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The Manned Submersible as an Effective Sampling and Imaging Platform

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I. ABSTRACT

Remotely Operated Vehicles (ROVs), tow bodies and autonomous undersea vehicles (AUVs) are increasingly being used as platforms for underwater measuring, collecting and imaging. However, there are tasks for which a free-swimming, manned vehicle is a cost-effective platform. The effectiveness of an in-situ operator, rather than one remotely located from the sampling or measurement platform, is primarily due to two factors: intelligent vision and adaptive decision making. In spite of the advances made in stereo-vision systems and telepresence, the on-site human eye often outperforms other vision systems. The presence of an operator on board the vehicle also allows decisions to be made rapidly, or an experiment to be modified when conditions are not as anticipated.

This paper will describe several successful, ongoing projects utilizing Harbor Branch Oceanographic Institution's (HBOI) manned submersibles. One project involved imaging natural and man-made objects near the ocean floor using a laser-line-scanning (LLS) system equipped with multiple receivers. This system was interfaced to the Research Submersible CLELIA and was employed on five missions during 1996. Spectacular high-resolution black and white, fluorescence and color images were obtained.

Inter-disciplinary research cruises to cold-seep regions of the Gulf of Mexico with the JOHNSON-SEA-LINK (J-S-L) submersibles allow multi-parameter probing of brine pools and specialized collection of biological, geological and geochemical samples. For example, methane ice samples are removed from deposits on the ocean floor at a depth of 2000 ft. and transported under pressure to a laboratory on board the support vessel for analysis.

The ability of the J-S-Ls to approach and collect, without contact, delicate zoo-plankton has been well known to midwater scientists for some time. Now, with the addition of a low-light auto radiometer (LoLAR) and a PS 1000 spectrometer, we are able to measure the visual environment of collected organisms even at the very dim light levels which many of these animals inhabit. Use of these instruments on an untethered, neutrally buoyant submersible eliminates many problems associated with ship and ROV deployments. These include surface coupled motion, ship's shadow, variable angle of the photosensor and unwanted stimulation of bioluminescence. While making measurements, the on-board scientists can observe animal behavior and their distribution patterns.

Specimens of deep-water, invertebrate animals are routinely located, identified, in-situ photographed and collected with the J-S-L submersibles for our bio-medical researchers. A large number of these samples are transported in our shipboard laboratories to Ft. Pierce for extraction and analysis of the bio-active chemicals. The presence of a scientific specialist within the submersible to visually identify the specimen and supervise the collection process is essential to the success of the mission.

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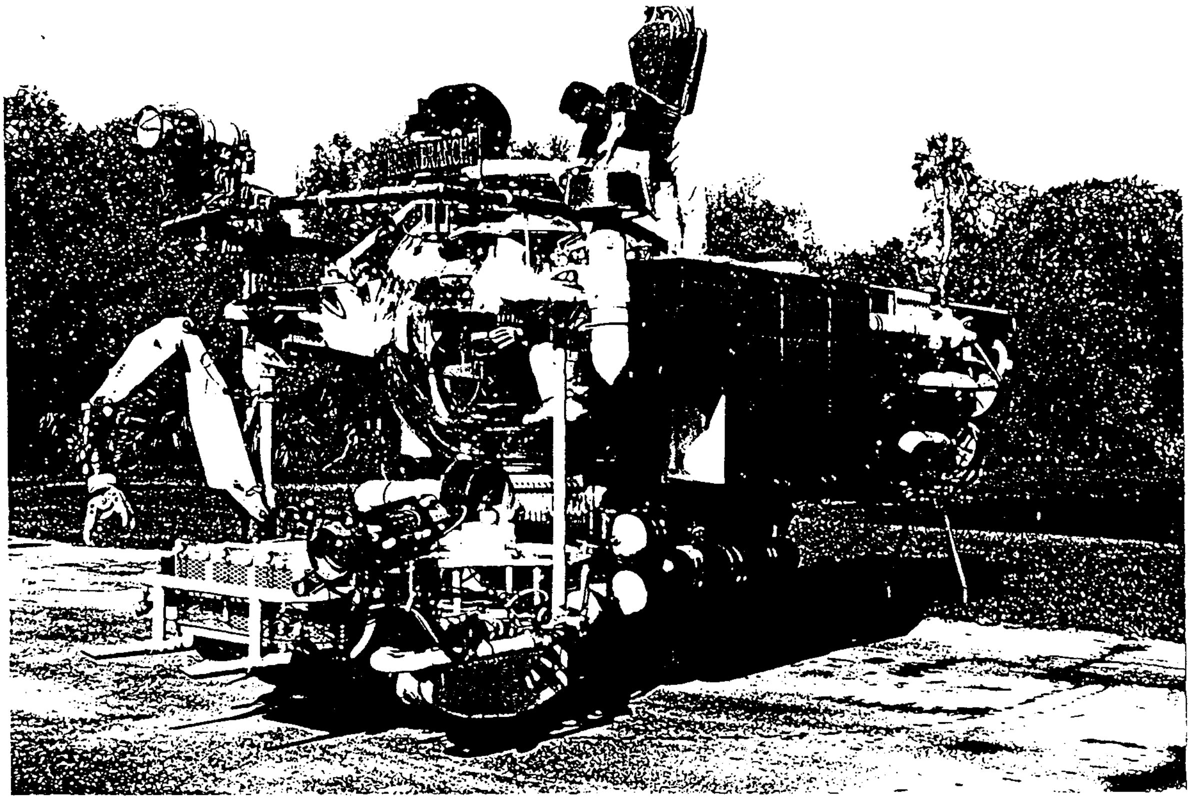

Figure 1. Harbor Branch Oceanographic Institution's JOHNSON-SEA-LINK II, a 3,000 ft.-rated, 4-person research submersible.

II. INTRODUCTION

Until 60 years ago, aquatic science in water deeper than a few meters was conducted with nets, traps, hooks and grabs. The pioneering use of Simon Lake's 1931 NAUTILUS and the bathysphere dives of Beebe and Barton in the 1930s marked the beginning of deep-water, in-situ observation and science (Beebe, 1934, Geyer, 1977). Although submarines have been around since the 17th century, their use for scientific data gathering and collecting did not catch on until the 1950s.

Cousteau's FLYING SAUCER, Piccard's TRIESTE I and II and Woods Hole's ALVIN are probably the most famous of the scientific manned submersibles built in the 1950s and 1960s. Since the 1970s, the use of manned submersibles for scientific sampling and quantitative observations has made steady progress. Today, the 3,000 ft-rated JOHNSON-SEA-LINK submersibles and the 1,000 ft-rated CLELIA provide the underwater scientific community with a wide selection of sampling and observation capabilities. (Youngbluth, 1983; Robison, 1983; Askew, 1984; Rechnitzer, 1986; Cooper & Babb, 1988).

Although manned submersibles and remotely-operated vehicles are sometimes considered to be competing technologies, those who have used both generally see them as complementary (Jannasch, 1990; Madin, 1990; Bowen & Walden, 1992; Takagawa, 1995). The fact that manned submersibles provide unique capabilities for exploring, studying and developing the resources of the ocean is as true today as it was 20 years ago when Richard Geyer compiled a number of comprehensive papers on the characteristics and use of submersibles (Gyer, 1977). As Sylvia Earle has recently said "there is no completely satisfactory substitute for being there" (Earle, 1995).

III. LASER LINE SCAN IMAGING

During 1996, HBOI provided highly specialized support to an Office of Naval Research sponsored optical-oceanography project involving modeling and field measurements of coastal waters and the benthic region. In addition to logistic and ship support to investigators from a dozen major U.S. laboratories, HBOI provided a stable underwater platform for operating a unique benthic imaging system. This system is a highly sophisticated laser-line-scan (LLS) imaging system somewhat similar to the ones used in the TWA Flight 800 search efforts (Sade & Carey, 1996) and the system mounted on the U.S. Navy's NR-1 nuclear research submarine during a recent photographic cruise in the Gulf of Mexico (MacDonald et al, 1997).

A major advantage of laser-line-scan imaging over more conventional methods is that it allows near-field back-scattered light to be greatly reduced by using a highly-collimated illumination source and a receiver that looks only at the region illuminated. This technique provides quality images at a range several times greater than conventional imaging systems including the human eye (Coles, 1988; Kulp et al, 1988; Gibby et al, 1993; Boston, 1993; Gordon, 1994).

Unlike the "standard" monochrome LLS imaging system, the one used on this project has four individual optical receivers. Each receiver can be fitted with a different optical filter allowing a wide variety of image types including multi-color fluorescence and color (this requires a special laser that produces red, green and blue emission). Perhaps the most spectacular and useful images produced are those obtained in the multicolor fluorescence mode. The diversity and health of a benthic ecosystem can be determined by a brief imaging fly over. A description and some applications of this LLS system were recently presented at the OCEAN OPTICS XIII CONFERENCE (Strand et al, 1996).

The multiple-channel LLS system, designed and built by Raytheon Co., was mounted on our research submersible CLELIA. The sensor subsystem, weighing 1000 lbs. and containing the laser and optical receivers, was mounted below the hull between the two battery pods looking downward. The display, signal processing and recording equipment was mounted inside the hull. Initially, the system was used to obtain fluorescence images of large areas of biologically-active ocean bottom in the Dry Tortugas region of the Florida Keys National Sanctuary. The many images recorded helped the researchers to pin-point areas of special interest which were then intensively studied by diver-supported in-situ methods (Akleson, 1996).

The multi-channel LLS imaging system was later used to obtain detailed maps of a small area of coral reef, sand and benthic algae (approximately 100 m long by 20 m wide). This region was successively imaged with the instrument configured for multicolor fluorescence, true color as well as monochrome. For the series of color images, an Argon/Krypton "white" laser was installed.

HBOI's CLELIA is an ideal platform for deploying a laser imaging system. A large number of constant-altitude, nearly-straight passes were made over the study sites during each dive. Multiple images at several altitudes were obtained with each of the several system configurations.

Vehicle roll, pitch and yaw variations can cause major distortions of the recorded images, requiring a large amount of data post-processing. During the runs over the target areas, CLELIA's trim and balance were carefully adjusted and the autopilot set to provide a straight track even in the presence of cross currents.

Uniform motion of the imaging system, decoupled from surface effects, is essential to this type of operation. In a previous attempt to operate the multiple-channel LLS system on a tethered vehicle, the tether introduced forces and vehicle motion which allowed only a few useful images to be obtained. For this earlier operation, the tether was necessary to provide power and control signals to the vehicle and to transmit the digital image back to the support ship.

On CLELIA, sensor control, signal processing and recording was performed on board with the electrical power supplied, via custom converters, from CLELIA's battery. Wide-band duplex data was transmitted between the image producing sensor subsystem and the electronics within CLELIA through fiber optic cables.

IV. SAMPLING OF COLD SEEPS

Since the mid 1980s, the J-S-Ls have conducted a large variety of scientific investigations at cold seeps in the Gulf of Mexico. These studies have been initiated by a multitude of universities and government agencies and have involved hundreds of dives to depths of over 700 meters.

The Cold Seeps are a very dynamic and majestic section of the Gulf. Small volcanoes created by warm water and mud flows are blanketed with bright orange and white bacteria feeding off the released methane. Methane is the essential ingredient to these chemosynthetic ecosystems which exist without sunlight. Crude oil boils from thin layers of sediment upon contact, often from within bushes of tube worms, which grow to over 2 meters, or from within the mussel beds. Glaciers of ice-like methane hydrate or clathrate are exposed under ruptured layers of sediment and within meter deep fissures in the upper crust. These features evolve daily, at times moving inches over night. There are also "brine pools" made up of dark water that is seven times as saline as seawater--water so dense that the sub floats on the surface as if it were a boat, sending ripples against the beaches of mussels.

The J-S-Ls have explored this incredible landscape with such tools as "bubblometers" that measure the rate of escaping gases from the sediment, Hydrate "pots" that protect the methane ice samples from decreasing pressures and thus preserve them for analysis, pore water probes that take water samples at precise depths below the sediment/water interface, variable suction samplers that remove the thin mats of bacteria without disturbing the sediment, and many others. Time-lapse video cameras have been deployed for periods of up to one year to film the growth of hydrate fissures, while simultaneously gathering temperature data from the surrounding sediments. Long term recording thermistor arrays have been deployed across hydrate mounds and a miniature hydraulic winch was installed on a J-S-L to lower a Conductivity-Temperature-Depth (CTD) recorder into a brine pool. A lead-line was later used with this winch to create a crude bathymetric map of the 30 meter diameter pool. Because of the J-S-L's large payload and precise variable ballast system, many of these sampling tasks and deployments can take place during a single dive.

Biological experiments and sampling have centered around the mussel and tube worm communities. The growth rate of the worms has been determined by two methods. A "bander" was developed by HBOI which, with video documentation, allowed the growth rate to be determined on subsequent visits (Tusting, et al, 1996). A more recent approach has been to use a "stainer" which stains up to 20 tubes at a time. During later visits the new growth appears very white compared to the previous blue stained material. Mussels have been collected and stored in a acrylic cooler during transportation to the ship-board laboratory and kept alive for up to a year. Often they are tagged and returned to the seafloor for later studies. Mussels have even been analyzed for possible aquaculture applications.

Reconnaissance missions have also been conducted to verify small anomalies on large scale bathymetric charts. Hundreds of precision, undisturbed box cores and punch cores have also been acquired, often with as many as 10 being taken on one dive.

Operations such as these have become more cost efficient and productive by the introduction of many new systems. Progress of the J-S-L along the seafloor is continuously monitored by the support vessel, which at times can be several thousand feet off station. Voice communication is established every 15-20 minutes while a short base-line tracking system provides the vessel operator with a constant position of the submersible. The ship's geographical position is fed into a computer along with the submersible's relative position. The result is a graphical presentation in real time of the vehicle's track in Latitude/Longitude coordinates. This data is printed and stored for later reference. Currently work has begun on integrating a modem connection to the sub to allow more rapid course corrections and generally increase navigational accuracy.

Experimental stations are relocated using the archived computer data. Simultaneously the sub scans the seafloor with an analog sonar which listens for the sound of a pinger left behind during the previous dive or mission. This allows for pin-point accuracy and rapid site relocation. Sites are routinely documented with 35 mm still photographs and Hi8 video. The video is annotated with date, time, depth, temperature, and salinity. These parameters, among others, are stored throughout the dive and are downloaded and plotted later in the lab.

V. Midwater Sampling And Bio-Optical Measurements

The J-S-L submersibles have been largely responsible for the pioneering studies of mid-water biology (Robison, 1983; Youngbluth, 1983). More recently, they have been equipped with custom optical sensors, low-light measurement and imaging systems and bioluminescence recording equipment (Widder, 1997). Over-the-side measurement systems have been used since the 1950s. Measurements obtained were often contaminated by:

- Ship shadow effects
- Uncontrolled orientation of sensors
- Unwanted stimulation of the bioluminescing animals to be studied.

In addition, surface-coupled motion of the instruments was omnipresent and selective observation and collection extremely difficult. The J-S-L submersibles, specially equipped with sensors and precision buoyancy control, have made this type of research practical and highly effective. Several experiments are generally performed during a single dive.

It requires a full day to outfit the submersible with the gear necessary to complete a mid-water mission. Some of the benthic gear is removed, such as the hydraulically operated sample basket and the clam bucket scoop, and some is modified by the addition of components like flow sensors and mission specific screen or mesh, as is the standard lower work platform.

The sub's hydraulic system has been made more versatile by the incorporation of a pilot operated spool valve manifold that shifts 9 of the 16 available hydraulic functions from one actuator to another. Load holding valves are placed in line on some functions to prevent drift or creep while shifted into the disabled mode. This increases the number of devices that can be operated on any one dive.

The mid-water gear is comprised of an 8 bucket collection rack mounted on two quick release hydraulic manifold plates. This allows quick installation with all the hydraulic plumbing already in place. This feature has been used on other equipment where quick change out or a jettison feature is desirable. The acrylic buckets are oriented vertically with a sliding door top and bottom on each bucket. This allows the pilot to ballast the sub slightly positive and collect samples with a minimum of disturbance to the surrounding water and samples.

Another collection device consists of 12 acrylic buckets on a hydraulically driven chain that rotates the buckets under a suction device. When indexed, the spring loaded doors on each bucket open to allow sampling and then close when rotated to the next position. This unit is mounted on the port main ballast tank with the bucket in use close to the pilots head and the suction funnel and tube in full view. This arrangement allows the pilot to closely observe the sample throughout the entire collection process and vary the flow rate to minimize damage to fragile specimens.

The top of the port main ballast tank is also the mounting site for a Remote Ocean Systems (ROS) pan and tilt mechanism with the HBOI Low Light Autoradiometer (LOLAR), an Osprey Intensified Silicone Intensified Target (ISIT) imaging camera and the lens end of the fiber optic line bracketed to it. This puts the sensing and imaging devices under direct control and observation of the operator and at the highest point on the vehicle for an unobstructed view of the water column above. A rectangular excitation screen is also mounted at this level on the forward work bar . It is used to stimulate the animals and trigger their bioluminescence in the field of view of the ISIT camera.

The Low Light Autoradiometer, developed at HBOI, has extended the capacity to measure downwelling light at 480 nm and 380 nm, by five orders of magnitude over commercially available instruments. By using this instrument on the submersible, the standard and almost insurmountable problems associated with shipboard deployed instruments – ship's shadow, variable and often unknown depths due to wave action, and variable angle of the photosensor – have been overcome. With this instrument on the J-S-L submersible, our scientists have been able to measure changes in the downwelling light field as the sun is going down, while simultaneously quantifying changes in animal distributions in response to the decreasing light intensity.

A through-hull fiber optic penetrator was also developed for use on the JOHNSON-SEA-LINK submersible. Coupled to a PS-1000 fiber-optic spectrometer, this innovation has allowed accurate measurements of the change in the spectral distribution of light with depth to 200 m, the deepest in situ measurements ever recorded.

The most recent addition to the mid-water sampling gear is the 3-D Laser Imaging Tracking Electro-Optic System (LITES). It uses a low power (6.5 mw) 677 nm diode laser to provide a surface map of objects within its field of view. Capable of up to 20 frames per second at 200 x 200 resolution or 800 x 800 resolution at 1 frame per second, this device stores each "FRAME" as 3-D data file containing a cloud of points having x, y and z coordinates for instantaneous display on a laptop computer or evaluation using standard 3-D analysis tools.

VI. Benthic Collection

The search for new chemical compounds is not limited to the Tropical Rain Forrest. The JOHNSON-SEA-LINKs have been used as the collection and documentation platform for a group of HBOI scientists dedicated to the discovery and development of therapeutic agents based on unique bio-active compounds found in marine organisms. While collections for this purpose are not unique to HBOI, most of those collections had been completed by SCUBA diving or bottom trawling. The integrated system approach of the J-S-L has overcome limitations of both of these techniques while enhancing the advantages of both.

There are many complex processes that must take place before a compound is ready for issue as a drug, but it all starts with the discovery of a unique natural product, molecule or compound and the ability to obtain an adequate supply of it for testing and study. A manned submersible when equipped and supported with the proper tools is well suited to both these tasks.

Being tether free is a major advantage for the sampling vehicle. Many habitats have been poorly sampled due to their topography. Vertical walls, overhangs and rugged or boulder littered bottom are easily worked with a free swimming highly maneuverable vehicle. Selective collections are generally made at depths well beyond those that can be worked by divers.

Couple this autonomy with a wide variety of collection tools mounted on a manipulator arm, i.e. overlapping jaws, cutting tool, suction sampler, clam bucket scoop, then the scientist can sample where a trawl net could never go. With the HBOI vehicles, investigators can now do it with precision, repeatability and most importantly, selectively. The J-S-L system can be equipped with either twelve 10" diameter collection buckets or twenty-four 7" diameter buckets for isolating individual samples or groups of samples. For documentation of collections, a running log is kept by the scientist on video and field notes, recording the sample number, description, habitat and CTD data. This information is used as a basis for a post dive sorting and identifying of each sample; obviously a step up from the jumble of items in a trawl. By storing individual samples in separate collection buckets, the scientist can be assured that any observed bioactivity is the result of that sample only.

Documentation of each sample is accomplished by a multi-step approach. The target in question is first still photographed using the submersible's laser aimed underwater 35 mm camera with a 85 mm telephoto lens and 150 watt second strobe. The lasers are fixed such that they intersect at the point of focus for that lens. Then, by maneuvering the sub and/or hydraulically tilting the camera assembly, a close-up, in focus slide of each organism can be taken before collection. Typically, 3 to 4 photographs per sample are taken in succession for use on a day to day identification basis and for archival purposes.

After still photography, video documentation is accomplished with the SEA-LINK's pan and tilt mounted Photosea 3000 color camera equipped with a Canon 6 to 48 mm focal length, (8 - 1 zoom ratio), remote zoom and focus lens. CTD data is continuously recorded by a Seabird SBE-25 Data Logger, as well as being displayed and overlayed on Hi 8 mm format video tape. This is accomplished by a Pisces Design Video Interface Unit. The information is always encoded on the tape, but the display can be easily toggled on and off so that an unlabeled image can also be available.

During this documentation process the surface is contacted to record a position fix and assign it a fix number. This is then relayed to the investigator for entry into the field notes and annotated on the video. The position is recorded on the ship's integrated mission profiler as a latitude and longitude of the submersible at the time of collection and is downloaded or printed post dive. If additional samples of an organism must be located and collected, this overlapping documentation is crucial to its relocation and recollection with speed and efficiency

The samples are tagged and vouchered post dive. They are then examined for taxonomic identification. It's here that the long process of drug discovery begins. If activity is found, the ultimate goal would be to synthesize the compound or grow the organism in the laboratory. This requires considerable time, study and technology. The manned submersible is a cost effective alternative in the early stages and facilitates the initial controlled, selective harvesting of samples for biodiversity prospecting.

The HBOI manned submersibles give the scientists the best of both worlds by freeing them from a decompression obligation, yet allowing them to see, collect and document the organism in situ, all in far greater depths and in more difficult terrain than either diving or trawling.

VII. Conclusion

This paper has briefly described some recent underwater science projects using HBOI's JOHNSON-SEA-LINK and CLELIA manned submersibles. These operations represent a few of those which can most effectively be accomplished with dedicated and well-equipped manned research submersibles. The development of innovative sampling gear at HBOI continues to enhance the effectiveness of our vehicles.

These systems, combined with many other field-proven traditional systems, contribute to the on-going success of science missions carried out by the HBOI manned submersibles, their skilled crew members and the dedicated support vessels.

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