Sensor Network Infrastructure: Moorings, Mobile Platforms, and Integrated Acoustics

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Abstract - **Much of the cost and effort of new ocean observatories will be in the infrastructure that directly supports sensors, such as moorings and mobile platforms, which in turn connect to a “backbone” infrastructure, such as cabled seafloor nodes. Three elements of this sensor network infrastructure are in various stages of development: a cable-connected mooring system with a profiler under real-time control with inductive battery charging; a glider with integrated acoustic communications and broadband receiving capability; and integrated acoustic navigation, communications, and tomography, and ambient sound recording on various scales.**

I. INTRODUCTION

There is currently much activity within the oceanographic community to develop many types of sensor networks: mobile, fixed, autonomous, and cabled. Several specific developments are reported here. The first is the development of a fixed mooring system, with a vertical profiler, cabled to shore (Section II). While early design considerations and development have been presented [1, 2, 3], there has been substantial progress. Gliding autonomous vehicles extend the spatial footprint of fixed systems. The University of Washington Seaglider has been equipped with a passive receiving hydrophone and an acoustic modem as one step in this process. Results from three field experiments are described (Section III). These two components – the mooring and acoustic Seaglider – are using acoustics to provide a unifying framework to connect fixed and mobile systems [4, 5, 6]. In future work, network-capable modem-equipped acoustic Seagliders will fly around the mooring system to demonstrate integrated precise timing, navigation, and communications, combined with science (Section IV). Future directions are given in Section V.

II. MOORING SYSTEM

To enable better vertical sampling of the ocean, a moored profiler system is being developed to connect to a cabled observatory node, thereby removing power as the major constraining factor (Figure 1) [7, 8, 9, 10]. A profiler docking station with an inductive coupler will transfer 200 W to the profiler, enabling a 95% duty cycle (Figure 2). Further, two-way inductive communications will be used to offload profiler data at modest rates in real time as well as transfer adaptive sampling commands. Secondary junction boxes on the subsurface float (Figure 3) and on the seafloor (Figure 4) will provide several hundred watts, 100 Mb/s Ethernet, and precise time to users, and be ROV-serviceable. Instrument packages (e.g., Figure 3) can be added on the subsurface float, such as a winched profiling system to carry point and remote sensors through the mixed layer to the surface.

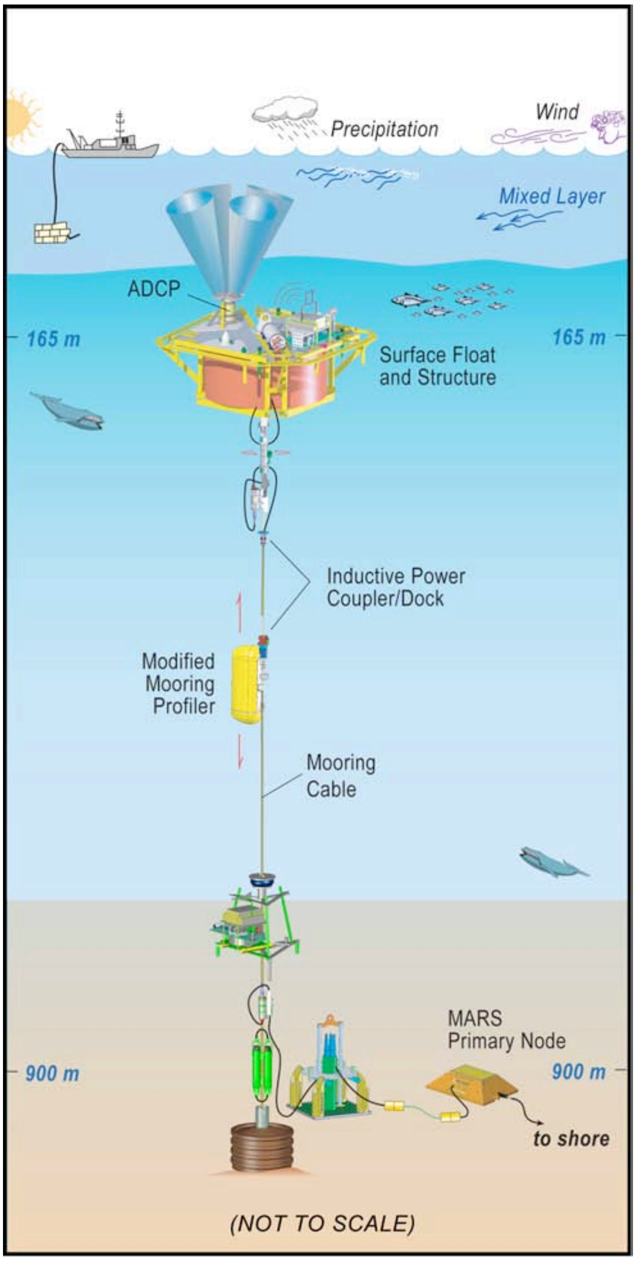

Figure 1. Schematic of the mooring system

The mooring system is considered a prototype for those called for in the planning for the ORION NEPTUNE regional cabled observatory project in the northeast Pacific [11, 12, 13, 14, 15, 16, 17, 18]. This particular mooring will be tested in April 2007 in Puget Sound and deployed on the MARS cabled observatory system in Monterey Bay, California, in 900 m of water in November 2007 [19]. At the time of this writing, a simple node has been installed at the APL-UW/OSC Marine Technology Seahurst Observatory in Puget Sound, just west of Sea-Tac International Airport. This node and associated sensors will be used for testing, and as part of an education program by the Sea-Tac Occupational Skills Center Marine Technology Program. A camera on the node took the picture shown in Figure 5.


Figure 2. The inductive power system coupler


Figure 3. The subsurface float and secondary node, with instrument package and ADCP

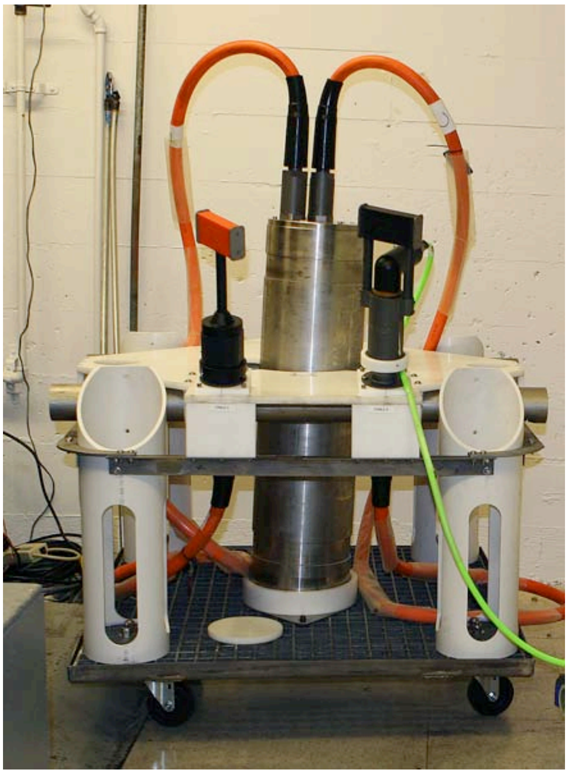
Figure 4. The seafloor secondary node

Figure 5. A picture from the Seahurst node – a harbor seal in the foreground

III. ACOUSTIC SEAGLIDER

Mobile acoustic nodes are essential elements of an ocean observing/surveillance system. These nodes are necessary to provide precise time, navigation, and communications infrastructure services [20]. Further, the acoustic receiving capability can serve multiple purposes: tactical sensing, tomography, and ambient sound recording (seismics, wind, rain, marine mammals). These will be useful tools for basic and applied research on temporal and spatial signal and noise coherence and coherent processing.

The short-term objective of the present work has been to integrate, demonstrate, and use acoustic communications and receiving capability in a Seaglider (Figure 6). Seagliders were equipped with a broadband hydrophone (5 Hz–30 kHz) acoustic receiver system (ARS) and a WHOI micromodem, operating in this case at

25 kHz [21]. The ARS can store raw data on a 60-GB disc as well as send back computed power spectra. The ARS is synchronized to GPS when at the surface, with 1 ms accuracy maintained during dive cycles. When on the surface, the glider communicates with shore-based pilots using the Iridium satellite system.

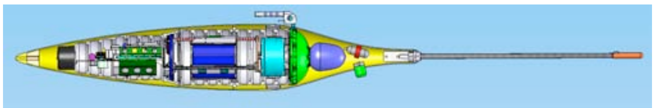

Figure 6. Schematic of the acoustic Seaglider with the hydrophone and modem in the tail

The gliders were used in three experiments:

1. LWAD-06 (29–30 July 2006, SG022, 14 dives): Measured signal transmission loss as a function of range, made ambient sound and temperature/salinity measurements in the Philippine Sea.
2. MB06 [12–25 August 2006, three gliders (number of dives), SG022 (61), SG023 (83), SG106 (131)]: In this major multi-project experiment in Monterey Bay, the acoustic Seaglider served as a communications gateway for subsea assets “talking” with shore via acoustic modem and satellite links. This was an important demonstration for the concept of undersea persistent surveillance.
3. Kauai (31 August–8 October 2006, SG023, 143 dives): Listened to the NPAL/ATOC 75-Hz source as a function of range and depth to demonstrate tomography signal reception, study signal coherence, long-range communication capability, and to collect ambient sound data.

A few illustrative results from these experiments follow. It should be noted that oceanographic data (temperature and salinity) are also routinely collected, and for MB06, assimilated into ocean models (Harvard and JPL) in near real time.

A. Acoustic Communications and Navigation

During MB06 glider SG106 relayed commands successfully from shore to a bottom-mounted University of Texas/ARL array and relayed associated status messages from the array back to shore. These demonstrated the capability for the acoustic Seaglider to serve as a communications gateway for subsea assets “talking” with shore via acoustic modem and satellite links. Ranges to ~4 km were achieved in ~100 m water depth with a small bias to deeper depths due to the downward refracting sound speed profile (Figure 7). In addition, one glider was tracked by MIT kayaks.

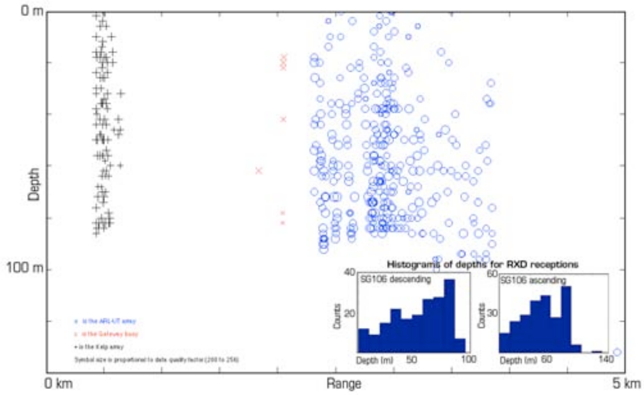

Figure 7. Depth and range positions where modem communications occurred

B. Signals

During LWAD low-frequency signals transmitted by a nearby ship as well as signals from a distant ship/source were received clearly. The “Lubell” source was received and Doppler measured during MB06. Off Kauai, the NPAL/ATOC transmissions at 75 Hz were received; coherent processing was possible (with 10 dB of gain) with the glider moving 136 m horizontally, 33 m vertically, and over a 12-minute period. Figure 8 shows relative travel time increasing by 3.8 ms (5.5 m)/27.28 s block, equivalent to 0.20 m/s, consistent with measured Doppler shift.

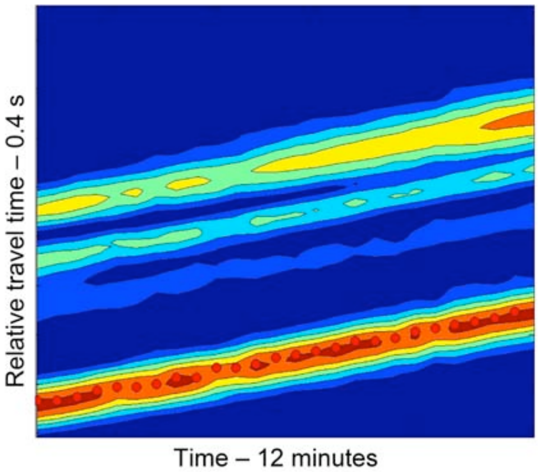

Figure 8. ATOC/NPAL acoustic transmissions received on the acoustic Seaglider

C. Ambient Sound

Average spectra were obtained in all locations. Many marine mammals were detected during MB06 (blue, fin, humpback, sperm, possibly killer whales, sea lions; Figure 9). The modem communications traffic was also detected on the broadband hydrophone (not shown).

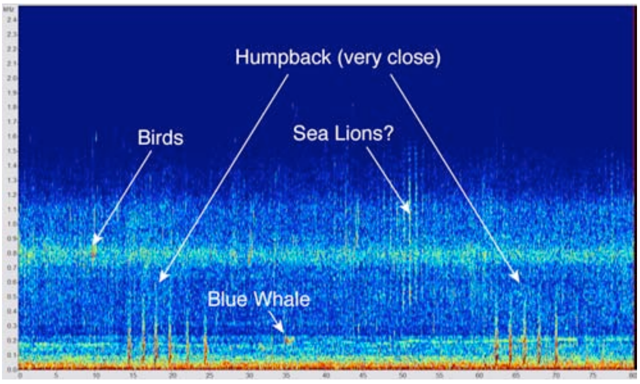

Figure 9. Marine animal sounds from MB06

IV. TOWARD INTEGRATION

When the mooring is deployed in Monterey Bay, several WHOI micromodems will be deployed with it and on the seafloor. Several gliders with modems will fly around the mooring, all communicating with one another, to test and demonstrate acoustic communications network protocols, and how to handle multiple units communicating at the same time in an environment with large latency and delays (Figure 10). This is one step toward using gliders (and other mobile platforms) as communications gateways, transporting data and commands between subsea platforms and shore via Iridium, as well as for integrating multi-scale navigation and acoustic tomography in such systems [22, 23, 24, 25, 26, 27].

V. CONCLUDING REMARKS

These sensor network infrastructure developments enable a wide range of new sensing modalities with fixed and mobile systems. On the mooring, one can put easily serviced winch systems [28] to sample the upper ocean and complex instruments (e.g., mass spectrometers, environmental sampling processors, acoustic imaging and tomography systems [29]). In addition to conventional ocean sampling, the mobile platforms can serve as data trucks, launched from a pier, going to remote areas (e.g., Southern Ocean) to retrieve data from long lasting robust instrumentation. This work continues efforts to provide essential infrastructure elements throughout the ocean volume – power, precise timing, communications, and navigation – necessary for any and all ocean observing efforts.

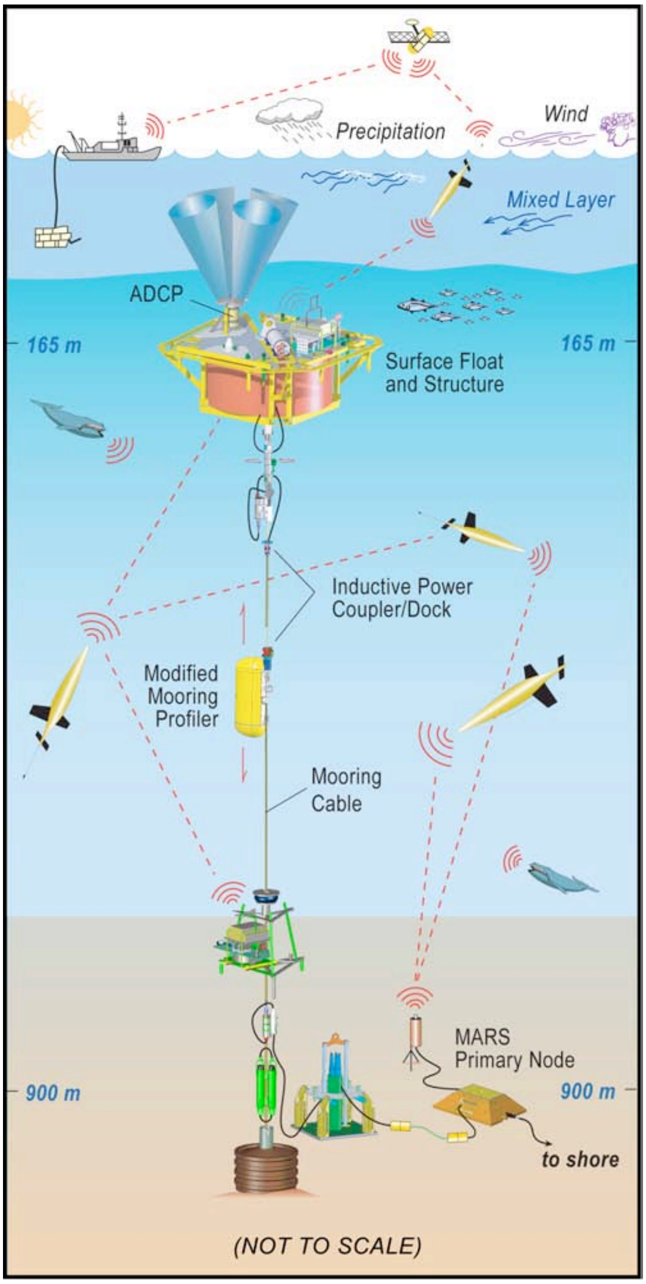

Figure 10. Combined mobile and fixed sensor network

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REFERENCES

[1] B.M. Howe and T. McGinnis, "Sensor networks for cabled ocean observatories," *Proceedings, Scientific Submarine Cable 2003 Workshop, University of Tokyo, 25–27 June 2003*, pp. 216–221.

[2] B.M. Howe, T. McGinnis, and J. Gobat, "Moorings for Ocean Observatories: Continuous, Adaptive Profiling," *International Ocean Research Conference, Paris, France, June 2005*. (poster presentation)

[3] B.M. Howe, T. McGinnis, and J. Gobat, "Moorings for Ocean Observatories: Continuous and Adaptive Sampling," *Proceedings, Scientific Submarine Cable 2006 Conference, Marine Institute, Dublin Castle, Dublin, Ireland, 7–10 February 2006*, pp. 172–181.

[4] C.C. Eriksen, T. J. Osse, R.D. Light, T. Wen, T.W. Lehman, P.L. Sabin, J.W. Ballard, and A.M. Chiodi, "Seaglider: A long-range autonomous underwater vehicle for oceanographic research," *IEEE J. Ocean. Eng*., 26, pp. 424–436, 2001.

[5] M.J. Perry and D.L. Rudnick, "Observing the ocean with autonomous and Lagrangian platforms and sensors: The role of ALPS in sustained ocean observing systems," *Oceanography*, 16, pp. 31–36, 2003.

[6] D.L. Rudnick, R.E. Davis, C.C. Eriksen, D.M. Fratantoni, and M.J. Perry, "Underwater gliders for ocean research," *Mar. Technol. Soc. J.*, 38, pp. 73–84, 2004.

[7] B.M. Howe, et al., ALOHA-MARS Mooring Project, http:// www.alohamooring.apl.washington.edu.

[8] B.M. Howe and T. McGinnis, “Sensor networks for cabled ocean observatories,” *Proceedings, Scientific Submarine Cable 2003 Workshop, University of Tokyo, 25–27 June 2003*, pp. 216–221.

[9] ALOHA Observatory, http://kela.soest.hawaii.edu/ALOHA

[10] B.M. Howe, et al., *SENSORS: ALOHA Observatory Mooring and Adaptive Sampling* (National Science Foundation funded grant proposal), 2003. http://kela.soest.hawaii.edu/ALOHA/NSF_Mooring_Fastlane_20030306_Text.pdf.

[11] NEPTUNE Phase 1 Partners (University of Washington, Woods Hole Oceanographic Institution, Jet Propulsion Laboratory, Pacific Marine Environmental Laboratory), *Real-time, Long-term Ocean and Earth Studies at the Scale of a Tectonic Plate. NEPTUNE Feasibility Study* (prepared for the National Oceanographic Partnership Program), University of Washington, Seattle, 2000. http://www.neptune.washington.edu.

[12] H.L. Clark, “New sea floor observatory networks in support of ocean science research,” *Proceedings, Oceans 2001 MTS/IEEE Conference, Honolulu, Hawaii, 5–8 November 2001*.

[13] G.M. Purdy and D. Karl (eds.), *RECONN: Regional Cabled Observatory Networks (of Networks)*. A report to the National Science Foundation on the Cabled Regional Observatory Workshop, 2004, 64 pp. http://www.geo-prose.com/cabled_wksp/mtg_report.html

[14] B.M. Howe, et al., *Science Planning for the NEPTUNE Regional Cabled Observatory in the Northeast Pacific Ocean: Report of the NEPTUNE Pacific Northwest Workshop, Portland State University, Portland, Oregon, 2003*, 72 pp. http://www.neptune.washington.edu/pub/workshops/PNW_Workshop/ws_reports_documents.html

[15] Ocean Research Interactive Observing Networks (ORION), http://www.orionprogram.org

[16] K. Brink, et al., *Ocean Observatories Initiative Science Plan*, 2005, 102 pp. http://www.orionprogram.org/PDFs/OOI_Science_Plan.pdf

[17] K.L. Daly et al., *An Interdisciplinary Ocean Observatory Linking Ocean Dynamics, Climate, and Ecosystem Response from Basin to Regional Scales*, ORION RFA Concept proposal, 2005. http://www.orionprogram.org/RFA/Abstracts/daly.html

[18] J.M. Barth, et al., *A Multi-Scale Ocean Observatory for Ocean Dynamics and Ecosystem Response along the Northeast Pacific Continental Margin*, http://www.orionprogram.org/RFA/Abstracts/barth.html

[19] *Monterey Accelerated Research System (MARS)*, http://www.mbari.org/mars/

[20] L. Freitag, M. Grund, S. Singh, and M. Stojanovic, "Acoustic communications for seaflorr observatories," *Proceedings, Scientific Submarine Cable 2006 Conference, Marine Institute, Dublin Castle, Dublin, Ireland, 7–10 February 2006*, pp. 244–250.

[21] Acoustic Communications, Woods Hole Oceanographic Institution, http://acomms.whoi.edu/

[22] P.F. Worcester, et al., *Gyre-scale Ocean Heat Content and Dynamics: Integral Constraints from Acoustic Remote Sensing*, ORION RFA Concept proposal, 2005, http://www.orionprogram.org/RFA/Abstracts/worcester.html

[23] T. Duda, et al., *Basin-scale Float Tracking and Ocean Interior Remote Sensing*, ORION RFA Concept proposal, 2005, http://www.orionprogram.org/RFA/Abstracts/duda.html

[24] *Integrated Acoustics Systems for Ocean Observations (IASOO)*, http://www.oce.uri.edu/ao/AOWEBPAGE

[25] B.M. Howe and J. H. Miller, “Acoustic sensing for ocean research,” *Mar. Technol. Soc. J.*, 38, pp. 144–154, 2004.

[26] T.F. Duda, B.M. Howe, and J.H. Miller, “Acoustics in global process ocean observatories,” *Sea Technol.*, 48, pp. 35–38, 2007.

[27] J.H. Elisseeff, P.H. Schmidt, and W. Xu, "Ocean acoustic tomography as a data assimilation problem," *IEEE J. Ocean. Eng*., 27, pp. 275–282, 2002.

[28] P.L. Donaghay, “Profiling systems for understanding the dynamics and impacts of thin layers of harmful algae in stratified coastal waters,” *Proceedings, 4th Irish Marine Biotoxin Science Workshop*, 2004, pp. 44–53.

[29] K.L. Daly, R.H. Byrne, A.G. Dickson, S.M. Gallager, M.J. Perry, and M.K. Tivey, “Chemical and biological sensors for time-series research: Current status and new directions,” *Mar. Technol. Soc. J.*, 38, pp. 121–143, 2004.