LEO-15
AN UNMANNED LONG TERM ENVIRONMENTAL OBSERVATORY

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Abstract — This paper presents a concept which involves the installation of a series of instrumented seafloor platforms which are linked to shore by an electro-optic cable. The use of an electro-optic cable permits these ocean-based systems to gather data continuously, for a long period of time, and at extended distances from shore. A system life time exceeding 20 years is possible. The electro-optic cable will transfer continuous electrical power and will provide a means of establishing a broad bandwidth fiber-optic link to the seafloor systems. The use of a broad bandwidth bi-directional fiber-optic link facilitates real time interactive control of ocean based experiments, instrumentation, and tethered and free swimming vehicle systems. Once data and control links are transferred to the shore station over the fiber-optic channel, they may then be made accessible for use in world wide education and research programs, through modern computing and communication technologies.

Specifically, this paper examines the design and installation of a Long Term Environmental Observatory which will be operated in 15 meters of water (LEO-15). LEO-15 will be located approximately 9 kilometers off the New Jersey Coast at Little Egg Inlet. The observatory will be linked to Rutgers, The State University of New Jersey, Institute of Marine and Coastal Science’s shore station at Tuckerton by an electro-optic cable which will be buried in the seafloor.

It has been determined that with some routine maintenance, a reliable long term system may be developed and put into operation. The successful installation and operation of the LEO-15 facility should provide the engineering experience and scientific motivation necessary to install additional observatories, worldwide, in both coastal and deep water sites.

1. INTRODUCTION

Man’s understanding of the ocean and our ability to model its processes are currently based on a relatively sparse set of independent observations which have been made worldwide over the past few hundred years. Our current inability to quantify cause and effect relationships and to establish long term trends both locally and globally stems from financial, political, and technical limitations, and from our inability to maintain a commitment to make frequent observations of ocean processes over long periods of time. The inaccessibility and incompatibility of existing data sets further frustrates this objective and the wide spread use of historical data sets. In order to understand the processes governing stability and change in the ocean, there is a need to make observations, in situ, over long periods of time. The ability to obtain experimental data, in real time, and to control and redirect underwater experiments, from a shore based laboratory, based on this real time data, will greatly enhance the quality of the data collected.

Unmanned seafloor observatories which are linked to Internet, an international computer communication system, via shore-based laboratories, offer a cost-effective means of establishing the commitment to produce a self consistent multi-dimensional data set which is readily accessible for use in international education and research programs. The interconnection of seafloor stations with the international academic data communication system will permit scientists to "Log into" and to obtain real time data from seafloor experiments while they are essentially anywhere in the world. The two-way link will permit scientists to redirect the course of the experiments based on data they have obtained.

A long term underwater observatory may be established by interconnecting one or more seafloor observatories with shore-based laboratories/control stations via an electro-optic cable. A system of this nature provides a means of operating a complex array of ocean-based sensors and vehicles for an extended period time. FIGURE 1 presents a conceptual image of a series of unmanned observatories which start in near shore coastal waters and extends down the continental shelf. Future systems should extend into the deep ocean. The seafloor cable will provide ample electrical power and broad bandwidth real time bi-directional communication to a large number of seafloor based systems. A partial list of different systems which could be coupled through a seafloor cable system include:

- operation of a series of instruments which make continuous measurement of environmental variables;
- operation of one or more observatories, each of which may contain numerous sensors which are directly linked to the electro-optic cable. The observatory(s) will take the form of single nodes spaced along the cable, some of which may have cable links to satellite stations emanating from them to form a star cluster;

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A key element in the success of systems of this nature is the electro-optic seafloor cable. Technical advances which have been made in the telecommunications industry involving the design installation and in-water repair of electro-optic seafloor cables provide the enabling technology which will permit ocean observatories to be installed, serviced, and maintained in a cost effective manner. Independent advances in the field of ocean engineering involving mooring design, underwater vehicles, acoustic telemetry, instrument development, and interconnecting hardware (connectors and cables) provide a technology base which allow scientists to make observations necessary to begin to understand cause and effect relationships. Sensor degradation due to micro- and macro-fouling remains the greatest impediment to the success of a truly unmanned system. Hazards to the submarine cable include:

- transport and erosion effects due to waves and currents, ice, and seismic activity;
- physical degradation due to corrosion, fouling, and attack by both micro and macrosopic marine organisms;
- mechanical damage due to recreational and bottom trawl commercial fishing activities, anchors which are unintentionally dragged by surface ships or buoys, ice scour, and “Acts of God”.

Hazards of this nature may be considered to be so severe that the long term survival of the seafloor cable will be questionable unless it is buried. However, once the choice has been made to embed the cable in the seafloor, it should be recognized that cable repair and fault location will become a much more complex and costly process. The cable design should permit the cable to be removed from the seabed by mechanical methods and repaired. The methodology required to disembed the cable and repair it must be devised before the seafloor cable is selected and installed.

The decision to bury the cable will generally hold out to the 100 fathom curve in most areas. In certain cases, it may be more practical to consider a selective embedment approach coupled with an inexpensive cable repair technique. Careful cable design and creative ocean engineering may make this approach quite practical in certain circumstances. In deeper water, there is normally no need to bury the cable.

Common hazards such as recreational and bottom trawl commercial fishing activities, ice scour, anchor dragings, and bottom scour may cause the cable to be broken if it is not covered by at least one meter of material when not in deep water. Historical data indicates that once a cable is buried, its chances for long term service are quite high. Details concerning the embedment of the cable in the seafloor are discussed later.

2. SATELLITE INTERFACE

Space-based satellite sensing systems are normally deployed for extended periods of time. During these extended deployments, the calibration of the sensors contained in the satellite may drift in some unpredictable manner. In order to
compensate for this fact, earth-based vicarious calibration methods are normally developed. Ocean sensing satellite systems typically rely on measurements made from ships, drifting buoys, and fixed moorings for these initial calibration and long-term validation requirements, as well as to develop and validate models and algorithms which describe the different ocean processes which are being observed.

Unmanned seafloor observatories, such as the type described in this paper, offer a new means by which calibration of space-based sensor systems may be accomplished. In certain cases, establishing a series of oceanic and atmospheric measurements from instrumentation linked to a seafloor cable system may provide a distinct advantage over traditional methods. Since the seafloor cable system is linked through the rest of the world Internet, a near real time communication link is established between the calibration sensors and the satellite receiving stations. This fact permits measurements to be compared directly with those being measured in space during each pass of the satellite. In addition, the ability to direct the time at which the samples are taken by instruments and to synchronize this timing with the passing of the satellite greatly enhances the utility of the data.

In-water measurements can be used for both direct comparison with those measurements derived from Satellite data, and to develop and validate models and algorithms. Typically, satellite based sensors can only resolve measurements within pixels which are on the order of a few square kilometers or more. If large spatial variations are found in the measurement being made over one pixel, then the data from a single point sensor will not be sufficient to calibrate the satellite measurements. If this is the case, then multiple measurements may be required over the pixel of interest in order to provide adequate ground-truthing. A solution lies in deploying multiple instruments in the form of a star cluster off a central node connected to the seafloor cable, where the star is the size of the required pixel element. The concept of synchronizing all of these independent measurements with the passage of the satellite is still valid.

As an example, consider the measurement of ocean color. The Nimbus-7 Coastal Zone Color Scanner (CZCS) satellite provided data which supported the theory that ocean color is a valuable tool for observing the optical properties of the ocean. This information also provides data on primary ocean production and global biochemistry, including the exchange of carbon and other biogenic elements. However successful, the CZSC system ceased operating in mid-1986. The SeaWiFS project involves the deployment of a second generation color scanning satellite which has been designed and is being developed based on the performance of the CZSC system. The goal of the SeaWiFS Project is to measure water leaving radiance to within 5% and chlorophyll "a" concentrations within 35% in clear blue ocean waters, globally, over a five year period.

FIGURE 2. REMUS VEHICLE

There is considerable interest in the deployment of one or more in-water radiometers at the LEO-15 installation to support the SeaWiFS system in near shore waters. The LEO-15 location, and its continuous sampling capabilities, make it an ideal candidate for SeaWiFS ground-truthing.

3. REMUS

A fundamental limitation of any seafloor based system is that it is spatially fixed. Buoys, which are anchored to the seafloor, may be moved with relative ease. A seafloor cable system, however, is not easily moved, especially if the cable is buried in the seafloor. By placing satellite nodes, with acoustic and electrical interfaces, along the cable track, and by altering the course of the cable during installation, an interesting distribution of environments may be established. Unfortunately, these locations are fixed in time, and, inevitably, the idea of making observations in new areas will become attractive.

In order to overcome this limitation seafloor cables can be linked to devices which may be moved about the ocean and communicated with over an acoustic link. Self powered instrumented systems which are deployed and recovered from ships offer an attractive means of accomplishing this goal. A bi-directional acoustic link will still permit interactive control, and the acoustic channel should provide ample bandwidth for most systems.

Of greater interest is how to exploit the real time deployed presence that the seafloor cable system offers to make measurements about episodic events which take place in locations which are remote from the cable. For instance, suppose a primary production event is detected by the SeaWiFS system. A rapid reaction is needed to make measurements concerning what caused the event, and to learn more about it. The Remote Environmental Measuring Unit(s) (REMUS) depicted in FIGURE 2 offers a potential solution when integrated into a seafloor cable system.

The REMUS concept involves a free swimming vehicle which is tracked and commanded over a low bandwidth acoustic link. The vehicle is set off on a preset heading, but the tracking/acoustic communication system offers the ability to make in-flight course corrections. The vehicle is low cost and simple in nature and may contain a limited number of sensors, which measure dissolved oxygen content, conductivity, temperature, and depth. An internal data logger which is synchronized before launch with the tracking system retains data
collected during a deployment. In this manner, data collected during a mission may be correlated with positions from the tracking system.

A REMUS vehicle may be operated in many modes. When used in conjunction with a seafloor cable system, it isvisioned that multiple vehicles would be housed in a subsa
launching system. Based on a need to make remote measurements, an operator at the shore based laboratory or anywhere in the world, could set an initial trajectory for the vehicles, and launch one or many vehicles at preset time(s). The vehicle would then be tracked and course alterations made as needed during the mission. Multiple vehicles could be in operation at one time.

During a mission of this nature, when the vehicle has reached minimum battery level or has been commanded to stop, it releases a foam block and anchors itself to the bottom. The vehicle is then recovered at a later date by a surface vessel which commands it to come to the surface over an acoustic link. The final location of the vehicle is known due to the tracking system. Once the vehicle is recovered, the data is correlated with the tracking system and analyzed. A new battery is then placed in the vehicle, routine maintenance is performed, and the vehicle is returned to the system by divers.

4. CABLE EMBEDMENT

The bottom conditions between the LEO-15 observatory site and the Tuckerton Shore station permit the cable to be embedded into the seafloor with a light-weight seafloor plow. The cable plow is quite simple in nature and consists of a "stinger" mounted on a sled which is pulled along the bottom by the surface equipment. The stinger permits the cable to be embedded in the seafloor by fluidizing the soil directly in front of it. As the sled is pulled along the seafloor, the cable is pulled off the surface reel and laid into the fluidized sediment. Often, in shallow water, a diver rides the sled to ensure proper installation and burial. Monitoring and ensuring embedment to the proper depth can be the most complex part of the burial operation. FIGURE 3 presents a block diagram of the embedment method.

The tasks associated with the installation of the cable are:
- perform a study to select the best cable route;
- establish route survey requirements and perform survey;
- establish specifications for termination and anchor points at both ends of the cable;
- file for and obtain installation permits;
- prepare contract for cable installation and burial;
- specify and purchase electro-optic cable.

During the installation of the main cable leg, all satellite cables, the main platform, and any other major components of the system should be installed.

The anticipated time to install and bury the cable for the LEO-15 system is two to three working days. It is estimated

that the cost of installation will not exceed $150 k. Other sites may have very different installation costs.

5. FOULING

Marine bio-fouling will degrade and alter the performance of sensors and increase corrosion rates and mechanical loading on instruments and structures. In order to combat this persistent problem submerged instrumentation and structures must be carefully designed, frequently inspected, calibrated, and most likely cleaned.

Current technologies try to inhibit fouling by leaching heavy metals and strong toxins into the environment. Other approaches involve slipper non-stick coatings and creating clam shells like enclosures which try isolate systems from the environment when not in use.

Countering the fouling problem with toxic coatings has been moderately successful against hard foulers, but bacterial coatings normally persist. Mechanical cleaning, with divers or robots, appears to be the most effective way to control fouling, especially in shallow waters. In deeper waters, the fouling problem is not as severe, but thin films of growth, which will alter sensor performance, develop rapidly and must be removed.

6. THE LEO-15 SITE

The LEO-15 observatory will establish a long term study site for the coastal waters of New Jersey. The observatory will be installed in vicinity of a sand-ridge approximately 9 kilometers off the New Jersey Coast near Little Egg Inlet. The sand ridge is approximately 4.5 km long and 1 km wide, and rises to within 7 meters of the surface in some places.

The area of the sand ridge was considered as a possible site for a nuclear power station during the 1970's. During this period the New Jersey Public Service Electric and Gas Com-
pany contracted EG&G, Environmental Consultants of Massachusetts to conduct a field study program of this area [1], [2]. During the summer of 1991, the east coast branch of the United States Geological Survey conducted a sonar survey of the same area. Bathymetric results of this survey agreed very closely with similar measurements made in 1974. Findings indicate that there has been little change in the sand ridge [3].

7. THE LEO-15 SYSTEM

The major components of the LEO-15 system should include:

- a surface control station;
- 9-10 km of electro-optic cable;
- the main observatory platform;
- a secondary satellite station;
- seafloor instrumentation tripods;
- an instrumentation suite including video and a vertical profiler;
- a Remotely Operated Vehicle system with precision acoustic tracking[4];
- a diver interface;
- a SeaWiFS coastal in-water calibration capability;
- a long base line tracking system;
- a free swimming vehicle, launching, docking, tracking, and programming capability.

The initial installation of the LEO-15 system will involve the main observatory and one secondary satellite. A one kilometer distance between these two nodes will form a long base line acoustic tracking system. This tracking system will be used to monitor the trajectory of free drifting surface and subsurface buoys as well as low cost free swimming vehicles which will be used to monitor frontal location and episodic events detected by elements of the observatory system such as the SeaWiFS satellite interface; (see REMUS).

The secondary satellite station will permit sensor installation and observations to be made from a second location. Smaller tripod units will be linked to either of these nodes.

The observatory will include sufficient data channels and support capabilities to permit short term projects to be "plugged into" the long term research effort.

A. THE ELECTRO-OPTIC SEAFLOOR CABLE

The cable currently envisioned for the LEO-15 system is a conventional three conductor composite cable design with three optical fibers placed in the interstices formed by the conductors. All of the voids in the core of the cable and the conductors are to be filled so that they are water-blocked.

The cable will be strengthened and nearly torque balanced with a double layer of counter rotating galvanized steel armor wires. The armor wires will be coated with tar and jute to increase the armor life by reducing corrosion rates.

![Diagram](image)

**FIGURE 4. DATA TELEMETRY BLOCK DIAGRAM**

B. FIBER-OPTIC TELEMETRY

A broad bandwidth telemetry system will be established between the Tuckerton shore station and the seafloor observatory. This system will consists of a bidirectional synchronous data telemetry link as well as a four channel near broadcast quality video link. The data and video links are discussed separately.

A block diagram of a ten channel synchronous telemetry system, which has been developed by the Oceanographic Systems Laboratory with funding from the National Science Foundation and the Naval Oceanographic Office, is shown in FIGURE 4. Ten channels, each sampled at 10 megahertz, provide both low and high speed bi-directional data transfer. The telemetry system is a modular design based on the VME 3U card format. This approach permits the development of special interface cards for use with essentially any instrumentation.

An Ethernet interface which allows the full 10 Mbit/sec bandwidth of IEEE 802.3 to be available across the link has also been developed. The Ethernet interface facilitates the use of networked system protocols and UNIX based real time operating systems such as VX Works. Some of the advantages which may be gained from systems of this nature are discussed in [6].

The LEO-15 system is intended to be used with a broadcast quality, interactive video link, between the Tuckerton shore station, the main Rutgers campus, and other educational facilities such as the Camden Aquarium. For this reason, the fiber-optic video link from the seafloor platforms must also be near broadcast in quality. A Grass Valley Group four channel audio/video system which meets EIA/TIA-250-C short hall
specification is envisioned for use in the system. The four video channels are transmitted on one optical fiber.

C. MECHANICAL DESIGN

The LEO-15 platforms will provide an interface for a variety of sensing instruments. Flexibility will be provided to allow for newly developed sensors. Deployment and recovery of instruments from the platform will be facilitated by using underwater mateable connectors and simple mechanical attachment techniques to allow diver servicing. All mechanical components will be designed to meet individual instrumentation requirements and to ensure long term survivability.

Both the shore station and LEO-15 platform will be modular in design to allow phased installation and easy maintenance. The platforms would be fabricated with an open framework to permit water movement in and around the sensors and reduce sediment entrapment. Corrosion protection will be provided by coatings and passive cathodic protection.

D. PLATFORM ELECTRICAL DESIGN

The seafloor cable's optical fibers and electrical power conductors will terminate in an oil-filled junction box mounted on the main platform. Inside the junction box will be the power transformers and rectifiers needed to convert the AC power transferred down the electro-optic cable to DC power. A set of cables will run from the junction box to the main electronics housing.

The main electronics housing will be a large diameter cylinder with flat end caps. On one end cap will be an array of underwater connectors for connecting the external modules and the subsea cable junction box. The main electronics housing will provide designated connectors for main platform sensors and additional connectors able to accommodate the different power and signal combinations that may be needed for satellite stations and future sensors.

E. TUCKERTON SHORE STATION

The primary shore station for the subsea system will be located inside the Rutgers University Tuckerton marine field station on Great Bay. The shore station will include the following major subsystems:

- a 5 kilowatt, high voltage, 3 phase power distribution system [5];
- a surface telemetry console;
- a diver communication system;
- a video recording and display system;
- a UNIX based surface computer system;
- an operator interface based on SUN's OPENWINDOWS graphical users interface[6];
- a data archival system;
- a network transparent, "Self Describing" data storage format based on NSF's Network Common Data Form interface[7].

F. LEO-15 INSTRUMENTATION

The LEO-15 system will be designed to handle a wide variety of existing and future sensors at the main platform and satellite stations. LEO-15 sensors will be designed to withstand long term submersion. Table 1 is a list of measurements which will be made, and or sensors which are currently envisioned for use in the LEO-15 system.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Instrument</th>
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<tr>
<td>Pressure</td>
<td>Current Meter</td>
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<td>Conductivity</td>
<td>Temperature</td>
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<tr>
<td>Dissolved Oxygen</td>
<td>Optical Backscatter</td>
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<tr>
<td>Fluorometer</td>
<td>Pan &amp; Tilt Video</td>
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<tr>
<td>Wide-band Hydrophone</td>
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<td>REMUS</td>
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<td>AUV Interface</td>
<td>Transmissometer</td>
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9. References


