NOAA Technical Report OOE6

Remotely Operated Vehicles — An Overview

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of Ocean Engineering

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Contents

Tables

REMOTELY OPERATED VEHICLES--AN OVERVIEW

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ABSTRACT. Four types of remotely operated vehicles (ROV's) are identified. The growth, application and utilization of the more than 180 vehicles constructed and under development is discussed. Current operational problems vary, but cable entanglement and system reliability are the dominant technical liabilities. Current development trends are aimed at specialized vehicles and equipment for support of offshore oil and gas exploration, development and production. The advent or low-cost, simplified ROV's has placed this technology in the hands of virtually any activity involved in utilization and investigation of the marine environment.

1.0 BACKGROUND

In 1953 the first Remotely Operated Vehicle (ROV) appeared - a tethered, free-swimming ROV called POODLE - derived from modifications to Dimitri Ribikoff's diver transport vehicle, PAGASUS. During the next 22 years, only 19 additional ROV's were constructed and the operators were almost exclusively governmental. The offshore oil and gas industry showed little, if any, interest in this new and burgeoning capability. However, since 1976, this figure has more than tripled - bringing today's total to approximately 180. If the Societie Eca's mine-neutralization vehicle, PAP-104, is included, the figure is closer to 310.

The cause of the present surge in ROV construction is apparent: the offshore oil and natural gas industry. From 1953 through 1974, 20 vehicles were constructed. Seventeen (85 percent) of these were funded totally or partially by various governments (U.S., France, England, Finland, Norway, Soviet Union). The nine vehicles produced by the U.S. Navy through 1974 made it the world's leading manufacturer. From 1975 through 1978, 85 additional ROV's were added to the world's inventory; 31 more are scheduled for completion by the end of 1979. This reflects the effects of the expanding offshore industrial market. Where industry accounted for 15 percent of the 1974 market, in 1978 it accounted for 90 percent. The year 1974 is significant because it was in this year that the OPEC nations increased the price of oil from approximately \$4/barrel to slightly over \$12/barrel. Consequently, offshore oil became far more profitable and development proceeded accordingly.

2.0 TYPES OF VEHICLES

Four classes of ROV's have been identified. These are listed in table I, and their characteristics are as follows:

Tethered, free-swimming vehicles: Powered and controlled through a surface-connected cable. Self-propelled by drive wheels, capable only of maneuvering on the bottom, remote viewing through CCTV.

Bottom-crawling vehicles: Powered and controlled through a surface-connected cable. Propelled by surface ship, capable of maneuvering only forward and up/down by cable/winch control. Remote viewing through CCTV.

Towed vehicles: Powered and controlled through a surface-connected cable. Propelled by surface ship, capable of maneuvering only forward and up/down by cable winch. Remote viewing through CCTV.

Untethered vehicles: Self-powered, controlled by acoustic commands or computer program. Self-propelled, capable of maneuvering in 3-dimensions. No remote viewing capability.

While the description "tethered, free-swimming" is paradoxical, it is used to differentiate this type vehicle from the bottom-crawling vehicles which are capable of maneuvering only in contact with the ocean bottom or on a fixed structure. The following discussion provides a more detailed account of the development, capabilities, utilization, and characteristics of each class of vehicle.

2.1 Tethered, Free-Swimming Vehicles

The pre-1974 ROV's were primarily, if not solely, dedicated to military and scientific research missions. The first commercial vehicle since Rebikoff's 1953 POODLE appeared in 1975: Hydro Products's RCV-225 (initially designated RCV-125). The two RCV-225's would be the first of a total of 30 such vehicles built by Hydro Products by 1979 to make it the world's leader in construction of industrially oriented vehicles.

At present there are 28 industrial, government, and academic manufacturers of ROV's. Approximately 140 will have been constructed by 1980 and at least 100 are now operating. Most ROV's are rectangular in shape and composed of an open metalic framework for enclosing, supporting and protecting the vehicle's components. Sizes range from the basketball sized RCV-225 (0.17 m diam.) to automobile-sized ERIC II (4.8 m length). All are slightly positively buoyant when submerged. All but two manufacturers rely on surfacesupplied AC power; the two exceptions rely on lead-acid, self-contained batteries. Power requirements vary but 50/60 Hz and 220/240 VAC are most common. All ROV's, except one, employ propellers for propulsion; the exception (SMARTIE) uses water jets. Maximum depth capabilities range from 100 to 6,096 m (328 to 20,000 ft). However, most ROV's (68 percent) operate at less than 1,000 m (3,280 ft) depth although many vehicles are capable of greater depths than those at which they are now operating. (The length of the umbilical cable limits them from maximum operational depths.) Speed at maximum operating depth averages 1.6 knots, but speed in itself is not an important factor; the ability to stay on the job and maneuver in the presence of fast currents has proved to be of prime importance.

TABLE 1. FOUR CLASSES OF ROV's

TETHERED, FREE-SWIMMING VEHICLES

Vehicle	Depth (ft/m)	Manufacturer	Operator
ANGUS 002	984/300	Heriot-Watt University	Same
ANGUS 003	1,000/305	Heriot-Watt University	Same
BOCTOPUS	2,170/661	British Oxygen Co., Ltd.	Same
CETUS	1,500/457	ULS Marine Ltd.	Same
CONSUB 1	2,000/610	Institute of Geological Sciences	British Aircraft Corp.
CONSUB 201	2,000/610	British Aircraft Corp.	Sub Sea Surveys Ltd.
CONSUB 202	2,000/610	British Aircraft Corp.	Same
CORD I	1,500/457	Harbor Branch Foundation	Same
CURV II	2,500/762	Naval Ocean Systems Center	Same
CURV II	2,500/762	Naval Ocean Systems Center	Naval Torpedo Station
CURV III	10,000/3,048	Naval Ocean Systems Center	Same
DART	1,200/366	International Submarine Engineering Ltd.	Same
DEEP DRONE	2,000/610	Supervisor of Salvage (USN)	Ametek Straza
ERIC II	19,685/6,000	C.E.R.T.S.M.	French Navy
ERIC 10	1,640/500	C.E.R.T.S.M.	French Navy
EV-1	1,500/457	Kraft Tank Co.	Same
FILIPPO	984/300	Gay Underwater Products	Same
FILIPPO	984/300	Gay Underwater Products	Nereides, Orsay, France
FILIPPO	984/300	Gay Underwater Products	Uncommitted
IZE	1,640/500	Sub Sea Surveys Ltd.	Same
MANTA 1.5	4,921/1,500	Institute of Oceanology USSR	Same
MURS-100	328/100	Mitsui Ocean Development and Engineering Co.	Same
MURS-300	984/100	Mitsui Ocean Development and Engineering Co.	Same
OBSERVER DL1	600/183	C. G. Doris	Same
OBSERVER III	984/300	C. G. Doris	Same
ORCA I	2,297/700	Saab-Scania	Oceaneering International
PAP-104	328/100	Society ECA	Various Nato Navies
PHOCAS II	1,000/305	Geologinen Tutkimuslaitos	Same
PINGUIN A1	330/100	VFW Fokker	Same
PINGUIN B6	6,500/1981	VFW Fokker	Same
RCV-150	6,000/1,829	Hydro Products	Martech International
*RCV-225	6,600/2,012	Hydro Products	Seaway Diving
RCV-225	6,600/2,012	Hydro Products	Martech International
RCV-225	6,600/2,012	Hydro Products	SESAM
RCV-225	6,600/2,012	Hydro Products	Esso Australia Ltd.
RCV-225	6,600/2,012	Hydro Products	Taylor Diving and Salvage
RCV-225	6,600/2,012	Hydro Products	Wharton Williams
RCV 225	6,600/2,012	Hydro Products	Oceaneering International
RCV-225	6,600/2,012	Hydro Products	Japanese Navy
RCV-225	6,600/2,012	Hydro Products	Same

*No RCV-225 has a cable longer than 1,212 ft (400m), but the vehicle is designed for 6,600 ft operating depth.

TABLE 1. FOUR CLASSES OF ROV's (Continued)

TETHERED, FREE-SWIMMING VEHICLES

Vehicle	Depth (ft/m)	Manufacturer	Operator
RCV-225	6,600/2,012	Hydro Products	Santa Fe Construction Co.
RCV-225	6,600/2,012	Hydro Procucts	Uncommitted
RECON II	1,500/457	Perry Oceanographics	Hunting Surveys Ltd.
RECON III	600/181	Perry Oceanographics	Oceanics Ltd.
RECON V	1,200/366	Perry Oceanographics	Same
RUWS	20,000/6,096	Naval Ocean Systems Center	Same
SCAN	328/100	Underwater Maintenance Co., Ltd.	Same
SCARAB I & II	6,000/1,829	Ametek Straza	AT&T Long Lines
SCORPIO	3,000/914	Ametek Straza	Stolt-Nielsen Rederi A/S
SCORPIO	3,000/914	Ametek Straza	Israel - Government
SCORPIO	3,000/914	Ametek Straza	Same
SEA INSPECTOR	3,280/1,000	Rebikoff Underwater Products	Same
SEA SPY	1,000/105	Admiralty Underwater Weapons Establishment	Underwater and Marine Equipment, Ltd.
SEA SURVEYOR	660/200	Rebikoff Underwater Products	Same
SMARTIE	984/300	Marine Unit Technology, Ltd.	Marine Unit Holdings, Ltd.
SMIT SUB-1000	3,280/1,000	Smit Tak International	Same
SMT 1 & 2	1,200/366	International Submarine Engineering Ltd.	Sonarmarine Ltd.
SNOOPY	1,500/457	Naval Ocean Systems Center	Same
SNOOPY	1,500/457	Naval Ocean Systems Center	Naval Facilities Command
SNURRE	3,280/1,000	Continental Shelf Institute	Same
SPIDER	820/250	Myrens Verkstad A/A	Same
TELESUB	2,000/610	Remote Ocean Systems	Same
TOM 300	984/300	COMEX	Same
TREC 1,2,3	1,200/366	International Submarine Engineering Ltd.	Martech International
TREC 4	1,200/366	International Submarine Engineering Ltd.	Horton Maritime Explorations
TREC 5,6	1,200/366	International Submarine Engineering Ltd.	Ocean Systems Inc.
TREC 7,8	1,200/366	International Submarine Engineering Ltd.	Sub Sea International
TREC 9	1,200/366	International Submarine Engineering Ltd.	Uncommitted
TROV B-1	1,200/366	International Submarine Engineering Ltd.	National Water Resources Institute
TROV 0-1	1,200/366	International Submarine Engineering Ltd.	(Not resolved)
TROV E-3	1,200/366	International Submarine Engineering Ltd.	J. Ray McDermott
TROV S-4,6,7	3,000/914	International Submarine Engineering Ltd.	Ocean Systems Inc.
TROV S-8	3,000/914	International Submarine Engineering Ltd.	Intersub
UFO 300	984/300	Submersible Television Surveys	Winn Technology
UTAS 478	1,312/400	General Video System	Same

BOTTOM-CRAWLING VEHICLES

Vehicle	Depth (ft/m)	Manufacturer	Operator
GRANSEOLA	150/46	INCOP, ANCONA, Italy	Same
JU 160	197/50	Hitachi Construction	Same
KVAENER MYREN TRENCHING SYSTEM	1,640/500	Kvaerner Brug A/S	Same
PBM	420/128	Sub Sea Oil Services	Same
RUM	6,158/1,877	Marine Physical Laboratory	Same

TABLE 1. FOUR CLASSES OF ROV's (Continued)

BOTTOM-CRAWLING VEHICLES

Vehicle	Depth (ft/m)	Manufacturer	Operator
SEABUG 1	1,000/306	UDI Ltd.	Same
SEACAT	656/200	Vickers Oceanics Ltd.	Same
SL 3	164/50	Land and Marine Engineering	Same
SUBTRACTOR	150/46	Maui Divers of Hawaii Ltd.	Same
TALPA	150/46	INCOP, Ancona, Italy	Same
TALPETTA	150/46	INCOP, Ancona, Italy	Same
TM-102	660/201	Techomare S.p.A.	Same
TM III, IV	246/75	Land and Marine Engineering	Same
TRAMP	(Not available)	Winn Technology Ltd.	Same
UNDERWATER BULLDOZER	23/7	Komatsu Ltd.	Same
UNDERWATER TRENCHER	70/21	Sumitomo Heavy Industries	Same

TOWED VEHICLES

Vehicle	Depth (ft/m)	Manufacturer	Operator
ANGUS	7,874/2,300	Woods Hold Oceanographics Institute	Same
BATFISH	650/198	Bedford Institute of Oceanography	Same
CRAB	13,123/4,000	Institute of Oceanology	Same
DEEP TOW	20,000/6,096	Marine Physics Laboratory	Same
DIGITOW	19,685/6,000	Jet Propulsion Laboratory	Same
DSS-125	20,000/6,096	Hydro Products	One Japanese and One German Industrial firm
GUSTAV	19,685/6,000	Dornier System GmbH	Same
MANKA 01	21,325/6,500	GPK Karlsruhe	Same
NRL System	20,000/6,096	Naval Research Laboratory	Same
RAIE I	19,685/6,000	CNEXO	Same
RAIE II	19,685/6,000	CNEXO	Same
RUFAS I	600/183	NMFS	Same
RUFAS II	2,400/731	NMFS	Same
S^3	6,000/1,829	University of Georgia	Same
SEP	19,685/6,000	Dornier System GmbH	Same
TELEPROBE	20,000/6,096	Naval Oceanographic Office	Same

UNTETHERED REMOTELY OPERATED VEHICLES

Vehicle	Depth (ft/m)	Manufacturer	Operator
EPAULARD	19,685/6,000	CNEXO	Same
OSR V & H	820/250	Mitsui Ocean Development and Engineering Co.	Same
ROVER	984/300	Heriot-Watt University	Same
SPURV I	12,000/1,650	Applied Physics Laboratory	Same
SPURV II	5,000/1,524	Applied Physics Laboratory	Same
UARS	1,500/457	Applied Physics Laboratory	Same
UFSS	1,500/457	Naval Research Laboratory	Same
Unnamed	2,000/610	Naval Ocean Systems Center	Same
Unnamed	3,000/914	University of New Hampshire	Same

Equipment requirements vary depending on the task and nature of the mission, i.e., industrial vs. military vs. academic. Some components are common to all vehicles, while others are designed for specific application. The heart of the ROV system is its closed circuit television system which enables the operator to perform various tasks required of the ROV. Lighting is generally provided by quartz iodide lights clustered on the bow. Other equipment common to ROVs are cameras, manipulators, echo sounders, directional hydrophones, scanning sonars, side-scan sonars, sub-bottom profilers. Metal flaw detection devices such as corrosion potential monitoring, ultrasonic thickness measurement, and radiographic testing are also available on a few vehicles. Visual navigation is supplemented by magnetic compass and, in many instances, more sophisticated positioning is provided through one of several long or short baseline acoustic systems. Launch/retrieval methods vary as a result of the wide range in dry weight and equipment capabilities. Sea state limitations of State 6 are common, although State 8 has been successfully encountered. The majority are deployed over-the-side from a stiff-legged boom. Personnel requirements also vary depending on the complexity of the vehicle, work task, and length of time required for continuous operation; crew complements range from one to as many as seven.

2.2 Bottom-Crawling Vehicles

Vehicles in this category are primarily designed to perform a specific work task. Significantly, except in one instance, all bottom-crawling vehicles are industrially oriented, and this orientation is overwhelmingly directed toward the offshore oil and natural gas market. The vehicles themselves are less numerous than the tethered, free-swimming ROV's. Also, bottom-crawling vehicles are all operated by the company responsible for their construction.

Bottom-crawling vehicles are designed to satisfy one of the following functions: pipe trenching, cable burial, bulldozing/dredging and general (inspection/manipulation) work tasks. Pipe trenching is predominant and present capabilities permit trenching of 400 mm-to 2.5 m-(16 in.-to 8.2 ft)-diameter pipe in water depths of 500 m (1,640 ft).

Two vehicles, SEACAT and TALPETTA, are designed for cable burial. In both instances the trench dug is approximately lm (3 ft) deep. Bulldozing and dredging tasks are similar to those conducted on land. However, the effectiveness of the three bulldozing vehicles constructed is uncertain since it is not clear if they have been used commerically.

Four general purpose vehicles have been constructed. All but one (RUM II which was built with U.S. Navy funds and has been inactive during the past six years), are directed toward the commercial market. Projected work tasks are cable burial, pipeline inspection, debris mapping/clearance, bottom route surveys, valve opening/closing, hydro couple installations, and site investigations. These vehicles have only been available for commercial operations within the past two years; consequently, their actual at-sea utilization is limited at present.

Bottom-crawling vehicles tend to follow no general configuration. The bulldozers are much like their land counterparts, but the remaining vehicles are uniquely configured and cannot be described generally. Undoubtedly, the most varied configurations are found within the pipe trenching and cable burial vehicles which virtually defy a geometrical analogy. One aspect in common with the trenching and bulldozing vehicles is their size: all are large and massive. Consequently, surface support platforms are much larger and the launch/retrieval capabilities required to handle these massive loads are more stringent. Cable burial vehicles and general purpose vehicles are, on the other hand, much smaller.

Vehicle speed requirements vary with the nature of the work task and the environment. In one instance, bulldozing, speed is less significant than the capability to move quantities of sediment. General purpose vehicles can obtain a maximum speed of 3 knots (6 km/hr) but this too is dependent on the type of bottom, the bottom slope gradient, and the ability of the bottom to support the vehicle's weight (i.e., trafficability).

All bottom-crawling vehicles, but one, receive their power through an umbilical cable from a surface platform. The exception, UNDERWATER BULLDOZER, is powered by an onboard diesel engine. Pipe trenching vehicles are propelled by either 1) using the pipe itself for traction or 2) using the sea bed for traction. Over half of the vehicles investigated fall into the first category, but in either case the vehicle provides its own propulsion. Bulldozing vehicles, similar to their land counterparts, use caterpillar tracks for propulsion. General purpose vehicles use either individually suspended wheels (4 to 6) or caterpillar tracks.

The primary tool of the trenching vehicles is the cutting device. Two means of excavation are used: water jets which fluidize the sediment and hydraulic cutters which mechanically breakdown the sediment. Instrumentation can also include inclinometers, air pressure gages, and hydraulic pressure gages. Cable burial vehicles employ essentially the same techniques and instumentation as do the trenching vehicles. General purpose vehicles are more akin to the free-swimming, tethered ROV's which utilize CCTV, manipulators, echo sounders, side scan sonar, directional gyros, and depth gages.

Navigation of pipeline trenching vehicles is relatively simple since the position of the pipe is known prior to the operation. The only remaining requirement is that of determining the position of the device as it proceeds along the pipe. Visual sighting and magnetic compasses with directional gyros are common, but bottom-mounted, acoustic navigation systems have also been employed.

The wide variation in size and mass of bottom-crawling vehicles naturally results in a wide variety of support ship requirements. Launching, retrieving, supporting, and maintaining a vehicle weighing up to 192 tons weight calls for surface platform of considerable magnitude, a highly-skilled crew, and extensive inventory of specialized equipment. For these reasons, many of the pipe-trenching and cable-burial vehicles operate from dedicated support platforms.

2.3 Towed Vehicles

Vehicles in this category rely solely upon a mobile surface support ship for propulsion and maneuverability, and generally depend upon a surface-connected umbilical cable for power and data telemetry. Ownership of towed vehicles is divided almost equally between the industrial and government/academic communities. Approximately 19 have been constructed, and 15 of these are operational. All industrially owned vehicles belong to corporations involved in assaying or mining deep-sea mineral deposits (i.e., manganese nodules).

Functional capabilities and work tasks for towed vehicles fall under three categories: industrial, military, and scientific research. Industrial vehicles are designed almost exclusively for assessment of manganese nodule deposits to depths of 6,096 m (20,000 ft). Functional capabilities include television, photography, and side scan sonar mapping. Military application vehicles are designed to conduct detailed sea floor surveys (photographically and acoustically) and to search, identify, and locate objects of national interest. Vehicles used in the scientific research areas are all supported directly or indirectly by government funding. Equipment and functional capabilities range from relatively simple TV and side-scan sonar capability to very specialized and sophisticated instrumentation.

Operating depths for these vehicles range from 400 to 6,096 m (650 to 20,000 ft), the average being 4,712 m (15,459 ft). Sixty-eight percent offer operating capabilities to 6,000 m and greater. This reflects the commercial interest in manganese nodule deposits and, from a military standpoint, a search capability to cover 98 percent of the ocean bottom.

Towed vehicle configuration is generally cylindrical. Unlike tethered, free-swimming ROV's, almost half of the towed ROV's are enclosed by fairings to reduce hydrodynamic drag; the remainder are unfaired and are of the open, metallic framework construction. Tow speed averages 3 knots to facilitate high resolution photography. Power is generally supplied via an umbilical cable from the support ship. Instrumentation is much the same as for tethered, free-swimming ROV's except that no manipulators are carried and CCTV is not heavily relied upon; dependence is more on photographic documentation.

2.4 Untethered Vehicles

Technology in this field is best described as emerging, even though the Applied Physics Laboratory, University of Washington has successfully operated the untethered SPURV and UARS vehicles for over a decade. Of the nine vehicles that have been identified, only three are operational, two are under construction, and three are in the development stage; the remaining vehicle's status is unknown. Because each vehicle is designed for a specific application/capability and only three vehicles are operational, little can be inferred regarding their general capabilities and future potential. There are several major technological areas where breakthroughs are required before untethered ROV's can equal the capabilities of their tethered counter-parts. The major breakthrough required is development of real-time, thru-water, television signal transmission.

3.0 VEHICLE UTILIZATION

3.1 Industrial Applications

The dominant user of tethered, free-swimming ROV's is the offshore oil and natural gas industry. Industrial applications and examples within each category are as follows:

Inspection: As opposed to monitoring, consists of determining and documenting the location and/or condition of undersea structures.

Geometrical configuration and position determination of pipelines and/or cables following installation.
Determination and documentation of the condition of pipeline concrete coating after installation.
Accurate determination of pipeline tie-in positions.
Leak detection.
Wellhead structural integrity.
Assurance of clearance for lowering/guiding lines.
External examination of concrete platforms.
Dam integrity inspection.
Mine shaft inspection.
VLCC hull inspection.
Structure NDT inspection (including cleaning) for
- Sea floor scouring
- Anode corrosion-potential measurements
- Ultrasonic thickness measurements
- Radiographic inspection of risers
- Bent and/or broken members
- Debris accumulation

Monitoring: Includes observation and/or measurement of tasks which are underway at the time of ROV deployment.

Grouting operations.
Piling installation.
Structure alignment/orientation checks.
Measurement and control of cable length during installation.
Observation of pipeline pull-in procedures.
Pipeline weighting procedures.

Survey: Involves measurement (i.e., mapping) and sampling of natural and man-made bottom features.

Confirmation of surface-obtained data.
Pipeline/cable route surveys.
Site surveys.
Pipe trench profiling.

Diver Assistance: Includes tasks in support of diver activities.

Diving support ship positioning assistance.
Continuous monitoring of the diver in terms of safety.
Initial diving gear checkout for leaks.
Augmented, surface understanding of diving conditions.
Precise location of dive site prior to diver deployment.
Evaluation of diver site conditions in terms of safety.
Mobile, independent light source.
Inspection of potentially diver-hazardous areas.
Inspection of area too small for the diver.

Monitoring of equipment installation by divers.
Monitoring and inspection of diver's work.
Documentation of diver's work photographically or with video TV.

Search/Identification: Entails locating and identifying objects intentionally and unintentionally placed on the ocean floor.

Location and identification of lost equipment and materials.
Location and identification of acoustically located objects.
Debris identification and location.
Location of sub-bottom pipeline taps.

Installation/Retrieval: Includes assistance in installation of fixed structures and pipelines/cables and assistance in retrieval of hardware.

Collection of small-sized artifacts.
Debris recovery assistance (attach lift lines, provide guidance, etc.)
Lost equipment and component recovery assistance.
Provision of real-time depth measurements during equipment installation.
Assistance during blowout preventer (BOP) installation (visual observations, depth and orientation measurements).
Cable burial by water jetting.

Cleaning: Includes cleaning activities preparatory to NDT inspection and hull cleaning of very large vessels.

Hull cleaning.
Structure cleaning.

3.2 Military Applications

Military applications of ROV's closely parallel those of the industrial sector. These are the deepest diving ROV's and reflect the interest shown by them in deep, as well as shallow, waters. Although details of some applications are not publically available, the following categories represent those which are:

Inspection: Aircraft crash assessment, sunken craft identification/assessment, and hardware inspection.

Survey: Military tasks do not require the high degree of accuracy of detailed bottom feature measurements needed in industrial applications, although those standards can be met if required.

Search/Identification/Location: One of the major tasks involves the location, identification, and, if feasible, the neutralization of underwater ordnance. However, since a great portion of work is considered classified, details on objects sought and techniques involved are not available.

Retrieval: This is probably the most frequent task military vehicles provide assistance; objects retrieved include drill bits, torpedoes, bombs, ships and manned submersibles.

3.3 Scientific Research Applications

The application of ROV's by the scientific research community has been minimal. Only two applications have been reported in the U.S. and only three other countries, England, Finland and Canada, are known to operate ROV's as scientific research vehicles. The work that has been conducted in this area can be categorized as inspection and survey. Significantly, well over 90 percent of all work now being conducted entails video inspection and documentation.

Only a very few tasks have required manipulation, and these are simple functions such as detaching or attaching lift lines.

To ascertain the degree of utilization of U.S. civilian ROV's during the FY 1978 period (1 October 1977 through 30 September 1978), a survey of operators was conducted in late 1978. At that time there were 11 operators who represented a total of 27 ROV's. Only three of the operators responded to the survey questionnaire (Taylor Diving Co., Martech International, and Rebikoff Underwater Products), but they operate a total of 15 ROV's which was somewhat greater than half of the U.S. vehicles operating. The total dive days of all 15 vehicles is 2,007. Significantly, all were in support of or aimed at the industrial market, and all were funded by the private sector.

These ROV utilization figures are interesting when compared against the activities of the 13 civilian operational manned submersibles for the same period. During FY 1978, U.S. manned submersibles operated a total of 510 dive days. Of this effort, 23 percent was funded by the Federal Government, 24 percent by a private research foundation, and 51 percent by private industry. The tasks conducted by manned vehicles are almost equally divided between scientific research (43 percent) and industrial applications (46 percent).

4.0 PROBLEMS

There are many recurring problems that are inherent in the design of the vehicle and its application in the field. Twenty ROV operators have been consulted, and the most prevalent problem they have encountered is entanglement of the umbilical cable or the vehicle. Entanglement in its most mild form can result in merely a short delay until the problem can be worked out by the operator. In its more serious form, it can lead to abandonment of the vehicle for several months until it can be retrieved or is a complete loss. Another problem identified by almost half the operators was frequent failure of the electrical connectors where the umbilical cable connects to the vehicle. Other areas include sediment disturbance which obscures visibility; cable rupture due to drag, stress, or abrasion; and electrical interference between the control, power, and video data transmission portions of the umbilical cable. Less severe problems lay in the area of support ship station-keeping ability, compass performance, power supply surges, currents, and sea state limitations. One area of particular importance is the need for greater numbers of qualified and experienced personnel; those with an electronic background and experience in undersea operations and shipboard handling techniques are most desired. A listing, by decreasing order of occurrence of problems encountered by free-swimming, tethered ROV's, is shown in table II.

5.0 CURRENT RESEARCH

Research and development in tethered, free-swimming ROV technology is being funded and conducted by a variety of sources; these include the governments of several nations and private industrial sources. In several instances, the project is funded jointly by both government and industry and the work is performed by the industrial partner. (This is particularly true in the United Kingdom.)

TABLE 2. ROV PROBLEMS REPORTED

Problem	Number of complaints
Entanglement	18
Electrical connectors	12
Vehicle disturbs sediments, obscures visibility	11
Cable ruptured by abrasion	10
Electrical interference in cable	8
Support ship cannot station-keep	6
Compass affected by structure	6
Ship power surges afffect vehicle operations	5
Current required aborting mission	5
Sea state required aborting mission	5
Vehicle damage during launch/retrieval	2
Vehicle station-keeping inadequate	2
Manipulation inadequate	2
Vehicle payload inadequate	2
Human engineering inadequate	2
Vehicle lost due to low surface freeboard	1
Electrical shocks due to inadequate grounding	1
Vehicle maneuverability inadequate	1
Water visibility required aborting mission	1
Television resolution inadequate	1

Most of the ROV research and development programs deal with highly specific aspects of technolgy. However, the English government has embarked on a program which deals with the field in its entirety. The major thrust of their program is to increase ROV capability and efficiency and lessen the hazard to humans by a remotely operated system.

Technological developments for untethered vehicles are being conducted by the Naval Ocean Systems Center, the University of New Hampshire, the Naval Research Laboratory, Heriot Watt University, and CNEXO.Much remains to be done in this category, and technological advances are needed before the full utilization of these vehicles will be known.

Two programs are underway to enhance the capabilities of ROV's as diver assistance vehicles. One program, funded by the European Economic Community, has as its goal the development of a diver assist vehicle for underwater inspection and maintenance duties. The second program, developed by NOAA's Office of Ocean Engineering, is aimed at conceptual configurations of a remotely operated diver assistance vehicle (RODAV). Since a major portion of NOAA diving is scientifically oriented, the RODAV should differ in many respects from a vehicle devoted to industrial applications.

A variety of programs to develop instrumentation and tooling for ROVs are being pursued by industrial concerns. Some are concerned with simple devices for a specific ROV; others involve development of more sophisticated technology. Details of some of these programs are considered proprietary company data and are not available. NOAA's Office of Ocean Engineering has several instrumentation development programs jointly funded by other government agencies and academic institutions. These include digital side scan sonar, remote sea bed sampling and analysis, and sub-bottom profiling.

Currently, untethered vehicles have an operational duration of 4 to 5 hours. For untethered vehicles to provide capabilities comparable with tethered vehicles, a higher energy density power source must be made available. To this end, the Continental Group, Inc., of New York has developed a lithium battery or power cell which can be packaged for ROV application. At present the battery is being field tested on the AUGUSTE PICCARD. The first phase will provide 1.2 MWhr of electrical energy and the subsequent phase will supply 36 MWhr.

Other areas of development include an inertial navigation system called HASINS (High Accuracy Submersible Inertial Navigation System) by Ferranti, which does not rely on acoustics and, therefore, has potential for Ltd., working within a structure and not be affected by reverberation. INTERSUB, a Marseille-based firm has intergrated ROV instrumentation, navigation system, and the support ship into a single operating entity for use in pipeline inspection. Exxon Production Research Company is developing a tethered maintenance vehicle (TMV) designed to perform observation and manipulative tasks on facilities and equipment associated with a deepwater marine production riser system. The maintenance system consists of the TMV, interchangeable tool packages, a launch/recovery system, a control van, and auxiliary surface support equipment. Plans include fabrication and testing to prove the system's effectiveness before employing it on an actual maintenance mission.

The operators of ROV's are fully occupied with the day-to-day problems of logistics, personnel, and contract performance; consequently, only a few companies are involved in inhouse research and development. The operators involvement with the present realities of ROV operations can be seen in the following listing which, in order of decreasing priority, tabulates their suggestions as to the research and development required:

Greater thruster power to maneuver and position heavy lift lines at great depths.
*Stronger, abrasion-proof tether.
*More power to vehicle.
*More thruster power.
*Lighter weight cable.
Fast acting crane for launch/retrieval.
High definition color TV.
Fiber optic link for TV signal transmission.
Accurate, inexpensive, inertial guidance underwater navigation system.
Increased data handling capability.

(*With no increase to cable mass.)

6.0 TRENDS

A close parallel can be drawn between the development of manned submersibles and the development of remotely operated vehicles. The first submersibles of the 1960's were termed general purpose submersibles. When an industrial market arrived for these vehicles in the early 1970's and experience in offshore industrial work accrued, specialized vehicles began to evolve. Diver lockout submersibles, one-atmosphere transfer vehicles, one-atmosphere observation/work bells, atmospheric diving suits (self-powered and electrically powered), and variations of these evolved as work tasks became more defined and shortcomings in the design of the earlier one-atmosphere vehicles were revealed.

Experience with ROV's has revealed a similar development history. As a consequence, specialization in vehicles is evolving. Concurrent with specialized vehicles are developments in specialized instrumentation to conduct the various tasks. Several development programs aimed at more specialized vehicles have been identified in the previous section; these include the diver assist vehicles, pipeline inspection systems, and riser system maintenance vehicles. Other programs in specialized areas are discussed below.

Underwater structure inspection requirements for the U.S. and Norwegian sectors of the North Sea have instigated development of vehicles specifically suited for inspection of structures. Sonarmarine, Ltd., of Ashford, Middlesex has perhaps the most comprehensive and versatile suite of instrument/tooling capabilities in the area of ROV-conducted structure inspection. The following system characteristics and capabilities of their SMT 2 vehicle demonstrates the vehicle's dedication to inspection tasks:

-Conformance with Lloyd's register requirements for operation on North Sea production platforms. The system satisfies safety requirements for Division Two areas and can operate directly from the platform rather than from an independent support craft.

-Three TV cameras with video recording capability, wide angle, low light level S.I.T. camera on a pan/tilt mechanism is used by the pilot for navigation, a vidicon TV is used by the surveyor for high definition mounted on either the pan/tilt mechanism or held in the vehicle's manipulator, and a third, neuvicon camera, is used as conditions dictate or mounted in a stern position as a navigation aid when working inside a platform.

-Stereoscopic cameras (with color film) are fitted on the pan/tilt mechanism to obtain detailed stereophotographs. Darkroom facilities are built into the vehicle control cabin for onsite film processing.

-A water jetting gun (5,000 psi, 10 gal. per min) with integral pump to remove marine growth prior to cleaning.

-A sand suction horn to clean sand from around a pipe or other object to permit inspection.

-A corrosion-potential (c-p) probe (silver/silver chloride reference cell) is carried in one of the manipulators to obtain potential readings which indicate the effectiveness of the cathodic protection system.

-An ultrasonic wall thickness gage held in the manipulator presents thickness measurements on a CRT display, digital display, or x-y plotter.

-A radiographic inspection system consisting of an isotope source and a photographic plate for riser inspection.

-A set of transducer assemblies that can be deployed from SMT 2 at a specified location on the structure to obtain acoustic signatures for acoustic emission analyses.

Sonarmarine's SMT 2 (and SMT 1) were constructed by International Submarine Engineering, Ltd., as a general-purpose vehicle. As these vehicles are employed more and more into very specialized tasks, shortcomings willl evolve which are beyond the vehicle's designed capabilities. In December 1978 and in collaboration with Vickers Slingsby, Sonarmarine completed design of a vehicle dedicated for platform inspection. While plans were not firm then to proceed with construction of the designed vehicle, it was felt that construction would be likely by 1980.

Underwater Maintenance Company, Ltd.'s SCAN vehicle is designed solely for hull inspection of very large crude carriers (VLCC's). Handheld camera surveys of fairly small areas on VLCC's, such as the rudder, intake girds, and sides, are performed adequately by divers. But the large flat bottom cannot be covered by divers within a realistic time frame or with any degree of accuracy. SCAN is designed to fill the gap left by divers and to comply with Lloyd's Register rules for inwater surveys.

The basic SCAN system consists of a diesel generator, control/display console, multiconductor cable, and the vehicle. The vehicle carries a 35-mm photographic camera, a low-light level TV camera (for distance viewing), a Videcon TV camera for close viewing and a tungsten halogen light.

Propulsion and maneuvering are by friction drive via two drive wheels with hydraulic motors. The vehicle is at neutral buoyancy when initially deployed; it is then maneuvered to the flat bottom of the VLCC where a central chamber is blown free of water by compressed air. When filled with air, the central chamber forces the vehicle up against the bottom of the ship and the drive wheels provide motion. Navigation of the vehicle can be by one of three methods: dead reckoning (measuring the x and y components of distance traveled), electronically (through pingers and transponders), or visually (by following physical markings on the hull). The latter method is preferred, and a system of white line markings has been proposed to meet the positioning requirements of Lloyd's rules. Since the inspection is solely reliant on TV, adequate water clarity is, obviously, imperative.

The only ROV known to be designed exlusively for hull cleaning is SCAMP. The vehicle is manufactured by Winn Technology Ltd., Kilbrittain, Ireland, and its services are marketed in the United States by Butterworth Systems, Florham Park, N.J. The vehicle holds three large, rotating brushes and propulsion is derived by three traction wheels which are held against the ship's hull by an impeller. The impeller provides a traction effect of 204 kg (450 lb) which permits use of the vehicle in currents up to 3 knots (5.5 km/hr). SCAMP can be directed to advance, stop, and reverse, or it can hold a parallel line of motion. It is remotely controllable or can be controlled by a diver.

The primary employment of SCAMP has been in the cleaning of large ship hulls. The cleaning is generally performed while the carrier is unloading or at anchor. A unique hull coating has been developed by the Ship Research Institute of Norway which is physically reactivated at intervals of 12 months using the SCAMP vehicle fitted with specially designed brushes. Pigmented with toxic cuprous oxide, the reactivation points are applied in layers to the ship's hull during drydock. Small amounts of the toxin are released as the ship transits. After approximately 1 year, the toxic effectiveness of the outer layer weakens to the point where it no longer inhibits marine growth. At this point the SCAMP abrasively removes the ineffective top layer of paint and exposes the still-active antifouling surface beneath. Color changes built into each layer of paint verify that reactivation (i.e., removal of the ineffective layer) has been achieved. SCAMP does not carry close-circuit television as part of its standard equipment.

AMETEK Straza's SCARAB represents a further design for specialized tasks. SCARAB, at 2,268 kg (5,000 lb), is one of the larger class ROV's and is specifically designed to assist in cable burial and repair. SCARAB's general configuration and control functions do not differ greatly from the field in general. Specialization is evident in its instrumentation and equipment suite which includes capabilities for cable location (by visually sighting or from sensitive magnetometer probes), cable deburial (using a dredger nozzle and 25 hp suction pump deployed on a manipulator), cable gripping, cable cutting, cable recovery (from the surface ship after the grippers with lift lines have been attached and ejected), and cable reburial (by a special jet nozzle and wheel assembly). SCARAB I & II, in the fall/winter of 1978/79, have been undergoing sea trials and will be operating for a consortium of cable companies headed by AT&T Long Lines.

The advent of microprocessor technology has begun to affect ROV design, particularly in vehicle control areas. Several manufacturers have introduced computers to assist the operator in controlling the vehicle. Marine Unit Holdings, Ltd.'s (Richmond, surrey) SMARTIE, for example, has computer aided controls to reduce operator fatigue. By activating a "hold" control on the pilot's console, the computer can provide offset control signals to counteract the effects of cable drag or cross currents. When a particular motion is required, the computer automatically carries out the necessary calculations to activate the combination of its six thruster jets needed to carry out the maneuver most efficiently. The vehicle's course can be preset and correction automatically applied by the computer to maintain an accurate course, but the pilot can manually override the program at any time and revert to it if conditions warrent.

In another instance of computer assistance, ULS Marine's (Stonehouse, Glostershire) CETUS system has a dedicated PDP II computer aboard the support ship which resolves information from the ship's compass heading, the vehicle's compass/gyro heading and depth, and the vehicle's relative bearing and range. This information is linked to a computer-driven graphic display unit to provide a continuously updated picture to the vehicle's pilot and navigator which porrays the heading of the support ship and the range/bearing and current heading of the vehicle. A second graphic display unit provides similar information to the support ship bridge. These are not the only vehicles applying computer technology to ROV operations; other vehicles are also interfaced with a variety of computer programs to assist the pilot and vessel master in vehicle/ system control and navigation.

Specialized vehicles are not exclusive to the industrial sector, the military has entered this area as well. The U.S. Naval Ocean Systems Center (NOSC) has developed a prototype solid rocket booster (SRB) dewatering system for the National Aeronautics and Space Administration. The device, referred to as a nozzle plug (NP) is a 4.3 m (14 ft) long, torpedo-shape vehicle designed to dewater expended SRB's jettisoned during space shuttle launches.

The SRB's assume a spar (upright) mode when in the water and they require a log (horizontal) mode for towing to port for refurbishment. The NP is launched from a support ship and maneuvered on the surface to the SRB where it dives to inspect the SRB casing using its TV system. The NP operator visually acquires the nozzle opening by the same TV system. The plug is then positioned beneath the SRB and, at the appropriate time, uses its vertical and horizontal thrusters to drive it up into the nozzle throat. When the NP has docked, indicator lights on the surface console show that it is seated and locking arms are deployed to hold it in position. Dewater air is activated through the umbilical cable and a pressure differential is attained which forces the water out. As the water leaves the SRB is raises out of the water and, becoming unstable, falls into the log mode. At this point a sealing bag is inflated on the NP to prevent loss of air and return of water. Dewatering continues until the SRB is emptied. The umbilical cables are then disconnected from the ship and both the SRB and NP are towed to port where the NP is removed and refurbishment begun.

The majority of industrial vehicles are manufactured by one company and sold to another company who sells its services in the field. A noticeable and recent trend seeks to bridge this separation of manufacturer from user. Several industrial firms in the United Kingdom manufacture ROV's but do not sell them outright. Instead, they train their own operators and lease the vehicle/operator system to the customer. In this manner the operational feedback, necessary to improve the vehicle's performance, is immediately made available and the operators are thoroughly qualified and familiar with the vehicle. This trend is not noticeable in the U.S. where manufacturer and user are independent corporations.

Merely 2 years ago ROV systems sold for prices ranging from $400,000 to well over $1 million. Undoubtedly the most dramatic development in this area has been the introduction of low cost, simplified vehicles for observation and video documentation. The most recent of these vehicles is International Submarine Engineering Ltd.'s DART (Deep Access Reconnaissance Television), a 366 m (1,200 ft) tethered vehicle weighing 33 kg (70 lb) equipped with four thrusters, CCTV, a depth sensor and a magnetic compass. DART's purchase price is quoted at $50,000, a price which makes ROV capabilities affordable to virtually any industrial, military or scientific research activity involved in undersea search, survey, inspection, or research.

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