AUV Docking

Mark Sibenac (PM/SysEng), Tarun Podder, Hans Thomas, Bill Kirkwood, Andy Hamilton, Rich Henthorn, Rob McEwen, Farley Shane, Ed Mellenger, Mark Chaffey, Keith Raybould, Jim Bellingham

INTRODUCTION

The objective of MBARI's AUV Docking Program is to enhance the exploration capability of the vast oceanic environment. There is a need for prompt deployments and prolonged operations of AUVs that avoids frequent and expensive deployment and recovery. Therefore, we are developing an AUV docking system that allows an AUV to autonomously navigate to a dock, take rest, transfer data and power, as required for long-term operations. The AUV docking system is a sub-system of the MOOS/MARS mooring system and, in the future, the technology and engineering experience will be made available to other observatories like the NEPTUNE cabled observatory.

A docked AUV allows for continuous and extended presence eliminating expensive support vessels and skilled operators. Time series data sets could be obtained easily which would characterize spatial variability and provide context for point measurements. Episodic events could be surveyed promptly without large latencies. Seafloor events like eruptions and landslides fall into this category along with weather driven and biological processes. As cabled observatories come online, docked AUVs could be used to extend the spatial coverage of the observatory beyond its own footprint.

Docking adds the capability for extended, interactive survey capabilities. Surveys could occur over a period of months or years versus hours to days for AUVs deployed from ships. The dock decouples science and ship schedules, so fewer ship days are required per mission. It also allows for rapid response without the mobilization effort and transit time of a ship. Docked AUVs are similar to gliders to some extent in the sense of extended presence, but AUVs are more controllable and can provide much more power for large payloads (10s to 100s W versus 0.1 to 1 W).

This docking program is a follow on to the Dorado program which was originally a sub-system of MOOS completed in 2002. AUV Docking is the next MOOS sub-system which we are currently engineering. It is expected to be another three year effort ending with a dock and AUV transferred to the Marine Operations group for use with MOOS in the Monterey Bay.

Work on the docking program at MBARI began this year in 2003. This first year is dedicated to gathering requirements and developing concepts. So far, research was done to understand previous docking efforts, and many journal papers were catalogued into a database with a summary. Scientists at MBARI were interviewed to understand what their research involved and how docked AUVs could be used to collect their data. Case studies were written up which describe the concepts of operation and what data would need to be collected. Functional requirements were extracted from these case studies for both the docking system and the AUV. Simple concepts were illustrated to show how docking fits into the MOOS system.

This poster shows some other possible uses of the docking technology created from this MOOS subsystem. The plan for the next couple of years is also summarized at the end.

Figure 1: Dorado AUV – This is an actual frame grab from the ROV Ventana which shows the Dorado AUV autonomously diving.

BACKGROUND RESEARCH

MBARI engineering is doing extensive background investigations into previous docking efforts. Sub-sea docking has been a topic of research for many decades for submarines, remotely operated vehicles and more recently for autonomous underwater vehicles. Considerable effort has been expended by government agencies and academic institutions over many years of research in autonomous docking. MBARI engineering is researching these efforts, which span across Europe, Asia, and North America, to gain the background and knowledge already gained by others. Each of the docking systems considered have historically had some success at a minimum. The common thread of experience and knowledge MBARI has gained from reviewing these systems is being applied to the challenging task of long-term underwater docking for MBARI's AUVs and science programs.

Figure 2: AUV Docks – These are pictures of AUVs docking systems being developed by other oceanographic institutes.

CASE STUDIES

Scientists at MBARI were interviewed about their research. The docking team wrote case studies which detailed each scientist's research including the data needed and basic survey properties. The following is a list of case studies that this docking program will address.

John Ryan, MBARI
- CASE 1: Consequences of small to meso-scale upper ocean circulation phenomena in the coastal ocean

Jim Barry, MBARI
- CASE 2: Long-term Observation of Benthic Animals/Creatures; Mapping of Vents, Seeps, and Cold Beds (shellfish)
- CASE 3: BIN-RIN Data and Power/Energy Transfer
- CASE 4: Periodic and Long-term Observation/Monitoring of Physical and Biological Processes in and around Monterey Bay Canyon system

Francisco Chavez, MBARI
- CASE 5: 3D Time-Series Study of California Current System (CCS).
- CASE 6: High Resolution 3D Tracking of a Particular Volume of Upwelling Water in Monterey Bay (study of its dynamics, subduction/disappearance at the edge of California Current, impacts on ecosystem and climate)
- CASE 7: Iron-Fertilization Experiment, its Short-term and Long-term Effects on Oceanic Environment (physical, biological, and ecological) as well as Effects on Global Climate
- CASE 8: Enhancement of CalCOFI Time-Series Measurements

Chris Scholin, MBARI
- CASE 9: High Resolution Spatial and Temporal Sample Collection for Monitoring and Research of Harmful Algal Blooms (HABs)
- CASE 10: Mapping and Monitoring of Trace Elements in Coastal Water for Developing a Regional Scale Model for Prediction of HABs

Ed DeLong, MBARI
- CASE 11: High Resolution (spatial and temporal) Eulerian Survey and Sample Collection for Microbial Organisms (0.2-2.0 micron size) in Upwelling Water in Monterey Bay
- CASE 12: High Resolution (spatial and temporal) Lagrangian Survey and Sample Collection for Microbial Organisms (0.2-2.0 micron bacterioplankton/picoplankton) in Monterey Bay
- CASE 13: Detection of Submarine Earthquake's Epicenter, Vent and Eruption; and Collection of Microbial (0.2-2.0 micron) Organism (archaea and bacteria) Samples in the Vicinity of the Epicenter, Vents, and Eruption Zones

Steven Haddock, MBARI
- CASE 14: Bioluminescence Measurement and Sample Collection in Upper-water Column (5m-50m)
- CASE 15: Bioluminescence Measurement and Sample Collection in Mid-water Column (500m-1500m)

Debra Stakes, MBARI
- CASE 16: Continuous and Long-term Observation of Active Mid-ocean Ridge Segment

Ken Johnson, MBARI
- CASE 17: Continuous Long-term Observation and Event Response inside Monterey Canyon
- CASE 18: Periodic and Long-term Survey and Tracking of Chlorophyll in the Light of Carbon Export Beyond Photic Zone
- CASE 19: Periodic and Long-term Observation/Monitoring of Chemical Agents and Trace Elements in Oceanic Environment

FUNCTIONAL REQUIREMENTS

Once the case studies were detailed, functional requirements were extracted to describe what the dock and AUV must satisfy. The following is a list of those requirements.

Note: This list constantly changes as case studies are added or modified. This is not the final list.

The dock -
- Shall be capable of capturing and releasing non-hovering, survey class AUV(s)
- Shall be capable of transferring data reliably
- Shall be capable of supplying power
- Shall be easily interfaced with MOOS moorings and MARS cabled observatories
- May assist AUV in locating dock and help in final navigation to capture mechanism
- Shall be capable of responding to any event promptly
- Shall be capable of being deployed in both shallow and deep water (250m to 4500m)
- Shall be capable of about 52 dockings per year
- Shall be maintained on the same schedule as its host (once a year for a MOOS mooring)
- Shall be deployable from Pt. Sur or smaller vessel
- May be capable of accommodating different types of AUVs

The docked AUV -
- Shall be capable of navigating and homing accurately to the docking position
- Shall be capable of locating the dock
- Shall be capable of capturing and latching with the dock
- Shall make reliable connections with the dock for data and power transfer
- Shall be capable of uploading data to the dock
- Shall be capable of downloading new missions from the dock
- Shall be capable of operating in deep water (up to about 4500m)
- Shall be capable of covering a long range (50km to 100km)
- Shall have high navigational accuracy
- Shall be able to accommodate both navigational and science sensors
- Shall be capable of charging batteries
- Shall be capable of responding to any event promptly
- Shall be capable of reliable, maintenance-free operation for at least one year
- Shall be maintained on the same schedule as its host (once a year for dock/MOOS)
- Shall be deployable from Pt. Sur or smaller vessel

BASIC CONCEPT

The current concept of MOOS includes a mooring with a surface expression. The buoy includes solar panels and a wind generator to power the system. On the seafloor, remote instrument nodes (RIN) are connected to the buoy through the use of cables and a benthic interconnect node (BIN). A riser cable between the anchor and the buoy transfer power and data to the seafloor. Cables laid on the seafloor then transfer power and data to the BIN.

The initial concept of the AUV docking system is to use a dedicated RIN, which would be connected to the mooring through a cable on the seafloor. This way a riser cable of any reasonable length could be connected to the RIN with a dock. A subsurface float is attached to the top of the riser cable to keep it vertical. A battery bank attached to the riser cable below the dock may be necessary for buffering the recharge energy. The exact configuration is not decided yet.

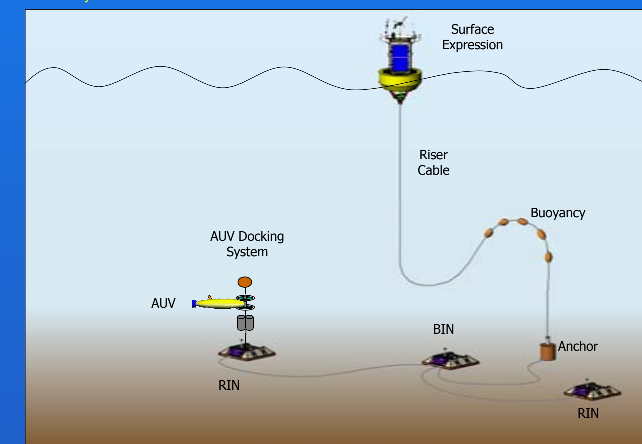

Figure 3: MOOS Concept – This is the concept for MOOS showing a mooring with an instrumented surface buoy, a benthic interconnect node (BIN), a remote instrument node (RIN) with instruments, and a RIN with an AUV dock attached to a riser cable.

SYSTEM DIAGRAM

The key technologies involved in the AUV docking system are listed below:
- Homing – finding and getting close to the dock
- Terminal guidance – navigating to the dock from a few meters away
- Capture – attaching to the dock
- Connection – establishing electrical and data connections
- Data download – extracting vehicle data
- Battery recharge – recharging vehicle energy source
- Mission upload – programming the vehicle with a new mission
- Undocking – releasing from the capture mechanism
- Acoustic communications – for communicating with the vehicle during a mission

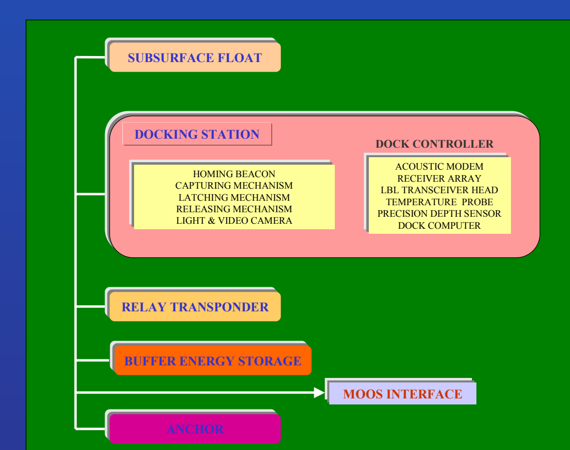

Figure 4: System Block Diagram – The basic system block diagram of an AUV docking system is shown here. This is only a starting concept.

EXTENDED USES

AUV Docking has many uses outside of the MOOS program. Environments exist where science could not be done without AUVs and docking. For example, much of the Arctic is accessible by ships only two months out of the year. The only way to measure ice thickness, take physical oceanographic measurements, and do other science under the ice is with a fully autonomous vehicle which can charge its own batteries and upload data to scientists automatically. Under ice docking will be taken into consideration when the MBARI docking system is engineered. The MOOS docking system has many overlapping requirements with an under ice dock. The plan is to develop one system to work with MOOS that would also work in the Arctic.

One concept of operation in the Arctic is termed Robo-Fram. The Norwegian Polarship Fram was designed to be locked into Arctic ice and carried with the circumpolar drift from Siberia to Greenland over a two-year period, passing near the North Pole in 1893. It was a successful trip, and now we have AUV technology which could repeat the trip with a dock anchored to an ice floe providing unprecedented oceanographic measurements of the Arctic basin. A picture below shows a basic concept.

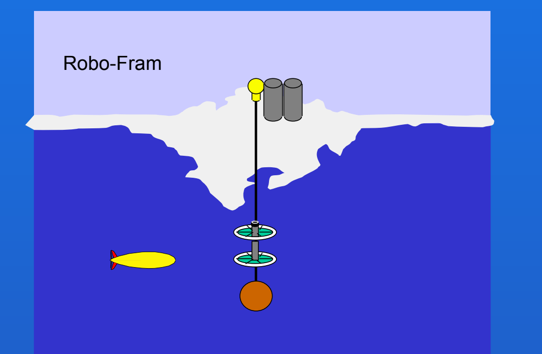

Figure 5: Robo-Fram Concept – An AUV dock is anchored to an ice floe in the Arctic. As the ice moves from one side of the basin to the other, the AUV runs surveys in different sections of water every week. Data is returned via low Earth orbit satellites to scientists during the transect.

DOCKING PLAN

MBARI's docking program is just in the conceptual phase this year. As the case studies come to a close this summer, trade-off studies will be completed to help decide which science cases should be focused on. The trade-off studies will also be used to determine the best concept and the exact scope of the program for the next two years.

The high risk elements need to be identified this summer, so work can begin as soon as possible to help mitigate risk. It is apparent that terminal guidance, homing, data and power connections, AUV sleep modes, and general AUV survivability without maintenance will be the tall poles to overcome.

Next year the design and engineering analysis of the docking system will be completed. A prototype dock will be built and tested in the MBARI test tank. The AUV will be outfitted with the necessary latches and connectors to test basic mechanical and electrical functionality.

In the final year, a dock will be manufactured and tested at sea in diver accessible depths. Once the system is proven on the test dock, a node will be installed with MOOS. The AUV will run routine science operations without any support ship standing by.

Many obstacles need to be overcome before there is actual hands-off autonomous operation of an AUV docking system. However, MBARI should have a basic system working in the Monterey Bay by 2005. Future ocean observing systems like MARS and NEPTUNE will benefit highly from MBARI's work.

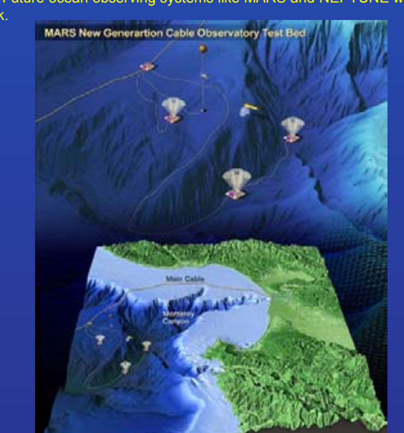

Figure 6: MARS Concept – AUV Docking will be an integral part of the MARS cabled observatory in the Monterey Bay. This technology will be directly transferred to NEPTUNE.

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