An Autonomous System for Ocean Acoustic Tomography

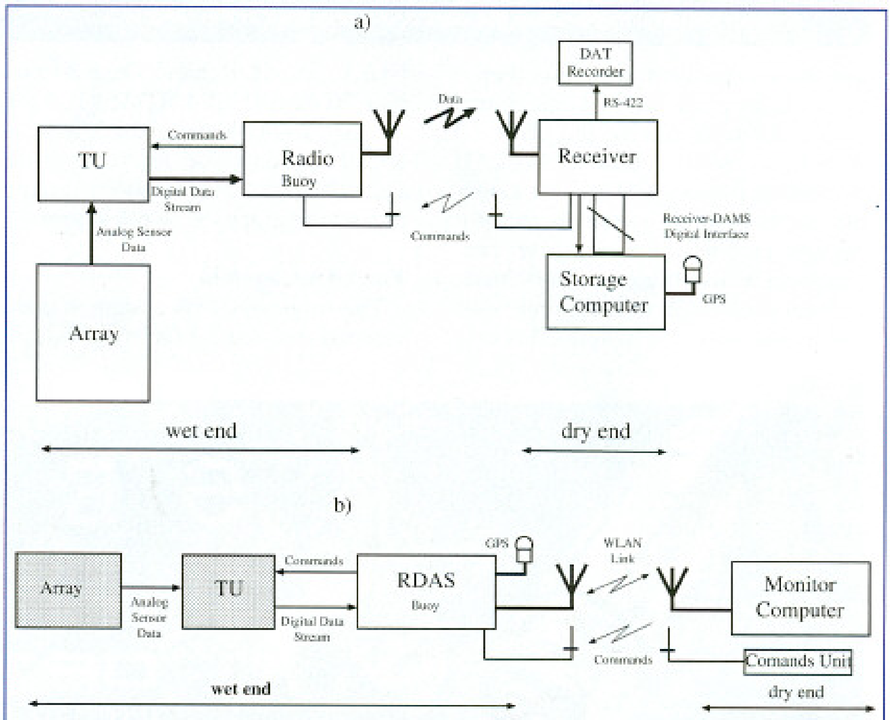
An Acoustic Vertical Array Based on Off-the-Shelf Components For Improved and Low-Cost Network Operation

By Paulo Felisberto
Assistant Professor
Cristiano Lopes
Systems Engineer
and
Sérgio Jesus
Associate Professor
SiPLAB
University of Algarve
Faro, Portugal

Vertical line arrays (VLA) are a widely used apparatus in underwater acoustics with applications in sonar prediction, underwater communications and acoustic tomography, among others. Recent developments in digital electronics and communications allow for off-the-shelf development of VLA systems, with a large number of embedded acoustic and non-acoustic sensors able to fulfill application requirements, as opposed to single or few receiver configurations available until only a few years ago.

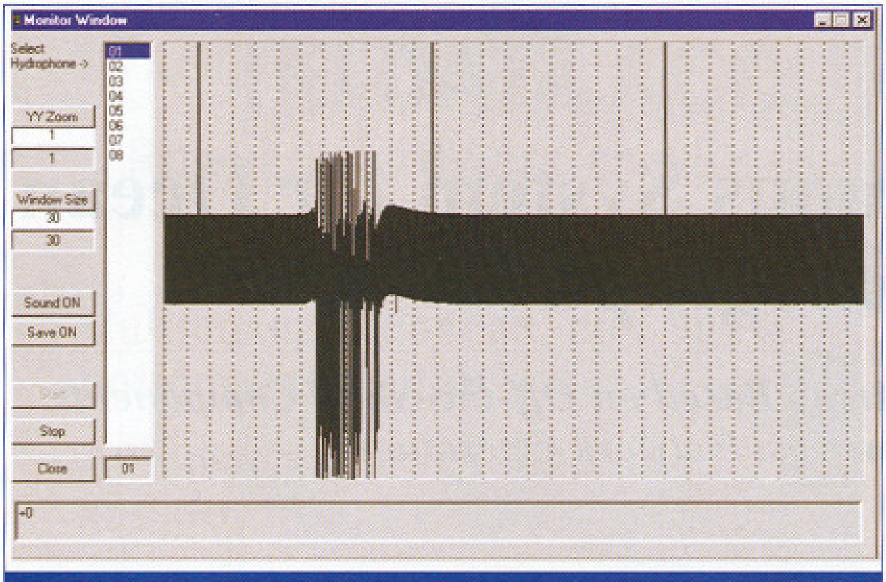
Very often, the flexibility in water column sampling is achieved by splitting the VLA into modules that can be assembled according to the application. Such systems can be deployed and recovered from small vessels with a shorthanded crew, and make it possible for research labs with reduced budgets and operational means (ships and manpower) to gain control over the whole development process, from data acquisition to post-processing.

SiPLAB, a signal-processing laboratory located at the University of Algarve, Portugal, recently acquired such a system to support its research under the Internal Tide Measurements with Acoustic Tomography (INTIMATE) project.[1] This ultra-light vertical array (ULVA) system can be configured with up to 16 hydrophones operating in the band of 10 to 2,200 hertz, and various non-acoustic sensors such as thermistors, tiltmeters and pressure gauges. In its original configuration, the data is transmitted either by cable (near-shore applications) or through a high-speed radio link to a remote location where it is stored and interfaced to a PC for monitoring purposes and online processing.



Schematic of the ultra-light vertical array (ULVA) with the original layout (a) and the modified ULVA with the remote data acquisition system (b). Original blocks are shadowed.

SiPLAB has successfully used the ULVA in a shallow-water experiment devoted to shallow-water acoustic tomography and communications.[2] Although the goals of the experiment were successfully achieved, some system drawbacks were identified during operation. The radio link was found to be the weakest part of the system since the directional antenna requires fine tuning, often incompatible with ship movement, and interference-free reception is only ensured within a two-kilometer range from the VLA radio buoy. Also, the power consumption of the transmitter on the array side reduces the system autonomy, which is a strong impairment for making long-period ocean observations. This is particularly relevant since the procedure for changing the batteries is strongly



Monitor window to visualize the data being acquired at the remote buoy.

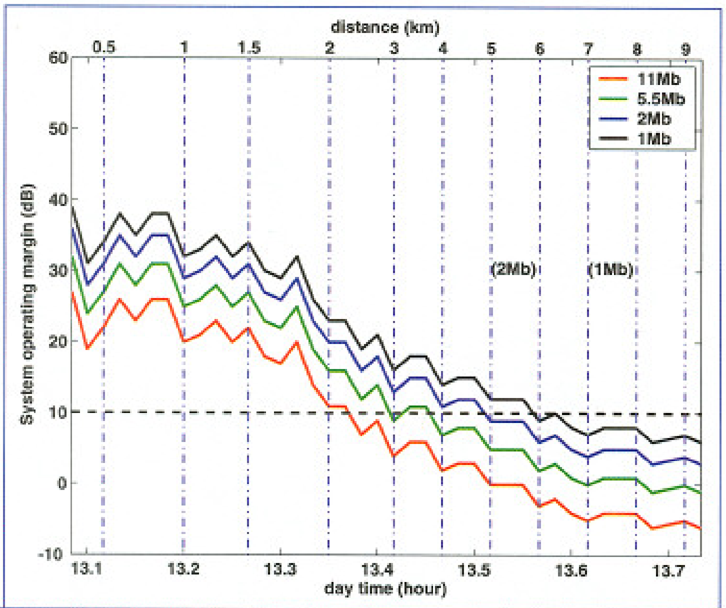
sea state-dependent and involves a high risk for personnel and equipment.

In order to overcome the observed drawbacks of the ULVA, SiPLAB decided to transform it into an autonomous acquisition system with local storage facilities, lower power consumption, capability of online remote quality control of the acquired data and positioning information. This new ULVA, named Remote Data Acquisition System (ULVA/RDAS) is based on open technologies, which are cost effective, allow for future upgrades and offer a relatively easy integration into a tomography network system.

The ULVA System

The original ULVA system was developed by Co.L.Mar. (La Spezia, Italy). It can be deployed and recovered from a small vessel (i.e., the 30-meter-long hydrographic research ship used during the engineering test). The ULVA system is formed by two main subsystems: a wet end subsystem composed of an array of acoustic and non-acoustic sensors, a telemetry unit and a radio buoy; and a dry end subsystem, onboard a ship, where data is monitored and recorded. Low-frequency acoustic signals are acquired by a 16-hydrophone array. The array is also instrumented with a number of non-acoustic sensors: two pressure gauges and two biaxial tiltmeters for the recovery of the array geometry, and 20 thermistors for the measurement of *in-situ* temperature profiles.

The array is split in three modules that can be assembled to obtain various configurations. The acquired analog signals are digitalized in the telemetry unit, multiplexed and sent to the radio buoy. The data stream is sent to the dry end of the system through a radio link operating at 1.28 gigahertz, with a bit rate of 2.5 megabytes per second. The receiver block at the dry end of the system demodulates the data stream, marks the acoustic data with a synchronization pulse derived



Measured system-operating margins of the WLAN using the omnidirectional antenna. The dashed line at 10 decibels is the WLAN manufacturer requirements for a good connection. The values within parentheses are the real throughputs achieved at given time/distance (only worst case values represented).

from a global positioning system (GPS) pulse and makes the data available in a RS422 port to interface to a digital audio tape recorder. The demultiplexed data are also available on a digital interface. A secondary radio link, working in the UHF band, is used to send simple dual-toned multi-frequency-coded control commands from the dry end to the radio buoy. With these simple commands, it is possible, for instance, to switch the array on and off, to control the array gain, etc. SiPLAB has developed a PC-based system called DAMS that monitors and stores the data collected from the digital interface online.[3]

The New ULVA/RDAS

The proposed objectives of the ULVA/RDAS were accomplished by introducing an embedded PC-based system on the buoy; an intelligent system that allows wide stand-alone operating capabilities. The acquired data is stored at the wet end using industry standard hard disks. The remote data quality-control and acquisition system status-monitoring is possible by a newly introduced wireless local area network link (LAN). The system runs an embedded Windows NT operating system (eNT), which is a convenient operating system, since a scalable kernel can be defined according to the needs, and is a de facto standard. Nearly all peripheral boards can run under this operating system. Embedded NT also provides a standard file system support for the disks and communication facilities like a transmission control protocol/Internet protocol (TCP/IP) stack that allows a high level of portability and upgradability.

Hardware. The strategy for the ULVA/RDAS was to build an alternative radio buoy system that fulfills the requirements for a new system without intervention on the existing telemetry unit and sensor array. The core of the system is a single-board PC with a low-power mobile Pentium 266 processor, as a compromise between performance and power consumption. The single-board PC provides an Ethernet connection to interface the wireless LAN, enhanced integrated device electronics controllers for the disks, parallel ports to control the power supply system and universal serial bus and serial ports (not used at the moment).

The chosen back plane holds PCI and ISA expansion slots to interface to GPS/timing and digital acquisition cards (DAC). The GPS/timing card provides GPS information and accurate pulse signals to mark the acquired acoustic data with microsecond precision, a must for tomographic applications. Two newly developed electronic cards accomplish the interfacing with the existing telemetry unit. Those cards transform the serial bit stream, coded in a biphase-like format received from the telemetry unit, into parallel transistor transistor logic (TTL) level signals and respective handshake suitable to the DAC card. The data throughput reached at the maximum sensor configuration required the selection of a DAC with direct memory access capability to avoid data loss and processor wasting. The acquired data is stored in two low-power consumption 30-gigabyte mobile hard disks with high anti-shock characteristics. The operating system and system control codes are installed on a 96-megabyte chipdisk, to prevent the use of mechanical parts in this critical sub-system.

A new power supply is designed to fulfill the requirements of the different electronic cards. The power supply is based on commercially available DC/DC regulators, with a newly introduced switching board that can switch off individual subsystems, remotely or by under-buoy computer control, as required, thus increasing the system autonomy. The communications between the RDAS buoy and the remote monitor computer are supported by wireless technology, allowing the usage of a TCP/IP stack in a transparent fashion and future easy integration in a network of instruments.

Software. The improvement of the ULVA/RDAS against the original ULVA was, in a large scale, reached by introducing an intelligent PC architecture into the buoy that runs the eNT operating system, and a customized application that controls the whole system. In fact, the application is distributed over the ULVA/RDAS buoy and the remote monitor computer, using a client-server concept and takes advantage of multi-threading, windows messages and other advanced interprocess communication facilities provided by Windows NT. The application at the monitoring computer, using a graphical interface, allows the user to fully parameterize the data acquisition process (e.g., the time to start acquisition, file names, continuous or paused acquisition, and other parameters). Also, a window with system status information, like ULVA/RDAS buoy localization and array depth, is provided.

Another important task performed at the monitoring side is the ability to visualize and listen to the data being acquired. At the buoy, the application acts as a server, controlling the acquisition process, which reads and stores the data, and also switches on and off selected subsystems to minimize power consumption, and provides status information and acoustic data to the remote monitoring computer. This part of the application is designed to, after parameterization, be able to control the system in a stand-alone mode, without the need of a communication link established with the monitor computer, performing all the data checking and local hard disk storage. The communication with the monitor computer can be activated at any time by the remote computer. This way, the ULVA/RDAS can be deployed, configured, monitored and than left unattended while the research vessel is free to perform other tasks.

At-Sea Test

An engineering test took place in September 2002 at Espichel Cape, off the port of Lisbon, in Portugal. The test plan was designed to evaluate the different subsystems (UHF and wireless LAN radio links, acquisition modes and monitorization). The wireless hardware was provided by YDI Wireless, while using a 12-decibel omnidirectional antenna installed seven meters above sea level, a rate of 11 megabytes per second was achieved up to a range of five kilometers, whereas at nine kilometers, a link of one megabyte per second could be obtained. Replacing the omnidirectional antenna with a 24-decibel directional antenna, the distances increased to seven and 15 kilometers for 11 and one megabytes per second, respectively. In both cases, the antenna at the buoy was an eight-decibel omnidirectional monopole mounted two meters above the sea level. The system was left at sea for only a few hours, but an extrapolation based on the measured power consumption could allow researchers to estimate that the system autonomy in a communication state was at least doubled when compared to the original ULVA. In future operations with the system left stand-alone in a power-saving mode, its autonomy can be increased accordingly. Direct data recording on the buoy allowed researchers to obtain a much higher data quality than that found in previous radio telemetered datasets.

Conclusions

The changes introduced into the original acquisition system include various important improvements such as an extended time of operation, stand-alone operation capabilities, the possibility of establishing communications at a longer range, and the local storage and time stamping of acquired data, eliminating noise and data drop-outs induced by communication link hazards. These improvements fulfill the requirements for the sea trial to be performed under the Acoustic Tomo-graphy System (ATOMS) project during the summer of 2004.[4]

One can remark that the new ULVA/RDAS system is based on open technologies that allow easy future upgrade and the introduction of new functionalities such as further data reduction using the onboard available processing power. Also, in the world of Internetworking, this new system could be easily integrated in a network of instruments.

Acknowledgements

The authors acknowledge the assistance of Angelo Carmo for his hardware support and Alessandro Barbagelata, from Co.L.Mar., for the original ULVA system design and his share of expertise. The support of the Instituto Hidrografico, for at-sea facilities aboard the NRP Andromeda research vessel is also greatly appreciated. The ULVA/RDAS system was developed under the ATOMS project (contract PDCTM/P/MAR/15296/1999) supported by the Science and Technology Foundation, Portuguese Ministry for Science and Higher Education.

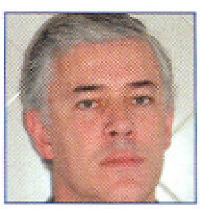
References

For a complete list of references, please contact the author Paulo Felisberto at pfelis@ualg.pt. /st/

For more information, e-mail oceanbiz@sea-technology.com.

Paulo Felisberto received an electrical engineering degree in 1988 from the Slovak Technical University, Czechoslovakia, and Ms.C. from the University of Algarve in 1995. In 1991, Felisberto joined the electrical engineering department at the University of Algarve, where he is currently an assistant professor.

Cristiano Lopes received a computer science and systems engineering degree from the University of Algarve in 2001. In 1999, he joined SiPLAB, where he became a systems engineer after graduation. Currently, Lopes is with the European Space Agency as a graduate trainee.



Sérgio M. Jesus received his doctorate in engineering sciences in 1986 from the Université de Nice, France. Jesus joined the staff at the University of Algarve in 1992 where he currently works as an assistant professor in the electrical engineering and computer department.