NeMONet: A Near Real-Time Deep Ocean Observatory

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Abstract—The New Millennium Observatory Network (NeMONet) system was deployed, by NOAA/PMEL, in the NE Pacific along the Juan de Fuca Ridge in September 1999. This system is one of the first remote underwater, near real-time observatories implemented with the capability of bringing scientific data directly from ocean depths to the desktop. Located approximately 300 miles offshore and 1500 meters underwater, the assemblage was positioned adjacent to a hydrothermal vent near an underwater volcano with the ability to collect and transmit near real-time images of vent activity and temperature measurements at specific intervals for approximately one year. The basic design goal was proof of concept and to accommodate a broad spectrum of scientific applications ranging from chemical to biological to geographical data collection in future deployments.

The NeMONet consists of a sub-sea unit that was strategically positioned on the seafloor with a Remotely Operated Vehicle (ROV) and a taut-line surface mooring that was deployed nearby. Communication from the seafloor to the surface is made possible by using commercial acoustic modems and from the buoy to shore via a geostationary satellite. All buoy and sub-sea communications are handled by carefully programmed controllers with hardware designed for low power and data compression to fit the narrow bandwidth of the transmission paths. The images and data are placed on the Web shortly after being received ashore.

The successful operation of the NeMONet system with the first deployment has given encouragement to develop a follow-on system and make plans for future enhancements to the Observatory. The next efforts will include the use of two-way communication from the desktop for direct remote interaction with seafloor instruments with a deployment planned for summer 2000.

I. Introduction

For the last two decades NOAA scientists have spent one or two months a year exploring and observing the vent fluids, seafloor geology, and the microbial biosphere with submersibles, towed vehicles, ROV's, and remote monitoring instruments. (See http://www.pmel.noaa.gov/vents/home.html). The site chosen for the NeMONet was the Axial Volcano, which is a seamount located at the intersection of the Juan de Fuca Ridge and the Cobb seamount chain. The Ridge is a spreading boundary between two of the earth's tectonic plates where the magma is near the surface with attendant hydrothermal venting water with temperatures in excess of 350°C and thriving exotic life forms. This surreal and dynamic area is an ideal location for a long-term observatory for the study of the planet. A major interest will be the bacteria that exist in the sub-sea biosphere due to their ability to thrive in these high temperatures and normally toxic environments. It is believed that these thermophilic and extremophilic bacteria may someday be significant in relation to their enzyme potential [1]. Learning more about these enzymes could lead us in the development and engineering of new drugs and other applications such as treating and restoring polluted areas. The long-term continuous study of this biosphere is critical simply because so little is presently known of its nature and content.

Acoustic signals from the NE Pacific have been monitored with the Navy's SOSUS arrays and have been used to show the location and frequency of seismic events along the Ridge, and the Axial Volcano has been observed as the site of intense earthquake swarms, magma intrusions, and volcanic eruptions. However, the events are episodical in nature and are not conveniently synchronized with research cruise efforts in the area. The limited observations made in the past show a need to be on site with monitoring and sampling capabilities to effectively assess and describe the interactions of the seafloor, the water column, and the biosphere.

In a continuance of the NeMO vision and in the effort to optimize the method used to collect data from the seafloor, the concept of a near real-time year-round observatory was formulated. The two alternatives for this capability are the use of a cable from shore to the site to provide power and data, or a moored system using on-site power and some form of RF communications. The cable approach, as presently advocated by the NEPTUNE Project http://www.ocean.washington.edu/neptune/, would yield two-way communications with high data rates and a large power source, but the high costs are beyond the reach of this effort [2]. However, the moored approach used here was conceived as a viable alternative using available hardware and technologies. A small budget and a tight timeline limited this development effort to building a robust prototype that would be only the first step of this project.

II. System Design

The surface buoy and the sub-sea electronic subsystems each have identical acoustic modems and master controller units (MCUs). Having the same components on both instrument packages simplified development and improved the reliability of the system (Fig. 1).

The underwater acoustic communication hardware used is based on the Datasonics Telesonar series of acoustic modems. The ATM-870 modem provides data rates up to 2400 bits/sec with a variety of options for coding, acoustic source levels, transducers, and handshake routines. PMEL has extensive

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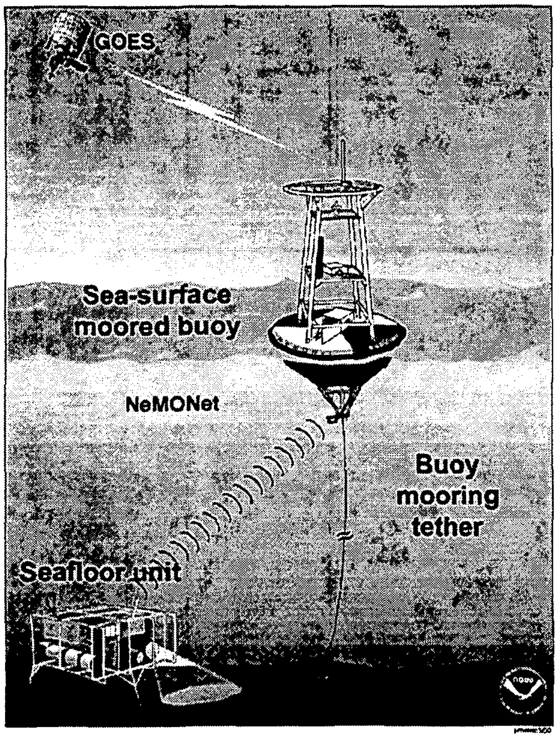

Fig. 1. Illustration of system design.

experience with these modems from applications in other projects and has worked to optimize these units for dedicated remote moored applications [3]. The modems use a high performance Digital Signal Processor (DSP) to control all functions, including coding the acoustic modulation. All transmissions use Multiple Frequency Shift Keying (MFSK) with 16 frequency bins of 300 Hz spanning a 5 kHz band with data redundancy for inherent reliability and a convolution coding technique in which a Viterbi algorithm is implemented to detect and correct errors. Other modulation schemes are implemented as needed, including 1 of 4 MFSK which allows for high-speed data transmission in a bandwidth efficient pattern, and a more complex Hadamard modulated MFSK to minimize the effects of frequency dependent fading. Also a selectable guard band, or delay between data frames, is used to minimize multipath interference [4]. The NeMONet modems were set up conservatively for this application to emphasize high reliability at the sacrifice of baud rates and coding efficiency. They operate in the 9–14 kHz band at 300 baud with Hadamard coding with rate 1/2 convolutional and 25 ms multipath guard period, 193 db source level, with a 55° directional traducer (AT-421). With the sub-sea transducer pointed straight up, this enables more power to be focused into the space occupied by the surface buoy. These configurations of an ATM-870 modem with the AT-421 directional transducer at both the top and bottom provide a very robust and reliable bi-direction link to the seafloor.

The master controller used in the buoy and the sub-sea package was designed around the Motorola 68332 system and was programmed in C. In addition, this 32-bit processor has the power to compute and multi-task simultaneous functions, and was built to be energy efficient for long-term battery powered deployments. The controller consists of 4 Mb of flash memory, a 12-bit A/D converter with 8 input channels, two RS232 channels, a hardware watchdog, a real-time clock, and 512 bytes of RAM. The function of the master controller is to implement and regulate all of the primary functions of the surface and seafloor units.

A. Sub-Sea Package

The sub-sea package consists of an acoustic modem, lights, master controller, temperature probes, battery cases, syntactic foam, and an aluminum pressure case with an acrylic lens (Fig. 2). A Sony PAL video camera and a PC-104 computer with a video frame grabber are used for imaging. This system was obtained from Desert Star as a result of a past SBIR grant for NOAA, and was less costly to implement compared to a true digital camera and strobe lights. On command from the master controller one of two 150-watt lights (Deep Sea Power and Light Model Deep Multi-SeaLite) are turned on and the camera streams video to the frame grabber that captures a single 760 × 568 pixel image. The image file is divided into 64 smaller files, each representing a small section, or tile, of the image. Each tile is compressed by a factor of 35:1 using wavelet theory to yield a complete image of approximately 16K using an 8-bit gray scale. The tiles are transmitted acoustically to the buoy with each tile as a single buffer. If the buoy receives the first attempt, the next buffer is sent. However, if there is no

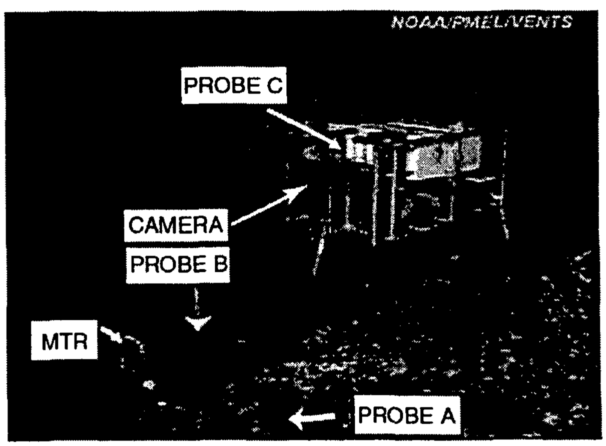

Fig. 2. Image of sub-sea package and accompanying temperature probes.

acknowledgment, the buffer is resent once. After all buffers have been sent the sub-sea unit asks the buoy if any tiles were not successfully received. If any tiles are missing, they are resent by the sub-sea package. This simple type of handshaking and redundancy was implemented to account for the unknowns in the acoustic environment, such as high surface winds, nearby ship interference, biological noise, or other possible causes of bit errors or lost data.

Temperature is measured in and around the hydrothermal vents at two different locations in view of the camera and a third temperature probe is located on the camera frame. The titanium probes contain a Resistive Temperature Detector (RTD) that is cabled to the master controller that gives a range of 400°C with a resolution of .01°C. Once an hour data from all three probes are sampled and stored and then transmitted to the surface via the acoustic modem at the end of each 24-hour period.

The system is powered with 564 Alkaline D cells housed in three aluminum tubes. A Mega Module DC-DC converter manufactured by Vicor is used to regulate power for the lights. This compact device is able to convert a wide input voltage range (10 vdc to 20 vdc) to 12 vdc and source more than 150 watts at an efficiency of 90% or greater.

B. Surface Buoy

The surface mooring uses a 2.5-meter diameter fiberglass over foam disk buoy with a gross displacement of 4000 kg. The mooring line is 19 mm 8-strand plaited nylon line with a rated breaking strength of 7100 kg and is deployed with a scope of 0.985. This maintains a tight watch circle to keep the buoy positioned within the narrow cone of the acoustic transmissions. A downward-looking transducer is mounted on the buoy bridle at a depth of 1.5 meters below the surface. A multi-layered baffle system of steel, lead, and syntactic foam shields the transducer and cushions it with rubber pads for a soft mount. This effort is designed to reduce surface noise and direct coupling to the float.

The surface buoy serves as a hub between the satellite and the seafloor, passing and formatting data. It holds an acoustic modem, master controller, a Geostationary Operational Environmental Satellite (GOES) transmitter, a Global Positioning System (GPS) receiver, and batteries in an aluminum instrument well. The surface acoustic modem is always listening for the sub-sea package and all data received is checked and processed by the master controller. When good data is received, as verified by a cyclic redundancy check (CRC) character attached to every message, it is placed in a buffer for transmission via the GOES system. This consists of a 10-watt transmitter, a 40-watt amplifier, and a full-wave quadrafilar helix antenna. The GOES system allocation for NeMONet is limited to one 60-second transmission window every hour, with a data rate of 100 bits/sec. Consequently, only one tile, which is always <250 bytes long, is sent every hour, with a temperature record sent daily on one of the hourly transmissions. A new picture is taken and sent every 4 days. The GPS is used to maintain accurate time on the buoy in order to align the GOES transmissions into their respective windows.

All buoy electronics, including the GOES transmitter, are powered from stacks of alkaline D cells. There are a total of 1208 cells with four different supplies for the various functions. The new cells have a long shelf life, are cost-effective, easy to configure, and because of volume manufacturing are made with quality control processes that minimize faults in the packs. Additionally no venting of the battery space is needed, as would be required with a charging system.

C. Implementation and Results

An excellent site was selected for the first NeMONet during an ROV survey in September 1999. The site is called Nascent Vent and is located on the SE side of the Axial caldera. It is characterized by water temperatures of 10–15°C and is an active site of tubeworms and other biota. The sub-sea package was dropped to the seafloor from the RV *Thompson* with a descent weight that impacted the bottom a few seconds before the package, which then slowed its decent to less than .5 meters/sec for impact. The ROV JASON was then used to move the package near the vent field and point the camera with the use of a 3 mW green laser (manufactured by Applied Lasers) mounted inside the case and aligned with the field of view of the camera. The camera was positioned and directed at the desired area. JASON was then used to detach two temperature probes and placed them in the field of view, as shown in Fig. 2. After a final inspection of the area the ROV was recovered. The surface mooring was deployed, beginning with putting the buoy in the water, streaming the line, and then dropping the anchor. The final location of the mooring in relation to the sub-sea package was critical for the acoustic communications, but with careful navigation and timing, the anchor landed within 300 meters of the sub-sea package.

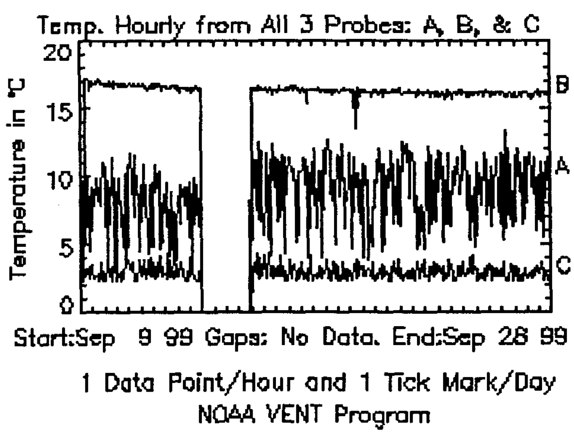

Fig. 3. Temperature data received over the GOES system.

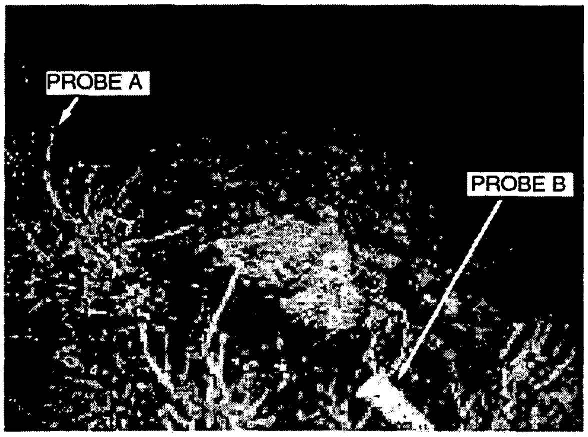

Fig. 4. Image created by tiles transmitted from sub-sea package.

An RF modem on the buoy transmitted data directly to the ship and an acoustic modem on the ship allowed interrogation and eavesdropping while in the area. A few tiles were acquired on the ship before departing.

In the month following the deployment of the NeMO Net project, temperature data were transmitted daily to NOAA scientists outlining the previous day's collection of hourly temperature readings. An example of the data received is illustrated in Fig. 3. The graph in this figure shows the variation of temperature dependent on the location of the probe. Probe C, placed on the sub-sea package assembly, provided the base for the surrounding temperature and it is evident that the temperature remained relatively constant. Probe B, positioned within the vent, showed a stable temperature as well. Probe A was located near the vent and the temperature readings reflected the significant flux in temperature due to vent fluid mixing with ocean water.

In addition to the temperature readings that were received daily, six pictures were transmitted showing a 99% tile retrieval rate. Unfortunately, five of the six pictures were blurry due to an insufficient amount of time given for the camera to focus while the lights were on. The sixth picture was focused and complete with the exception of one missing tile, and the picture clearly outlined many details of the ocean floor (Fig. 4).

In reflecting on the problems experienced with this project, it is evident that the short timeline hampered this prototype system; however, the data received clearly exemplifies the value of promoting the further development of a real-time observatory.

III. Conclusion

The NeMONet has proven to be a successful concept for monitoring the seafloor in near real time. Its deployment is only the first step in constructing a network of buoys whose function will be to provide real-time links among many continuous, long-term experiments.

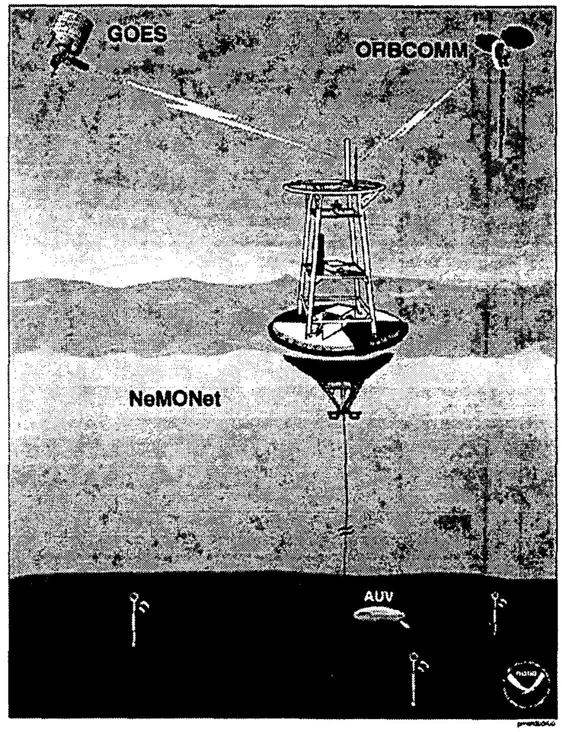

Fig. 5. Future system with the addition of a LEO and an AUV.

Beyond incremental additions for testing the overall concept, future additions to this project include an increase in the number of monitoring instruments deployed that are acoustically linked to the surface buoy. As advocated in workshops and documents for event detection and response, an autonomous underwater vehicle (AUV) will be added that will act as a first response agent to episodic events (Fig. 5). Also, the GOES satellite is not well suited to this application, as it does not permit two-way communications, requires high-powered transmitters, and is very data limited. Low Earth Orbiting (LEO) satellites will be incorporated that allow bi-directional communications from the surface buoy to the desktop without the limiting features of the geostationary satellites. Acoustic modems with much higher data rates will be incorporated as they are proven for these applications. The direct intervention from the desktop with high bandwidth will be necessary for full implementation of an AUV capability and will bring the full realization of this concept.

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