REQUIREMENTS OF A DOCKED AUV FOR SCIENCE MISSIONS

Tarun Podder, Mark Sibenac, Jim Bellingham

INTRODUCTION

The objective of MBARI's AUV Docking Program is to enhance the exploration capability of the oceanic environment. There is a need for prompt deployments and prolonged operations of AUVs to study episodic events and transient phenomena. To achieve this, the ability to recharge an AUV docking system that allows an AUV to autonomously navigate in a dock, latch with it, and transfer data and power, as required for sustainable science missions. The AUV docking system is a sub-system of the MOOS-MARS (MBARI Ocean Observing System/Monterey Accelerator Research Sites) mooring system, and in the future, the technology and engineering experience will be made available to other observatories like the NEPTUNE (Ocean observatory initiative).

Episodic science science missions.

- Extend spatial coverage of observatory nodes
  - Ability to deploy beyond observatory footprint
- Acquire high resolution 4-D data sets
  - Characterize spatial variability
  - Provide context for point measurements
- On-demand operations (no ship scheduling required)
- Event detection through modeled, embedded surveys
- Autonomously respond to episodic events
  - Weather driven processes
  - Seafloor events (eruptions, slides…)
  - Detection of biological processes

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

Basic features of current Dorado vehicle:

- Dorado 1.2 m x 1.2 m x 4.2 m (4.5 meters external)
- Modular payload in nose and/or parallel mid-body
- CTD, ADCP, CSM, Nitrate, Silicon, Fluorometer, Dissolved O_2 and other science sensors
- 1-100m detection (10^3), 3.8km length typical
- 450m depth rating
- Dorado transitioned to operational status in 2003
  - 1000km in missions
  - 16 hour mission (typ.w 20K science payload, 50km)
  - 6 hour battery recharge

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, the majority of these efforts, which span across Europe, Asia, and North America, to date have focused on docking with a fixed or mobile platform. The current technology is well understood and has achieved a high level of sophistication. This combined broad 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, Benthic Ecologists, Geologists, Ocean Chemists, Marine Mammalists, Fish Biologists, and Benthic Ecologists were interviewed to know how their science missions can be enhanced and utilized by using a docked AUV.

Highlights of the case studies:

- Proposed survey ocean zones where scientists would be can significantly improve the quality and quantity of data and sample collection
- Identified twenty-one science ventures that need to be with AUVs to cover all 27 cases and assessed the science payload for each mission
- The cases spanned all regions of the ocean including polar regions. They were extend into three different vertical zones covering the supernatant, thickened and benthic zones. A majority of the missions are in the supernatant column.
- Event response is one of the most compelling science requirements and an AUV docking system can be very useful for this purpose.
- There are mainly two types of science missions, 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 sample in laboratory, process the data and archive it, examples are microbial organisms, microbial Algal Blooms (HABs), larvae, sediment, and rock sample collection, etc.

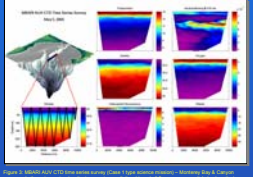

Figure 3: MBARI AUV CTD time series survey (Case 1 type science mission) – Monterey Bay & Canyon. Self-propelling, water density, temperature, salinity, chlorophyll fluorescence, particle backscattering, dissolved oxygen, and nitrate.

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, & 12; (2) the offshore regions – Case 4 & 16; and (3) the polar regions – Case 25. It is evident that several scenarios are coming. This commonality will help us to accomodate many scenario 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. Moreover, the parameters such as temperature, salinity and depth appear to be common for most of the cases. On the other hand, parameters like CO_2, pH, Fluoging, etc. are highly dependent. The range of the AUV's operations may vary from a few meters to hundreds of kilometers. The optical sensor can be used to observe also very solitary depending on the mission. Additionally, the range of the sensors for the docking system degrade significantly on the science missions. It may range from a few seconds to months in years.

Table 1: Representative science missions

Science mission	Science data required	Range and resolution	Science sensors required
CASE 1: Correlation of coastal ocean upper ocean ocean circulation phenomena in the coastal ocean	Temperature, salinity, ocean current velocity, optical backscatter, nitrate, dissolved oxygen, chlorophyll, CDOM, pH	**Range:** horizontal~100-1000km; vertical ~0-100m or deep bottom on the shelf **Resolution:** horizontal sub-kilometer; vertical sub-100m, temporal~hours, or at least 4 times per day	CTD, ADCP, fluorometer, pH sensor, Oxygen
CASE 4: Periodic and long term monitoring of physical and biological processes in the coastal waters, Monterey Bay Canyon System	Temperature, salinity, ocean current velocity, particle abundance, chlorophyll, dissolved oxygen, nitrate, chlorophyll fluorescence, CDOM, and dissolved O_2	**Range:** horizontal~40-100km; vertical 0-1km but subject to observation, and up to ~500-800m depen seafloor for benthic observations **Resolution:** horizontal~100m; vertical~1-10m; temporal~1-10min for physical observations; vertical ~50m for observations; vertical ~50m (for observations); temporal ~minutes to years for 2-3 years	CTD, ADCP, fluorometer, optical sensor, Oxygen sensor, Nitrate sensor, Fluorometer
CASE 12: High resolution spatial and temporal sampling of the coastal ocean for monitoring and research of internal tidal bores (HAB)	Temperature, salinity, ocean current velocity, particle abundance, chlorophyll, CDOM, pH, dissolved oxygen, nitrate, acoustic backscatter	**Range:** horizontal~100-1000km; vertical ~0-100m **Resolution:** horizontal~1km; vertical~1-10m; temporal~hours, or at least 4 times per day	CTD, ADCP, CDOM, fluorometer, pH sensor, Oxygen sensor
CASE 16: Continuous and long-term observations of the upper ocean upper ocean segment	Temperature, salinity, ocean current velocity, particle abundance, chlorophyll, dissolved oxygen, nitrate, microbial organisms, and water sample	**Range:** horizontal~100-1000km; vertical ~0-100m **Resolution:** horizontal~1km; vertical~1-10m; temporal~hours, or at least 4 times per day **Sample Collection:** Sampling frequency ~20min - several days, sample volume ~2liters, sample time ~1min, for 3-4 years	CTD, ADCP, fluorometer, pH sensor, Oxygen sensor
CASE 25: Molecular biologists and microbiologist to use docked AUVs and Autonomous Underwater Vehicles (AUV) to study microbial ecosystems	Temperature, salinity, ocean current velocity, dissolved O_2, nitrate, fluorescence, particle abundance, microbial agents, abundance and distribution of microbial species	**Range:** horizontal~100-1000km; vertical ~0-100m or deep bottom on the shelf **Resolution:** horizontal ~20km - vertical~50m, temporal~hours, or at least 4 times per week throughout the year	CTD, ADCP, standard O_2 sensor, ARM DNA, Gene Algal Probe, Fluorometer, resolution may 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-homing, 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
- Must assist AUV in docking the dock and help in final navigation to the capture mechanism
- Shall be capable of being deployed in both shallow and deep water (upto about 4500m)
- Shall be capable of about Six moorings per year
- Shall be capable of withstanding harsh oceanic environment
- Shall be maintained on the same schedule as its host node
- Shall be deployable from R/V, tug or another 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 and downloading new scripts from the dock
- Shall be capable of operating in deep water (upto about 4500m)
- Shall be capable of covering a long range (about 100km)
- Shall be capable of navigating in a hazardous efficiently and safely
- Shall be able to accommodate both navigational and science instruments
- Shall be capable of responding to nearby event prompts
- Shall be capable of reliable and maintenance-free operation for at least several months
- Shall be rechargeable for at least seven days if not attached to the dock

DOCK SUB-SYSTEMS

The key technologies involved in the AUV docking system are listed below:

- Homing – finding and getting close to the dock
- Terminal navigation – 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
- Unlocking – 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 main 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 this power distribution from a cabled observatory, the dock to recharge the AUV's batteries will be large at a minimum. Without a cable, discharge time becomes large (in the order of days with our rechargeable 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 sea sub-node from the main node.

Figure 5: MOOS Concept – This is the concept for MOOS showing a mooring with an AUV docking system, 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 maximize.

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 many 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 in least tested in the MBARI tank/water test tank. A rough design and engineering analysis of the complete docking system will be evolved on. A prototype dock will be built and tested in the test tank. The AUV will be outfitted with the necessary ratches 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 Monterey Bay using the MARS cable. We will be using the MBARI AUV fleet to test the docking system stations 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 identifying to.

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 MBARI's AUV docking system. We believe that this work will be a good starting point for how for the NEPTUNE observatory and also for other ocean-floor observatories. However, the reliability of the AUV and the dock seems to be one of the most challenging criteria to meet for long term autonomous underwater operation.

ACKNOWLEDGMENTS

We would like to thank David and Lucile Packard Foundation for supporting this work. We would like to extend our thanks to marine scientists at MBARI, especially - Jim Barry, Francisco Chavez, Ed DeLong, Steve Haddock, Ken Johnson, Charles Fisch, Bruce Robison, John Ryan, Craig Dawe, Dave Ebeling, Dave Fleischer, Dave Cline, Dave Caron, Jim Bellingham, Mark Chaffey, Rob Sherlock, Roy Gomez, Ed Mellinger, Farley Shane, and Hans Thomas who provide valuable insights into this project. Our external collaborators who provide many good ideas are Steve Rock (Stanford University), Dana Yoerger (WHOI), Al Bradley (WHOI), and Hanu Singh (WHOI).

Contact Information:

Monterey Bay Aquarium Research Institute
7700 Sandholt Road
Moss Landing, CA 95039-9644
T.601.775.1779

Mark Sibenac, sib@mbari.org
Tarun Podder, tarun@mbari.org
Jim Bellingham, jgb@mbari.org

AIAA/CNES Ocean Research Conference, Honolulu, Hawaii, February 19-26, 2004