ANNUAL REPORT TO ONR
DISTRIBUTED SURVEILLANCE SENSOR NETWORK - ONR-3220M

TASK NAME DSSN (Distributed Surveillance Sensor Network)

LONG TERM GOALS Develop capabilities for multiple undersea vehicles to support and interact with assorted undersea surveillance sensors in a manner which enhances the overall capabilities of the Fleet in the area of undersea ISR.

OBJECTIVES Integrate the technologies developed by the AOSN (Autonomous Ocean Sampling Network), the ULITE underwater acoustic sensor array and the Flying Plug underwater connectivity device into a coherent demonstration of new technological capabilities in which the whole is greater than the sum of the various parts (Figure 1).

APPROACH Integrate optical docking technology with the AOSN Odyssey vehicle, giving it the ability to mate with a fixed underwater node (universal docking station) for subsequent battery recharging and data transfer. Dock the Flying Plug connectivity vehicle with the universal underwater docking station while it is connected to a source of surveillance data, the ULITE array. Demonstrate that Odyssey can, in principle, deposit data and Flying Plug can extract it from such a docking station. Integrate the Flying Plug and universal dock with a ULITE sensor array and demonstrate the transfer of realistic surveillance data to a remote user in real time (Figures 2 and 3) in San Diego Bay.

WORK COMPLETED

The initial half of FY96 involved modifying an Odyssey UUV to enable docking via optical guidance. Month-long Odyssey vehicle docking experiments conducted at Buzzard's Bay, MA were successfully completed. The tests were organized by the MIT Sea Grant Office under ONR guidance to compare different undersea docking and homing technologies. The ability to dock an autonomous undersea vehicle with an underwater node to charge its battery and exchange data is critical to the overall AOSN concept. NRAD Code 746 was one of three participating groups bringing Odyssey vehicles outfitted with unique docking sensors to the test. The NRaD approach was based upon optical guidance, the EDC (Duke University) system upon magnetic guidance and the Wood's Hole Oceanographic Institute system employed acoustic guidance. Optical docking hardware and software designed to sense and home to a 40 Hz chopped light source (originally developed and tested for Flying Plug) was modified and integrated with the NRaD Odyssey test vehicle. System checkout trials were performed in San Diego Bay prior to the Buzzard's Bay experiment. On location, the NRaD docking system performed reliably: achieving acquisition ranges of up to 28 meters in the relatively clear, shallow water of Buzzard's Bay. Various search strategies were attempted: the out-and-back and survey raster missions proving most successful, but even unsuccessful strategies provided valuable system performance data.

The second half of FY96 involved integrating Flying Plug with the ULITE acoustic sensor array and developing software which enabled the Flying Plug to dock with a universal data node (Socket) design similar to the docking station which was previously deployed during the Buzzard's Bay trials. The first major goal during this period of time was to develop and debug the required software primitives and enough of the more advanced vehicle behaviors to conduct a basic acquisition and docking mission using the Flying Plug in San Diego Bay. San Diego Bay was selected for this demonstration due to the low cost required to conduct operations there, but its shallow, murky water and high acoustic noise levels make the operation of the Flying Plug system very difficult. Early testing was performed in the TRANSDEC test pool and consisted primarily of vehicle automatic control loop verification and tuning. The following autonomous behaviors (associated with given sensors) were implemented:

- Heading hold (using magnetic compass)
- Tilt and dive hold (using pitch pendulum)
- Depth hold (using hydrostatic pressure transducer)

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- Heading hold (using magnetic compass)
- Tilt and dive hold (using pitch pendulum)
- Depth hold (using hydrostatic pressure transducer)
- Acoustic-to-optical guidance handoff (using 4-quadrant optical docking sensor)

The acoustic homing system was checked out for proper operation and the emitted SPL levels were verified by direct measurement against a calibrated transducer. The "collision" and "dive and flare" high level vehicle behaviors were implemented utilizing the software primitives developed previously. The system was operated initially in TRANSDEC and subsequently in San Diego Bay once confidence that the hardware and software were performing reliably was established.

The earlier optical 100 MBit/sec video data transfer system was removed from the Flying Plug and the Socket data couplers and replaced by an optical system designed to transfer data from the ULITE acoustic sensor array at its native rate of 1.1 Mbit/sec. The new data coupler design utilized an array of IR-LED emitters, making it less sensitive to misalignment than the previous implementation. The data couplers were integrated with the Flying Plug vehicle, ULITE array and Socket in an end-to-end test and shown to perform in a non-critical and totally error-free manner preceding the docking trials. For purposes of preliminary system testing and debugging a simulated data signal was generated at the Socket instead of actually deploying the ULITE array each time tests were conducted.

Testing in San Diego Bay was pursued during the latter portion of FY96 and culminated with the Flying Plug vehicle docking reliably with the redesigned "universal" Socket, which had improved sensing (magnetic compass, orthogonal tilt pendulums), communications (serial RS-422) and latching (pressure-activated pistons) subsystems installed. The SeaGrant Odyssey vehicle is able to dock to the same Socket design (as verified earlier in the year in both San Diego and Buzzard's Bay), hence the "universal" designation for the docking station.

Visibility is typically less than 3 meters during summer months in San Diego Bay and the snapping shrimp also emit their highest acoustic levels during this time. Acoustic noise and the shallow operating area (approximately 10-13 meters) limited acoustic guidance to an effective maximum radius of less than 100 meters, and the reduced acquisition range of the optical tracker (less than 10 meters) resulted in a "sweet spot" for the acoustic to optical guidance handoff which was small, hence very critical. Nevertheless, by judicious adjustment of the mission parameters it was possible to launch the Flying Plug in autonomous mode, have it home acoustically to the Socket and automatically hand off to optical guidance after entering the light beam emitted by the docking beacon and dock. Latching and switching into data transfer mode were accomplished via manual switch over, and the vehicle's return to the pier was also accomplished under manual control.

The final test involved deploying both the Socket and the ULITE array (data source) in San Diego Bay and replacing the Socket test pattern generator with an interface to the ULITE fiber optic trunk cable. The Flying Plug docked multiple times with the Socket and each time it transferred real time data, error free to the ULITE analysis computer located on the pier (data sink). Thus, the final goal of the DSSN project was demonstrated.

TECHNICAL RESULTS Both a modified Odyssey UUV and the Flying Plug can dock with the universal Socket (docking station) for the ultimate purpose of interaction and cooperation. The Odyssey is a powerful, low-cost UUV platform which is potentially configurable for a wide variety of sensor and support operations. It represents emerging technology to support mobile, adaptable undersea surveillance sensor networks and unattended sensors. Integrating the ability to reliably dock an Odyssey UUV with a fixed docking station in order to recharge its batteries, transfer data or simply park during standby periods opens up an entirely new range of exciting surveillance applications. The Flying Plug underwater connectivity device can transfer meaningful surveillance data from an advanced data collector such as a ULITE array to a remote user. To our knowledge this is the first time that high speed digital data from an underwater surveillance array has been transferred in real time to a remote user with the data connections established after array deployment, broken off and reestablished multiple times. We believe that this connectivity device can transfer meaningful surveillance data from an advanced data collector such as a ULITE array to a remote user. To our knowledge this is the first time that high speed digital data from an underwater surveillance array has been transferred in real time to a remote user with the data connections established after array deployment, broken off and reestablished multiple times. We believe that this demonstration represents a new benchmark in the capability of underwater surveillance technology and enables an entirely new data flow architecture which is based upon the agile establishment (and disestablishment) of fiber optic data links upon demand.

It is believed that, with clearer ocean water, reduced acoustic noise from snapping shrimp and adequate operating depth to reduce the acoustic multipath, the acquisition, guidance and docking operations would be much easier to perform; making this series of tests in San Diego Bay a real "trial by fire" for the Flying Plug concept. We would expect the overall acoustic acquisition range of the prototype hardware to approach 300-350 meters using the current 170 KHz acoustic homing system and the size of the sweet spot for acoustic-to-optical handoff to become much larger, hence less critical, in typical coastal waters such as are located a few kilometers off the shoreline of Southern California.

SYSTEMS APPLICATIONS Collection and transmission of data gathered by a fleet of underwater platforms and unattended sensors and transmission to users. Underwater telephone booth for data connection of maritime and amphibious assets with the Global Grid. Periodic recovery of data from remotely-situated underwater sensors which have been deployed in denied areas.

TRANSITIONS None has been identified. Recommend a project be initiated by ONR to demonstrate that this capability can be achieved in deeper coastal water. Such a demonstrated capability could potentially lead to OPNAV and SYSCOM interest which leads to an Advanced Technology Demonstration or its equivalent.

RELATED PROJECTS No related work is currently ongoing in this area. DSSN was specifically funded by ONR as a one-year project which would be completed by FY97.

PUBLICATIONS APPLICATION OF ROBOTIC UNDERSEA VEHICLES TO UNDERWATER DATA CONNECTIVITY, Dr. Steve Cowen, Ms. Susan Briest and Mr. James Dombrowski of Naval Command, Control and Ocean Surveillance Center Advanced Concepts Branch in San Diego, California U.S.A. presented at PACON in Honolulu, HI on 20 June 1996.

FLYING PLUG: A SMALL UUV DESIGNED FOR SUBMARINE DATA CONNECTIVITY, Dr. Steve Cowen, Ms. Susan Briest and Mr. James Dombrowski of Naval Command, Control and Ocean Surveillance Center Advanced Concepts Branch in San Diego, California U.S.A. to be presented at 1997 Submarine Technology Symposium in Baltimore, MD.

PATENTS None

STATISTICAL INFORMATION

Number of Graduate Students	0
Number of Post-doctoral researchers	0
Number of females	2
Number of minorities	0
Presentations & briefings	2 conferences, approximately 50 briefings
Honors & awards	0
Service on committees, panels outside NRaD	0
Percent of funds sent to other performing organizations	0

Distributed Surveillance Sensor Network

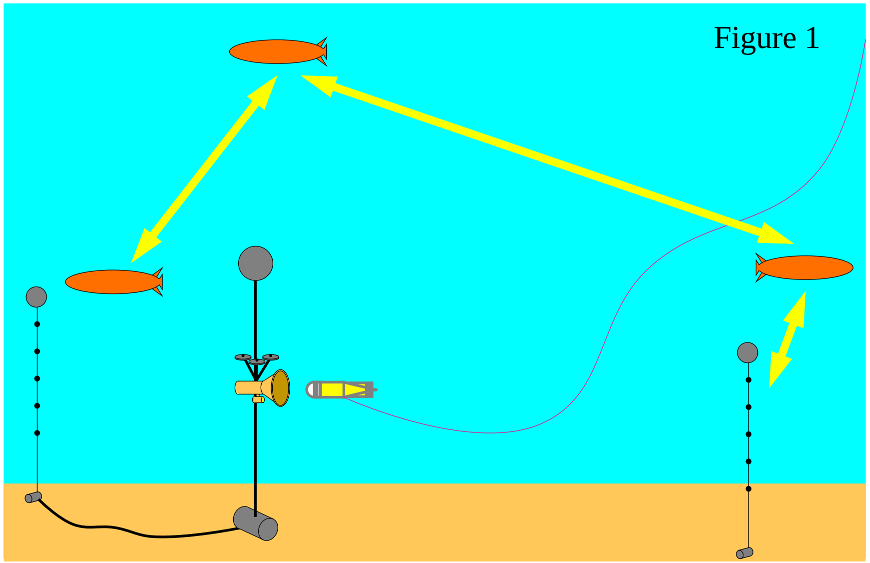

Figure 1

Project Objectives: Conduct a demonstration which passes data around in the ocean: simulating a mobile surveillance sensor network.

- **Modify an Odyssey UUV to enable docking to recharge batteries and transfer data**
- **Design universal docking station which is compatible with Odyssey and Flying Plug**
- **Interface ULITE acoustic surveillance array with docking station as data source**
- **Dock the Flying Plug UUV with the docking station and transfer ULITE data to the surface**

Technical Approach: Develop enabling technologies required to support the project objectives and demonstrate functionality in a littoral context.

- **Docking accomplished using optical terminal guidance to a beacon on docking station**
- **Dock using skeletal funnel permits simple, reliable coupler alignment after UUV entry**
- **Optical data transfer utilized to transmit ULITE digital data from Socket to Flying Plug**
- **Initial homing using high frequency acoustics with handoff to optical terminal guidance**

Accomplishments

Successfully performed docking using a modified Odyssey during FY96 Buzzard's Bay operations

Designed prototype docking station compatible with both the Odyssey and Flying Plug UUV's

Developed control software to enable Flying Plug to automatically home and dock with Socket

Successfully demonstrated docking and transfer of digital ULITE data on location in San Diego Bay

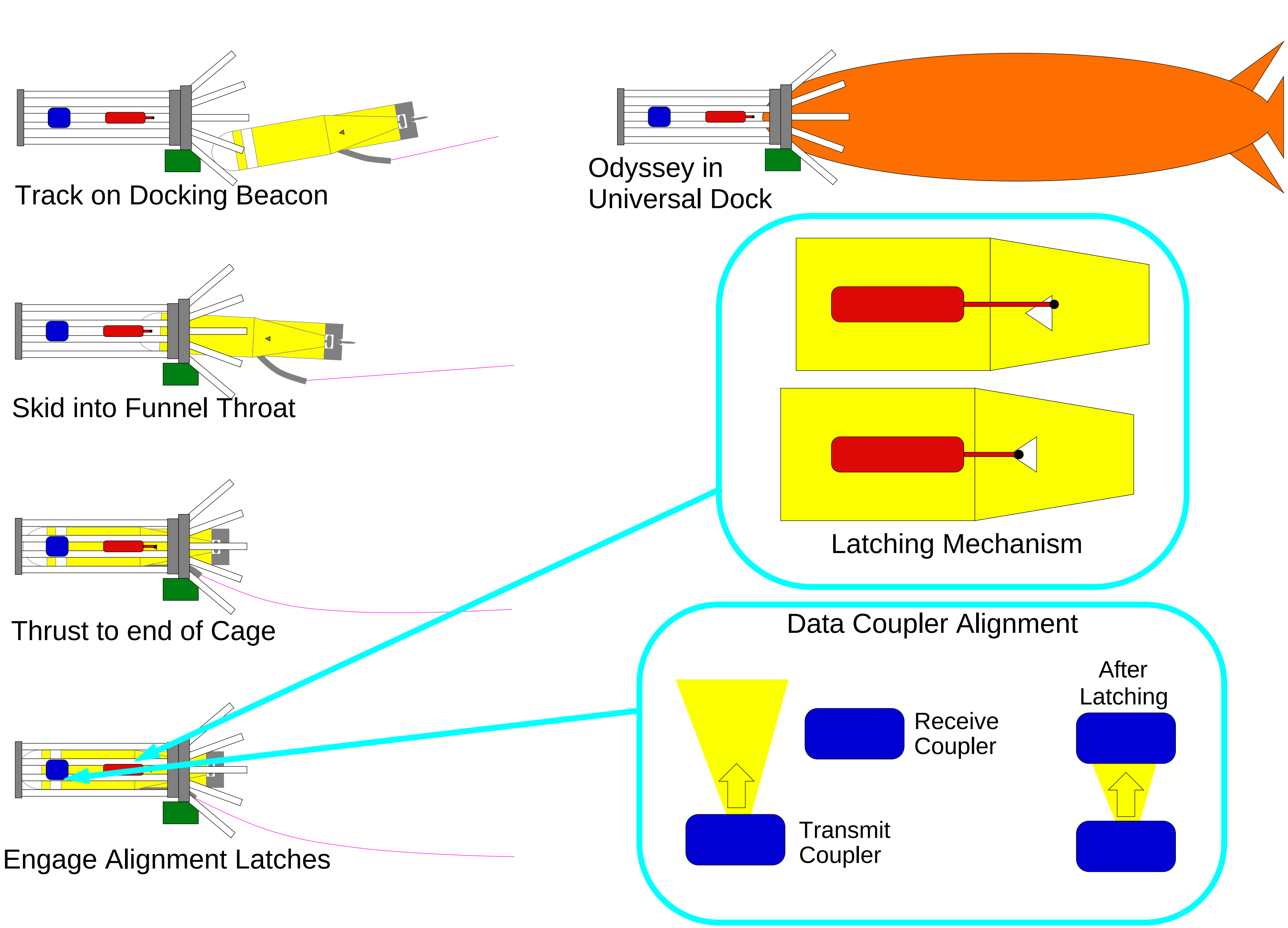

Figure 2: Details of Universal Docking Station

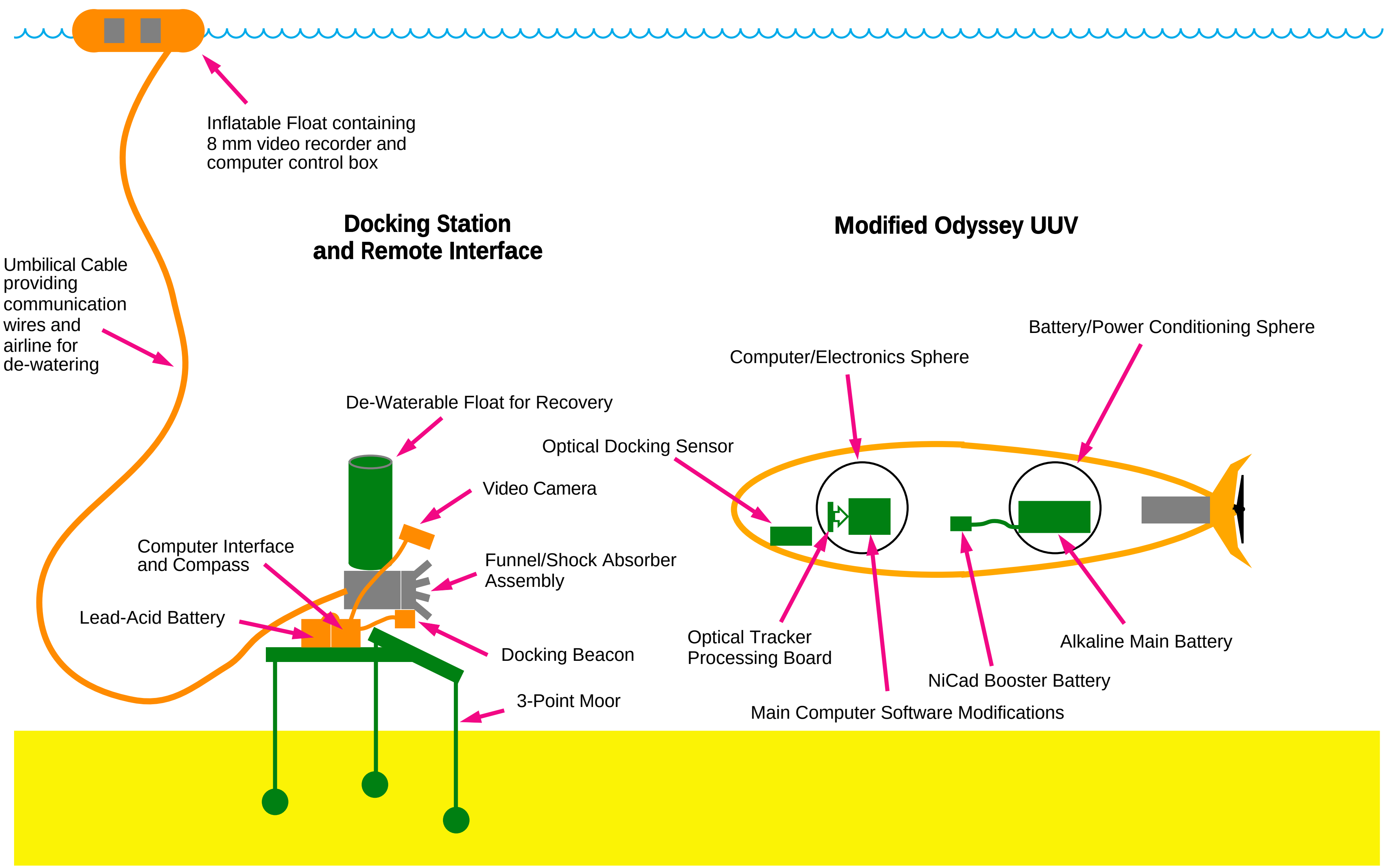

Figure 3: Docking Station and Modified Odyssey used at Buzzard's Bay Operation