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The ROV'92 Conference and Exposition, the 10th in a series of successful high technology events, was held on 9–12 June 1992 in San Diego, California, USA. The conferences, sponsored by the Remotely Operated Vehicle Committee of the Marine Technology Society has been held in San Diego in 1983, 1984, 1985, 1989, and 1992. Other locations included Aberdeen, Scotland (1986), Bergen, Norway (1988), Vancouver, British Columbia, Canada (1990), and Hollywood, Florida, USA (1991). The systems and technology presented at the ROV'92 conference have shown the great strides which have been made in this area. Tethered ROVs, both free-swimming and bottom crawling, have reached a highly reliable and capable level of development.

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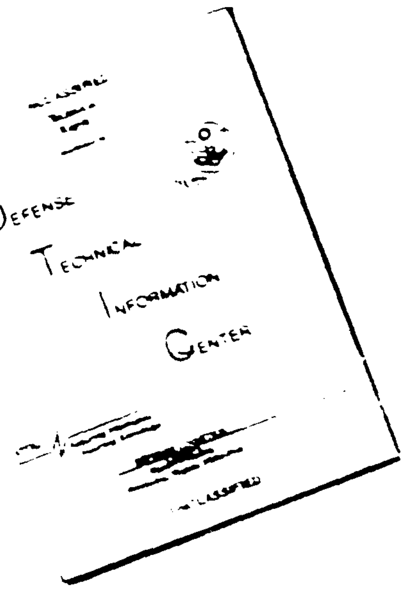

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An International Perspective On ROV Technology

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ABSTRACT

The ROV'92 Conference and Exposition, the 10th in a series of successful high technology events, was held on 9 - 12 June 1992 in San Diego, California, USA. The conferences, sponsored by the Remotely Operated Vehicle Committee of the Marine Technology Society has been held in San Diego in 1983, 84, 85, 89 and 92. Other locations included Aberdeen, Scotland (86), Bergen, Norway (88), Vancouver, British Columbia, Canada (90) and Hollywood, Florida, USA (91). This paper will provide an overview of the technology presented at the conference and a discussion of it's relevance.

INTRODUCTION

The conference exhibition provided an array of products and systems which underscore the maturity of todays ROV technology. State-of-the-art manipulators, displays and deep ocean systems have now reached a level of reliability unknown a decade ago when the first ROV conference was held. The integration of advanced technologies into operational systems was highlighted by the U.S. Navy's exhibition at the entrance of the exhibit hall. The goal of conducting search and work to depths of 20,000 feet was represented by the Advanced Tethered Vehicle (ATV) and the Advanced Tethered Vehicle (ATV) and the Advanced Unmanned Search System (AUSS). The ATV, developed by the Naval Command, Control and Ocean Surveillance Center's Research, Development, Test and Evaluation Division and now operated by the Submarine Development Group's Unmanned Vehicle Detachment holds the present depth record of 20,600 feet. This accomplishment is matched by the success of the Navy's CURV III vehicle operated by Eastport international which was the first to reach 20,000 feet only days earlier. The ATV was designed to be the recovery vehicle, complementing the search capability of AUSS. The AUSS, a semi-autonomous, acoustically controlled search system was designed to provide an order of magnitude increase in the efficiency of the search rate. Having no tether, it can efficiently search a large area without being tethered to a ship and the constraints imposed by such a leash. Sonar images and pictures displayed of a bomber located off the coast of California, which were transmitted topside via the acoustic communication link, provided proof of the maturity of such technology and how a dual system such as ATV and AUSS provide a logical compliment. Also on display at the Navy's booth were acoustic communication link techniques, fiber optic communication links, and advanced ceramic pressure hulls, all of which will play significant roles in the future on Navy systems. These technologies will be discussed later in this paper.

It is fitting that the Navy display encompass the overall capability of ROVs since the Navy spearheaded the development of ROV technology. This historical perspective was recalled by Shaefer and Metzler as they discussed the Navy's development of the first Mobile Underwater Vehicle System by VARE Industries in 1961 called the XN-3 (1). This was a time when shaft seals failed, the cameras were damaged by sunlight, the electrical systems were noisy and the reliability was "very poor, hard to maintain and keep operational."

The early stages of vehicle development and the associated problems are countered by the latest high tech system under development in Japan by the Japan Marine Science and Technology Center (JAMSTEC) (2). The new system, which is scheduled for operation in 1993, will be a 10,000 meter tethered vehicle which will be operated from the support ship Yokosuka. It will have a towed search capability and an integral ROV with a short tether which can be deployed for work and inspection. The most important consideration, however, is the capability it provides to recover the manned submersible Shinkai 6500, which will operated off the same support vessel, in an emergency. The operational capabilities which exist today and the emerging technologies that allow the development of such 10,000 meter systems will be discussed in the following sections.

OPERATIONAL SYSTEMS

This section will discuss the capabilities which exist with systems which are presently operational in the field.

Recovery and Salvage

The exploits of Eastport International are becoming well known as they tackle jobs from flight recorder recovery to insurance investigations. Their latest venture resulted in the recovery of a helicopter from a depth of 17,250 feet (3). This test of systems and ingenuity was conducted by the U. S. Navy's Supervisor of Salvage working with Oceaneering and Eastport. The initial search phase was conducted using the ORION towed search system, operated by Oceaneering for the Navy which uses 36,000 feet of fiber optic cable. The recovery was ultimately completed by the CURV III vehicle operated by Eastport thorough the use of traction winches, heave compensators and specially built reels of Kevlar lift line which are taken to the sea floor for attachment. It is obvious that few objects are now beyond the reach of today's technology.

Complimenting the exploits of the Navy is the work conducted by AT&T's SCARAB (Submersible Craft Assisting Burial And Repair) vehicle (4). These systems (4 in all), operated by their subsidiary, Transpacific Communications, Inc., provide the capability to locate, cut and recover telecommunication cables. In addition, they can use the jetting and excavation skid to re-bury the cable. These systems provide some of the latest control techniques for the operator including computer graphics and pull-down menus which assist in proper deployment configuration based on the underwater operating conditions. The displays provide the data necessary for the operator to complete the burial process. Using these graphical techniques and large high definition monitors, the banks of switches and gauges previously used have been totally eliminated. Such technology is responsible for saving AT&T a revenue loss of $1,000,000 per hour.

Subsea Intervention

In the early days of ROV intervention in the oil patch, the talk revolved around the "all purpose" vehicle, a system which could do everything for everyone. This concept was soon proven to be unworkable, except for very minor tasks. The reality of subsea intervention was that tasks were for the most part very complicated and often required very large "tools" or forces to complete the task. When the work was being performed at diver depths, the ROV intervention techniques were often considered a secondary approach, since one always had the diver. Unfortunately for the diver, the future dictates that subsea wells will be located in waters far beyond their capability, a realm where only ROVs will be able to work.

The future of subsea intervention was highlighted in several presentations where "ROV friendly" subsea equipment is developed. Such equipment can be worked on modular vehicle system easily reconfigured to take the required tooling to the work sight. The Exxon Company, USA, is funding a program to develop a system to be used for installation and maintenance of deepwater pipelines, up to 20 inches in diameter (5). This work includes tasks such as cutting a 20 inch pipeline and docking with a special 3,500 lb assembly which is flown to and mated with the bottom structure.

In a similar fashion, the Italian Oil Company, AGIP SpA is funding the SAF (Sistemi Alti Fondali) Project which also use modular tooling systems at depths to 3,000 feet (6). They too are adapting graphic and animate forms of presentation of the status of the underwater modules on large screen displays with touch screen input. Their "Master Vehicle" weighs about 5,000 lbs in water and has a cable assisted lift capability of approximately 40 tons. In addition to the modular capability, it carries a secondary Rov for minor tasks and visual inspection assistance.

Work being conducted by Mobil North Sea Ltd, FSSL Ltd and Slingsby Engineering Ltd is a also addressing remote intervention to 3000 fool depths (7). Their work, which uses a Slingsby Trojan MRV to move modular tool packages, also considers the automatic docking of the system with the subsea equipment. Based on the success of their work, they feel that have reached "a major milestone on the road to developing autonomous Rov intervention systems."

Trenchers

The subsea trenchers may not be free flying ROVs, however, they are large, impressive and "high tech." For example, Tecnomare Spa's TM 1602, which can cut 2 meter deep trenches, is using animation to provide visual representation of the geometric configuration of the vehicle and in's moving parts (8). By using specially developed control software, they expect to control the vehicle completely in an automatic mode in the future. BT (Marine) Ltd's tracked ROV weighs in at 19 tons (9). Called the Eureka system, it can cut 1 meter deep trenches at depths of 1,000 meters. The system will bury pipelines up to 20 km long at speeds up to 500 meters per hour. It also includes a Junior NUFO ROV which acts as the systems "Flying eye". Possibly the most sophisticated and capable of all the trenchers is the new Sea Bed Tractor developed by AT&T (10). This 10.4 metric ton vehicle is expected to clock 1 meter burial depth speeds up to 1000 meters per hour in depths to 1,400 meters. It also includes a 3 ton crane and a package which has a Schilling manipulator and assorted tool package for more delicate jobs. With the capability which is being integrated into such large systems, and the increasing size of modules being transported by free swimming ROV's, it probably won't be long before the gap between these methods closes completely through the development of more diverse hybrid systems.

TECHNOLOGY

Although the systems previously described are becoming highly reliable and are incorporating the latest technology, there appears to be more advances on the horizon. This section will address those technologies which are expected to provide advanced capabilities in the future.

Fiber Optics

The integration of fiber optic cables into Rov power umbilicals is now common place, however, future battery operated systems will be using *expendable fiber optic micro-cables*. Two of the presentations provided an excellent overview into the design problems and capabilities of such communication links. Alan Grey of Norther Telecom Defence Systems provides the main trade-offs for a range of Rov applications and environments including electrooptic conversion and bidirectional communication using wavelength multiplexing (11). He projects that though the use of high performance laser sources, optical communication links with data rates above 1 Gbit/s will be realized over 100 km lengths without repeaters. His projection is exceeded, however, based on work performed at the U. S. Navy's NRad research facility (formerly the Naval Ocean Systems Center) where 150 km unrepeatered lengths are projected (12).

Two significant events identified by NRad include the successful docking of an underwater fiber optic connector using an Rov and the development of a high speed micro-cable manufacturing technique which was subsequently transferred to industry. The underwater mating provided the capability to transfer 220-Mbps from the remote site back to the launch platform. The new manufacturing process is used to make a .031 inch diameter cable by laminating an annulus of fiberglass yarn and an ultraviolet curable resin around a standard, dispersion-shifted, single-mode optical fiber. This is cured through the application of a dose of intense ultraviolet light. This process was transferred to industry via the Navy's Manufacturing Technology Program. The future application of such communication links include use on expendable systems such as torpedoes or in providing high bandwidth communication links with advanced battery powered systems. The the next logical step in eliminating the tether from the Rov, as onboard processing capability and sensing continually increases, is through the application of expendable micro-cables.

Navigation

Long base line navigation and tracking systems have been around for some time, however, it has just been recently that the capability to accurately navigate a vehicle on a micro scale has been available. The Marquest Group recently developed the SHARPS (Sonic High Accuracy Ranging and Positioning System) system which uses a hardwired configuration and one-way travel times between transceivers on the vehicle and those in the met (13). Using an update rate of 10 fixes/second, a resolution of 1 cm at a range of 100 meters is available. The latest version out of Marquest is called the EXACT (EXact ACoustic Tracking) system, which is a wireless version of the Sharps system (14). It is projecting to have a positioning capability of 2 cm at 100 meter ranges with a repeatability of 0.5 cm. Using a sampling rate up to 3 Hz, it is adaptable to rivers, lakes, ponds or the open ocean. The development of such systems allows the use of programmable trajectory planners, allowing the operator to choose vehicle velocities, accelerations, paths and waypoints. The capability to automatically dock a vehicle using this technique has been demonstrated, a capability which will be highly useful by the systems described in the previous sections of this paper.

Lasers and Optics

Lasers are playing a constantly increasing role in underwater applications. New underwater imaging systems are coming on line and various applications are being developed by researchers around the world. Japan is investigating applications of the pulse laser for depth-sounding and observation of underwater structures and hopes to develop underwater laser camera systems (15). Work being done in the Peoples Republic of China uses a laser scanning system to present a TV image which gives 3-D information (16). They expect this to be very useful in the control of ROVs and manipulators in the future. Ongoing work at the Harbor Branch Oceanographic Institution in the USA uses a beam-splitter and a motorized mirror to provide a pair of parallel laser beams which can be used as a "non-contact pair of calipers" (17). They are also investigating scanning lasers to provide three-dimensional maps. Automatic tracking of objects, using TVs mounted on pan and tilts which follow a laser dot projected onto a target, is being researched at the Monterey Bay Aquarium Research Institute and Stanford University in the USA (18). Their successful testing indicates that vision processing is the only technology required to make the automatic tracking system operational.

Manipulators and Work Systems

Advances are continuing to be made in the integration of manipulators, vision and control systems. The goal of providing a real "human presence" at the work site is continuing and will eventually make the ROV system transparent to the human operator. In work being conducted in the U.S. by the National Aeronautics and Space Administration (NASA), ROVs are being used to investigate telepresent controlled vehicles for use during the future exploration of Mars (19). Their investigations included the use of a head mounted display and a magnetic field sensor to track the position of a helmet worn by the operator. The data is then used to drive the TV and the pan and tilt mechanism providing the operator with the feeling of remote reality".

Another area where great strides are being made is automatic cleaning and inspection of offshore structures. The Norwegian institute of Technol-

ogy is conducting investigations with a manipulator using a force transducer in the wrist to grind welds for inspection (20). They feel that their technique is workable if a robotically controlled manipulator can be built with enough bandwidth in the force control loop.
To alleviate the problem of high bandwidth control systems, University College London is investigating the use of a compliant wrist unit to absorb errors in manipulator motion (21). They expect this to be a technique available for use with little prior knowledge of the weld geometry. A more geometric approach to the problem is taken by GKSS in Germany (22). As part of the OSIRIS (OffShore Integrated Robotic Inspection/Intervention System), they are developing a control system which will use off line programming and graphical simulation of the system to allow an ROV operated manipulator to conduct NDT tasks. Such techniques will eventually be combined with call up graphical representations of the structure being worked on, and when used with properly programmed manipulators and end effectors, will be able to fully automate the inspection process.

Pressure Resistant Structures

Conventional materials used for deep ocean pressure vessels have included stainless steels, aluminum and titanium. Advances have now been made where materials such as ceramics can be used which provide anywhere from 3 to 5 times higher strength for each pound of material (23). Alumina ceramic pressure housings can now be developed with weight to displacement ratios in the 0.4 to 0,6 range for 20,000 foot applications. This can be pushed too 0.35 using boron carbide ceramic. Several large diameter hulls, developed by the U.S. Navy's research division, NRaD, were on display at the conference. The AUSS vehicle, also on display, uses another technique to provide buoyancy, graphic reinforced plastics (GRP). The vehicle has a GRP housing 2.5 feet in diameter and 2.5 inches thick with titanium end bells to house the electronics and batteries of the system. Also on the AUSS vehicle is the latest in fairings which use Spectra composites. These composites are made with extended-chain polyethylene (ECPE) fibers marketed under the trade name spectra (24). These fibers have the highest strength-to-weight ratio of any known fiber and are extremely resistant to cutting and abrasion. With the future of ROVs heading in the direction of autonomous systems, the potential for application of non-metallic pressure resistant structures is extremely high. They may provide the key in the development of efficient, streamlined structures and components for future vehicles.

CONCLUSIONS

The systems and technology presented at the ROV'92 conference have shown the great strides which have been made in this area. Tethered ROVs, both free-swimming and bottom crawling, have reached a highly reliable and capable level of development. The developers of equipment used in the oil fields have now realized that remote intervention can be achieved using ROVs if they are included in the initial design stages. The future for advanced autonomous systems looks good as the technology needed to achieve this capability is nearly at hand. When considering the technology base available during the development of the XN-3 by the Navy over 3 decades ago, and the advances made since then, the capabilities which will be achieved during the next 3 decades should be truly astounding. The age of virtual reality, programmed operation and totally autonomous systems is just around the corner.

REFERENCES

All of the references included herein are found in the ROV '92 Conference Proceedings published by the Marine Technology Society, Washington, D. C., USA. For simplicity, an abbreviated reference format using only authors and title will be used.

1. **G. V. Shaefer and A. R. Metzler**, Sr., XN-3 - The U.S. Navy's First ROV.

2. **Y. Iwai, A. Takaobushi and K. Kaneko**, Key Technologies of 10,000 m class ROV System Under Construction.

3. **K. Cooper**, Search and Salvage Operation in 17,251 Feet of Water.

4. **R. Bannon**, Deep Recovery and Inspection - Advanced Scarab Systems.

5. **W. Gray, D. Gray and W. McDonald**, Wet Tests, Diverless Deepwater Tie-In System.

6. **P. Foscoli, A. Rossolini and A. Radicioni**, An Installation and Maintenance Vehicle for a Deepwater Subsea Production System.

7. **D. Langrock, P. Richards and J. Howard**, ROV Intervention System for Installation and Maintenance of Subsea Oil Wells.

8. **D. Falbo and V. Penzo**, The TM 1602, A Large Pipeline Trencher.

9. **L. Bonnon**, EUREKA - The Development of an Advanced ROV System for the Post Lay Burial of Cables and Pipes.

10. **F. Messina and F. Pacifico**, Seabed TRactor - AT&T's New Multipurpose ROV.

11. **A. Grey**, Dispensed Fiber-Optic Capabilities for ROV Control and Data Transmission.

12. **M. Brininstool and J. Dombrowski**, NRaD Undersea Fiber Optic Development and Technology Transfer.

13. **D. Yoerger and D. Mindell**, Precise Navigation and Control of an ROV at 2200 Meters Depth.

14. **T.Somers and F. Geisel**, Subsea Dynamic Positioning of ROVs.

15. **Y. Nakazono and K. Yoshimori**, Underwater Characteristics of Laser for Depth Sounder.

16. **Z. Guoxing and Z. Bing**, A New Laser 3-D Image Information Display Method for ROV.

17. **R. Tusting and D. Davis**, Recent Advances in Quantitative Undersea Photographic Methods.

18. **H. Wand, R. Marks, S. Rock, M.Lee and R. Burton**, Combined Camera and Vehicle Tracking of Underwater Objects.

19. **O. Gwynne, C. Stoker, D. Barch, L. Richardson and P. Ballou**, Telepresence Control of ROV's: Application to Undersea and Future Space Exploration.

20. **T. Lien and T. Thomessen**, Force Feedback Controlled Grinding in Underwater Operations.

21. **A. Grieg, Q. Wang and D. Broome**, Weld Tracking with a Manipulator Fitted With a Compliant Wrist Unit.

22. **E. Aust, M. Gustmann, H. Niemann and G. Schultheiss**, 1100 m Subsea Robot Starts Wet Working.

23. **J. Stachiw**, Engineering Criteria Used in the Selection of Ceramic Composition for External Pressure Housings.

24. **F. Sloan and H. Nguyen**, Use of Extendedd-Chain Polyethylene (ECPE) Fiber in Marine Composite Applications.

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I have had the pleasure of Chairing the ROV Committee and the ten ROV Conferences held during this past decade. The forum provided by these conferences has promoted the interaction of the best technologists from all facets of the industry and all corners of the world. I would like to thank those who have participated in these conferences and the opportunities which they have provided for all of us to broaden our horizons. In particular, I would like to thank the officers of the ROV Committee who have organized the conferences and remained loyal to the quest of providing a "Decade of Excellence".