AUVFEST 05

Quick Look Report of NPS Activities

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INTRODUCTION

During the period June 6-16 2005, NPS participated in AUV Fest 2005 held at Keyport, WA. The ARIES vehicle, seen in Figure 2, was used for the first time at these events. ARIES was equipped with a Blazed Array Forward Look Sonar (FLS) in order to demonstrate a dynamic obstacle detection and avoidance behavior that is planned to be implemented in the REMUS vehicles through the SAHRV program. In all, it was a very successful exercise, during which various separate stages of the development were demonstrated and accomplished.

OBJECTIVES

The main objective is to direct a UUV to avoid objects in the water column that represent impediments to forward progress. Sub-sea objects such as sea mounds, reefs, and sunken ships represent threats to the current class of small UUV in use. Using a small low power blazed array sonar from Blue View Technologies, forward looking sonar images are collected, analyzed and used to declare the presence of such objects. Not only range, but also height of these objects are determined and passed to the vehicle controller. An appropriate avoidance behavior is then triggered in the vehicle. This closed loop process was developed and demonstrated.

APPROACH

A sunken barge at the southerly end of Op-Area 4 was selected as the primary target for this exercise. The ARIES vehicle was tasked to drive south over the target, turn around and head north so that two passes over the target area were obtained on each run. The approach was incremental in that the separate stages of the closed loop process were separately demonstrated. These are

1. Object Detection
2. Object image analysis
3. Networked linkage of data from image processing computer to control computers.
4. Vehicle response to synthetic images previously gathered.
5. Closed real time object detection, declaration, and vehicle response.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 2005**	2. REPORT TYPE	3. DATES COVERED **00-00-2005 to 00-00-2005**
4. TITLE AND SUBTITLE **AUVFST 05 Quick Look Report of NPS Activities**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School ,Center for Autonomous Underwater Vehicle (AUV) Research,Monterey,CA,93943**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
AUV Fest 2005, June 6-16, 2005, Keyport, WA

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**12**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Over the several runs made, the barge was repeatably found and imaged which allowed for evaluation of each step above. As described here, the results given later were based on the full closed loop detection and response cycle.

RESULTS

The series of tests conducted at Keyport were in Op-Area 4 at the southerly edge of which was a sunken barge. The barge was estimated initially at 7 meter high and represents a serious threat to an otherwise blind vehicle. Figure 1 shows a graphic of Op-Area 4 in relation to Keyport.

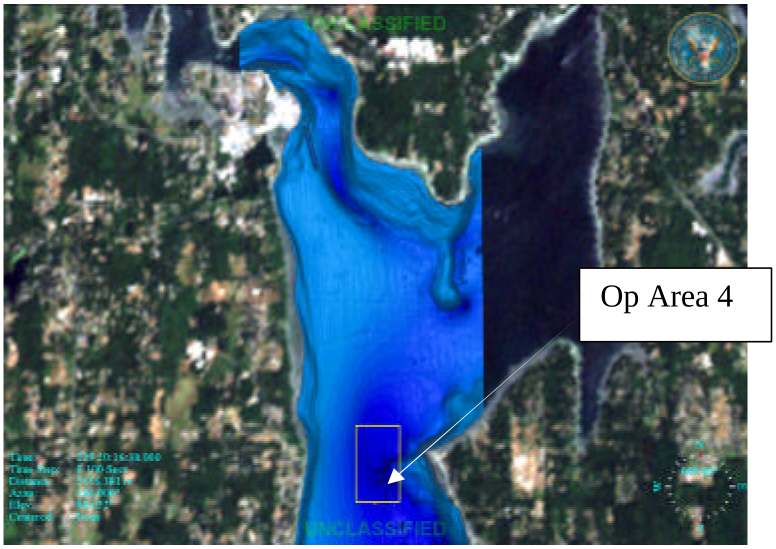


Figure 1a. Op-Area 4 in Relationship to Keyport

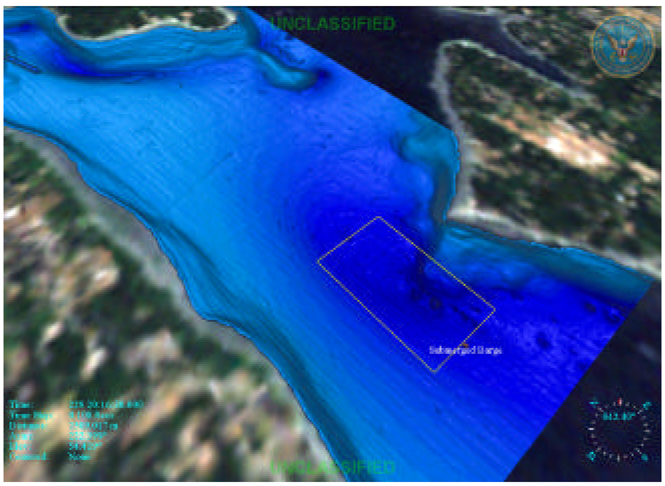


Figure 1b Bathymetry Map of Op-Area 4 Showing Location of the Sunken Barge on Its Southerly Boundary.

Several runs using the ARIES vehicle were accomplished each day of operations to expand the technology demonstration. The ARIES is shown in Figure 2.

Figure 2 ARIES AUV

Inside the clear nose cone, the two staves of the forward looking sonar are mounted in the vertical configuration. Since this experiment was focused on obstacle detection and avoidance in the vertical plane so that the vehicle responds by increasing its altitude above bottom, the 2 staves were mounted as shown in Figure 3

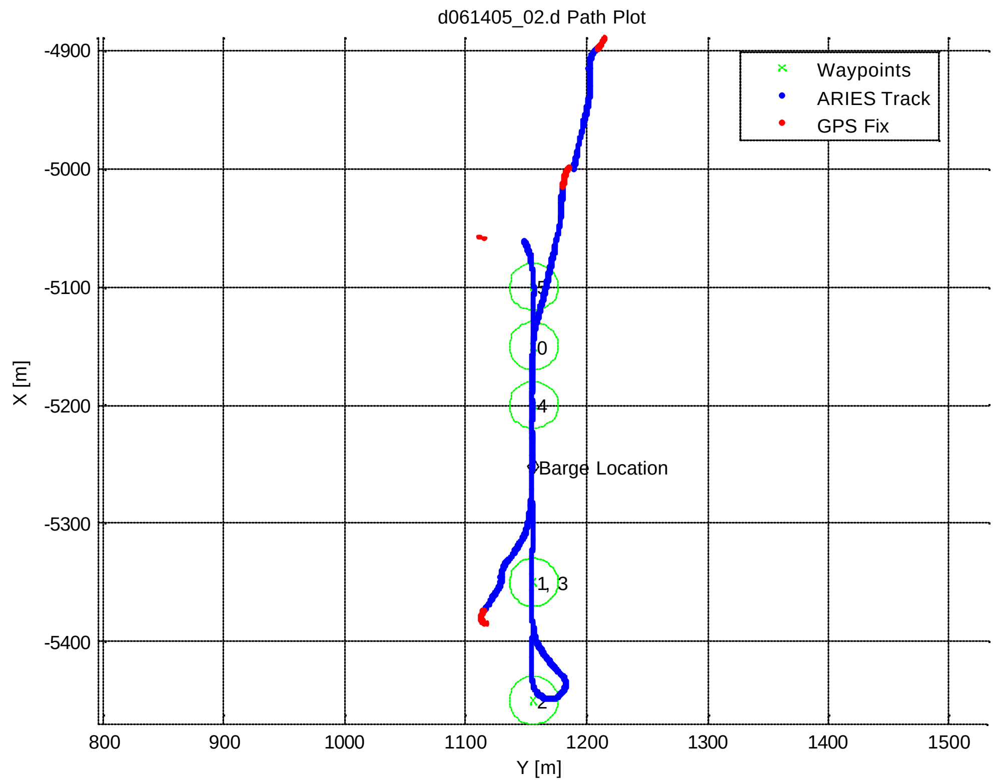
Figure 3 Blazed Array Vertical Configuration. Top View at Left, Side View at Right

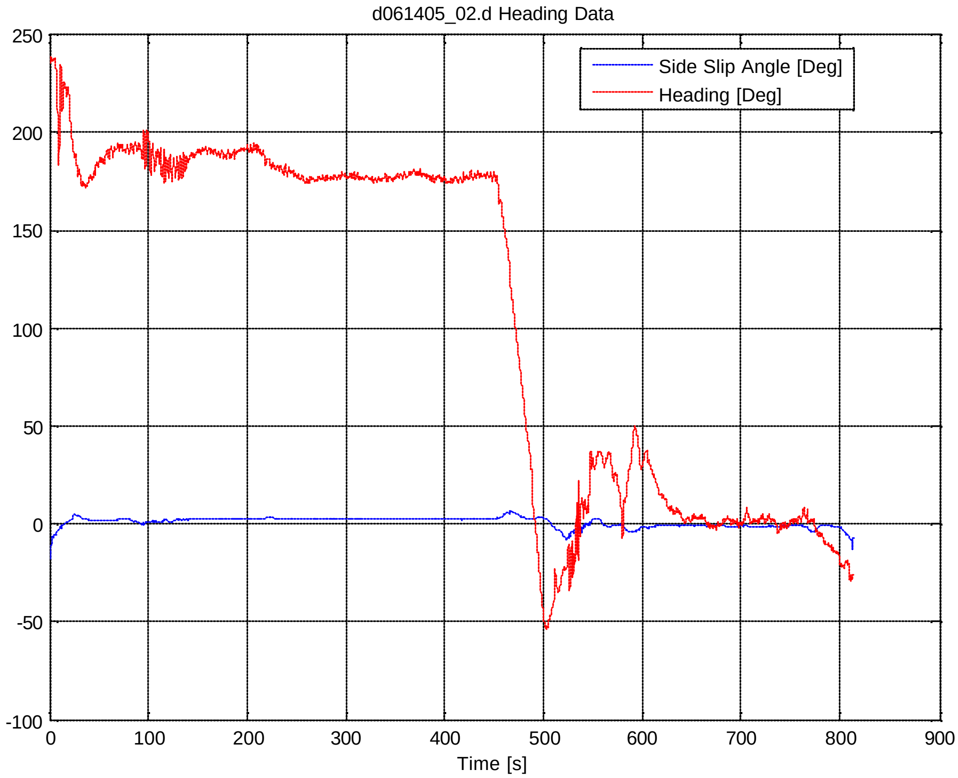
In Figure 3 the view from above shows the right and left-hand staves are angled at about 12 degrees apart so that they project forward into slightly overlapping but distinct zones. In this way targets dead ahead will show in both staves equally, while targets to the port or starboard sides will show separately.

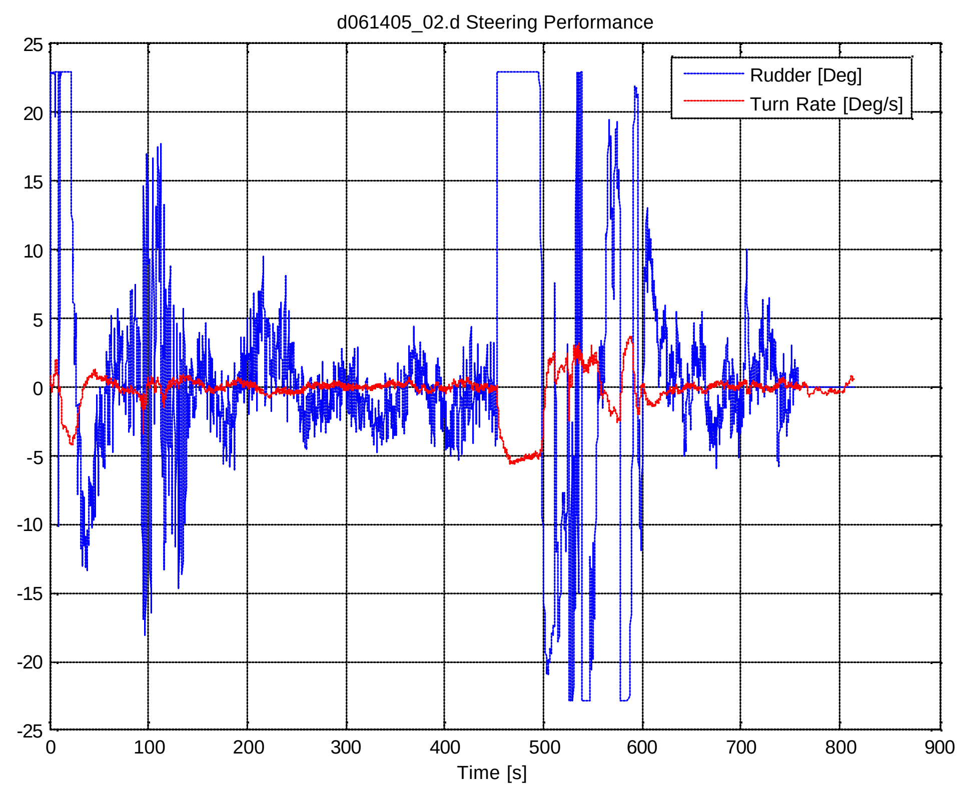
Vehicle Path and Motion Response

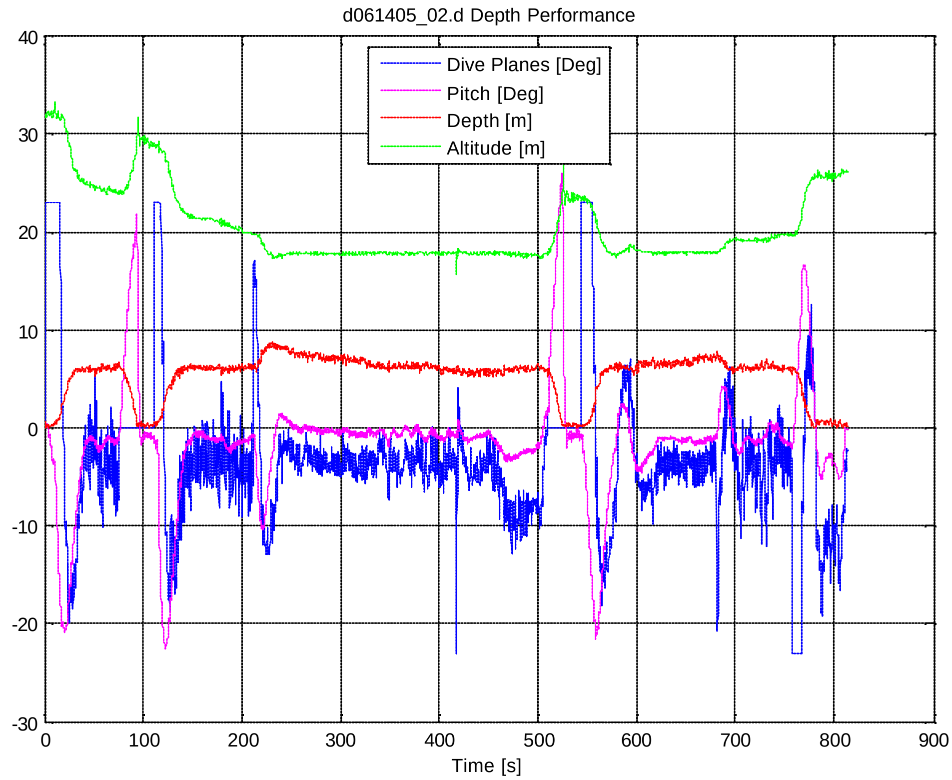
In general, a track set was devised that included a southerly approach to the barge, turning around beyond it. This was followed by a northerly return and second pass over the barge. Several pictures follow showing the path of runs taken and vehicle diving and steering and state response obtained. In the following Figure 4 plots, the runs given by the data file d061405_07.d represent the final closed loop performance runs of the exercise.

Results from Run 061405_02:

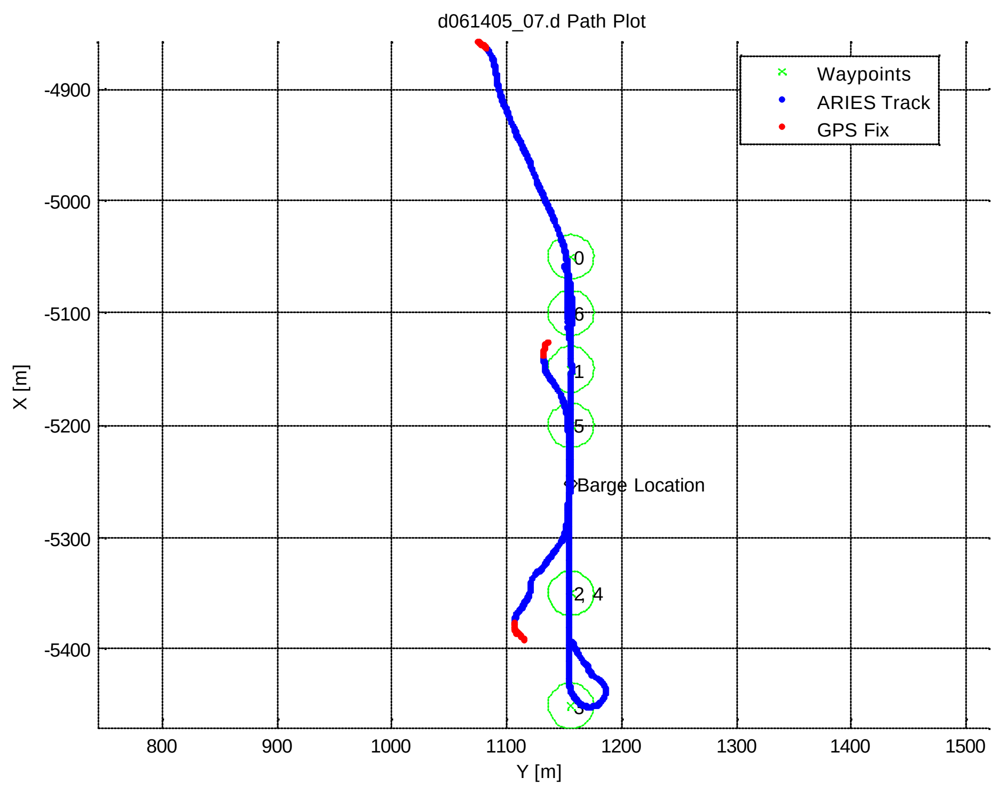


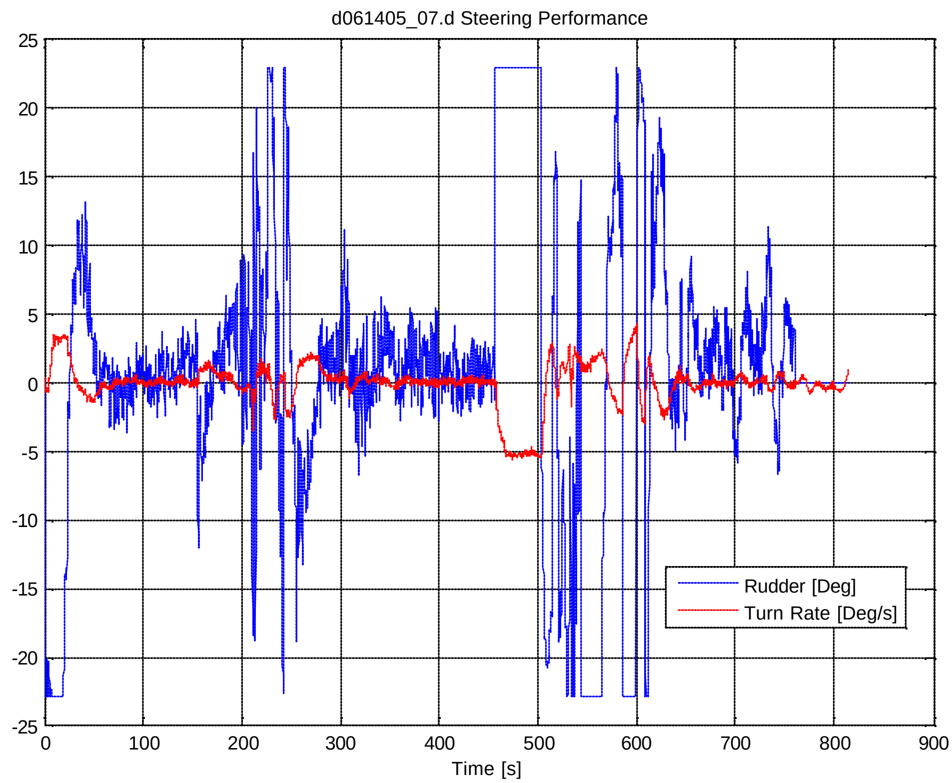

d061405_02.d Heading Data
Side Slip Angle [Deg]
Heading [Deg]
250
200
150
100
50
0
-50
-100
0
100
200
300
400
500
600
700
800
900
Time [s]

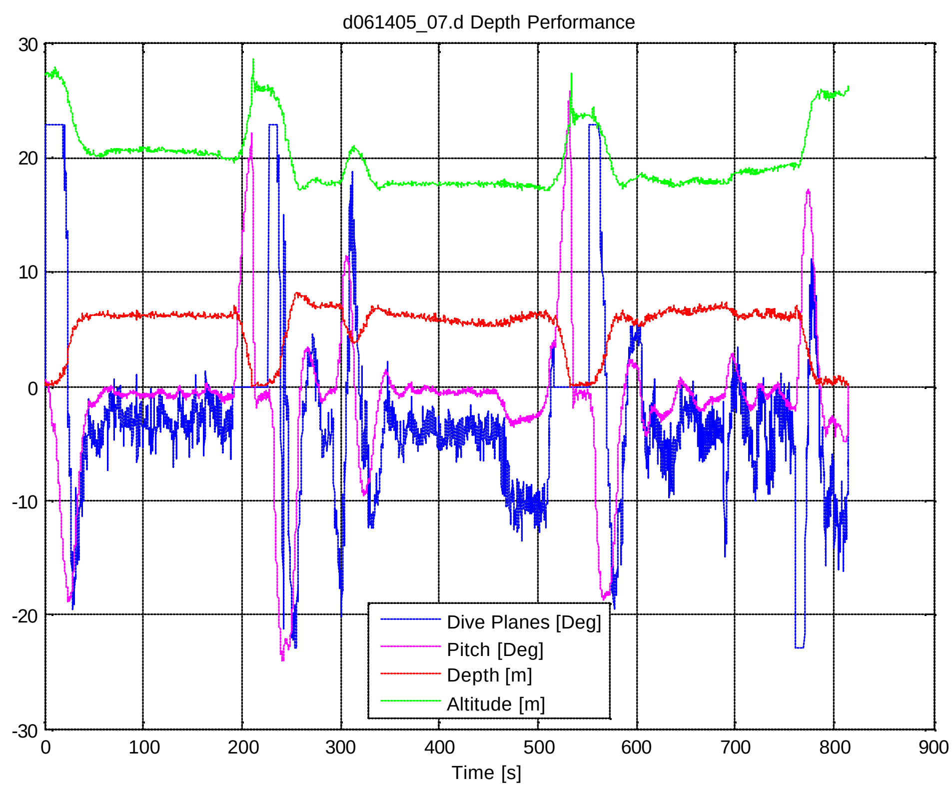

d061405_02.d Steering Performance
Rudder [Deg]
Turn Rate [Deg/s]
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
100
200
300
400
500
600
700
800
900
Time [s]



Results from Run 061405_07:




d061405_07.d Steering Performance
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
100
200
300
400
500
600
700
800
900
Time [s]
Rudder [Deg]
Turn Rate [Deg/s]


d061405_07.d Depth Performance
30
20
10
0
-10
-20
-30
0
100
200
300
400
500
600
700
800
900
Time [s]
Dive Planes [Deg]
Pitch [Deg]
Depth [m]
Altitude [m]

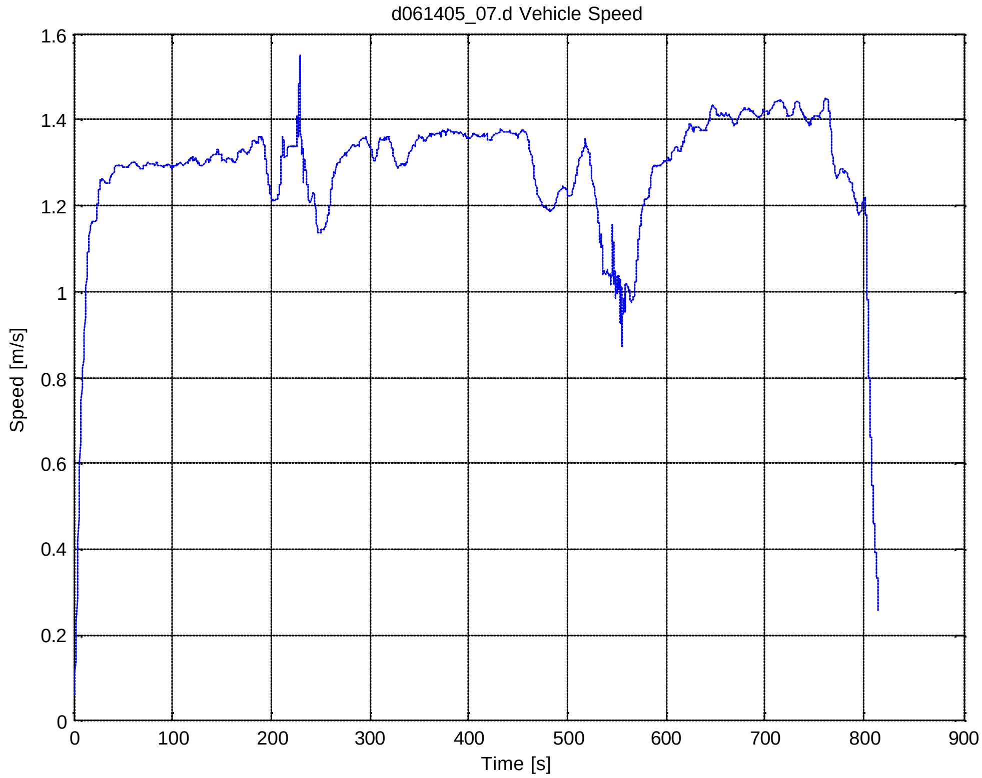


Figure 4 Plots of Vehicle Data from Run 2 and Run 7 on June 14, 2005. The above plots include vehicle track, steering performance, and dive performance. The dive performance plot from run 7 shows an obstacle avoidance behavior over the barge (300 s into the run).

Network Link

Images are gathered on the PC-104 Cool Runner image processing computer which runs windows XP and both gathers images and performs real-time image processing. We were able to maintain a 1.5 Hz. rate giving a 0.667 second update for a vehicle flying at about 1.4 meters per second. That translates into an update every 0.93 meters of distance traveled. One of the important features of this networking architecture is that when surfaced, the radio link allows the user to bring up a remote desktop application and log into the PC-104 Cool Runner so that the sonar image files may be viewed without recovering the vehicle to the support ship.

Figure 5 shows the Network Architecture linking Perception to Response. Communications between the two computers are by IP sockets in which vehicle state information, which resides on the Ampro control computer, is fed to the Cool Runner image processing computer, while the results of the image analysis are written on the socket for communication to the vehicle control processes. The data used to perform vehicle response is restricted to object height and range. The declaration of an object is based on both single ping analysis (target lies inside critical envelope above the sea bottom, and a multi ping analysis for a consistent track towards the vehicle. A sequence of six consecutive range measurements is used to declare a consistent track.

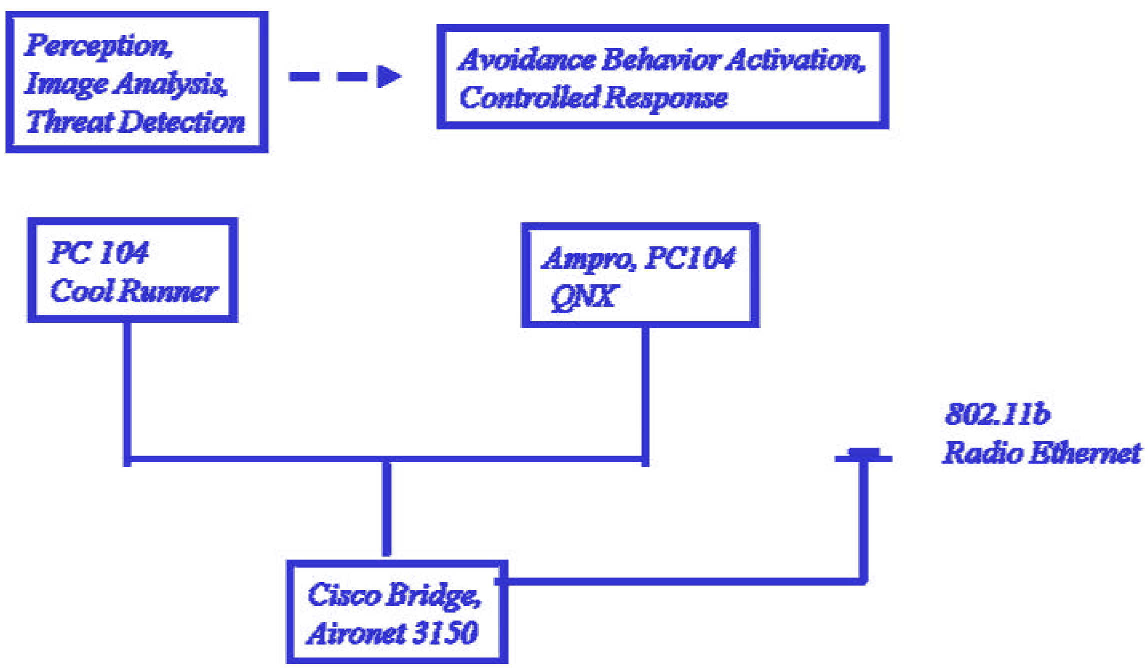


Figure 5 Network Layout Linking Perception with the Blazed Array to Avoidance Response. Both Computers Are Linked And Visible Through The 802.11 Radio Ethernet Communications Link When Vehicle Is On Surface.

Sonar Image Collection

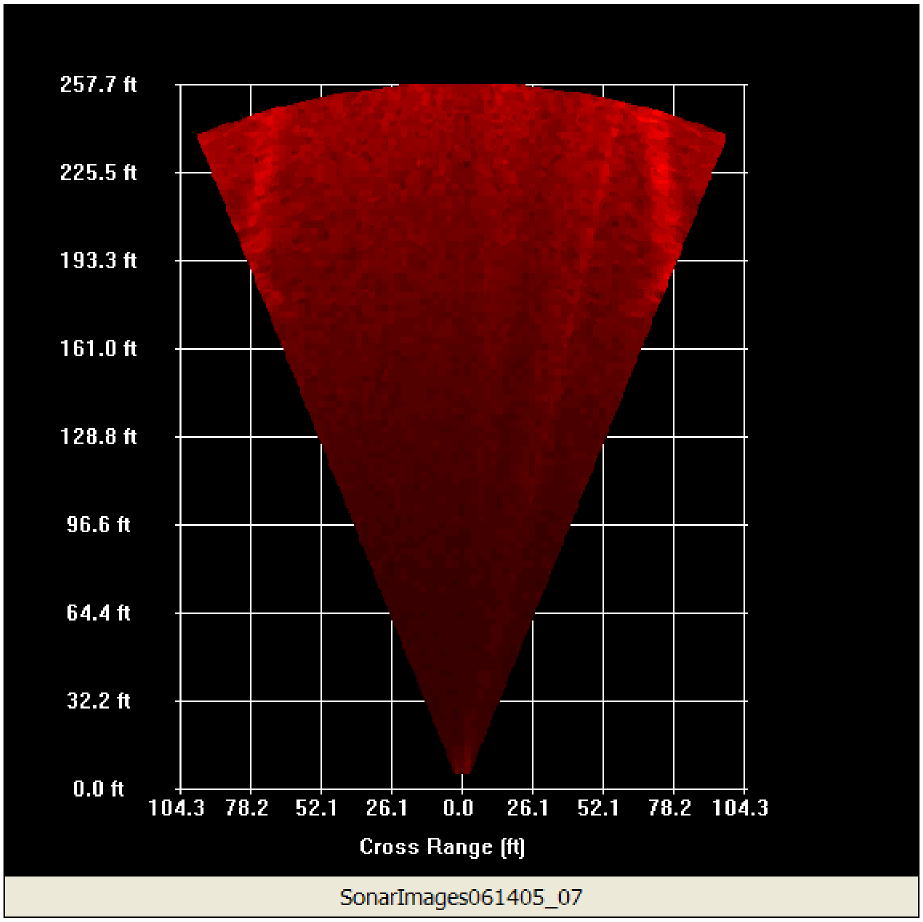


Figure 6 Movie file of Entire Run (*.avi File Just click on image to run movie) Showing Vehicle Response To Observed Images Of Barge. The Vehicle Response Is Seen As An Opening Of The Sea Bottom Lines, Followed By A Closing Of The Lines As The Vehicle Pitches Downward. The Barge Is Clearly Seen As An Object Between The Sea Bottom Lines In Both Sides Of The Image.

In the movie, the picture is divided into two halves, one for each stave. Each stave sees the ocean bottom as a strong straight line. The area inside the lines corresponds to the water column above the sea bottom. The barge is seen twice. First on the southerly approach, and secondly on the northerly return. The barge is seen as a strong object visible in both staves almost equally. The long straight lines are the ocean bottom and the maximum height of the object above bottom is measured at about 18 feet (6 meters). As the vehicle pitches up during the avoidance maneuver, the sea bottom lines move outwards and then later, as the vehicle pitches down, they move together. Stills from the movie as in Figure 7, clearly show the barge.

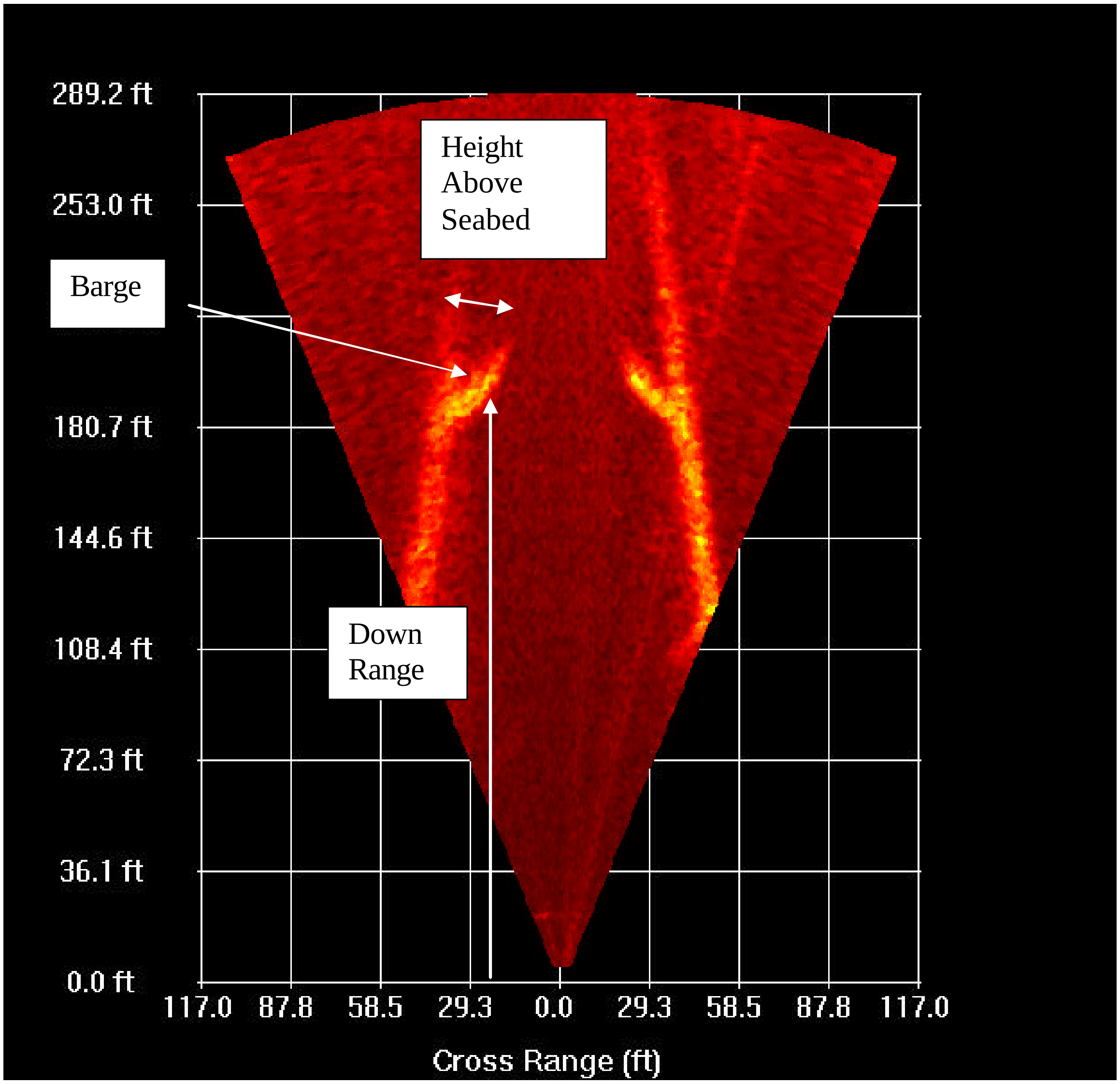


Figure 7 Sonar Still Image Of The Barge Standing Up Proud Of The Sea Bottom

Vehicle Response to Barge Detection

We have studied the question of what response is appropriate for the REMUS vehicle to avoid bottom objects and find that the most generally acceptable method is to use a full Gaussian function as an additive command on the nominal altitude command for the track that the vehicle is executing. The Gaussian function may be easily tuned for length through its standard deviation, and the added height may be set directly. ARIES uses a Gaussian added altitude function where the two unknowns are the range, and height. The image analysis provides range and height. In Figure 8 below, a Gaussian response to the command for avoidance is illustrated quite clearly. Shown are the altitude, depth and plane deflection results.

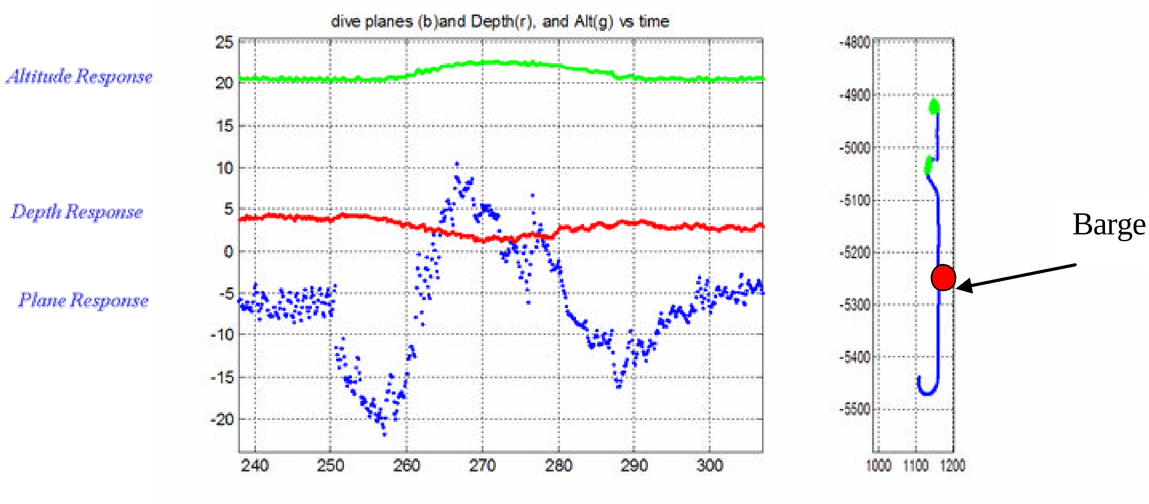


Figure 8. Gaussian Response To The Detection Of The Barge. Response Maximum is Placed at the Estimated Position of the Barge.

CONCLUSION

We have demonstrated clearly the full closed loop response of object detection, threat declaration, size and location determination, and a Gaussian additive altitude response for the ARIES vehicle, this is a first important step in the development of a robust obstacle avoidance capability design for small to mid-sized AUVs.