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Woods Hole Oceanographic Institution

Advanced Engineering Laboratory Project Summaries: 1995–1996

Editor: Daniel E. Frye

July 1997

Technical Report

Funding was provided by the Applied Ocean Physics & Engineering Department of the Woods Hole Oceanographic Institution.

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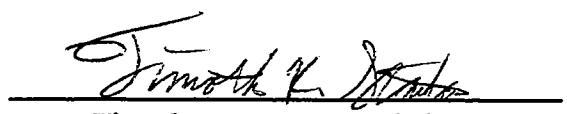

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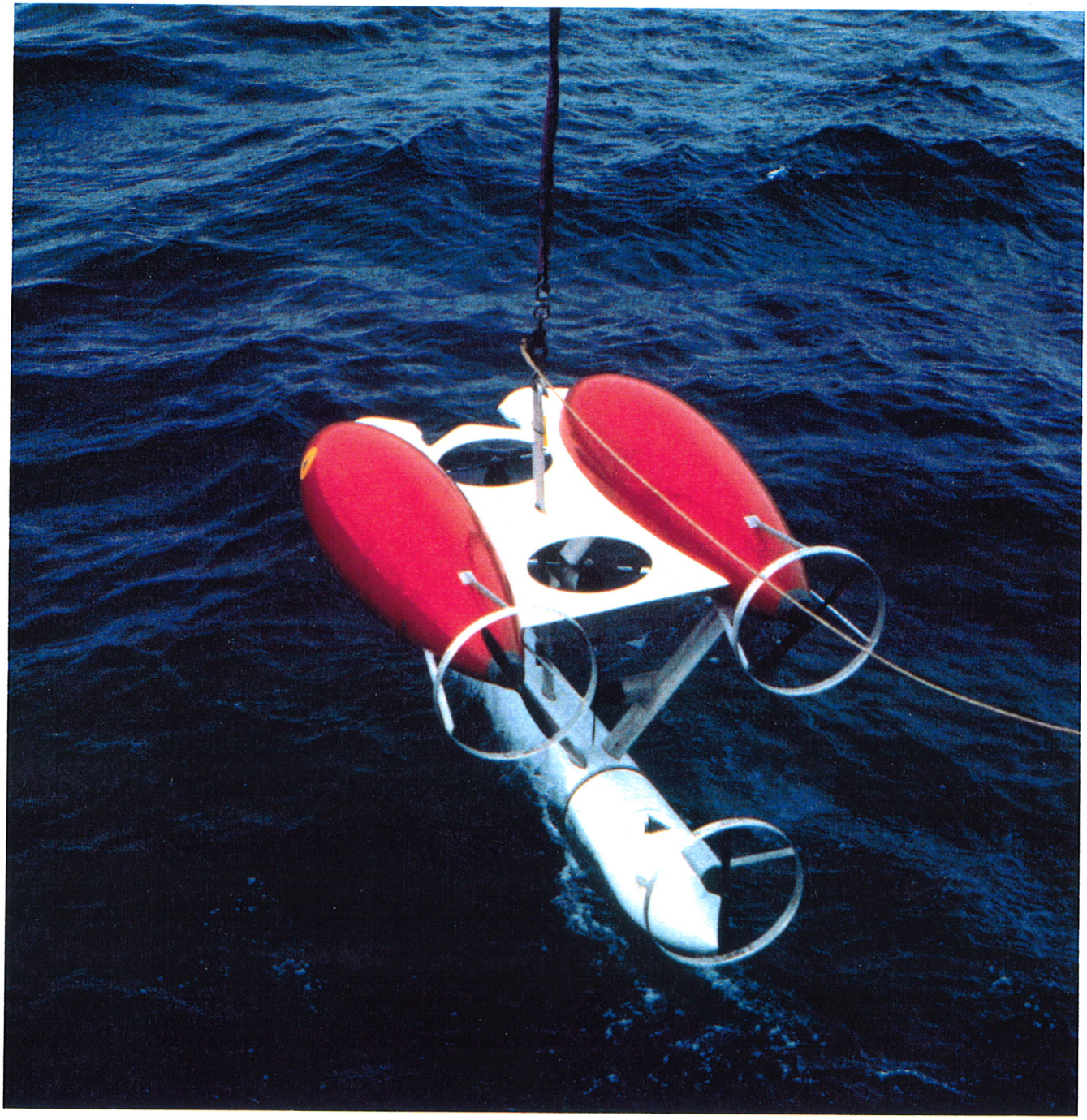
Department of Applied Ocean Physics and Engineering



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ABSTRACT

The Advanced Engineering Laboratory of the Woods Hole Oceanographic Institution is a development laboratory within the Applied Ocean Physics and Engineering Department. Its function is the development of oceanographic instrumentation to test developing theories in oceanography and to enhance current research projects in other disciplines within the community. This report summarizes recent and ongoing projects performed by members of this laboratory.

Photo on frontispiece: First deep-ocean deployment of the Autonomous Benthic Explorer (ABE) offshore Bermuda, 1993.

An AB(l)E Bodied Vehicle

Albert M. Bradley, Dana R. Yoerger and Barrie B. Walden

ABSTRACT

The Autonomous Benthic Explorer, known to its friends as ABE, is a robotic vehicle designed for deep-ocean exploration and monitoring. ABE is an example of the class of systems known as Autonomous Underwater Vehicles, or AUVs, that are being developed for a variety of missions by military and civilian groups. ABE is different from most of the other AUVs under development in that it is designed for long-term monitoring missions and will spend the majority of its time asleep, attached to a simple hitching post near the area of interest. At regular intervals ABE will wake up, let go of the latch, and, using an acoustic navigation system to guide its movements, travel around its survey area taking video snapshots and making a variety of measurements. At the end of the survey, ABE will return to its hitching post, latch on, and like a mountain climber roped into a hammock on the face of cliff, simply go to sleep until the next scheduled survey.

Funding provided by: National Science Foundation under Grant OCE-92-16775.

Published in *Oceanus*, Vol. 38, No. 1, Spring/Summer 1995, pp 18-20.

The AMS Operating System: A Prototyping Environment for Signal Processing

Matthew Grund and Mark Johnson

ABSTRACT

The major focus of the Acoustic Telemetry Group at Woods Hole Oceanographic Institution has been the development of underwater acoustic communication and remote sensing devices. These are typically deployed in buoys, underwater vehicles, or in ocean-bottom packages. The devices communicate acoustically with a surface station, conveying scientific results to observers, and accepting commands.

A significant milestone in the evolution of such platforms has been the development of an operating system (called AMS) for embedded signal processing. This system allows rapid algorithm prototyping using a high-level, matrix-based language specialized to DSP targets and real-time data-flow processing. A key feature of AMS, distinguishing it from other high-level DSP specification software, is that the language is interpreted as well as executed by the target DSP. Performance is maintained by (i) coding time-critical algorithm steps in C or assembly language, and (ii) using multiple DSP devices in a loosely-coupled network.

In this paper, the motivation for, and development of, the AMS Operating System are reviewed. The potential for rapid algorithm prototyping using AMS is demonstrated by way of two applications in underwater acoustic signal processing.

Funding provided by: Advanced Research Projects Agency MDA-972-94-10016.

Published in IEEE International Workshop for Rapid Systems Prototyping, North Carolina, June 7-9, 1995, pp 182-186.

Analysis of the Impact of Channel Estimation Errors on the Performance of a Decision Feedback Equalizer in Fading Multipath Channels

Milica Stojanovic, John G. Proakis and Josko Catipovic

ABSTRACT

A coherent receiver with a decision feedback equalizer (DFE) operating on a Rayleigh fading channel under a suitable adaptive algorithm is considered. In the analysis of a DFE, a common assumption is that the receiver has perfect knowledge of the channel impulse response. However, this is not the case in practice, and for a rapidly fading channel, errors in channel tracking can become significant. We analyze theoretically the impact of these errors on the performance of a multichannel DFE. The expressions obtained for the achievable average MPSK bit error probabilities depend on the estimation error covariance. In order to specify this matrix, we focus on a special case when a Kalman filter is used as an optimal channel estimator. In this case, the probability of bit error can be assessed directly in terms of channel fading model parameters, the most interesting of which is the fading rate. Our results show the penalty imposed by imperfect channel estimation, as well as the fading induced irreducible error rates.

Funding provided by: Office of Naval Research Contract MDA972-91-J-1004.

Published in IEEE Transactions on Communication, Vol. 43, No. 3, March 1995, p 877-886.

The Atlantic Long Term Oceanographic Mooring (ALTOMOOR)

**Daniel Frye, Steve Merriam, Bob Eastwood, John Kemp,
Neil McPhee, Steve Liberatore, Ed Hobart,
Alex Bocconcelli and Susan Tarbell**

ABSTRACT

The Atlantic Long-Term Oceanographic Mooring (ALTOMOOR) has been maintained offshore Bermuda since 1993 as a testbed for the evaluation of new data telemetry technologies and new oceanographic instrumentation. It is currently a joint project between the Woods Hole Oceanographic Institution and the University of Southern California. This report documents the WHOI contributions which have focused on development of new data telemetry methods and new mooring technology. Details of the instrumentation evaluations will be published separately.

A new inductively-coupled telemetry technology for ocean moorings was developed and tested on ALTOMOOR. The inductive link uses standard plastic-jacketed mooring wire as the transmission path for data generated at the individual instruments installed on the mooring. The signals are inductively linked to the mooring wire via toroids clamped around the wire, thus avoiding the need for multiconductor electromechanical cables terminated at each instrument. Seawater provides the electrical return path. The inductive modems send and receive data at 1200 b/s. A controller in the surface buoy collects data from each of the subsurface instruments and forwards the data to shore by traditional satellite telemetry (Argos) and by short range radio using a nearby ship as a store and forward node. The buoy-to-ship link operates over about 2 km at 20 kBytes/sec. When the ship docks, data are offloaded automatically to a computer on shore which can be accessed via Internet.

Funding Provided by: Office of Naval Research - Ocean Engineering and Marine Systems under Contract Nos. N000-14-90-J-1719 and N000-14-94-0346. The National Science Foundation's Ocean Technology Program provided funding to USC under Grant OCE-96-27281 for much of the instrumentation and scientific data collection performed on ALTOMOOR.

Published in Woods Hole Oceanographic Institution Tech. Rpt. WHOI 96-02, March 1996.

The Autonomous Benthic Explorer: an Instrument for Deep Ocean Survey

A. M. Bradley and D. R. Yoerger

ABSTRACT

The Autonomous Benthic Explorer (ABE) is a vehicle designed to perform autonomous long-term repeated surveys in the deep ocean. ABE has a working depth of over 4500m and, depending on type of batteries used, can travel between 10 and 100 km at a speed of 1 to 2 knots. ABE can hover, maneuver in three axes and follow bottom contours within a few meters. It navigates in an acoustic net using two or more transponders and can glide to a specified spot using minimal power while descending to the work area. ABE currently carries sensors for salinity, temperature, magnetic field and distance off the bottom. It also utilizes a snap-shot video system to record stress image pairs digitally on an internal hard disk. Additional sensors can be easily accommodated.

ABE has performed near bottom surveys of magnetic anomalies along a tectonically active segment of the Juan de Fuca Ridge. ABE has also mapped a hydrothermal plume from an area of diffuse venting along the ridge axis. The stereo video images accurately record benthic geography and plume activity.

Based on our experience with ABE, we present a series of suggested scenarios for supporting scientific studies with AUVs. These include using an AUV in conjunction with a manned submersible to preview areas for potential detailed study, using an ROV to pre-survey a site for long term deployment of an AUV with docking capability, and using an AUV to iteratively survey a site without additional support.

Funding provided by: National Science Foundation under Grant No. OCE-92-16775.

Presented at the AGU/ASLO Ocean Sciences Meeting, San Diego, CA, February 12-16, 1996.

The Bermuda Testbed Mooring Program

T. Dickey, D. Frye, M. Stramska, H. Jannasch, E. Boyle, D. Manov, D. Sigurdson and A. Michaels

ABSTRACT

A mooring has been in operation over one year near Bermuda to provide the oceanographic community with a deep-water testbed for developing, testing, calibrating and intercomparing instrument systems under funding from NSF, ONR, and NASA. The mooring is near the JGOFS Bermuda Atlantic Time Series (BATS) station, 80 km southwest of Bermuda (water depth of 4567 meters). A rich historical database is available from the nearby 40-year Hydrostation S program and the more recent BATS activity. Several complementary sampling programs take place near the site. These include: sediment trap sampling, atmospheric sampling, and monthly cruises to obtain comprehensive physical, chemical, biological and optical measurements as part of the BATS program. Local area coverage remote sensing data are available from BBSR. The R/V Weatherbird II, a 115 foot UNOLS research vessel, is used to execute monthly time-series studies, service the mooring (every 4 months), and conduct specialized cruises. Presently, basic meteorological measurements are made from the buoy tower. Currents (fixed depth and ADCP profiles), temperature, conductivity, several inherent and apparent optical properties, dissolved oxygen, and nitrate are being measured every few minutes at several depths. A clean water sampler is being used to collect samples every two weeks for trace element analysis. Several data types are sent to shore in near-real time. It is anticipated that sensors, analyzers, and systems tested on the mooring may eventually be used on shipboard sampling systems, drifters, ROVs, and AUVs as well as moorings.

Interestingly, Hurricane Felix passed very close to the mooring August 15, 1995 providing both an exceptional test of mooring hardware and instrumented systems as well as an extraordinary data set. Examples of data collected from the mooring will be presented. Investigators interested in participating in the Bermuda Testbed project are encouraged to contact Tommy D. Dickey.

Funding provided by: Office of Naval Research under Contract N000-14-94-1-0346 and NSF under contract OCE-96-27281 (to USC).

Presented at the AGU/ASLO Ocean Sciences Meeting, San Diego, CA, February 12-16, 1996.

Development and Testing of Thermocouple/Thermistor Array Packages for Monitoring Temperature at Hydrothermal Vent Sites

A. M. Bradley, M. K. Tivey, S. P. Liberatore and A. R. Duester

ABSTRACT

Two temperature monitoring instruments used for in-situ long-term monitoring of vent phenomena were developed and deployed August 6, 1994 at the Monolith and Table vents on the northern Cleft Segment, Juan de Fuca Ridge. They were recovered June 27, 1995. The time-series approach produced continuous records of fluid temperatures, recorded once per minute, at 18 to 20 discrete points in each of 4 areas (2 sites of high temperature venting and 2 sites of lower temperature diffuse flow). These data are now being analyzed, and results will be presented. Each instrument package consists of a central data logger with cables leading to discrete sensor modules. Each module contains a microprocessor for coordinating the multiplexing of the sensors and the analog to digital conversion. The module also contains the thermocouples' cold junction and a thermistor to monitor the cold junction. The sensor modules are designed to serve both thermistors and thermocouples (up to 48 total per module). The large number of sensing points can provide a 3-dimensional array of data. Configuration of the sensor arrays is simple and flexible. We have created a "tinker-toy" set of temperature sensors, with 6 clusters of 8 thermocouples or thermistors per module that can be adapted in a few hours to a selected site. The ability to have several independent sensor modules allows multiple target sites to be recorded simultaneously. An inductively coupled link that allows communication with the instrument packages from the submersible by bringing a 4" diameter communication coil within 2" of the companion mounted on the instrument was also developed. Actual physical or electrical contact is unnecessary. The link hardware allows half duplex bidirectional communication from the sub to the deployed instrument. It was used to monitor how well the equipment was working during descent to the seafloor, and to verify that the sensors had been placed in areas of elevated temperatures. The instrument packages were designed to become a component of an ocean bottom observatory. Additional sensors (e.g. flow velocity, pH, salinity, etc.) can easily be added to the instrument packages due to the bus structure. We anticipate that these instruments will be continually upgraded as additional sensors are developed.

Funding provided by: National Science Foundation Grant OCE-93-00434.

Published in Proceedings, AGU 1995 Meeting, San Francisco, CA, December 11-15, 1995.

Development of an Unattended Gas Chromatography System for the Investigation of Sea-Air Gas Exchange

John Dacey and Robin Singer

Quantifying the dynamics of trace gases at the ocean surface is critical to understanding key problems in the global climate. One of the more important gases in this respect is dimethylsulfide (DMS) which is formed in the upper ocean. The concentration of DMS in the upper ocean is very dynamic: it is determined by myriad biological, chemical and physical processes. After entering the atmosphere, DMS oxidizes to compounds which tend to form aerosols in the lower troposphere. These aerosols may affect earth's radiation balance by reflecting incoming solar radiation back to space.

In order to examine the kinetics of exchange of DMS, an automated gas chromatography system was developed for deployment on R/P FLIP as part of the NSF Coastal Ocean Processes / ONR Marine Boundary Layer experiment in April-May, 1995. The principal goal of the project was to make the first simultaneous measurements of DMS profiles in the water column and in the atmosphere to estimate the rate of DMS flux to the atmosphere under a range of meteorological conditions. The second goal was to increase our understanding into the nature and causes of the temporal variability of DMS on the time scale of hours to days.

These research goals drove the development of an instrument capable of collecting and analyzing closely spaced samples of seawater and air. A modular sampling and GC analytical system was developed and deployed on R/P FLIP and after a substantial number of unexpected problems were solved, data was acquired during the final days of the cruise. Having been built and tested at sea, the instrument is now ready for further research with little modification.

The analytical hardware centers on a gas chromatograph (Figure 1). In this case a Varian pulsed flame photometric detector (PFPD) was used for sample analysis, but the system could work equally well with other chromatographs and other detectors. The PFPD detector was a new product from Varian, promising increased sensitivity and selectivity over the older steady-state FPD. A 24-bit relay board controlled a series of solenoid flow sampling valves and pneumatically-actuated sampling syringes for flushing sampling tubing and for sample collection. Samples were concentrated on a gold wool trap on a 6-port rotary valve, were desorbed by heating and were injected into the GC for quantification.

The system controller consists of an NEC Versa 486 laptop PC with two commercially available add-on boards, the ComputerBoards PCM-DAS-16 12-bit Analog to Digital converter and the ComputerBoards 24-bit Digital I/O board, residing in the two Type II PCMCIA slots of the laptop. The controller provides both manual and automatic control of the gas measurement system and acquires, stores, and displays the measurements. The program, written in Microsoft Visual Basic, operates under the Microsoft WINDOWS 3.1 operating system, making the data

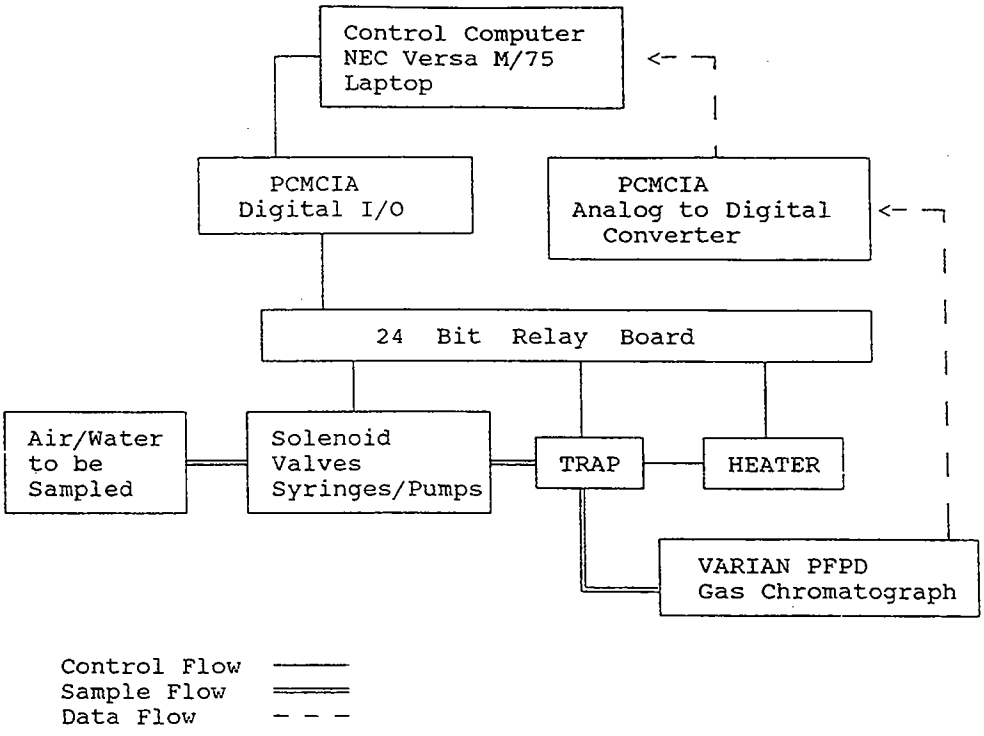


Figure 1: Unattended Trace Gas Measurement System

easily accessible for use with other Microsoft WINDOWS and MSDOS programs. Manual operation gives the user control of the individual hardware units. The relays, the analog to digital converter, and the clock can each be controlled with a Visual Basic form for use during system testing.

Automatic operation of the system is highly configurable for optimum system development. The user can set up schedules for both water and air sampling times by typing in the times on a list and can remove them by double clicking. The sequence of the sample analysis along a sampling profile is programmable so that random orders can be used to avoid sampling order artifacts. The water depths and air elevations for sampling points and the valve locations (and concentrations) of standards are entered by the operator on the settings form for documentation. The system time can be set from within the program to synchronize with related measurements. A variety of automatic timing parameters, such as "water sample fill time", "air flush empty time", "sparge time", and "trap heat time" determine the rate of sampling and rinsing and are set by the user. The number of strokes for the pneumatic cylinders is also configurable. During automatic operation, chromatograms are digitized (Figure 2) and the GC signal scrolls across the display as well as being saved to disk. The output directory can be selected for the sampled signals as can the vertical scale of the display. There are status messages indicating the general and specific tasks being performed by the system. As files are

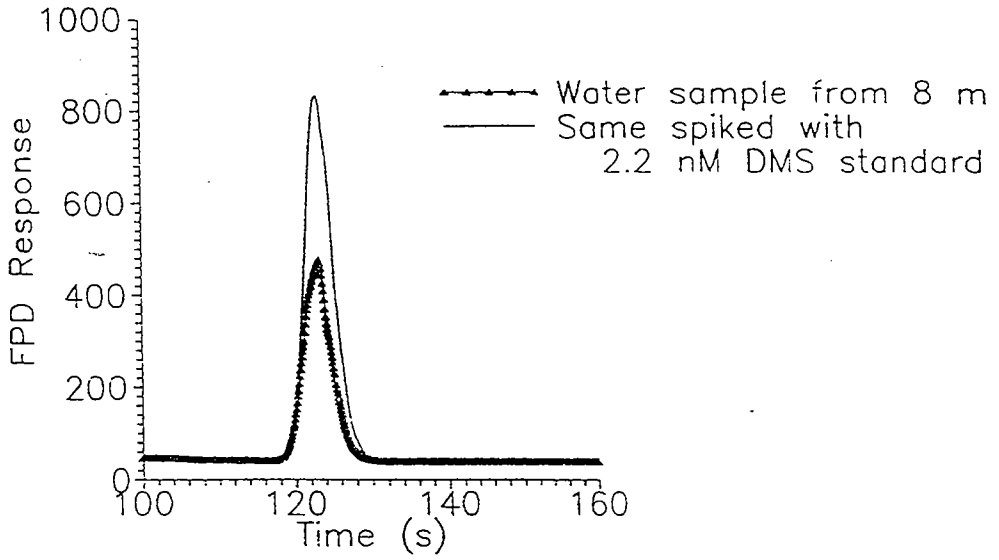
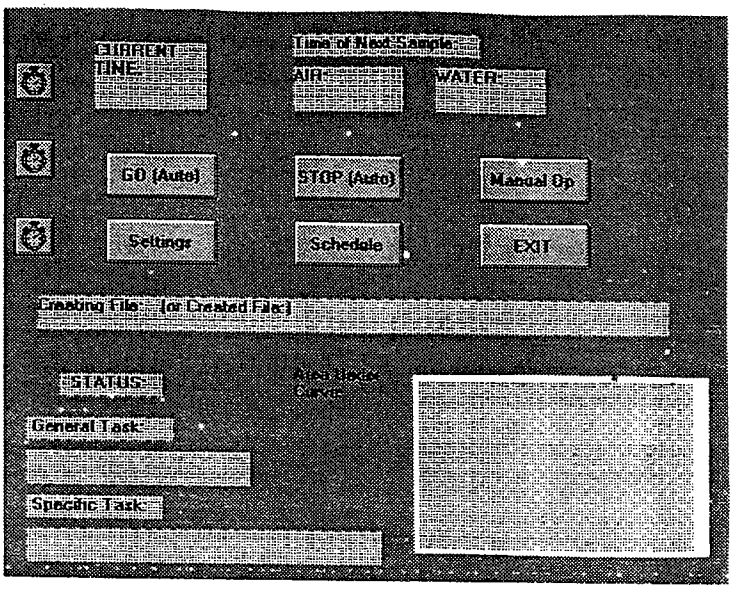


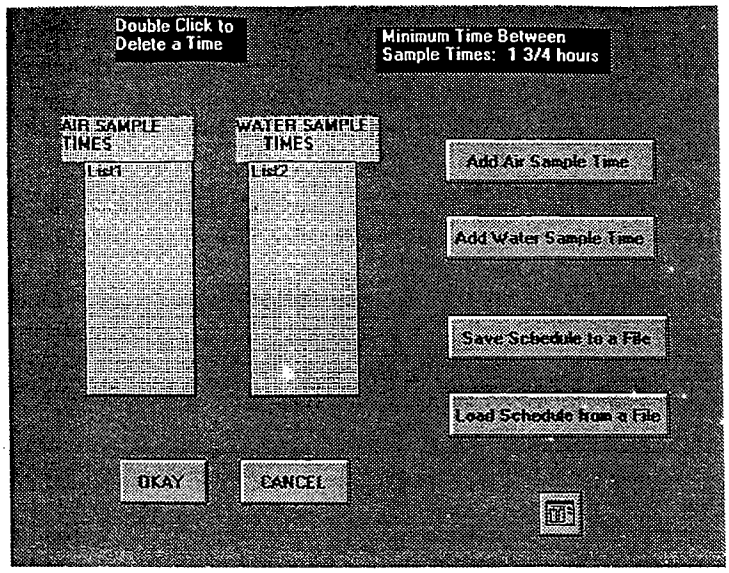
Figure 2: Chromatograms showing detector offset as a function of time for a water sample before and after a 2.2 nM DMS standard addition

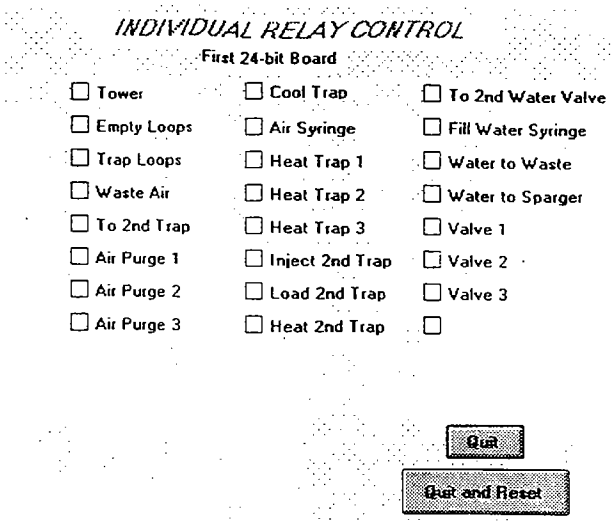
created, they are recorded on the screen along with the time of the next scheduled air and water sample. Figure 3 shows some of the forms used in the system.

The user can interrupt and restart automatic operation at any time. The creation of files under the WINDOWS operating system enables immediate evaluation of the acquired samples with MATLAB, a mathematical software package which runs under WINDOWS 3.1. The baseline and area under the curve can be easily calculated using MATLAB m files during the interval between samples.

Automation of sea-going instruments with a laptop PC and PCMCIA cards has made acquisition of oceanographic data much more portable. Tools to facilitate the development of complex graphical user interfaces give scientists a more immediate look at data, and access to powerful analytical tools as the data are collected. Development of this capable gas chromatography system promises to facilitate the study of the dynamics of trace gases at the ocean surface.







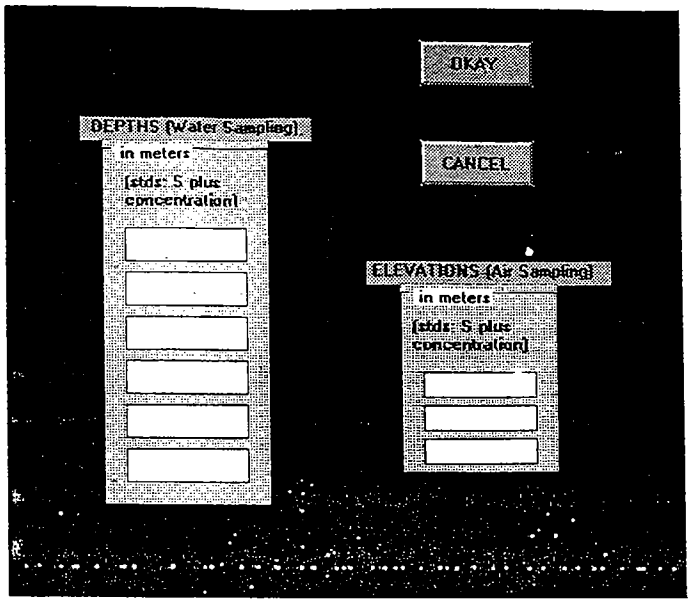
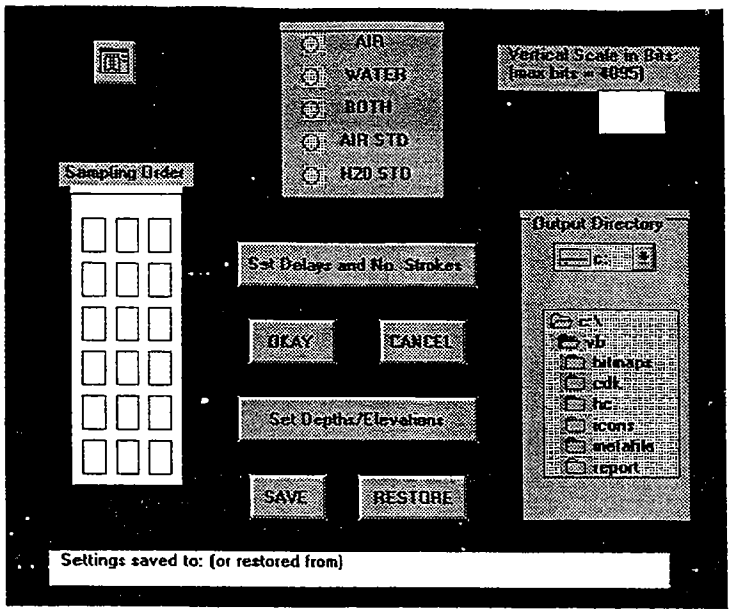
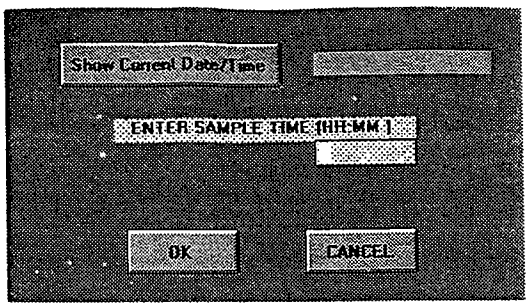
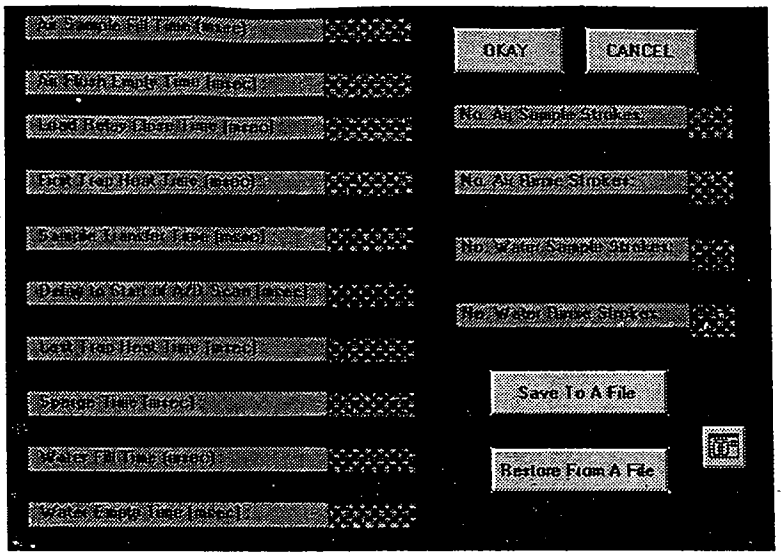


Figure 3a: Selected Forms from Gas Measurement System







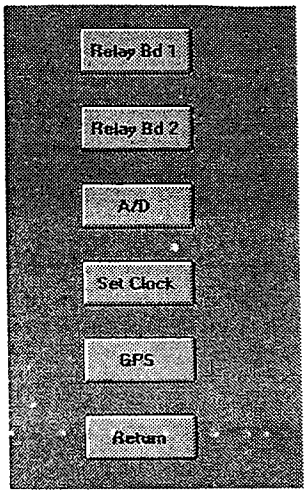


Figure 3b: Selected Forms from Gas Measurement System

Funding provided by National Science Foundation under Grant OCE-94-11497.

Expendable Oceanographic Mooring - XMOOR

Daniel E. Frye and Janice D. Boyd

ABSTRACT

In a joint effort, Woods Hole Oceanographic Institution (WHOI) and the Naval Research Laboratory (NRL) have developed a low-cost oceanographic mooring (XMOOR) for use in the coastal zone. The device is packaged in a cylinder 6 7/8 inches in diameter by 66 inches long and weighs 100 pounds. It is completely self-deploying and automatically adjusts for water depths between 30 and 300 feet. The sensor payload includes up to 25 levels of temperature measurements, three levels of conductivity and pressure, as well as air temperature and barometric pressure. Real-time data are available via Argos DCS and short range radio. Deployment life is up to three months.

Funding provided by: Office of Naval Technology through NRL under Contract No. N00014-92-C-6028 as part of the Tactical Oceanography Program and by the Office of Naval Research (ONR) under Contract No. N00014-95-1-0774. At NRL, the project has been funded by the Office of Naval Technology and then by the Office of Naval Research, both under program element 62435N.

Published in *Sea Technology*, August 1996, pp 61-65.

An Expendable, Self-Deploying Coastal Mooring: Mechanical Design and Function

D. E. Peters, R. Arthur, D. E. Frye and J. Boyd

ABSTRACT

An expendable, self-deploying mooring (XMOOR) for shallow water applications has been developed to meet Navy requirements for monitoring the coastal region. The project has been conducted in concert with the Naval Research Laboratory at Stennis who developed the electronic systems which are described in a companion poster. A total of eight prototype systems have been fabricated. Testing of the units is on-going.

The XMOOR system is designed for water depths from 10-100m, for deployments of three months duration, and for automatic deployment and depth adjustment within the deployment range. Its sensor suite includes barometric pressure, air temperature, water temperature at 22 levels, and conductivity and pressure at 3 levels. Data telemetry is accomplished by line of sight UHF radio and Argos transmitter.

The mechanical system consists of three modules. The surface module includes an inflatable nylon buoy which supports the surface sensors and antennae and a pressure housing containing the system controller, batteries, and inductive telemetry link. A line canister module contains up to 100m of 4.8mm Vectran line which is packaged for self-deployment and includes a number of discrete lock-up points for mooring scope self-adjustment. CTD instruments packaged in 7.5cm x 15cm diameter "pucks" are clamped to the line at two points. Miniature thermistor chains, each with 11 thermistors, plug into the pucks and are integrated with the mooring line using thin polyester sleeving. The CTD pucks contain batteries and inductive modems and telemeter data to the surface via a single conductor in the Vectran line. The third module contains a unique folding anchor and 15m of 6mm chain to provide scope and holding power for the anchor. Total system weight is approximately 45 kg.

Funding provided by: Office of Naval Technology through the Naval Research Laboratory under Contract N000-14-92-C-6028 as part of the Tactical Oceanography Program and by the Office of Naval Research (ONR) under Grant No. N00014-95-1-0774.

Abstract presented at the AGU/ASLO Ocean Sciences Meeting, San Diego, CA, February 12-16, 1996.

An Expendable, Self-Deploying Coastal Mooring: Telemetry and Sensors

J. Boyd, R. Burnes, B. Bricker and D. E. Frye

ABSTRACT

Climatologies and infrequent, large-footprint remote sensing measurements cannot capture essential details of the temporal and spatial variability of oceanographic conditions in littoral areas. Timely in-situ measurements are also needed. The Naval Research Laboratory (NRL) and the Woods Hole Oceanographic Institution (WHOI) have collaborated on the development of a low-cost, self-deploying, moored sensor system to address this problem. Known as XMOOR (for Expendable Oceanographic Mooring), the system is suitable for a variety of meteorological and oceanographic sensors, may be deployed (and, if desired, retrieved) rapidly by untrained personnel, and automatically adapts the length of deployed line to the water depth, so depth need not be known. A two-way radio-link with the user allows both real-time reception of data and transmission of command and control messages to the unit.

The XMOOR mechanical system, the primary responsibility of WHOI, is described in the companion poster. The sensor suite, internal and external telemetry systems and data collection system were the primary responsibility of NRL. In its prototype configuration the sensor suite consists of air temperature and pressure, sea surface temperature and conductivity, and one or more subsurface thermistor strings with CTD "pucks" clamped onto the line at selected locations. Other small, low powered sensors are also possible. Internal data transmission is accomplished via an adaptation of WHOI-pioneered inductive telemetry. A spread-spectrum UHF link and ARGOS telemetry are used for external telemetry of data; the data are also internally recorded. The UHF link is two-way and commands may be sent to the XMOOR to change sampling rate, "transmit data now," and so on. The system controller, a Tattletale Model 5 microcomputer, controls data acquisition, the command and control radio link, and the data transmission via ARGOS at appropriate times.

Eight prototype units have been fabricated, and testing and modifications are ongoing in both research and operational deployments.

Funding provided by: Naval Research Laboratory under Contract N000-14-92-C-6028 as part of the Tactical Oceanography Program and by the Office of Naval Research (ONR) under Contract No. N00014-95-1-0774. At NRL, the project has been funded by the Office of Naval Technology and then by the Office of Naval Research, both under program element 62435N.

Abstract presented at the AGU/ASLO Ocean Sciences Meeting, San Diego, CA, February 12-16, 1996.

High-Resolution Nutrient Variability in the Sargasso Sea

H. W. Jannasch, C. M. Sakamoto, T. Dickey and D. Frye

ABSTRACT

Three osmotically pumped in situ nitrate analyzers (OsmoAnalyzers) have been deployed on the ALTOMOOR mooring located at the Bermuda-Atlantic Time-Series Study (BATS) site over the last two summers. The analyzers autonomously monitored dissolved nitrate concentrations for about 3 ½ months at a time, and were deployed at 80 (2 analyzers) and 200m. Other instruments on the mooring included temperature and salinity (T/S) sensors, a METS weather station, current meters, fluorescence and transmission meters and PAR sensors.

Results show that within the generally low nitrate conditions observed by the approximately monthly sampling trips of the BATS program, we find periods with very short (6-18 h) nitrate spikes as well as longer high nutrient events (days to weeks). The short nitrate spikes were observed during a relatively quiescent period in June 1994 and did not correlate with changes in T/S. The longer events were observed in the storm-ridden summer of 1995, and show a clear T/S relationship. Although it is not possible to ascertain from a single mooring whether these observations are temporal nutrient injections or drifting patches, we believe that the short nitrate spikes are biologically produced, while the longer ones are a result of physical forcing. In any case, these nitrate injections could account for a significant level of primary production. A further analysis of the data and its implications will be presented.

The datasets show that continuous monitoring of chemical concentrations is essential toward understanding non-steady state biological and geochemical processes. Advantages of OsmoAnalyzers over collecting bottle samples and running laboratory analyses include higher data densities at a greatly reduced cost, minimal contamination potential, near real-time data feedback, and long-term fully automated data collection at remote locations.

Abstract presented at the AGU/ASLO Ocean Sciences Meeting, San Diego, CA, February 12-16, 1996.

Inductive Telemetry for Ocean Moorings: Operational Experience

R. Eastwood, T. Dickey, J. Kemp and D. E. Frye

ABSTRACT

A general purpose inductive telemetry link for oceanographic moorings has been developed and implemented on an operational mooring deployed offshore of Bermuda. The Bermuda Testbed Mooring, a project funded jointly by ONR and NSF, was established at the JGOFS Bermuda Atlantic Time Series (BATS) site in 1994 to test new ocean instrumentation and new real-time data collection techniques.

Inductive modems, which transmit data using standard oceanographic mooring wire rope, were developed and interfaced to a variety of instruments on the long-term surface mooring. Modems were connected to the mooring wire via split ferrite cores clamped around the wire, thus requiring no direct electrical connection. A controller in the surface buoy polled each instrument via a unique address and stored the received data to hard disk. A subset of the data was telemetered to the Argos DCS and all of the data were forwarded to the R/V Weatherbird via a high speed RF LAN link when the ship passed near the surface buoy on monthly visits to the site.

The inductive modem link proved to be very reliable following an initial period of implementation problems. Data and commands are transferred at 1200 b/s. The inductive modems have a quiescent power drain of 5mW which allows them to collect data from their host instruments at any time and an active power drain of 50mW. They are very small and are meant to be installed inside the host instrument using the host instrument battery which eliminates the need for special pressure housings and extra batteries. The modem technology has been transferred to an commercial vendor who now produces the modems for under $1,000.

Funding Provided by: Office of Naval Research under Contract N000-14-94-1-0346.

Abstract presented at the AGU/ASLO Ocean Sciences Meeting, San Diego, CA, February 12-16, 1996.

An Integrated Approach to Multiple AUV Communications, Navigation and Docking

H. Singh, J. Catipovic, R. Eastwood, L. Freitag, H. Henriksen, F. Hover and D. Yoerger

ABSTRACT

In this paper we report on our progress in two topics related to the development of an autonomous oceanographic sampling network. The first topic deals with the use of a flexible DSP system on the Odyssey class AUV which provides acoustic communications and ultra-short baseline navigation, while the second topic details our efforts in integrating these capabilities for the purpose of autonomous vehicle docking. We present an algorithm for homing in on a beacon and our results of testing this approach at sea. We show how our docking approach may be extended to allow coordinating multiple vehicle operations and demonstrate this approach for the case of two vehicles conducting a coordinated survey. We also include results from the at-sea tests of our acoustic communications system.

Funding provided by sub-contract from the MIT Sea Grant program through Contract N00014-95-1-1316.

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Monochromatic Single Mode Excitation in Shallow Water Using Feedback Control

J. Buck, J. Preisig, Mark Johnson and Josko Catipovic

ABSTRACT

An algorithm is presented to excite a single mode in a shallow water channel using a vertical source array controlled by feedback from a reference hydrophone array. The algorithm iterates between computing the source weights based on its current estimate of the mode coupling in the channel, and updating its estimate of that coupling based on the modes observed at the feedback reference array. This allows us to excite high fidelity modes with confidence at a given location. The ability to control these modes depends on the accuracy with which they are observed. To this end, we compute the error for the linear least-squares mode estimator for scenarios where the feedback array does not span the entire water column. Finally, we present preliminary results obtained in a laboratory wave guide illustrating the successful convergence of the algorithm in a physical experiment.

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A Moored, Profiling Instrument for Long-Term Hydrographic Observations

D. E. Frye, K. W. Doherty, A. Hinton and J.M. Toole

ABSTRACT

To adequately monitor climatic rends in ocean water properties, accurate measurements are needed at many locations over decadal and longer time scales. Traditional methods for collecting these data involving research ships are logistically difficult and prohibitively expensive. We have developed a moored instrument to answer this need, capable of repeatedly cycling a CTD between the ocean's mixed layer and 5000m depth, thus maintaining a hydrographic time-series station autonomously. The instrument (we have termed the Moored Profiler) can make approximately 100 round trip profiles over this depth range in the course of a year-long deployment.

The Moored Profiler, a small oblate-spheroid (36cm wide by 71cm diameter), uses a traction drive to move up and down a long continuous shot of 0.64-cm plastic-jacketed wire rope. The spring-loaded drive wheel is turned by a small, efficient electric motor which consumes 1-2Watts as the instrument moves vertically at 0.3-0.4 m/s. Power from the motor is transmitted through a magnetic coupler to the drive wheel, thus eliminating power-robbing seals. The vehicle carries an accurate CTD which collects a data scan twice per second. At normal profiling speed this yields an observation approximately every 15 cm. Data are stored internally on a 500 byte hard disk; a satellite data telemetry system is presently in the design stage.

An initial one-month test deployment of the Profiler was conducted in November/December 1994 offshore Bermuda in 4500m of water. During this test the Profiler ran continuously and traversed 1,000,000 m of ocean (thus meeting the endurance design target). Following this trial, a six-month deployment was initiated in June 1995.

Funding provided by: National Science Foundation under Grant OCE-94-20647.

Abstract presented at the AGU/ASLO Ocean Sciences Meeting, San Diego, CA, February 12-16, 1996.

Multichannel Processing of Broadband Multiuser Communication Signals in Shallow Water Acoustic Channels

Milica Stojanovic and Zoran Zvonar

ABSTRACT

High throughput multiple-access communication networks are being considered for use in underwater acoustic channels. Bandwidth limitations of underwater acoustic channels require receivers to process broadband communications signals in the presence of several active users. To deal with the resulting multiple-access interference in addition to high intersymbol interference, spatial variability of ocean multipath is exploited in a multichannel multiuser receiver. Two configurations of such a receiver, a centralized and a decentralized one, are presented in fully adaptive modes of operations. While greatly reducing intersymbol and multiple-access interference, spatial diversity implies high increase in adaptive multiuser receiver complexity. To reduce the complexity of the optimal multichannel combiner, spatial structure of multipath is exploited. The complexity of resulting adaptive decentralized multichannel multiuser receiver is reduced at almost no cost in performance. Comparison of proposed multichannel receivers in an experimental shallow water channel demonstrates superior performance of spatial signal combining. The use of multiple input channels is shown to provide high level of tolerance for the near-far effect in both centralized and decentralized receivers. Decentralized receiver with reduced-complexity combining is found to satisfy the performance/complexity tradeoff required for practical receiver realization in shallow water networks.

Funding: Part of this work was conducted while the authors were with the Woods Hole Oceanographic Institution and was funded under Advanced Research Projects Agency Contract No. MDA972-91-J-1004.

Published in IEEE Journal of Oceanic Engineering Vol. 21, No. 2, April 1996, pp 156-166.

Near-Bottom Magnetic Surveys of the Coaxial Ridge Segment Juan de Fuca Ridge Using the Autonomous Benthic Explorer Survey Vehicle

D. Yoerger, A. Bradley, R. Bachmayer, R. Catanach, A. Duester, S. Liberatore, H. Singh, B. Walden and M. A. Tivey

ABSTRACT

The autonomous survey vehicle ABE (Autonomous Benthic Explorer) was successfully used for the first time in a series of near-bottom magnetic profiles over the 1993 eruptive lava flow area of the Coaxial Ridge segment of the central Juan de Fuca Ridge. Over 20 km of tracklines were obtained using ABE over both the Flow Site, which includes the 1993 lava flow and associated graben and which is thought to mark the location of the dike that fed the lava flow, and over the Floc Site, 25 km south of Flow along-ridge strike, where a narrow, lineated graben contains a zone of continued hydrothermal activity that was initiated during the Coaxial eruption event.

The ABE vehicle carried out untethered operations at an altitude of 5 to 100 meters above the seafloor obtaining vector magnetic field, depth, altitude, and water column data. Several profiles also collected digital on-bottom stereo video still images of the new flow. ABE conducted its surveys using both surface and in-hull long baseline acoustic navigation, allowing it to vector to a specific starting point on the seafloor. Using an acoustic altimeter, ABE was able to maintain bottom contact and safely clear obstacles in its path. A solid-state low-power gyro enabled ABE to maintain heading despite magnetic anomalies exceeding 20,000 nT associated with the new lava flow.

Preliminary magnetic results find that a narrow notch-like anomaly low found in 1993 magnetic surveys over the new lava persist in the 1995 surveys. This suggests that the notch anomaly locates the presence of a now cooled dike intrusion zone that fed the Coaxial laval flow eruption. Magnetic field measurements linked with the rapid survey and response capability of ABE thus provide a unique opportunity to map the subsurface and time critical events such as seafloor eruptions and hydrothermal activity. The ABE platform also provides an efficient use of survey time allowing a multitude of sensor measurements to be obtained over a tightly constrained survey near the seafloor without the need for large winch and ship operations.

Funding provided by: National Science Foundation under Grant OCE-92-16775 and OCE-93-00434.

Presented at the AGU Fall Meeting, San Francisco, CA, December 11-15, 1995.

Ocean Data Telemetry Update: A Review of Options Available to Ocean Researchers

Daniel E. Frye

ABSTRACT

In 1987 Mel Briscoe and I published a paper that summarized the options available to ocean researchers for retrieving data in real time from in situ ocean instrumentation. Surprisingly, little has changed in that picture to this point in time, but we appear to be on the brink of a major revolution in the field of mobile communications. Rapid progress in this field is being driven by new technology, deregulation of the frequency spectrum, and emerging markets for low-cost, mobile, voice and data links. Fortunately, we may be able to take advantage of these new systems to enhance our ability to conduct ocean research. As an oceanographer interested in establishing real-time, two-way links with remote instruments, it has been a frustrating period, knowing that much of the communications technology exists to link remote instruments to the lab, but that useful implementations have been waiting for substantial markets to be developed. This presentation presents an overview of the existing telemetry technologies used by ocean researchers (the atmospheric side only, since other presenters will be discussing in-water technologies), which might be called first generation systems, and compares them functionally to the new emerging technologies, which could be labeled second generation systems. The discussion will be focused on data telemetry from unmanned ocean platforms including buoys and AUVs where power, size, directionality, and autonomous operation are key elements. The emphasis will be placed on general purpose global solutions as opposed to special purpose, coastal solutions.

Emerging mobile communications systems will be summarized and evaluated in terms of their usefulness in oceanographic applications. While most of the new satellite-based systems have published dates for when service will start, these plans remain volatile and are dependent on both financial and launch realities. Systems to be discussed include short range radio and cellular telephone systems, geostationary satellite systems, and "Big- LEO" (low earth orbit) and "Little-LEO" systems.

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Presented at the MIT Sea Grant Collegium Symposium, *AUV Research: Challenges and Opportunities in the Coastal Environment*, March 7-8, 1995.

A Pressurized Chemostat for the Study of Marine Barophilic and Oligotropic (Oligocarbophilic) Bacteria

H. Jannasch, C. Wirsen and K. Doherty

ABSTRACT

A continuous culture system that allows bacteria to be grown in steady-state populations under pressures of up to 700 atm (71 Mpa) was constructed and tested. With readily available or slightly modified high-pressure chromatography equipment, a continuous flow of sterile medium is pressurized and passed through a 500-ml nylon-coated titanium reactor at flow rates of 0.01 to 10 ml min^{-1}. The pressure in the reactor is controlled by a back-pressure regulator with greater than 1% accuracy. In test experiments, a culture of a phychro- and barophilic marine isolate from a depth of 4,900 m (strain F1-A, identified as a *Shewanella* sp.) was grown at 1, 300, and 450 atm (0.1, 30.4 and 40.5 MPa) and dilution rates of 60 and 90% of the organism's maximum growth rate (determined at 1 atm) in the required complex medium at levels of 3.3 and 0.33 mg of dissolved organic carbon per liter in the reservoir. Growth limitation by carbon was assured by an appropriate C/N/P ratio of the medium. The data indicate that barophilic growth characteristics in steady-state cultures of this psychro- and barophilic deep-sea isolate were positively affected by a decreasing growth rate at the higher of two substrate concentrations in the reservoir. After a 10-fold lowering of the substrate concentration, the effect was reversed. Under these conditions the cell viability increased significantly, especially at the higher of the two pressures tested. The basic design of the system can principally also be used for growth studies on hyper thermophilic bacteria and archaea.

Funding: The work was supported by a substantial contribution from the Woods Hole Oceanographic Institution, giving us a head start in building the instrument that made funding by National Science Foundation Grant No. OCE-94-15371 possible.

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Real-Time Frontal Mapping with AUVs in a Coastal Environment

H. Schmidt, J. Bellingham, Mark Johnson and D. Farmer

ABSTRACT

A new oceanographic measurement concept is presented, combining a tomographic network with small autonomous underwater vehicles. Using wireless local area network technology, the acoustic tomography data are recorded and processed in real time for achieving a low-resolution estimate of oceanographic parameters. The results are used to focus direct measurements by a network of small AUVs in areas of high spatial and temporal variability. By combining the high coverage but low resolution of the tomography with the high resolution capabilities of the AUVs, oceanographic phenomena with small scale dynamics controlled by large scale environmental forcing can be mapped. The feasibility of the new measurement concept has been demonstrated in connection with a June '96 experiment in Haro Strait, BC, aimed at mapping the properties of coastal fronts driven by combined estuarian and tidal forcing.

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Published in Proceedings OCEANS'96, Ft. Lauderdale, Vol III, September 23-26, 1996, pp 1094-1098.

Reducing the Computational Requirements of Adaptive Equalization in Underwater Acoustic Communications

Mark Johnson, D. Brady and M. Grund

ABSTRACT

A key component in coherent underwater acoustic communication systems is an adaptive equalizer capable of tracking changes in the acoustic environment. The computation requirements of this equalizer can be very high, requiring substantial computation hardware and high power consumption.

Several techniques have been devised for reducing the computational load of the equalizer by exploiting structure in the acoustic environment. In essence, these methods trade equalizer decoding performance for computational efficiency by reducing the number of equalizer parameters, the complexity of the update algorithm, or the rate of parameter updating.

In this paper, a generalized equalizer model is developed combining several such complexity reduction techniques. From this viewpoint, the potential and limitations of each technique are discussed. Results are presented showing that computation savings in excess of an order of magnitude are possible.

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Report on the Acoustic Network Arctic Deployment March 1994

Mark Johnson, David Herold, and Josko Catipovic

ABSTRACT

This report describes the March 1994 Arctic deployment undertaken by the Acoustic Telemetry Group of WHOI. The deployment was a part of the 1994 SIMI (Sea Ice Mechanics Initiative) project and was based at the west SIMI camp, approximately 150 nautical miles northeast of Prudhoe Bay, Alaska. The goal of the deployment was to install a network of six high-performance acoustic modems, developed at WHOI, and to obtain a data set demonstrating the communications and acoustic monitoring capabilities of the network.

The six modems in the network were deployed over an area of 22 square km and communicated via radio ethernet with a computer at the SIMI camp. Each modem had a global positioning system, and acoustic source and an 8-element receiving array. The network was operated in a round-robin broadcast mode (i.e., each modem in turn transmitted a packet of data while the others received). The transmissions were 5000 bps QPSK with a 15 kHz carrier. An extensive data set including raw acoustic data, source localization information, and modem position was collected during the deployment.

An additional function of the acoustic network was to communicate with and track the Odyssey, an autonomous underwater vehicle operated by the MIT group at the SIMI camp. To this end, the Odyssey was equipped with a Datasonics modem configured for periodic QPSK transmission to the network. A data set was obtained from which both the up-link communication and localization capabilities of the network can be determined.

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Short Term Variability of Optical Properties in the Oligotrophic Ocean in Response to Surface Waves and Clouds

M. Stramska, T. Dickey, D. Frye, H. Jannasch, A. Michaels, D. Manov and D. Sigurdson

ABSTRACT

Our general understanding of the short term variability of optical properties of the ocean is still seriously limited because optical data typically have been collected by instruments lowered from ships. This type of data is limited in temporal resolution as well as by errors due to ship movement and shadowing. We have conducted an experiment in which acquisition of time series of water pressure, spectral downwelling irradiance and upwelled radiance (412, 443, 490,510, 555, 665, and 683 nm) data was accomplished with fixed-location moored instrument systems. The mooring was deployed in the Sargasso Sea near Bermuda in September 1994. The measurements were made at 15 and 35 m at 6 Hz, for 2 or 5 min periods, once every hour from 6 am to 8 pm local time. Our data show several sources of variability in the optical signals. Under clear skies, strong fluctuations in the downwelling irradiance prevail in the surface waters as a result of the focusing and defocusing of sunlight by surface waves (e.g., Dera and Gordon, 1968; Stramska and Dera, 1988). Another source of variability is the attenuation of light over a fluctuating pathlength associated with water surface displacement due to wave motion (Stramska et al., 1992). Finally, the intensity of light and its angular structure vary in response to clouds passing over the mooring site. Our analysis indicated that all these effects influence the estimates of apparent optical properties such as radiance reflectance and vertical diffuse attenuation coefficient. The importance of these effects depends on environmental condition, including surface wave characteristics, water clarity, meteorological conditions and solar elevation.

Abstract presented at the AGU/ASLO Ocean Sciences Meeting, San Diego, CA, February 12-16, 1996.

Sonar Mapping with the Autonomous Benthic Explorer (ABE)

H. Singh, D. Yoerger, R. Bachmayer, A. Bradley and W. K. Stewart

ABSTRACT

We examine the task of fine-scale acoustic mapping from the Autonomous Benthic Explorer (ABE). The grid occupancy method is used to stochastically model the sonar beam and an entropic measure of sensor efficiency is defined to model the sampling constraints on underwater mapping. This allows us to derive the optimum speed for mapping from the vehicle based on the actual rate of information being put out by the sensor. The grid occupancy method is also used in conjunction with a potential field method to formulate an algorithm for doing autonomous terrain following. Finally, we look at using the echo-sounder as a generic sensor and examine the issues related to tasks such as gradient following.

Our formulation for these sonar mapping applications was tested by applying it to data obtained during autonomous mapping surveys conducted in a lake. Very good bathymetric data exists for the site and served to ground truth our data set. The data obtained serves to confirm the validity and robustness of our algorithms.

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Surface Suspended Acoustic Receiver

Lee Freitag, Daniel Frye and John Spiesberger

ABSTRACT

Rates and occurrences of climate variations such as El Nino, global warming, and a 1,000-year cold spell following the last ice age are influenced by the ocean's capacity to store and transport vast amounts of heat. Our understanding of how the ocean does this is limited by data to test models and theories.

A surface-suspended acoustic receiver (SSAR) has been developed to gather the required temperature data in the global ocean's volume. It measures how long it takes low-frequency pulses of sound to cross an ocean. Travel times are converted to temperature. If the temperature of the ocean rises, the speed of sound increases and the travel time of a pulse decreases.

The acoustic thermometer was demonstrated in 1983 by transmitting 133 Hz pulses over 3,700 kilometers between a source cabled to the north shore of Oahu, Hawaii, and a U.S. Navy Sound Surveillance System (SOSUS) station off the coast of northern California. Changes in section-averaged temperature could be measured within ±0.02°.

Between 1983 and 1989, seven SOSUS stations intermittently listened to the same source to measure the spatial structure of the temperature variations in the northeast Pacific. However, the spatial structure had scales too small to resolve with these data.

Satellites and ocean models now indicate that many of the climate variations in the northeast Pacific have spatial scales of 500 kilometers and larger. There are not enough SOSUS stations and available cabled-to-shore sources to resolve this structure. Thus, the SSAR was developed to provide an economical method to map the oceans at 500-kilometer resolution. Acoustic systems built from SSARs, low-cost autonomously moored sources, and available cabled-to-shore sources can be optimized to provide this resolution at minimum cost in near real time. The overlapping sections are pieced together to provide temperature maps using tomographic techniques similar to those used to map the three-dimensional structure of the human body from medical CT scans.

Funding: The development of the SSAR was conducted with funding from the SERDP Program under contract to Advanced Research Projects Agency under Contract MDA-972-93-1-0004.

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Surface Telemetry Mooring - Two Extremes

Daniel E. Frye

ABSTRACT

Ocean researchers are being pushed by opposing forces to develop measurement strategies that are both more capable and lower cost than conventional technologies. While advances in electronics and satellite communication offer some means to achieve these divergent goals, similar advances in the mechanical realm are more elusive. The two-sided nature of this challenge is illustrated by two projects at WHOI involving surface moorings with real time data telemetry from a number of subsurface sensors.

Case 1 is a deep water mooring deployed offshore Bermuda as an instrumentation and data telemetry testbed. It uses conventional mooring technology combined with inductive telemetry, satellite and short range RF telemetry, and supports an extensive suite of physical, optical, and chemical instrumentation. It has been operating for several years with scheduled turnarounds every 4 months. It survived the passage of several hurricanes this summer, but recently experienced a failure in an instrument cage that resulted in the buoy going adrift and most of the instrumentation falling to the bottom where some instruments were crushed. Case 1 maintenance and field operations require an experienced crew and a large, well-equipped ship to keep it operating.

Case 2 is at the other extreme. This case is a shallow water surface mooring that combines satellite and short range radio telemetry, inductively-coupled sensors distributed throughout the water column and three month deployments. Rather than use conventional mooring technology, Case 2 is self-deploying and expendable (inexpensive). Its sensor load is more limited than Case 1, but still includes 2-11 channel thermistor strings, several full function CTD's, and a few meteorological sensors.

The presentation will discuss the design and operation of these two mooring systems focussing on their similar functionality and their dissimilar design approaches. It will illustrate the quandary of the ocean engineer in trying to meet the rigors of the ocean environment while minimizing the cost of monitoring the environment.

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Presented at: ONR/MTS Buoy workshop, San Diego, CA 3/27-28/96.

A Tethered Free-Fall System to Facilitate Shipborne Hydrographic Profiling

K. W. Doherty, D. E. Frye, R. C. Millard, J. M. Toole and J. S. Merriam

ABSTRACT

The design and performance of a new style underwater frame for supporting instrumentation and water collection bottles used in hydrographic sampling are presented. Unlike conventional frames which are affixed to the end of the sea cable, the new frame is free to slide vertically along the wire. In operation, frame mass and drag are adjusted so that the terminal descent velocity of the underwater unit equals the average wire lowering speed. Because the frame is free to move relative to the sea cable, the underwater instrumentation is effectively divorced from ship roll on down-cast. Improved data quality from CTD instrumentation, reduced station time and greater ability to work in more severe sea conditions are anticipated. Furthermore, the chance of wire damage that occurs when wire speed (lowering rate plus ship roll velocity) exceeds the terminal velocity of conventional underwater packages is greatly minimized. Frame descent past the wire termination is blocked by a large mass attached to the wire (that aids in wire payout). An energy-absorbing arrangement ameliorates shock-loads when the wire-termination weight and frame meet at the end of a lowering, and during upcast. Absence of direct electrical connection to the underwater instrumentation necessitates an alternative scheme for command and control and data acquisition. Acoustic methods, adapted from commercially available components, are described for real time monitoring of the oceanography and instrument performance, as well as effecting collection of water samples at user specified depths.

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Presented at the AGU/ASLO Ocean Sciences Meeting, San Diego, CA, February, 1996.

Tomography via Motion-Decoupled Surface Buoy

J. Lynch, H. Berteaux, J. Bouthilette, P. Boutin, T. Duda, D. Frye, H. Fujimori, E. Hobart, J. Kemp, S. Kery, S. Liberatore, I. Nakano, A. Newhall, W. Paul, K. Peal, U. Send and W. Witzell, Jr.

ABSTRACT

Ocean acoustic tomography is a remote sensing method for making "CAT-scans" of the internal temperature and current structure of large volumes of ocean. Since 1979, this technique has gone from the sea-trials stage to a routine-measurement capability in the oceanographer's toolbox.

As with many oceanography techniques, tomography has relied heavily on the internal storage of data in moored instruments, which means that one doesn't know how well the instruments did or what was seen until recovery. In order to enable a researcher to check on an acoustic tomography experiment, use the data in real time, and talk to the instrument (giving it global positioning system time, etc.), we have designed a surface telemetry buoy usable with deep-ocean acoustics instruments - the S-Tether system.

The requirements that acoustics instruments put on such a buoy are:

- No appreciable motion can be transmitted from the surface buoy to an acoustic transceiver (combination source and receiver) - the acoustic signal can be lost to this "motion" noise.
- A large-bandwidth telemetry channel is needed to handle the requirements of multichannel acoustic array data.

The S-Tether remote, deep-ocean-moored telemetry system complements two other telemetry schemes currently available: (1) direct cable systems, which supply both power and bandwidth to a mooring but are generally expensive and usually limited to near-shore sites, and (2) acoustic telemetry, which (like cables) avoids any surface mooring expression but is somewhat power hungry and range-limited. The S-Tether system, in comparison, can be deployed at any remote deep-ocean site and be amply powered.

The concept, in which one uses a flexible S-shaped cable link from a subsurface float to a surface buoy to decouple the surface buoy's motion from the instruments, has been utilized previously with current meters, also sensitive to surface-buoy induced motions. S-tether-TOMO is a transfer of this design to acoustic devices, which are even more sensitive to motion effects. The first trial of the system was in the context of the Thetis Experiment in the western

Mediterranean, a large multinational tomography experiment aimed at both exploring the oceanography of the western Mediterranean and developing large-scale, long-term monitoring capabilities usable in a wide variety of ocean basins.

The mooring was deployed successfully, along with six other moorings, in January 1994 for a 10-month period; however, the telemetry system met with only partial success. Local fishing activity off Mallorca severed the telemetry-link electrical connection between the surface buoy and subsurface instruments half way through the experiment. However both the surface buoy and the subsurface buoy still worked autonomously, which allowed us to achieve our full objectives scientifically.

Funding provided by: Office of Naval Research, Office of Naval Technology, and Japan Marine Science and Technology Center.

Published in *Sea Technology*, September 1995, pp. 25-31.

Upper Ocean Temperature Response to Hurricane Felix as Measured by the Bermuda Testbed Mooring

T. Dickey, D. Frye, J. McNeil, D. Manov, N. Nelson, D. Sigurdson, H. Jannasch, D. Siegel, T. Michaels and R. Johnson

ABSTRACT

Hurricane Felix passed over the Bermuda Testbed Mooring August 15, 1995, providing a unique opportunity to observe the response of the upper ocean to a hurricane. In the vicinity of Bermuda, Felix was a particularly large hurricane with hurricane force winds over a diameter of about 300-400 km and tropical storm force winds over a diameter of about 650-800 km. Felix moved northwestward at about 25 km h^{-1} with the eye passing about 65 km southwest of the mooring on August 15. Peak winds reached about 135 km h^{-1} at the mooring. Complementary satellite sea surface temperature maps show that a swath of cooler water (by ~3.5 to 4.0 °C) was left in the wake of Felix with the mooring in the center of the wake. Prior to the passage of Felix, the mooring site was undergoing strong heating and stratification. However, this trend was dramatically interrupted by the passage of the hurricane. As Felix passed the mooring, large inertial currents (speeds of 100 cm s^{-1} at 25 m) were generated within the upper layer. The e-folding decay time scale of the inertial currents was about 9 days. The mixed layer depth was about 15 m prior to the arrival of Felix and deepened to about 45 m within three days after Felix's passage; the temperature at 25 m decreased by ~3.5 to 4.0°C. Large amplitude temperature oscillations (~1.5°C) near the inertial period (inertial pumping effect) were set up by the hurricane in the seasonal thermocline resulting in vertical displacements of isotherms of ~15 m at 60 to 70 m. Scale analyses of the upper ocean responses to Hurricane Felix and Hurricane Gloria (1985) indicate that they have several similarities.

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A Wire-guided, Free-fall System to Facilitate Ship-borne Hydrographic Profiling

J. M. Toole, K. W. Doherty, D. E. Frye and R. C. Millard

ABSTRACT

The design and performance of a new style underwater frame for supporting instrumentation and water collection bottles used in hydrographic sampling is presented. Unlike a conventional frame that is fixed to the end of an electromechanical cable, the new frame is free to slide vertically along its tether. Allowing the frame to move relative to the sea cable decouples the underwater instrumentation from ship roll on down-cast. Improved data quality from CTD instrumentation and the ability to work in more severe sea states result. Furthermore, the chance of cable damage that occurs when wire speed (lowering rate plus ship roll velocity) exceeds the terminal velocity of conventional underwater packages is greatly reduced. Absence of direct electrical connection to the underwater instrumentation necessitates an alternative scheme for real-time data display and command of water sample collection. These are accomplished with an acoustic telemetry system, implemented using commercially available components.

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The Advanced Engineering Laboratory of the Woods Hole Oceanographic Institution is a development laboratory within the Applied Ocean Physics and Engineering Department. Its function is the development of oceanographic instrumentation to test developing theories in oceanography and to enhance current research projects in other disciplines within the community. This report summarizes recent and ongoing projects performed by members of this laboratory.

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