AUV Docking for MBARI's Ocean Observing Systems

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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, latch with it, and transfer data and power, as required for long-term operations. The AUV docking system is a sub-system of the MOOS/MARS (MBARI Ocean Observing System/Monterey Accelerated Research Site) 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 (10 - 300 W vs. 0.1 - 1 W).

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

The MBARI docking program is a follow on to the Dorado AUV development program which was originally a sub-system of MOOS. Since the transfer of the Dorado AUV from MBARI's engineering team to MBARI's operations team in early 2003, over 1000km of surveys were run for scientists. Physical oceanography payloads with these instruments were run on the vehicle: CTD, dissolved oxygen, fluorescence, bioluminescence, particle size distribution, nitrate, and optical backscatter. Energy was provided by several configurations of 1 kWh and 2 kWh lithium-polymer rechargeable batteries. The longest single mission run to date lasted 16 hours at an average speed of 1.5 m/s.

Work on the docking program at MBARI began in 2003. We gathered requirements and developed some docking concepts. So far, research was done to understand previous docking efforts, and extensively surveyed the available literature which was catalogued into a database with a summary. Over a dozen scientists 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 a remote observatory system.

We did 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. We researched 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.

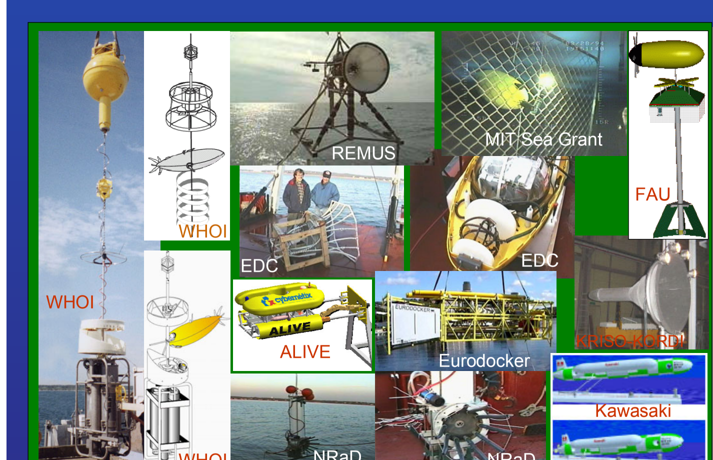

Figure 2: AUV Docks – These are pictures of AUVs docking systems being developed by other oceanographic institutes.

CASE STUDIES

A wide range of marine scientists, such as Physical Oceanographers, Biological Oceanographers, Molecular Biologists, Marine Microbiologists, Midwater Ecologists, Geologists, Ocean Chemists, Evolutionary Biologists, and Benthic Ecologists were interviewed to know how their science missions can be enhanced and fulfilled by using a docked AUV. As a result, we have come up with twenty-seven strong cases where docked AUVs can significantly improve the quality and quantity of data and sample collection as compared to other oceanographic platforms, such as moorings, ships, towed instruments, drifters, gliders, and ROVs. A sample data set (for the Case 1 type science mission) collected by MBARI's Dorado AUV is presented in Figure 3 below. Science missions can broadly be classified into two categories, based on the data collection methodology, namely: (1) Data Collection - in situ data collection such as temperature, salinity, depth, current, chlorophyll density, bioluminescence, etc., and (2) Sample Collection – collect samples quickly and then analyze the samples in a laboratory, process data and archive it; examples are microbial organisms, Harmful Algal Blooms (HABs), larvae, sediment, and rock sample collection. A docked AUV can cover the science missions for both the categories as mentioned above excluding the force contact type data or sample collection.

Based on the operational zone of the AUV, the science cases can be categorized into two ways: (1) Oceanic region wise – three oceanic regions, namely, coastal, offshore & polar, and (2) Position in the water column – three levels in the water column, namely, upper water column, midwater & benthic. A zonal distribution of these science cases shows that about 50% of the total operation of the AUV is confined to the upper water column and approximately the other two quarters are evenly distributed in the midwater and benthic zones. However, a methodical study of the entire water column is very important to understand the complex oceanic phenomena.

Some of the representative science missions are presented in Table 1 below. These missions cover all the three oceanic regions namely: (1) the coastal regions – Case 1, 4 & 9, (2) the offshore regions – Case 4 & 16, and (3) the polar regions – Case 25. It is noticed that several sensors are common. This commonality will help us to accommodate more sensors on the AUV which in turn will widen the window for the science missions. The type of data collection, range and resolution of measurement vary significantly for different science missions. However, the parameters such as temperature, salinity and depth appear to be common for most of the cases. On the other hand, parameters like CH4, pH, imaging, etc. are mission dependent. The range of the AUV's operations may vary from a few kilometers to hundreds of kilometers. The spatial and temporal resolutions also vary widely depending on the mission. Additionally, the deployment duration of the docking system depends significantly on the science missions; it may range from a few weeks to months to years.

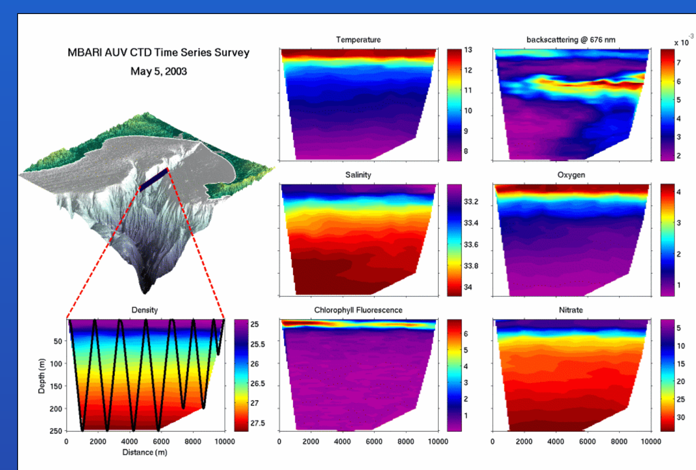

Figure 3: MBARI AUV CTD time series survey – Monterey Bay & Canyon bathymetry, water density, temperature, salinity, chlorophyll fluorescence, particle backscattering, dissolved oxygen, and nitrate.

Table 1: Representative science missions

Science mission	Science data required	Range and resolution	Science sensors required
CASE 1: Consequences of small to meso-scale upper ocean circulation phenomena in the coastal ocean.	Temperature, salinity, chlorophyll fluorescence, optical backscatter, nitrate, ocean current velocity, and dissolved O_2.	*Range:* horizontal ~20-100km^2; vertical ~0-300m (or near-bottom on the shelf). *Resolution:* horizontal sub-kilometer; vertical sub-meter. *Others:* synopticity <1day, at least twice in a week in different seasons.	CTD, ADCP, fluorometer, BBD/OBS, O_2 sensor, ISUS.
CASE 4: Periodic and long-term monitoring of physical and biological processes in and around Monterey Bay Canyon System.	Temperature, salinity, ocean current velocity, particle abundance, seafloor surveying, visual observation (digital images), and dissolved O_2.	*Range:* horizontal ~50-100km^2; vertical 3-5m above the seafloor for observation, and up to ~300-500m above seafloor for benthic boundary layer observation. *Resolution:* horizontal ?100m (for survey), ?250m (for observation); vertical ?50m (for observation). *Others:* once/twice a week for 2-3 years.	CTD, ADCP, BBD/OBS, multibeam sonar, low-light imager, O_2 sensor, fluorometer.
CASE 9: High resolution spatial and temporal sample collection for monitoring and research of Harmful Algal Blooms (HABs).	Temperature, salinity, ocean current velocity, nutrients, phytoplankton, zooplankton, particle scattering, and water sample.	*Range:* horizontal ~10km x 10km; vertical ~0-200m. *Resolution:* horizontal ~0.5-1.0km; vertical few meters. *Others:* regular observation, once HAB is detected then daily sampling for several weeks.	CTD, ADCP, OBS/BBD, ESP, fluorometer, pH sensor, O_2 sensor.
CASE 16: Continuous and long-term observation of active mid-ocean ridge segment.	Temperature, salinity, ocean current, dissolved O_2, nutrients, microbial organisms, and water sample.	*Range & Resolution:* for regular/ continuous observation - horizontal ~10km x 20km; vertical ~50-200m off the seafloor (single lawn mowing pattern). After events - horizontal ~20km x 60km; vertical ~50-1000m off the seafloor (lawn mowing patterns at 250m, 500m, 750m and 1000m layers off the seafloor). *Others:* synopticity <1day, for 2-4 week time series after events.	CTD, ADCP, BBD/OBS, ISUS, ESP, multibeam sonar, digiscanner, pH sensor, O_2 sensor.
CASE 25: Midwater surveying and monitoring in ice-covered Arctic or Antarctic regions using Lagrangian and Eulerian platforms.	Temperature, salinity, ocean current, dissolved O_2, ice-thickness, particle distribution, chemical agents, abundance and distribution of midwater animal.	*Range:* horizontal ~5km-10km circle; vertical ~entire water column. *Resolution:* horizontal <200m; vertical<50m. *Others:* twice/thrice per week throughout the year.	CTD, ADCP, dissolve O_2 sensor, BBD/OBS, color digital camera, (or high-resolution low-light camera).

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 that this list is not the exhaustive one, however, it captures high-level functional requirements.

The dock -

- Shall be capable of capturing and releasing non-hovering, survey class AUV(s)
- Shall be capable of two-way communication with the AUV
- Shall be capable of supplying power to the dock and to the AUV
- Shall be easily interfaced with the MARS cabled observatory
- May assist AUV in locating the dock and help in final navigation to the capture mechanism
- 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 node
- Shall be deployable from Pt. Sur or smaller class vessel
- May be capable of accommodating different types of AUVs

The AUV -

- Shall be capable of locating the dock
- Shall be capable of navigating and homing accurately to the docking position
- Shall be capable of 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 (about 4500m)
- Shall be capable of covering a long range (about 100km)
- Shall have high navigational accuracy
- Shall be able to accommodate both navigational and science instruments
- Shall be capable of charging batteries
- Shall be capable of responding to any nearby event promptly
- Shall be capable of reliable, maintenance-free operation for at least one year

DOCK SUB-SYSTEMS

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 – latching to the dock
- Data transfer – downloading vehicle data and upload mission scripts
- Power transfer – recharging vehicle batteries
- Undocking – releasing from the capture mechanism
- Communications – for communicating with the vehicle during a mission

BASIC CONCEPTS

For a cabled observatory like MARS or NEPTUNE, the AUV docking concept uses a dedicated structure like a remote instrument node (RIN) to attach to the seafloor. The RIN would be connected to the main node through a cable laid on the seafloor (Figure 4). This way a riser cable of any reasonable length could be connected from the RIN to the dock. A subsurface float may be attached to the top of the riser cable to keep it vertical. The exact configuration is not decided yet.

With the power available from a cabled observatory, the time to recharge the AUV's batteries will be kept at a minimum. Without a cable, recharge time becomes large, on the order of days with only renewable energy sources. Data transfer in the cabled observatory can be in the Gbps range. Without a cable to shore, data transfer will be limited by satellite and radio bandwidths on the order of several Kbps.

The MOOS concept includes a mooring with a surface expression (Figure 5). The buoy includes solar panels and a wind generator to power the system. On the seafloor, RINs 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. A battery bank attached to the riser cable below the dock may be necessary for buffering the recharge energy.

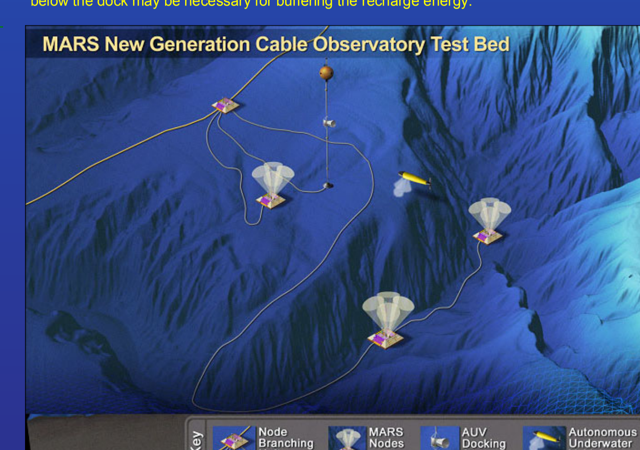

Figure 4: MARS/NEPTUNE Concept – This is the concept for a cabled observatory which shows an AUV dock on its own sub-node from the main node.

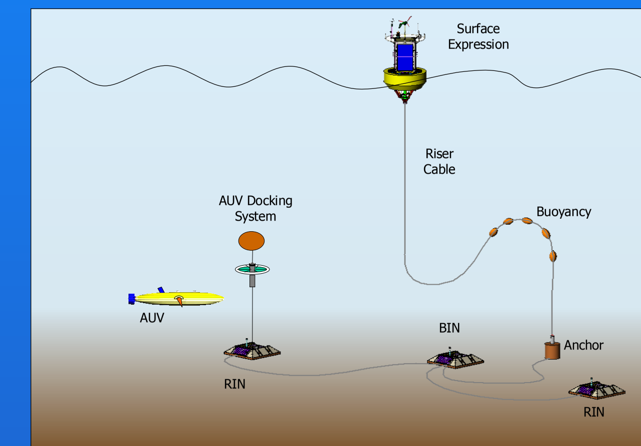

Figure 5: MOOS Concept – This is the concept for MOOS showing a mooring with an instrumented surface buoy, a benthic interconnect node (BIN), a remote instrument node (RIN) with instruments, and a RIN with an AUV dock attached to a riser cable.

WORK PLAN

We are starting to identify the high risk elements, so work can begin as soon as possible to help mitigate risk. It is apparent that terminal guidance, homing, data and power connections, AUV low-power sleep modes, and general AUV survivability without maintenance will be the tall poles to overcome.

In 2003 we performed a background analysis of all docking systems that were published, interviewed scientists and came up with case studies, generated a list of functional requirements, and started the concept design. We have consulted other institutes and discussed AUV docking ideas with them at every opportunity.

In 2004 we plan on sub-system testing, concentrating especially on the homing system. Prototypes of the other sub-systems will be designed, constructed, and at least tested in the MBARI seawater test tank. A rough design and engineering analysis of the complete docking system will be worked on. A prototype dock will be built and tested in the test tank. The AUV will be outfitted with the necessary latches and connectors to test basic mechanical and electrical functionality.

In 2005, the final design of the docking system will be completed. As the MARS cable is being installed in the Monterey Bay, we will be manufacturing and testing the docking system at sea in shallow depths. After sufficient testing of the docking system with the AUV, and once the success statistics meet the requirements, the dock will be installed on the MARS network. This installation will probably not happen until 2006. The AUV will then be able to 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 NEPTUNE will benefit highly from MBARI's work.

CONCLUSION

We have consulted a wide range of marine scientists to understand their requirements for various science missions that can be accomplished and enhanced using a docked AUV system. An effort has been made to project how the science requirements motivate the technological development for a daunting task like developing an AUV docking system. Detailed case studies helped us in driving functional requirements for the docking system. A brief discussion on available docking systems and various subsystems have been included. Finally, we have discussed the docking plan for the MARS cabled observatory and also pointed out the availability of the technological know-how for the NEPTUNE observatory. However, the reliability of the AUV and the dock seems to be most challenging criterion to meet for long-term autonomous underwater exploration.

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