

Multi-User Autonomous Underwater Vehicle Docking Systems

Edgar An
Associate Professor
Department of Ocean Engineering
Florida Atlantic University
Dania Beach, Florida 33004
Phone: (954) 924 7231 Email: ean@oe.fau.edu

William E. Baxley
Lead Engineer
South Florida Testing Facility
Phone: (954)-926-4015 Email: baxleywe@nswccd.navy.mil

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LONG-TERM GOAL

The general objective is to investigate problems associated with the efficiency of reconnaissance performance in littoral waters in support of autonomous operations and future naval capabilities.

OBJECTIVES

The objectives of the proposed work are to 1) design, build and test a modular, cost-effective, and reliable bottom-mount docking sub-system for a 12" SFOMC AUV¹, as well as other vehicles of similar geometry and capability, and 2) carry out vehicle acceptance tests for the SFOMC AUV. FAU and SFTF will collaborate to achieve these goals. The synergism is built upon the existing SFOMC AUV research, testing, and evaluation capabilities, one of which is the existing MUX system that provides real-time data and control communication to shore.

APPROACH

This proposal will consider all the docking concepts that have been developed thus far, and determine and design an appropriate docking mechanism for a 12" AUV. The emphasis is focused on the reliability, and testing and evaluation of the proposed system. Our broad design goal is to have a docking sub-system that has minimal impact on routine AUV operations, specifically the following:

- Non-nose mechanical capture – minimal interference with nose mounted sensors
- Sonar interference – minimal interference with the navigation component in the docking sub-system

¹ A Bluefin 12" autonomous underwater vehicle (AUV), which is currently scheduled to arrive at SFOMC in June of 2004

Report Documentation Page

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- Hydrodynamics – minimal drag induced during transit
- Launch and recovery
- Omni-directional – minimal constraint on the vehicle approaching angle

FAU and SFTF will collaborate on the design, development and testing of the proposed docking sub-system. We believe this collaboration is highly complementary in that FAU can provide technical expertise on AUV systems and sub-systems whereas SFTF is specialized in testing and evaluation, and systems' reliability design. SFTF has extensive testing facilities and expertise on deployment, in-water testing and evaluation of systems, and mechanical design and integration specifically dealing with corrosion, bio fouling and hardening constraints. In particular for T&E, we will leverage our existing MUX system with an electro-optic cable connected to shore, which was designed and built using the previous SFOMC funding. The MUX can provide adequate power, data and control to the bottom-mounted docking component.

WORK COMPLETED

From April through June of 2003, a preliminary study, which is to determine the boundary of the design solutions with respect to existing concepts and their possible refinement, was carried out. We are currently in the design phase, which will be completed by January of 2004. We have met during the summer of 2003 with both Bluefin Robotics and Hydroid Inc, and discussed the constraints and resources available with regard to designing a docking sub-system for their 12-inch AUVs. A summary of the meeting outcome with Hydroid has been written, and sent to ONR, whereas the summary of the meeting with Bluefin Robotics is being written at this time, and will be sent to ONR when it is completed.

Proposed Docking System Design

The following provides the proposed design in terms of mechanical interface, navigation, power and data transfer mechanisms.

Mechanical Capture: Funnel Type

A funnel type docking station satisfies most of the requirements and is the most simple and robust in terms of capture mechanisms and protrusions required on the vehicle itself. Trapping the vehicle inside the funnel tube not only protects the vehicle during its visit, but also facilitates easy alignment of the data and power transfer systems, which can also be used to hold the vehicle in place; eliminating the need for additional latches and their inherent release mechanisms. A funnel style docking station can be easily rotated and aligned so that the vehicle can approach at a minimum speed into any ambient current. Orienting the funnel entrance downstream also minimizes the build-up of flotsam within the tube, and allows debris to more easily wash over the entire docking station. Any floating matter that is caught on the station will likely be on the exterior and thus not interfere with the function of the capture, or power and data transfer systems. Additionally, a funnel type system is relatively compact and hence easily deployable, and is readily suited to adaptation to ship or submarine tube mounted configurations.

We believe that these favorable characteristics make a funnel type docking station the most practically attractive and achievable given the resources and available time, however we acknowledge that there could be a significant drawback in that the vehicle nose section impacts with the dock. However, by designing the docking payload as a stand-alone unit with navigation, power/data transfer systems that are essentially independent of the capture mechanism, it would be relatively easy to investigate future modifications to the docking station that would not require significant interaction with the vehicle nose section and hence allow for a more varied instrumentation suite.

Navigation: USBL

An ultra-short baseline navigation system is ideal for this application. USBL offers long-range performance, and its accuracy increases as the separation of the vehicle and docking station decreases which is ideal. Modern microelectronics and a small array size also allow for a compact footprint that can relatively easily be incorporated into the vehicle payload. Having the USBL system on the vehicle itself, reducing the time between fixes and errors due to the vehicle translation.

Florida Atlantic University is currently building a small USBL system based on its new multi-purpose acoustic modem. We propose to investigate incorporating this system into our docking payload to provide the navigation necessary to enter the docking station and an inherent communication channel between the dock and/or support vessel. Since this system is still in the prototype stage there is an inherent risk in this approach. For this reason it is also proposed that investigation as to the suitability of off-the-shelf commercial systems be continued as a back-up.

Power Transfer: Inductive Coupling

The proposed method is based on some of the same conclusions that are in the article “Power Systems for Autonomous Underwater Vehicles” [1]. The Inductive Power Transfer in [1] was 180 to 220 watts but the new 12-inch diameter AUVs require over 1000 watts for battery charging and vehicle operations. This is primarily due to higher capacity batteries, which need to be charged in the same amount of time. The weight and size of the transformer, in the previous Inductive Transfer System, was over 11 lbs and 6.5 inches in diameter, so increasing the size and weight to accommodate the extra power would not be very practical for a 12-inch diameter AUV. However to accommodate the increased power some compromises must be made. Using some of the best features of inductive transfer and direct electrical contact methods will yield a hybrid that can meet the goals:

- The main advantages of Inductive Power Transfer are:
 - no physical electrical contact.
 - the surfaces are tolerant to inaccurate mating and bio-fouling.
- A Probe Inserting System will provide wiping action and cover protection to the magnetic gaped surfaces. The decrease of bio-fouling and foreign objects allows the magnetic gap to be minimized. This smaller gap than in previous designs will provide a means to transfer higher power without increasing the transformer size.

With the end of the receiving section open, all foreign objects will be pushed out and not trapped in the magnetic gap. The probe may also be used to lock the AUV in the Docking Station. The Spring Loaded Cover on the AUV's Docking Unit prevents drag and protects the unit from bio-fouling.

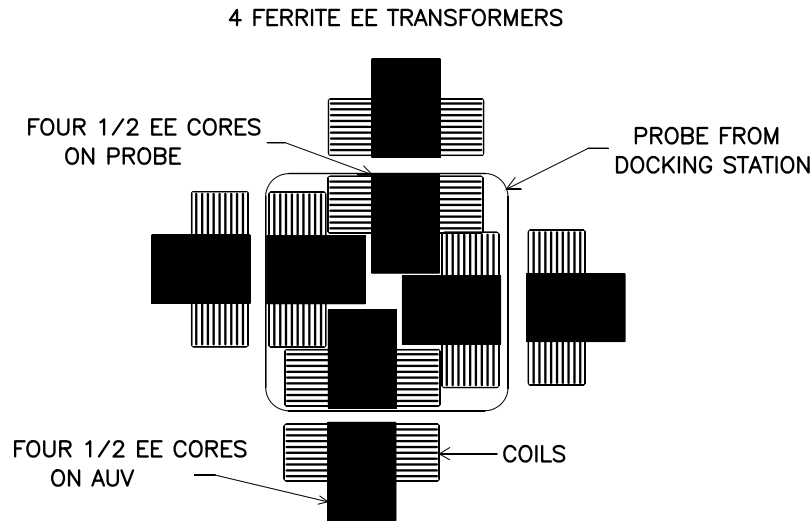


Figure 1. Cross section of inductive

To aid the alignment of the magnetic surfaces the Probe will have 4 flat sides. Each side will have an inductive transferring surface. The flat surfaces will also enable the transformers to be constructed with standard off the shelf EE Ferrite Cores. Each transformer will transfer over 250 watts, which totals over 1000 watts.

The Probe size will be approximately 2 inches square by 4 inches long and weight about 5 lbs. The AUV transformer section will be approximately 5 inches square by 5 inches long and should weight less than 5 lbs.

As the Probe moves from side to side in the AUV, the effective average gap between the 4 surfaces will remain relatively constant. As one gap gets larger the opposite gap gets smaller. A relatively constant gap will in turn keep the leakage inductance constant and that will enable a simple and highly efficient over all design.

A special feature will be added to the electronic circuit, which will degauss the Ferrite Cores at the end of each Power Transfer Cycle. This will prevent residual magnetism from causing an error in the AUV compass readings.

The inverter section of the Power Transfer System will have a pulse-skipping mode to keep the efficiency high during small loads. This will be useful when the Docking Station is being powered by batteries.

Data Transfer: RF LAN Coupling

Data will be transferred from the Docking Station Probe to the AUV with standard RF LAN modules using either loop or patch antennas. The RF frequency can be as high as 2.4GHz. The interference between the relatively Low Frequency Power Transferring Circuit and the Very High RF LAN frequency should be low. Also the antennas may be positioned in a location where the power transformer magnetic fields are lowest.

IMPACT/APPLICATION

This project will foster the development of autonomous operations for mine reconnaissance tasks.

REFERENCES

1. **Underwater Docking of Autonomous Undersea Vehicles Using Optical Terminal Guidance**, S. Cowen, S. Briest, J. Dombrowski, Oceans 97 Conference, pp.1143-1147.
2. **Autonomous Underwater Vehicle Homing/Docking via Electromagnetic Guidance**, M. Feezor, Y. Sorrell, P. Blankinship, J. Bellingham, IEEE Journal of Oceanic Engineering, Vol.26, No.4, pp.515-521, October, 2001.
3. **Implementation of the Ocean Explorer AUV Dock for Use With the Morpheus AUV**, Joe Lambiotte, M.S. Thesis, Ocean Engineering Department, Florida Atlantic University, 2001.
4. **Intelligent Docking for an Autonomous Ocean Sampling Network**, H. Singh, et. al, Oceans 97 Conference, pp.1126-1131.
5. **Enabling Technologies for REMUS Docking: An Integral Component of an Autonomous Ocean Sampling Network**, R. Stokey, et. al, IEEE Journal of Oceanic Engineering, Vol.26, No.4, pp.487-497, October, 2001.
6. **Feasibility Study for 12 Inch Class AUV Docking System Design**, Technical Report, Ocean Engineering, Florida Atlantic University, June, 2003.