoustic Modem are also present.

The AUV is designed for operations from small vessels with minimal support equipment. It has an operational depth of 2000 meters and at 1 m/s can run for up to 10 hours and survey 36 km per mission.

Navigation is performed with standard long baseline (LBL) acoustic nets and a Doppler Velocity Log (DVL), which also performs water column current measurements. Update rates are in the order of 5 Hz, allowing closed loop control of position. Depth is measured from a Paroscientific pressure sensor while altitude is obtained from the DVL. A Crossbow AHRS provides heading, pitch and roll readings. Current capabilities allow positioning accuracy on the order of 0.1 meters.

Table 1: SeaBED Vehicle Characteristics

Vehicle	Depth Capability	2000 m
	Size	2.0m(L), 1.5m(H),
	Mass	200 kg in air
	Speed Range	(Typical) 0-1.5m/s (1.0m/s)
	Batteries	2kWh rechargeable Li-ion Pack
	Propulsion	Four DC thrusters Fore 100N Lateral 50N Vertical 50N
Navigation and Attitude	Attitude & Heading Depth Position Altitude	Crossbow AHRS Paroscientific pressure sensor, 0.01% LBL+ 300 kHz RDI navigator, 0.1-1 m RDI navigator, 0.1 m
Optical Imaging	Electronic Camera Lighting Separation	Pixelfly 12bit 1280x1024 bw CCD one 200 Watt-second strobe 1m from Camera to light
Acoustic Imaging	Sidescan sonar	MST 300 kHz (300 m depth capability)
Other Sensors	CTD ADCP	Seabird 37SBI 300 kHz RDI navigator

Why is it different and what have we accomplished?

From the start our goals were to design a small, but capable, AUV for imaging research and long term untended deployments in shallow water and the deep ocean.

Based on our design constraints some of the highlights of SeaBED include

- A mechanical design that is hover capable, and passively stable in pitch and roll. This makes it ideally suited for imaging applications such as sidescan sonar surveys, bathymetric surveys and video transects.
- Our thrusters use permanent magnets for coupling thereby bypassing the shaft seal problem. Moreover, we made a conscious decision not to use oil-filled thrusters so that we did not have to worry compensation oil volumes over deployments lasting months.
- Our software uses standard C and Perl and runs on a PC-104 (Pentium 133 MHz with 64 Meg RAM) system with Redhat Linux version 6.2. We felt that we could easily achieve soft real-time performance under this operating paradigm. We are currently running our control cycle at 10Hz with 20%-30% CPU utilization, i.e. have no real concerns about current or future computational requirements.

What we have under our belts

- We have an extremely reliable AUV (at least so far - we haven't opened the electronics or battery housing in weeks!).
- We have demonstrated sidescan sonar (from Marine Sonics Technologies) deployments in shallow water in both altitude following and constant depth mode, with transducers that are rated to full ocean depth (see our interesting story about finding a "wreck" in Buzzards' Bay :-).
- We have demonstrated several missions that were hour long and beyond and see no problems with running ten hour missions associated with full battery capacity.
- We have completed seven (so far), sealed charge / discharge cycles of our Lithium Ion battery chemistry in a sealed pressure vessel.
- We have demonstrated missions in very high current environments - we worked off of Muskeget Channel off of Vineyard Sound where the current was flowing at 3-4 knots. We decided to simply fly with the current while holding heading and depth.
- We have demonstrated very precise navigation, trackline following, using our RD Instruments ADCP (see Figure 1 below for an example).
- We can operate the entire vehicle with one person (of course two people means that we can check up on each other) off of very small platforms such as the 40 foot R/V *Asterias*.

Here's data from an example mission

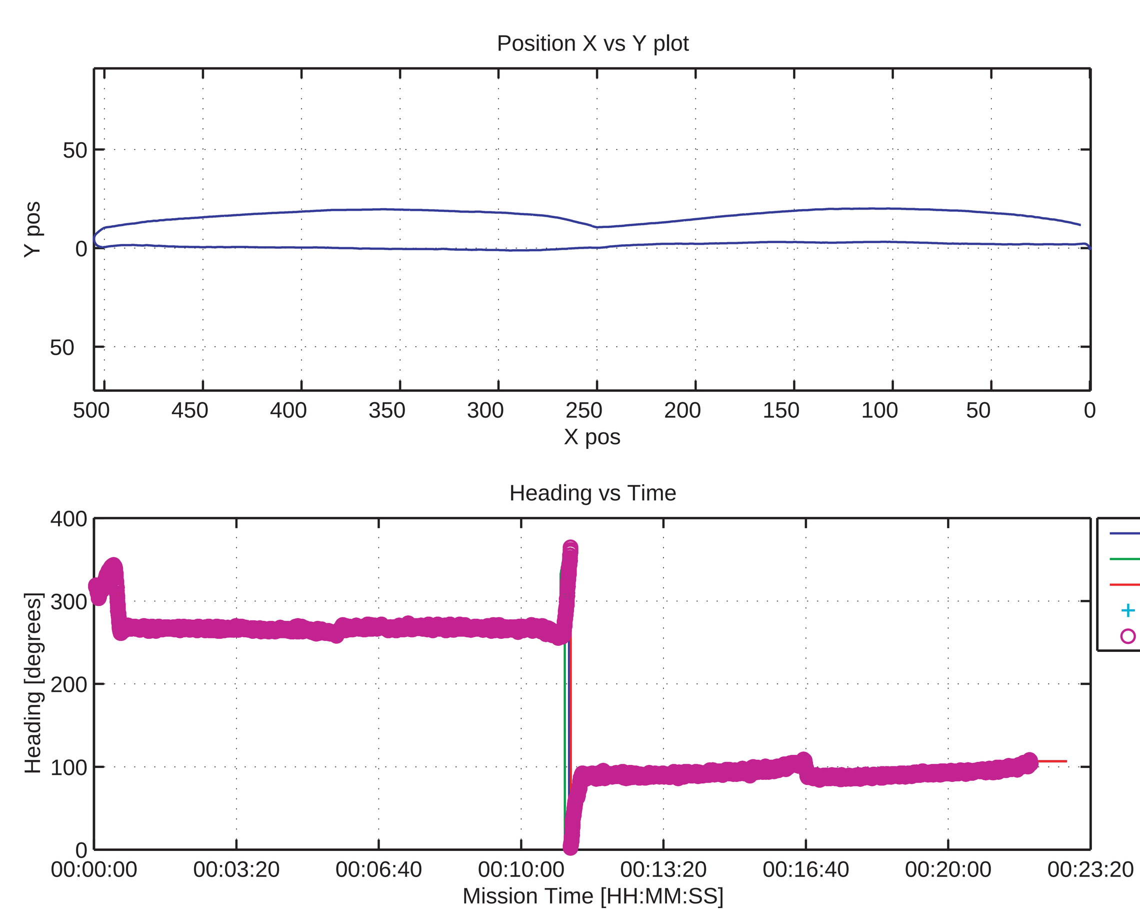


Figure 1. XY navigation plot (top) and Heading (below)

This was a side scan sonar mission in waters off of the Wee Pecket Islands. This site was used as a bombing range immediately after the Second World War and as can be seen in the imagery provides a profusion of targets. We had a 500m leg due west, a 10m leg to the North, followed by another 500m leg to the East. We used intermediate goal points at 250m while making our westward and eastward legs.

In Figure 1, the XY plot is shown on the top while the heading plot is shown on the bottom. In this case we were not track-following, instead just going to goal points but the performance in XY is stellar. Our heading servo also seems to be very tight (<1 deg).

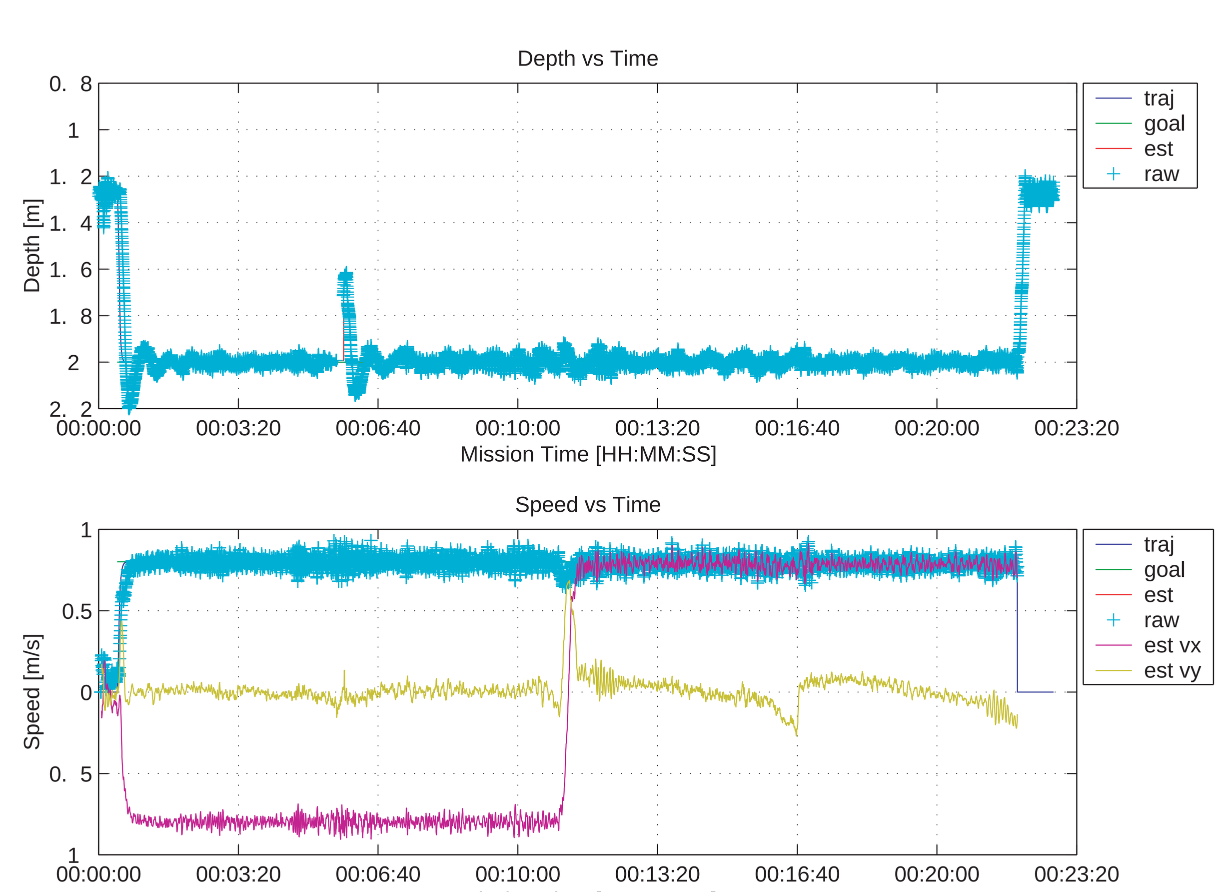


Figure 2. Vehicle depth (top) and Velocity (bottom)

Figure 2 shows the depth plot on top, and vehicle velocity on the bottom. We see that we are holding depth to a few centimetres and that our commanded velocity (we were doing closed loop velocity control at 0.8m/s in this mission) is within a couple of percent. An interesting glitch (one of the reasons I picked this mission to highlight) is the vehicle depth oscillation at ~5minutes into the mission. Our software "ages" or fixes the time of the last good sensor reading. We can set an error condition, continue on based on the last good value, or abort the mission based upon the age of a particular sensor reading. In this case we had a five second Paroscientific depth sensor dropout (during which the vehicle drifted up 0.4m). We had set the value of our "age" to ignore dropouts less than 10 seconds and to abort on dropouts of greater than 10 seconds.

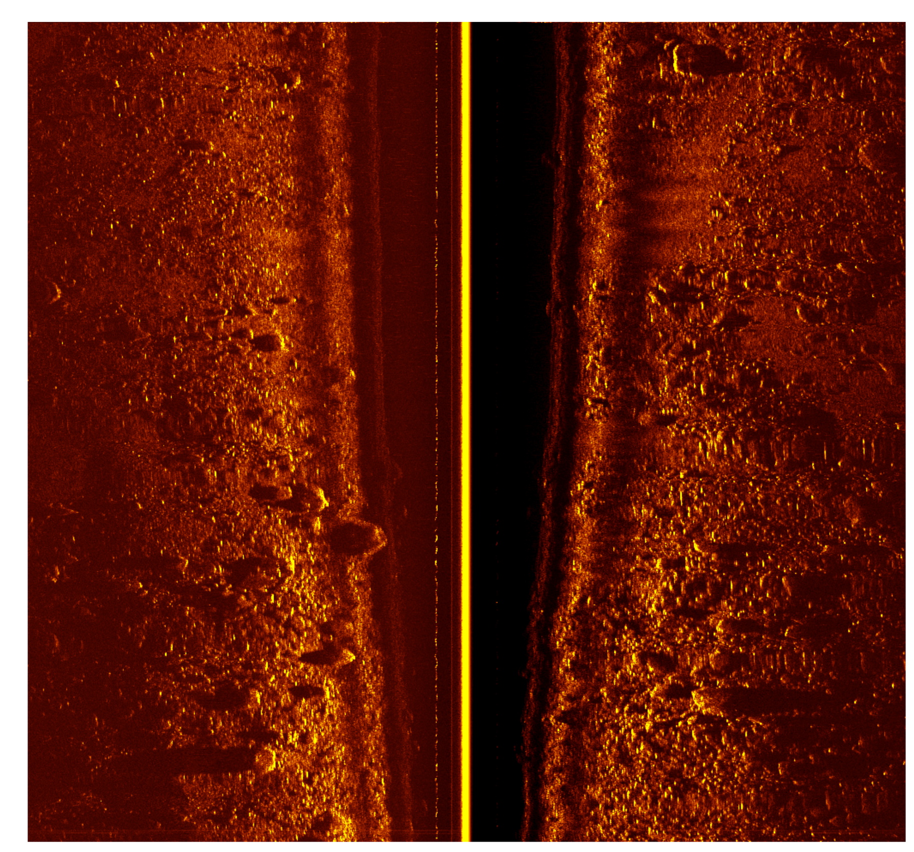


Figure 3 Sidescan sonar data. Overall water depth varied from 2 to 12m. Swath width displayed is 60m

Figure 3 shows a section of the sidescan sonar data. I haven't got around to mosaicking the sonar data yet but it is going to happen in the next few days (or so I have been saying for the last few weeks!).

The first "wreck" we discovered...

One of our initial sidescan sonar missions was in Buzzards Bay where the bottom is flat mud with very few features. So we ran a mission and imagine our surprise when we saw this beautiful outline of a boat on the bottom (Figure 4) We had great nav and always knew we could go back to it but I was more concerned about evaluating our sonar performance so we trundled off to the Wee Peckets and ran a couple of missions there. Figures 1 through 3 were from one of the missions we ran there. That night while reviewing all our navigation and sonar data I found

- That the time associated with finding the wreck was right at the end of our mission when the vehicle was drifting on the surface.
- Also, we found what looked like the same boat (Figure 5) at the very end of one of our Wee Pecket missions. That it too turned up right at the end of our mission, and more interestingly it had a wake associated with it ;-), really got me thinking.
- Quick calculations showed we were imaging ourselves (the R/V *Asterias*!). While a sidescan sonar usually assumes that the ground is fixed and the towfish is moving, in this case we had a stationary fish, flat calm waters.
- (i.e. ideal conditions for surface reflections) and a moving object on the surface!!! The good news - our side scan sonar has very good sensitivity.

Figure 4 The "wreck" we discovered in Buzzards' Bay

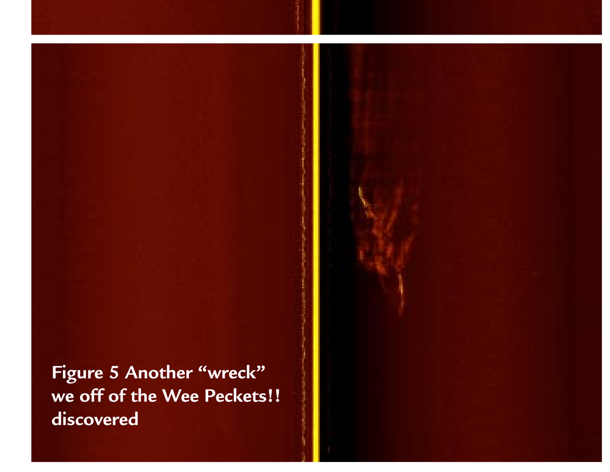


Figure 5 Another "wreck" we off of the Wee Peckets!! discovered

What's next...

In March we've teamed up with our ERC partners Luis Jiminez and Fernando Gilbes at the University of Puerto Rico at Mayagüez in a joint project aimed at the long term health assessment of coral reefs. We'll be making yearly visits to a coral reef site and constructing color photomosaics from the unstructured imagery collected with our 12-bit CCD camera. Temporal change detection and repeatable surveys will be key aspects of the problem.

In addition we will have a very full year next year with deployments off of Martha's Vineyard to look at MCM and in the fall we'll be teaming up with the University of Concepcion in Chile in a biological application to assess the health of lobster populations off the coast of Chile.

Acknowledgements:

The vehicle core team is composed of Hanumant Singh, Ryan Eustice, Christopher Roman, Oscar Pizarro and Neil McPhee.

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Contact Information

We did a number of missions and have a lot of data that could not be packed into this document. I'd be happy to show you more data and to talk about possible collaborations in the future. Feel free to contact me at hanu@whoi.edu.