A Multi-Vehicle Testbed based on the Sea Perch Robotics Platform

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The goal for this research is to create a reliable testbed for coordination control laws. We often see coordinated control in nature such as flocks of birds or fish. At the Collective Dynamics and Control Lab (CDCL) at the University of Maryland (UMD), control laws that mimic those seen in nature are developed for use in military and civilian applications. The theory of control laws must be development with testing to verify the results when applied to vehicles. The multi-vehicle testbed will create a fleet of wireless Sea Perches to work in coordination using an underwater motion capturing system in order to test these control laws. Through testing we have seen that the Sea Perch makes for a reliable testing platform with the motion capturing system provides us with the necessary data to implement control laws.

1. Introduction

Coordinated control allows for complex and time consuming tasks to be completed more quickly and efficiently. A search and rescue operation using coordinating movement will allow people to cover the most efficient area possible without backtracking over places already searched. A testbed for coordinated control laws creates an environment where control algorithms can be tested in the real world.

At the CDCL, research in developing a reliable test bed for these control laws is being implemented. Initial research with the Sea Perch platform was done using a tethered (remotely operated) model. Using this original configuration, we have examined the adaptability of the vehicles structure. After this initial research, the ability to use the vehicle to implement closed loop control was explored. The controllability of the vehicles and desire to create a multi-vehicle platform has lead to the creation of a wireless Sea Perch testbed.

Currently one wireless Sea Perch is in operation being using to configure the setup of the components. In the future there will be multiple vehicles starting with an addition three Sea Perches. This paper describes the components behind the wireless Sea Perch multi-vehicle testbed along with the testing that led to its creation.

2. Background

The testbed we are developing consists of three components. The first components are the wireless Sea Perches. Each Sea Perch is equipped with a wireless unit, and five reflective markers attached for motion tracking. The second component is the Neutral Buoyancy Research Facility (NBRF). The NBRF is a 25 feet deep, 50 feet in diameter underwater testing facility in which we conduct our research at the University of Maryland. The Qualisys underwater motion tracking system is the third component and is what allows for close-loop control of the vehicle. The tracking system consists of twelve motion-tracking cameras that track the location of the Sea Perches. The data from the cameras is streamed in real time to a computer that processes the tracking data. The computer is used to compute close-loop control and output commands to a control devise for the Sea Perches.

2.1 Sea Perch Underwater Robotics Platform

A Sea Perch is a simple underwater rover which can be used in a number of underwater applications. The Sea Perch platform was chosen as our test platform due to its ability to be easily manipulated for different projects in the lab. Due to the simplicity of the Sea Perch, it is easy for other researchers to adapt the vehicle to their needs. The Sea Perches are constructed from PVC pipe and PVC connectors. Attached are three 12V DC motors encased in wax that are used for propulsion, steering, and depth control. The original Sea Perch is powered by a 12V lead acid battery and controlled from the surface using a control box. In our research the original configuration has been changed with the final result being a wireless Sea Perch controlled by an RC transmitter under close-loop control.

2.2 Neutral Buoyancy Research Facility

The NBRF is a 25 feet deep, 50 feet in diameter tank that holds 367,000 gallons of water. It is a shared facility on the campus of UMD being used in multiple research projects. The NBRF currently houses twelve underwater motion capturing cameras. For our research we are using the NBRF as an underwater environment in which to test the Sea Perches and create a multi-vehicle testbed.

2.3 Underwater Motion Capture System

The NBRF houses a Qualisys underwater motion tracking system. The system consists of eight cameras in sets of two at the top level of the tank and four cameras at the mid level. These cameras can detect the location of reflective markers in the tank. The data from the cameras is streamed in real time where the marker data is reconstructed into its 3-D position in the tank. The system allows multiple markers to be constructed into a rigid body with a reference frame. Information on the position and orientation of this body are available in real time. The system is able to track multiple rigid bodies at once, allowing the system to allow multiple vehicle research to be conducted. Multiple bodies can be detected by the different orientations of their reflective tracking markers attached to the Sea Perches. The motion tracking system allows for multiple Sea Perches to be under close-loop control despite having no on-board sensors.

3. Sea Perch Research at UMD

The CDCL Sea Perch platforms have been modified for use in multiple research applications. For each application the Sea Perch was modified to suit the needs of the experiment. This was done by changing the shape, adding motors, and adding equipment as necessary for the job. In each case, the Sea Perch vehicle showed versatility in function and adaptability. The applications increased in complexity with our most recent and ongoing project being the design and implementation of a multi-vehicle testbed.

3.1 Recovery Sea Perch

The first test of the Sea Perch's ability to perform a task was the Recovery Sea Perch. The objective was to quickly rescue sunken vehicles from the bottom of the NBRF. Due to the depth of the NBRF, if a vehicle sunk to the bottom of the tank a certified diver is required to retrieve the object. This process takes time which is a constraint when the object is leaking water onto vital electrical components. To solve this problem, a Sea Perch platform was modified to be able to recover a sunken vehicle, specifically a submarine, from the bottom of the NBRF.

The Sea Perch platform was modified to be able to cover a large area and enclose the tail of a submarine inside a slipknot. To do this the height of the Sea Perch was increased to be able to straddle a sunken submarine. The Sea Perch was then widened to allow a larger capture area making it easier to grab the submarine. Due to the increase in weight from the modifications an addition vertical motor was added for vertical control. To ballast the Sea Perch polystyrene foam was used due its ability to not significantly compress or absorb water at a depth of 25 feet.

The recovery Sea Perch demonstrates the adaptability of the Sea Perch platform. This versatility shows the Sea Perches advantage as platform in the multi-vehicle testbed. A YouTube video of the Recovery Sea Perch is available online at http://youtu.be/4UgiFsTNBKo.

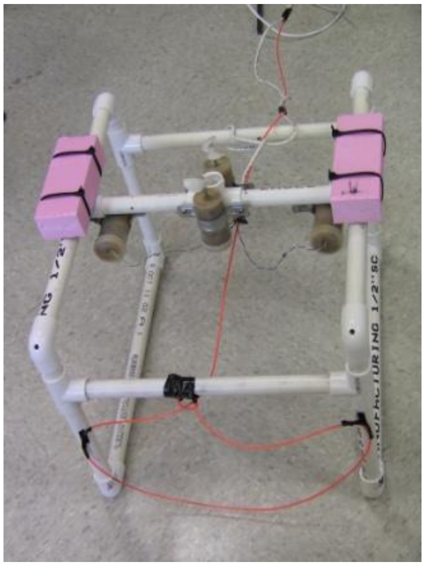

Figure 1: Recovery Sea Perch

3.2 Junkshot Sea Perch

The 2010 oil spill in the Gulf of Mexico was the motivation to demonstrate a simulation of the situation in out lab. One of the solutions presented was for a remotely operated vehicle to be sent down to the pipeline to drop "junk" into the pipeline. The junkshot Sea Perch was designed to simulate this real world solution. It was outfitted with a small assembly designed to encompass the pipe, and allow for junk to be dropped into it. At the depth of the oil spill the vehicles had to be driven without direct visual observation. To simulate this scenario cameras were attached to the Sea Perch which streamed real time video to the surface. To complete the task, the junkshot Sea Perch was driven by operation the controls based on the video being filmed on-board the Sea Perch. This trial with the Sea Perch

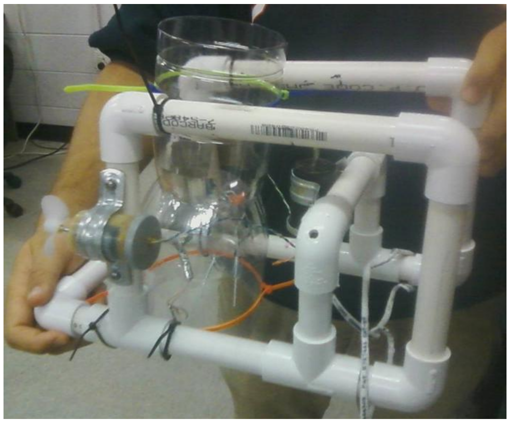

Figure 2: Junkshot Sea Perch

shows the vehicles ability to be modified to the degree which allows it to be easily controlled to orient correctly onto a small pipe. A video of the Junkshot Sea Perch is available online at http://youtu.be/SRF16_Qm_no.

3.3 Depth-controlled Sea Perch

Depth control is important part of underwater-vehicle research and was the first step in developing full closed-loop control of a Sea Perch. The depth controlled Sea Perch was outfitted with a pressure sensor, motor controller and Arduino microprocessor to achieve close-loop depth control. The depth was set by a potentiometer which had a linear input to the Arduino microprocessor. To verify the Sea Perch performance, reflective markers were attached to the vehicle to allow tracking using the underwater motion tracking system. This allowed z position data that was stored on the Arduino to be compared to a ground truth from the motion tracking system.

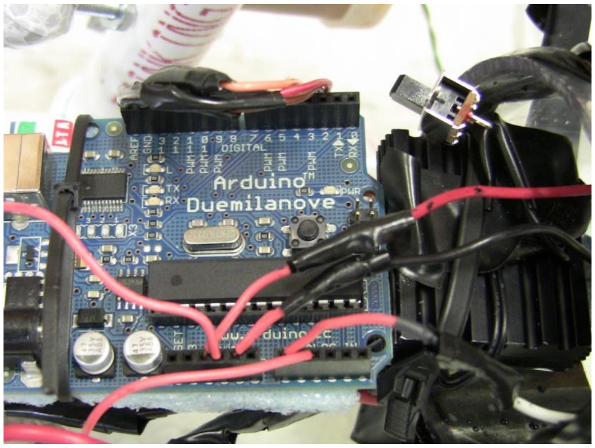

Figure 3: Control Device, Arduino (right), Motor Controller (left)

To begin testing the pressure sensor had to be calibrated in the range of the NBRF. This was achieved by recording the output from the pressure sensor to the Arduino at the surface of the tank, and at a depth of 25 feet, the bottom of the tank. A linear plot was fit between these two points giving a good estimate for the actual depth versus measured pressure.

Using the calibration for the pressure sensor, the Arduino was programmed using the Arduino language, which is based on C++. A proportional controller was used to control the depth by coding a preset value into the board. To change the depth, turning the potentiometer on the surface effectively changed the present value by adding the potentiometer value inputted to the Arduino to the preset value. The output to the motor controller required being banded between 50 and 130 for full climb and descent.

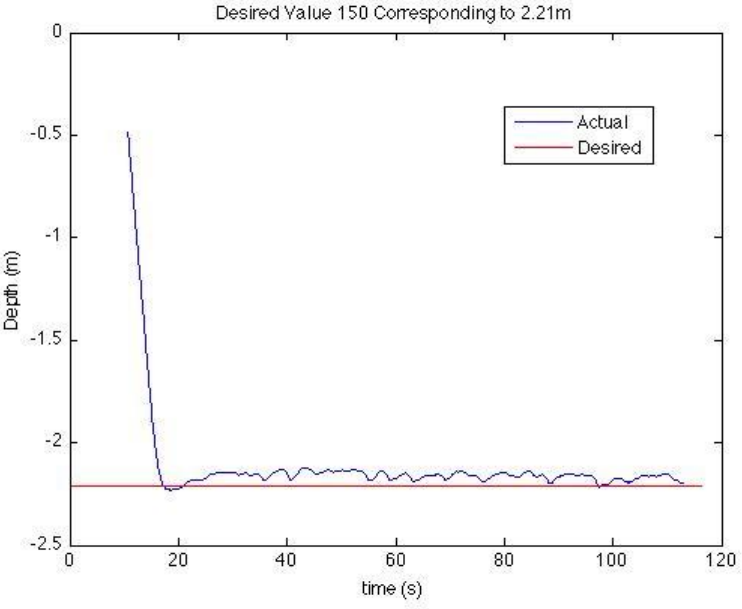

Figure 4: Motion Capture Data for Depth Controller

Using the underwater motion capture system, data was collected on the performance of the depth controlled Sea Perch. From this data the depth of the depth controlled Sea Perch was plotted against time. The vehicle quickly converged to the set depth with close to six inches of fluctuation. This noise was attributed to the proportional controller and the lack of vertical force from the motor relative to the pull from the tether when close to the set depth. A video of the depth-controlled Sea Perch is available online at http://youtu.be/OTlyE34oc4E.

3.4 Autonomous Sea Perch

The motion capture system allows for a vehicle testbed to be created without the use of on-board sensors. Using the motion capture system to track the vehicles position and orientation, the data can be directly streamed into C++ code running on the same computer. This code can then output to a control box to create close-loop control of the vehicle.

The Sea Perch used in this experiment was converted from the base configuration too having one directional motor controlling yaw, a vertical motor for depth and thrust motor for forward and reverse. This allowed the vehicle act like a point mass on a two dimensional horizontal plane, decoupled from the depth control. Five reflective markers were attached to the ASP to allow for motion tracking and rigid body definition.

The motion tracking system defined the rigid body with the center at the geometric center of the five markers and axis aligned with NBRF axis definition in the software. The motion tracking system streams the ASP’s three dimensional position along with yaw angle. This data is then used to compute a control output for depth, heading and forward speed. This output is sent to a National Instruments NI-6501, which is a digital i/o board. Using output pins which could be set high or low, two pins were used to control each motor. That output is used to switch an in house board to control the motors. When both pins were in the same setting for a given motor, the voltage drop across the motor was 0. When one was high and the other low, it created either a +12 or -12 voltage drop across the motor. This board uses six 5VDC/1A single pole single throw reed relays. Each reed relay is switched from the output of the NI-6501. Twelve volts is run through each of the reed relays which switch one of six 5VDC single pole double throw switches. The switches are wired to control the three motors and set them to either off forward or reverse.

Pin		Motor Output
1	2	
High	High	Off
Low	Low	Off
High	Low	Forward
Low	High	Reverse

Figure 5: Motor Control Logic

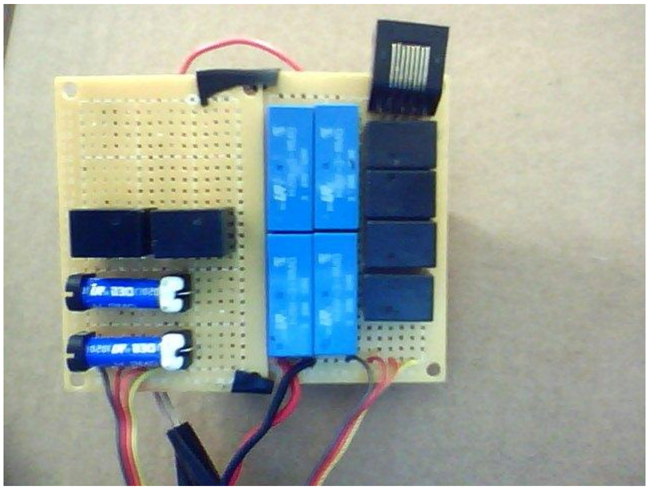

Figure 6: In House Control Board

The control setup can be used to demonstrate the ability for the Sea Perch to follow waypoint control using the underwater motion capture system. A point in the tank can inputted into the C++ code and the ASP can drive to the point and maintain its position autonomously. This is done by computing the heading angle required by the vehicle to drive striate at the target. This angle is then compared to the vehicles current heading angle which is outputted by the motion capture system.

$$\theta = \tan^{-1}\left(\frac{y_f - y}{x_f - x}\right) \qquad (1)$$

$$\emptyset = -\sin(\theta - \psi) \qquad (2)$$

This comparison controls the output to the yaw control motor. Inside a band that is towards the waypoint the motor is off. Outside the motor corrects to turn the vehicle to face target. The distance to the waypoint is computed by using the position of the vehicle.

$$r = \sqrt{(x_f - x)^2 + \left(y_f - y\right)^2} \qquad (3)$$

This distance controlled the forward motor. If the distance is outside of a set radius the motor is on forward. If the Sea Perch is inside the radius the motor is off. The vertical motor was controlled by setting a band of acceptable depths, about 0.01m, where the motor is off with the motor on either full or reverse outside of the band trying to return.

While the test takes place the real time position of the Sea Perch is plotted in a 3-D setting. After the test the positions can be plotted in this setting to show the vehicles path. In figure 7, the position data is shown for a test that first took the vehicle to the center of the tank, then to a point 1.5m offset from the x-axis and -1.0m offset from the y-axis. The vehicle quickly converges on the banded values required for waypoint control. The vehicle however jitters back and forth between the banded areas due on off nature of the control. The vehicle will also try to drift once at the set waypoint. This is due mainly to the tether still attached to the vehicle.

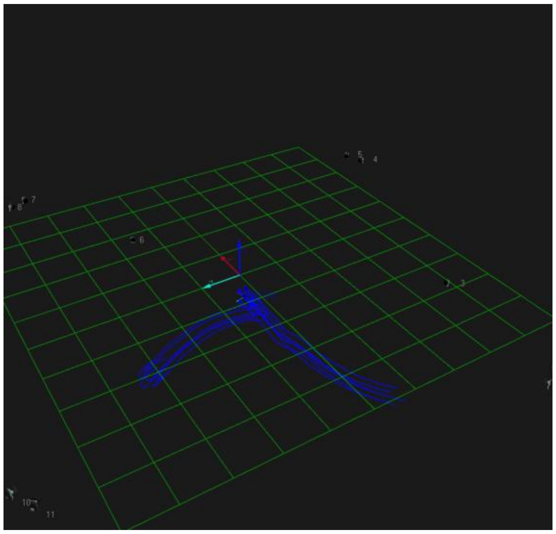

Figure 7: Qualisys Tracking Data

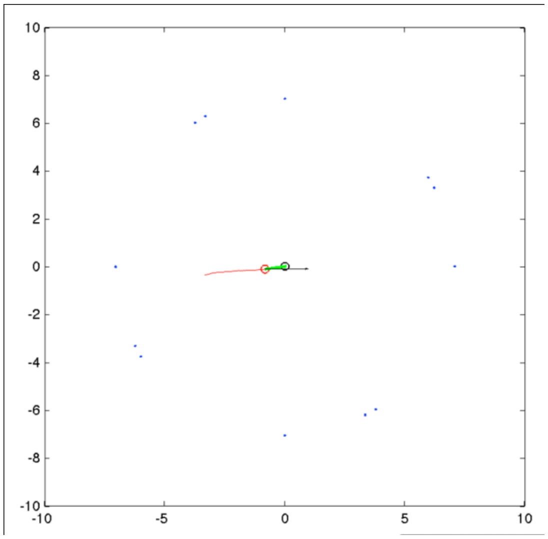

Figure 8: X-Y Plot of Position and Orientation

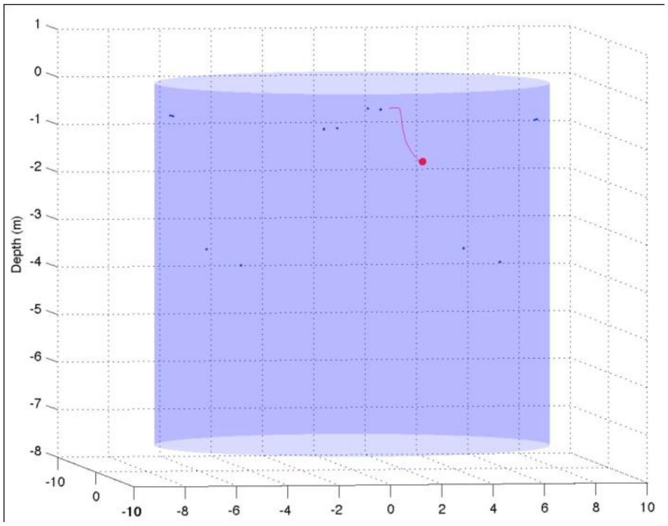

Figure 9: 3-D View of Vehicle Path

In post-processing using MATLAB, the Sea Perches position and orientations can be plotted in time. This data can also be used to create video of the path the Sea Perch took in the tank. In figure 8, the Sea Perch's heading is plotted with an arrow, while the green indicates the path to the waypoint. In figure 9 the position of the Sea Perch is plotted in 3-D with a trailing line of the path of the Sea Perch.

3.5 Wireless Sea Perch

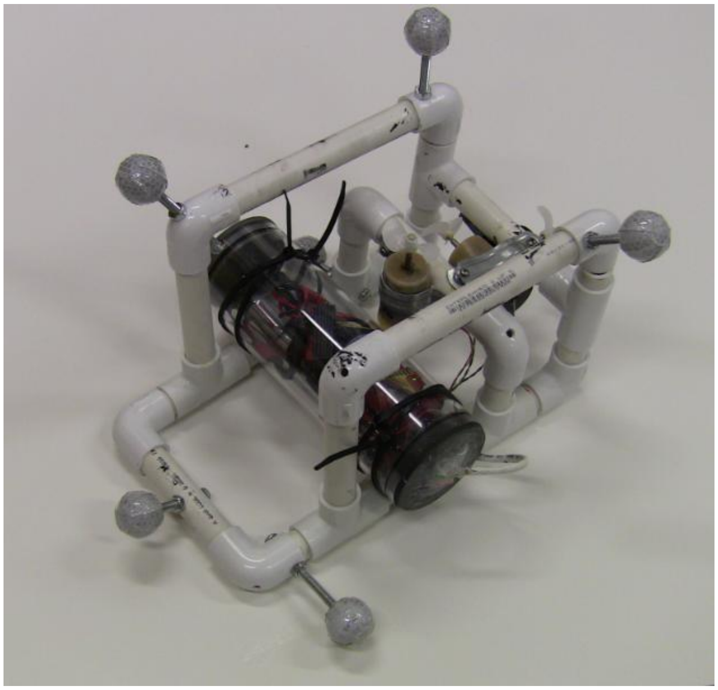

Figure 10: Wireless Sea Perch

The wireless Sea Perch is modified from the original Sea Perch configuration is several ways. Reflective markers were added to the body to allow the vehicle to be seen by the motion capture system. The motors were reoriented for easier control using the code. The motor configuration allows for one motor dedicated to propulsion, one dedicated to steering, and one dedicated to depth control.

To control the Sea Perch a wireless unit is attached inside a pressure vesicle. The wireless unit is composed of three Viper 10 speed controllers, one Tenergy 9.6V NiMH battery, and one Hitec Supreme 8 CH RF receiver. The wireless unit is connected to the motors through holes made in the end caps. The end caps are then sealed using silicone. Each speed controller is wired to a separate motor, which are attached in parallel to the battery. The speed controllers get their input from the RF receiver. The transmitting controller can be controlled under human input or attached to receive input from the motion capture computer. Once all the components are attached to the vehicle polystyrene foam is added to make the Sea Perch neutrally buoyant.

4. Development of Multi-Vehicle Testbed

The wireless testbed was developed through successive testing and modifications to the Sea Perch platform. When first using the Sea Perch platform the versatility of application was explored with projects such as the Recovery Sea Perch and Junkshot. The ability to change both the direction and number of motors allows for multiple projects and control laws to be implemented with little effort to modify the vehicle. This adaptability is advantageous for a test platform so it can run multiple experiments without large changes. The depth-controlled sea perch confirmed the maneuverability and response time of the Sea Perch under close-loop depth control. The next iteration was the autonomous Sea Perch. This configuration was integrated with the underwater motion tracking system. Testing with the autonomous Sea Perch demonstrates the ability to run closed-loop control using the underwater motion tracking system.

Additionally the testing demonstrated the ability for the system to converge with waypoint control. The wireless testbed is anticipated to house and operate up to fifteen wireless Sea Perches all capable of coordinated closed-loop control without the hassles associated with tethered operation. Currently the testbed operates one Sea Perch which we can be used to test depth control and waypoint control. Once we have more Sea Perches we'll be capable of running algorithms for multi-vehicle control including follow the leader and parallel motion.

5. Conclusion

5.1 Summary of Paper

This paper describes the goal of a multi-vehicle fleet of Sea Perch vehicles able to implement close-loop control laws. The vehicle has been shown to be highly adaptable for test that could be run in the future. The controllability of the vehicle has been demonstrated in both human control and close-loop control on and off the vehicle. The Junkshot Sea Perch demonstrated the ability to have fine control in its ability to align with a small target at the bottom of the NBFR. The Depth-controlled Sea Perch and Autonomous Sea Perch demonstrated the ability for the Sea Perch to be used with closed-loop control. These characteristics demonstrated in previous experiments have shown the wireless Sea Perch to be an ideal vehicle for a multi-vehicle testbed.

The multi-vehicle currently consists of one wireless Sea Perch capable of depth control. Using information from past tests the platform will be expanded to include four Sea Perches capable of multi-vehicle coordination.

5.2 Future Research

The wireless test platform currently has one Sea Perch operational. Work is being done to increase the number to fifteen wireless vehicles. This will allow more control laws that mimic large groups of fish. The motion tracking system allows for position and orientation data for large numbers of vehicles. With this capability control laws for parallel motion and other coordinated maneuvers can be tested. Using a water pump, the vehicles will be tested under flow field conditions. This testbed will hopefully be able to explore the implications of controllability in a flow field greater than the vehicles speed. Having an adaptable multi-vehicle test platform will help in future research to be accomplished at the CDCL.

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References

Foutain, Henry. "Junk Shot Is Next Step for Leaking Gulf of Mexico Well." *The New York Times* 14 May 2010, New York ed., sec. U.S.: A10. *The New York Times - Breaking New, World News, and Multimedia*. Web. 29 Apr. 2011.

N. Sydney, S. Napora, S. Beal, P. Mohl, P. Nolan, S. Sherman, A. Leishman, S. Butail, and D. A. Paley. A Micro-UUV Testbed for Bio-Inspired Motion Coordination. In *Proc. 2009 Int. Symp. Unmanned Untethered Submersible Technology*, Durham, New Hampshire, August 2009.

Nelson, Robert C.. *Flight stability and automatic control* . 2nd ed. Boston, Mass.: WCB/McGraw Hill, 1998. Print.

"Qualisys - Motion Capture System - Indoor and Outdoor - Above and Under Water." *Qualisys - Motion Capture System - Indoor and Outdoor - Above and Under Water*. N.p., n.d. Web. 21 Apr. 2011. <http://www.qualisys.com/>.

"SeaPerch Teach Build Become." *SeaPerch Home Page*. The Society of Naval Architects and Marine Engineers, n.d. Web. 13 Apr. 2011. <www.seaperch.org/index>.