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ROV TECHNOLOGY UPDATE FROM AN INTERNATIONAL PERSPECTIVE

Robert L. Wernli
Naval Ocean Systems Center

Jack E. Jaeger
Hydro Products, Inc.

The second annual Remotely Operated Vehicle (ROV'84) Conference and Exhibition sponsored by the Marine Technology Society San Diego Section and Undersea Vehicle Committee and the University of California Institute of Marine Resources drew over 2,500 attendees to San Diego, CA. A balanced program was supported by ROV designers from academia and industry, ROV operators associated with service companies, as well as offshore oil company and government users representing 20 nations including the USSR and the PRC. The four-day conference, with its 150 exhibits and 70 technical session presentations involved a dynamic exchange of ideas and financial transactions all tied to what has been described as an "explosion" in the ROV industry. The technical program provided quality presentations on session topics including ROV Subsystem Development Status, Deep ROV Systems, Pipeline Survey Systems, Structure Inspection Activities, Innovative Applications, Operational Characteristics, Platform Integration, International Developments and Autonomous ROV Developments. Copies of the Proceedings run 400 pages and are available, along with copies of the "Operational Guidelines for ROV's" publication and ROV'85 information, from the San Diego Section, P.O. Box 82253, San Diego, CA 92138.

INTRODUCTION

This manuscript will present many of the technological highlights of the detailed conference proceedings. The intent is to provide those unable to attend ROV'84, with an update on the state of the art of ROV technology, including how and where it is being applied. Many of the opinions expressed herein are those of the original authors and not necessarily the coauthors of this paper.

ROVs are performing a widening range of tasks today, deeper and cheaper than manned submersibles or human divers and without risk to the operator. Most of the more than 400 ROVs in operation are used for servicing oil rigs, marine salvage and other operations that are a key factor in reducing costs. The potential savings and increased efficiency through employment of ROV systems has generated a flurry of interest in the ROV industry and considerable income for their inventors, manufacturers and users. A chain reaction is now in force, generating investments in research and development in hundreds of ROV components from cameras to highly sophisticated, artificial intelligence type computer systems, that are certain to benefit other industries as well.

Developments in the ROV industry represent a "quantum leap" in inner space exploration. ROVs are opening new frontiers, much as technology in the space program has opened new frontiers in the exploration of outer space. Through the use of ROVs, oil rigs are now serviced routinely and new ROVs are working to depths of 8,000 feet. In the near future, ROVs should be able to extend their capabilities to 20,000 feet, which will provide access to 98 percent of the world's oceans and bring much of its wealth closer to financial feasibility.

SESSION HIGHLIGHTS

The following paragraphs provide a synopsis or abstract of many of the technical session presentations as further documented in the proceedings.

ROV Viewing Developments

Dr Rebikoff noted that true stereo vision imposes requirements for the highest precision matched optics with depth of focus ranging from lens contact to vision limits in order to preclude focus control. Only such fully corrective optics will ensure headache-free vision all day long, according to the author, who also noted that "our built-in CPU is very able to give us continuously a fair estimate of distance and dimensions of every feature viewed".

A complementary yet somewhat divergent viewpoint was expressed on factors affecting visual performance with stereoscopic television displays where operator fatigue under various video system configurations was measured by NOSC, Hawaii Lab in conjunction with a geometrical model. No difference in observer fatigue was found between any of the camera configurations tested. It was concluded that stereopsis was particularily useful under degraded viewing conditions, such as those found in many underwater environments.

Sonar Developments

Klein Associates provided an overview of experience relating side scan sonar techniques toward inspection of the face of vertical or sloped surfaces, such as the Ocean Thermal Energy Conversion (OTEC) cold water pipe. Correspondingly, AMETEK Straza Div. described experience combining CTFM sonar with recent developments in high speed memory and microprocessor components to allow a continuously updated sonar display.

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Manipulator Developments

Robotic Systems International (RSI) prescribed the "Ten Commandments for Manipulator Arm Use", an attempt to focus on some of the key issues of manipulator design and use such as: ROV manipulator selection, integration with fail safe operating procedures, safety, reliability, maintenance, required operator skills including innovation and continuous user/manufacturer communications. A closed loop, position-controlled, electro-hydraulic manipulator system is being developed by University College of London to provide autonomous inspection capability for sub-sea structures. When deployed by an ROV at a tubular joint, it will be able to determine required trajectories, then clean an area prior to deploying NDT sensors.

Navigation and Vertical Positioning Developments

As technology continues to advance in the ROV industry, the increasing need for accurate acoustic navigation becomes apparent. The acoustic theory of an ultra-short baseline tracking system with unique features to meet the demanding requirements of both commercial and military applications was presented by EDO Corp/Western Div. The ratio of maximum stand-off distance to operating depth has been increased from 6:1 to 20:1. Further development of the super short baseline principle was discussed by SIMRAD, wherein an electronically steered narrow beam transducer allows tracking of one or more reference transponders.

A later presentation by Ferranti/ORE explained that slant range between underwater vehicles and their support vessels is usually measured by means of a responder or transponder. These devices require an external electrical or acoustic key signal sent from the surface. In practice this can be very difficult. A means for obtaining accurate range data without requirements for signals from the surface, termed a synchronous pinger, is being developed. Also, a small, four gimbal directional gyro platform that can be used to obtain heading, pitch and roll information for the guidance and control of an underwater vehicle was described by Humphrey, including the basic principles of operation, its construction, and advantages and disadvantages.

Advanced Cable Developments

A small vehicle 'Hornet-500' (Figure 1) currently under development by JAMSTEC, utilizes an optical fiber cable. A slender tether cable (7mm diameter) consisting of two optical fibers and a pair of electric power conductors was recently developed in order to receive high quality color TV signals, digital control signals and to reduce cable drag.

Due to such developments, ROV handling systems require electrical and fiber optic slip rings for use with umbilical or tether winches. Nova Scotia Research Fondation has incorporated fiber optic technology into more conventional ocean going slip rings. A new generation of full capability units which can handle high voltage power, low voltage data, and optical signals in one integrated submersible package has been developed.

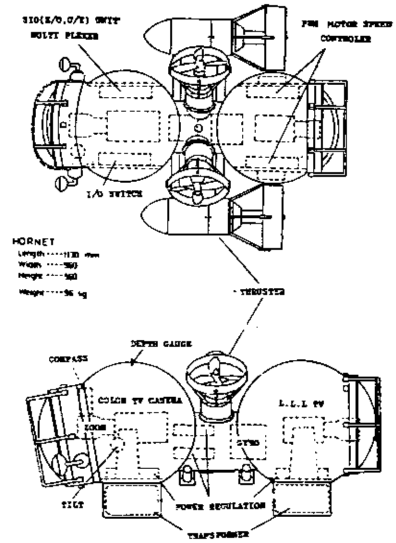


Figure 1. Hornet 500 Vehicle Equipments

Deep ROV System Developments

Woods Hole's Deep Submergence Laboratory (DSL), in addition to supporting the manned submersible ALVIN, is developing and operating a variety of unmanned vehicle systems used from both surface ships and submersibles. DSL's emphasis is upon large area search and close-up inspection with its present operational systems including ANGUS, Mini-ANGUS, a Klein side-scan sonar and the Benthos RPV. In addition, DSL is presently upgrading its 6000 meter remotely operated vehicle AMUVS, procuring a Sea MARC I Sonar System, and developing a new search and inspection vehicle system called ARGO/JASON (Figure 2).

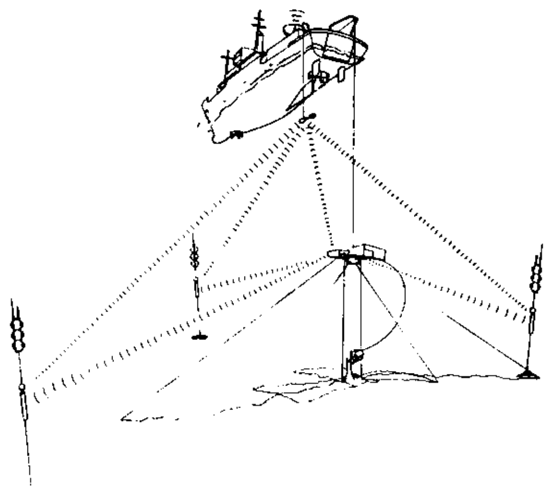


Figure 2. JASON Deployment From Dynamically Positioned ARGO

Referring to unique problems associated with deep-water drilling support operations, Oceaneering International stated that in 1983 the exploration for offshore oil and gas reserves moved into both deeper waters and increasingly hostile environments. With the expansion of deepwater leases in the U.S. and the growth of drilling programs in frontier areas, this trend is likely to continue. A number of the operational problems that had to be addressed and solved in order to support drilling operations on dynamically positioned drill-ships and semi-submersibles were discussed.

Motion compensation and handling for ROVs was introduced by Ocean Equipment Development. In order to extend the weather operations window of tethered ROVs, it is not only desireable, but necessary to include a motion compensation system in the basic system hardware. The need becomes more critical as the size, weight, depth of operation, and cost of the vehicle increases. The background and field experience with the motion compensated boom, that is claimed to reduce the total vertical acceleration of the tow point by 85%, with in-band motion reductions of as much as 96%, was described.

Pipeline Surveying Developments

Operational experience on pipeline survey and inspection projects utilizing Scorpio ROVs was presented by Stolt-Nielsen Seaway Submersibles. Over the past 10 years ROVs have played an increasingly major role as the primary work tool for survey and inspection of underwater pipelines, during design and construction, and also for routine resurvey and maintenance activities. At the same time, the technology to record, process and present the survey inspection data to the client has advanced to a point where final drawings of pipeline position, profile and condition can be produced onboard the support vessel within a few hours of collecting the data. This capability allows the client essentially real time information on pipeline conditions, significantly improving response time in those cases where intervention work or other maintenance measures may be required. Examples of recent operations include construction work in the North Sea in water depths to 1,000 feet, and inspection of existing pipelines in the Mediterranean to water depths of 2,000 feet using a Scorpio (Figure 3).

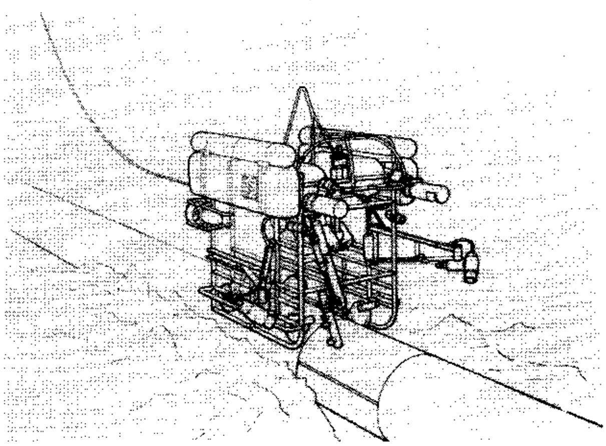


Figure 3. Scorpio Pipeline Inspection

Structure Inspection Activities

1983 saw the installation of one of the most innovative offshore platforms ever designed, the Lena Guyed Tower. Exxon decided very early to select state-of-the-art technology for underwater intervention in 1000 feet water depths. The tower was installed ahead of schedule partially due to the tasks performed by two light work RCV-150s that made a major contribution to the projects success.

Operations from construction barges was described by SONAT Subsea Services, Scotland, including the work involved during the installation of large structures. Included in the scope of work performed by ROVs were site surveys, settlement of the structure, observations of piling operations and diver monitoring. Much of this work was carried out by RCV-225 and RCV-150 vehicles working together for 24 hours each day. Requirements for survival on deck coupled with the extreme maintenance problems created by the RCVs operating inches away from powerful underwater hammers were addressed. Cathodic Potential (C.P.) probes on ROVs for inspection of offshore structures has been a heavy ROV activity. Issues, including new problems and difficulties in obtaining accurate readings, conditions and area monitoring for C.P. operations during platform construction, measures taken to obtain quality readings, ROV interfaces (Figure 4), and particulars concerning remote C.P. sensing with advantages and disadvantages were discussed.

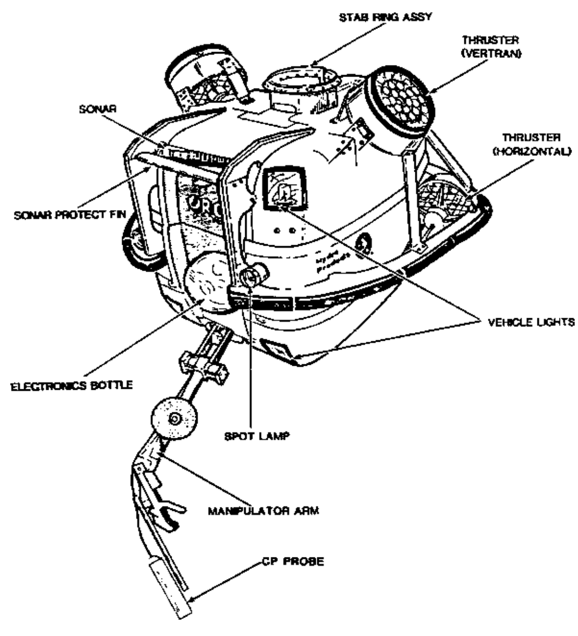


Figure 4. RCV-150 With CP Functions

Hydra 2500M Deep ROV

The Oceaneering Dual Hydra 2500 Meter Deep ROV including analytical considerations, design, and testing of the system during development was presented (Figure 5). Design areas discussed included the surface handling system, main umbilical and vehicle tether cables, subsurface launch and retrieval garage, connectors and terminations, and the vehicle. Specific areas addressed are mechanical and fiber optic designs for the main umbilical cable and the neutral, oil-filled tether cable. The traction winch system was described along with the design decision criteria for rejection of an approach incorporating a motion compensation system.

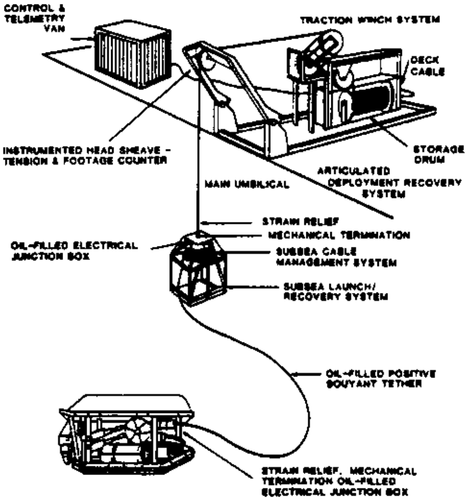


Figure 5. Dual Hydra 2500 System

ROV Development Activities

The inspection and maintenance of offshore structures performed today are specific pre-planned programs requiring the use of divers. Although a number of ROVs work with divers during these projects, their role has been secondary and primarily observation oriented. The PROES ROV described by OMIS provides an alternative to divers for platform inspection and maintenance tasks. PROES, by utilizing Cavijet^{tm}, without a retrojet, will prove to be a superior and safer cleaning system when compared to diver operated units per the author.

Various modular system designs have been developed by Hydro Products which were derived from proven systems presently in use. The offshore industry continues to evolve toward the requirement of special purpose built systems to support underwater maintenance and inspection requirements, while manufacturers strive to satisfy this need through the development of modularized subsystems to enable customized configurations. All are concerned with a cost effective system to provide operational flexibility and lower total capital costs to an operator, as well as minimal non-recurring engineering and product support costs. Both have the objective of a truly modular system capable of configuration for a number of tasks, without compromise, while minimizing specialized documentation; training and logistics cost.

Innovative Application Activities

Inspection and repair of OTEC structures is a recent ROV application area. The planned power plant is shelf-mounted and has a 26-foot diameter cold water intake pipe mounted on the seafloor at a depth of 2600 feet. The platform and pipe require inspection and repair during their 30-year design lifetime requiring special tools and techniques. The use of ROVs for inspection and repair below diver depths is a critical requirement. In order for ROVs to be most effective, their early integration into OTEC plant designs is mandatory. Cooperation between ROV manufacturers and OTEC planners must begin now to investigate the need for inspection, maintenance, and repair which can be met by ROVs.

Seahorse, a research and applications testbed is a unique ROV within the UK which is dedicated to the requirements of R&D in the field of underwater technology. As available on a commercial basis to industry, it also plays a major role within the Heriot-Watt University's extensive marine technology research program. Some of its recent applications include precision sea-bed sediment sampling, a capability that was sought by the Institute to augment its environmental monitoring service which is used by several North Sea operators.

Operational Characteristics & Considerations

International Underwater Contractors (IUC) is presently using the ROV Mantis as a deep water inspection/work vehicle in support of an exploratory drilling program in water depths of 2,000 ft, in the Gulf of Mexico, using three vehicle modes of operation: 1) as a surface controlled ROV, 2) with a pilot in partial control, assisted by a surface operator and 3) with a pilot in full control.

Due to the ever increasing advances in ROV technology, the requirement for on-site testing facilities has become essential. These facilities are paramount for ROV testing and evaluation as well as ROV crew training. In addition to a well-equipped electronic workshop, the testing facility must have a large enough water tank to accommodate an ROV in an offshore, working type of environment. The water tank should have the ability to produce variable water currents to simulate actual offshore conditions. Such a facility has been constructed by Sonat Subsea Services.

The dynamic simulation of ROVs is being performed in England at the Cranfield Institute of Technology. A mathematical model is the basis of the computer program which highlights those features unique to ROVs. This program is currently being used in conjunction with extensive model tests to predict the motion of the Seapup vehicle. This work, undertaken to enable the prediction of the physical performance of ROV umbilical cables, has involved the development of computer programs to predict the steady state and dynamic behavior of the umbilical. Measurements were also made on simulated umbilicals and towed cables. In both sets of measurements, large amplitude cable strumming was observed and an associated increase in cable drag was measured.

Positive material identification (PMI) has been an area of major concern. More than 10% of the materials received by Hydro Produts have been erroneously certified. A good PMI program gives excellent product quality assurance to both the company and its customers. Many companies use the program as a positive, pro-active approach to selling their products over competitors who do nothing according to Mobile Metal Analysis.

Dutch Delta Barrier

A special Netherlands session described the Dutch Delta Project application of ROVs for inspection and acoustic surveys, including the advantages and limitations of several free swimming ROVs. Experience with the purpose built seabed crawler 'Portunus' was given in relation to the work of 50 divers. The Trigla (Figure 6) is claimed to be the world's smallest 'free swimming' ROV for special inspections. It measures 43mm diameter by 825mm length.

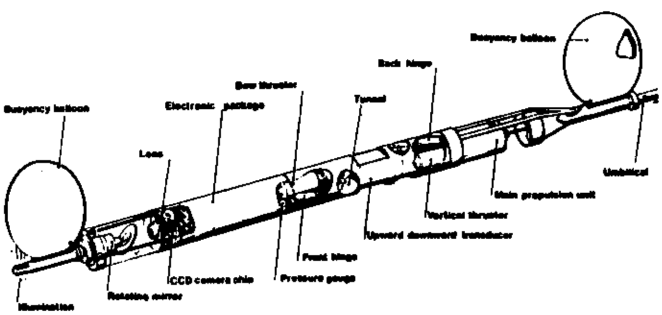


Figure 6. TRIGLA Equipments

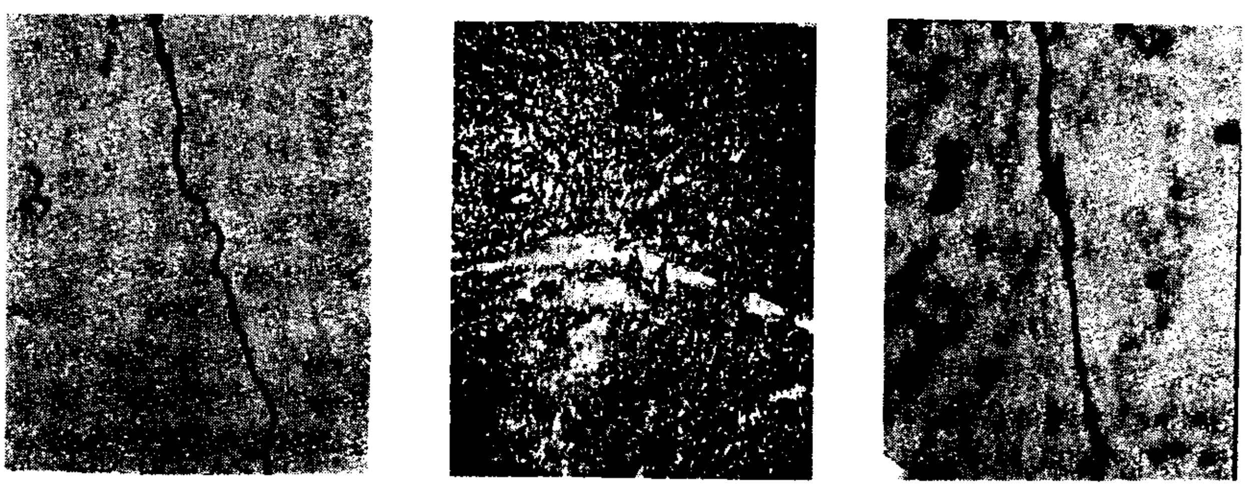
ROV operated sonars for very high resolution imaging during underwater inspections have been developed. They use high frequency (50 kHz to 2 MHz) to image the subbottom up to 1.5m and to detect any buried small objects like pipes, cables, mines, etc. For optimal results the acoustic sensor has to be located at a short distance, 0.3 to 2m, from the seabottom, looking vertically downward. The sonars are microprocesor controlled with a high degree of automation. Four applications of ROV operated shallow subbottom profilers have been investigated: a sediment classification and layer thickness measurement system; a miniaturized sandlayer profiler; an acoustic cable detection/tracking system; and an acoustic camera (Figure 7) below.

Platform Integration Techniques

The problem of underwater navigation and positioning of an ROV or a diver within and in the vicinity of an offshore structure is a major problem. The problems of reverberation and background noise in such environments are of major concern. Field tests of a prototype system, called Octopus, in the Veritas' structure resulted in an accuracy close to the requirements of $\pm$10cm, even with background noise levels well above what can be expected in an offshore environment.

Oceaneering International explained how offshore California is on the forefront of integrating ROV technology with conventional diving operations to achieve a more cost-effective result. This is driven by the high cost of conventional divers on the West Coast, as well as the fast rate that water depth increases offshore. In 1983, Oceaneering performed a variety of typical underwater projects including platform, pipeline and subsea wellhead inspection, maintenance and repair. Each job utilized ROVs to their maximum capabilities by performing all inspections and simple work tasks as engineered during the project planning.

Deep Ocean Technology's Bandit, is a new guidewire - deployed remotely operated vehicle designed specifically to support offshore exploration drilling. It has been operated in the Gulf of Mexico to depths of 1200 ft. Using its two sensory manipulators, it has performed such tasks as AX ring recovery, cleaning, guidewire cutting and replacement as well as attaching cables for recovery of drill pods and drill strings.



OPTICAL PICTURE OF CLEAN CONCRETE BLOCK

CONCRETE BLOCK WITH SOFT MARINE GROWTH

ACOUSTICAL PICTURE NOT DISTURBED BY MARINE GROWTH

Figure 7. Acoustic Camera Performance

Operational Systems Designed For ROV Actuation

Diverless Systems continued to note the fact that when the offshore oil field operator installs subsea equipment, it undoubtedly will require intervention at some time during its life. When this is required, the conditions associated with offshore subsea operations are such that the cost to the operator will be high, in terms of spread costs and/or production down time, under the best of circumstances. When the intervention has not been anticipated and the subsea equipment has not been adapted for it, the cost may well be 10 times higher.

In another often heard theme, AMETEK, stated that the universal ROV for subsea oil and gas work does not exist and probably never will. A basic ROV, designed judiciously to accept a variety of work interface modules has been determined to be the most efficient method for deep subsea servicing. Interface modules or tool sets should be designed in conjunction with the designers of the sea floor equipment. This symbiotic relationship should carry through to the dry land stack-up tests. Some examples of tool sets suggested for a basic ROV are: hydraulic power module with stab, wellhead mandrel AX seat refacer, restricted access manipulator module, and inspection module.

International System Developments

An ROV system has been produced which will provide operators with cost effective means of reconfiguring the vehicle at the worksite to perform diverse tasks. The AMETEK modularized GEMINI work system (Figure 8) represents solutions to industry needs developed over the past four years with experiences on virtually hundreds of ROVs. Dramatic increases in operating depth, propulsion, stability, and heavy work capability as well as associated control and display systems will be available; integrated pilot controls and displays will greatly reduce demands on the operators.

The USSR contribution toward ROV technology addressed the development and application of ROVs at the Shirshov Institute of Oceanology, Academy of Sciences. The Institute of Oceanology currently has a variety of underwater vehicles used for scientific research as well as for search and rescue. Underwater vehicles are used mostly in conjunction with traditional methods of oceanological investigations conducted by over-the-side instrumentation. The correct combination of different technological means and techniques determines the efficiency of scientific or technical underwater operations. For instance, detailed geological investigations of the ocean bottom usually begin with a geophysical survey of a relatively large area, and entail collecting the following data: bathymetry, seismic profiling, magnetics, and gravity. On the basis of these data, a smaller area is selected for more detailed investigation by using a towed vehicle. In the last phase manned submersibles and ROVs are used to collect detailed information from a very small section within the area of interest. Experience has shown that the most effective control of an ROV is a supervision method that reduces the operator's participation to a minimum.

Three vehicles have been constructed and two are under construction in JAMSTEC. They are JTV-1, JTV-2 (operational depth 200m) and Mosquito (operational depth 100m). Two other vehicles under construction utilize fiber optic cables which were tested in a high pressure test tank with no degradation of signal at design pressure. These are HORNET-500 (500m) and Dolphin-3K (3300m). The basic system, HORNET-500, was completed last February. Dolphin-3K will be completed in 1986.

Insight into a class of ROVs, somewhat out of the conventional concept, was offered by Technomare, Italy on the subject of operational experience with remotely operated tracked vehicles as in (Figure 9) to depths of 160 meters.

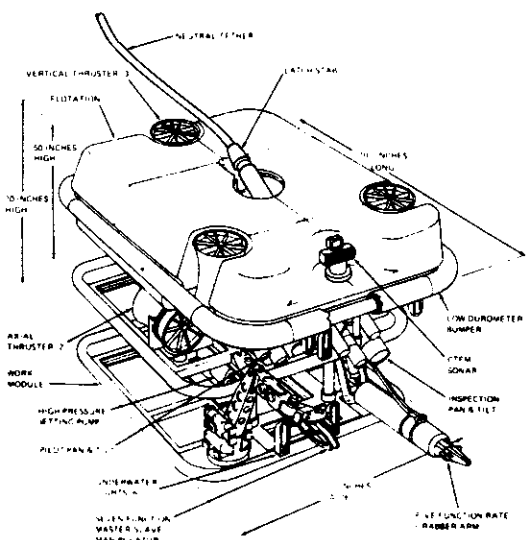


Figure 8. GEMINI Work Vehicle

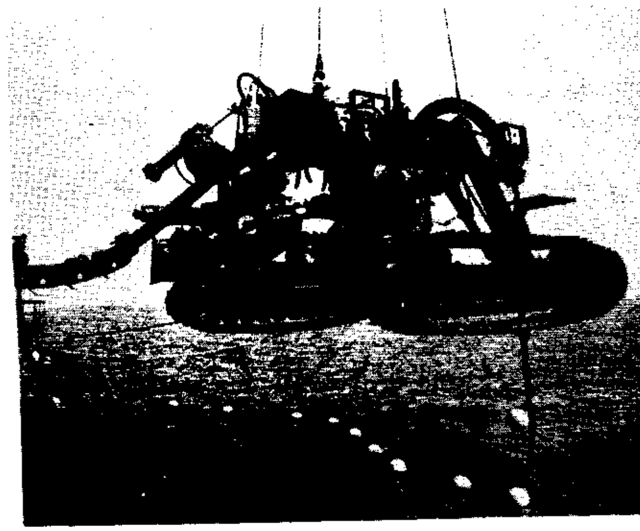


Figure 9. TM402 Cable Trenching Vehicle

Field Trials of I.S.E.'s Dolphin (Figure 10) are underway at the Bedford Institite of Oceanography. Construction of the vehicle has been completed, and extensive operational trials have been carried out which culminated in very successful tests in 3m high waves off the East Coast of Canada.

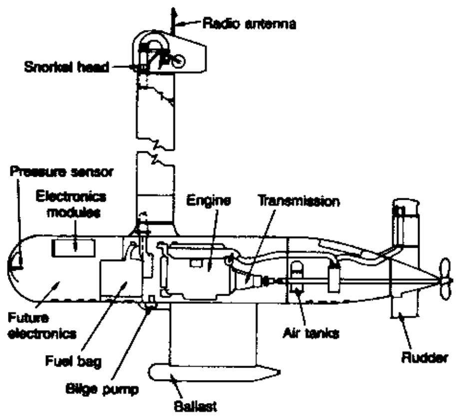


Figure 10. Dolphin Autonomous Vehicle

Dragonfly - a modular ROV produced by a modular design process was conceived as a five year development program between OSEL and Marconi Avionics to implement state-of-the-art technology in a series of advanced ROV's. Rather than develop a range of similar ROVs, it was decided to produce a modular system in which a sophisticated base ROV would be used to carry a number of service modules for different applications. There has been a tendency in the industry to regard base ROVs as merely tractor units, but if the requirement for true modularity is to be met, the base unit is a sophisticated ROV in its own right. It must carry all the flight control electronics, the video encoders, the spare hydraulic outlets, the major electrical services, and most important, the module interfaces.

Autonomous System Developments

Evaluation of the capabilities of advanced autonomous vehicles to satisfy current requirements, that have historically been satisfied with diver's and more recently by tethered ROVs, is continuing at a high level. Epaulard, a working autonomous survey vehicle system is expanding its capabilities. IUC stated that the Epaulard was contracted by government agencies off the U.S. West Coast to evaluate its capabilities on two projects including the search and location of a lost plane in 3800 ft. of water and a general area survey of the Gorda Rift offshore Oregon. Epaulard can presently cover 12 nautical miles in various search patterns at a depth of 6100 meters with a payload of up to 5000 photos.

CNEXO described Epaulard as the first unmanned untethered deep vehicle, operational since 1981, as now having accomplished over 130 dives. This experience has led to several design improvements including the capability of going through more difficult topography and video transmission feasibility tests. These new concepts along with confidence gained from operational results has increased the contemplated range of applications.

The ARCS is an autonomous remotely controlled submersible for under-ice survey being developed for the hydrographic service by ISE. Five separate sonar systems are used for telemetry, survey, and guidance. Telemetry is achieved through a 50 bps fsk link. The low data rate, necessitated by the severe multipath constraints of the shallow under-ice environment, demands a high degree of on board intelligence and some novel operator interface methods. The on board computer is modeled after the hierarachical command structure of a naval submarine. The 'navigator' uses sophisticated statistical estimation algorithms. Most of the onboard equipment is off the shelf, but there was a requirement for some custom designs. Preliminary sea trials were carried out in April 1984 and full scale under-ice trials are scheduled for late 1984. The ARCS vehicle is representative of the state of the art in autonomous underwater vehicles in particular, and commercial autonomous robots in general. ARCS, as configured, provides the basic architecture for a family of autonomous vehicles, the geometry and capabilities of which will be dictated by the mission profile. Future developments will allow these vehicles to be used not only under ice, but also in the deep ocean.

There are a number of missions that could utilize an unmanned, autonomous, submersible vehicle in carrying out their objectives. Both military and non-military applications exist. Typical of these are: underwater weapon systems; early-warning detection; recovery and salvage; ordnance and nuclear waste disposal; submarine tracking; and underwater decoys. And, TRW is investigating an isotope (Pu^{238}) powered organic Rankine cycle engine for such applications. This engine would be capable of providing sufficient electrical energy to a motor so that the power delivered to the water for a low-drag-shaped hull is 2.5 kW_E. Although expensive, there would be several advantages of this engine over electrochemical energy systems for long-duration, high-total-energy missions.

CONCLUSION

This paper has attempted to provide an overview of the ROV technology presented and discussed at ROV'84. Unfortunately, not everything presented could be addressed here, and the reader is thus referred to the conference proceedings for more completeness and detail. The area of ROV technology is quickly expanding. ROVs are now accepted as a useful tool and not as a novelty item. This fact has been further supported by the recent completion of the "Operational Guidelines for ROV's". This publication, available from MTS, carries on the ROV story including what these exciting systems can, and cannot, do for us. The excellent and open interaction of those working in this field has led to the success of international forums such as the ROV conferences. This, in turn, is a primary reason for the accelerated application of ROV technology in the field. The conclusion, as exemplified in this paper, is that ROVs are here to stay. The only question is how far we want to carry the advancement and application of this technology to operational problems. It's totally up to us.