The MIT/Marine Industry Collegium

Opportunity Brief

UNTETHERED ROBOT SUBMERSIBLE INSTRUMENTATION SYSTEMS

A Project of the
MIT Sea Grant Program

The MIT/Marine Industry Collegium

UNTETHERED ROBOT SUBMERSIBLE
INSTRUMENTATION SYSTEMS

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Sea Grant Program

ADMINISTRATIVE STATEMENT

In 1975 the MIT Sea Grant Program formed the MIT/Marine Industry Collegium, a working partnership between MIT Sea Grant and U.S. Industry to promote the commercial development and application of new marine technologies. In seeking to meet this objective, the Collegium acts as an information resource for industrial members, conducts meetings, workshops, and special programs, and publishes information on new ocean-related business opportunities.

The principal publications of the Collegium are Opportunity Briefs. These 15-25 page papers deal with specific business opportunities growing out of Sea Grant or other MIT sponsored marine research. Opportunity Briefs describe a new technology or process, outline economic and marketing implications, review technical requirements, and consider environmental, regulatory, and political factors. Briefs are a joint effort of subject experts, the MIT Sea Grant Marine Industry Advisory Service and Collegium members. The briefs remain anonymous to give greater freedom in the expression of opinions and in speculation about particular future opportunities.

The five Opportunity Briefs prepared during the Collegium's 1975-1976 year were:

Chitin and Chitin Derivatives

Offshore Mining of Sand and Gravel

Telemanipulators for Underwater Tasks

Advances in Underwater Welding

Untethered Robot Submersible Instrumentation Systems

Each of these Briefs was first issued to Collegium members in draft form. Following this, we held meetings to explore the topic in more depth and to discuss further directions with representatives of interested companies. The Brief in its edited form incorporates many of the comments and suggestions that we received from members through correspondence, phone conversations, and Collegium meetings.

If you would like to receive any of our other Opportunity Briefs, or wish to pursue further any of the topics covered, please contact the Marine Industry Advisory Service, MIT Sea Grant Program, Room 1-215, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139.

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Director

August 15, 1976

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1.0 A BUSINESS PERSPECTIVE

Oceanographers, mariners, and weather forecasters have traditionally been the primary users of instruments and equipment for measuring the physical, chemical, and biological properties of the ocean. Today, the instrumentation and equipment requirements have been extended to meet the data needs for production, exploration, construction, and transportation facilities for offshore oil and minerals. These applications require capabilities not only for measuring but for "seeing" beneath the ocean by means of sonar, video, or photography.

Both the traditional markets and the newer markets have been served by instruments and arrays of instruments anchored to one spot, towed behind a ship, or lowered from a platform. With a few notable exceptions, these systems have one common characteristic--they are attached to cables.

If the instrumentation is heavy, or is intended to operate at any appreciable depths or at appreciable towing speed, the cable must be correspondingly strong. Long, strong, sea-worthy cables are expensive. Winches to handle them are large and heavy and must therefore be mounted on sizeable vessels (with sizeable crews) or platforms. Also, winching the instruments in and out from shipboard is time-consuming.

Untethered submersible systems now being developed at MIT and elsewhere hold the potential for providing underwater measurement and inspection capabilities with greater cost-effectiveness than existing methods.

Because these systems sense their environment and use that information to control themselves, they may be described as robot submersibles. The decrease in cost and size of micro-processors for control of such robots means that the systems can be small and easily handled. Compared with tethered systems, the support equipment is minimal. No heavy winches are needed for long cables, anchors, and the like, so small ships and small crews can be used. The potential savings in operational and logistic costs are very large.

Two untethered submersibles have been developed as student projects at MIT, and a third is being worked on. These experimental prototypes are sophisticated, inexpensive instrumentation systems. There is reason to believe that cost-effective commercial systems derived from these could be developed. Extensions of present capabilities might include video, photography, or sonar for "eyes," and a "hand" for grasping.

The MIT developments and their applications are described in Sections 2 and 3 below. In Section 4, we speculate on future systems and applications.

Our objectives are two-fold: first, to suggest to potential manufacturers and users the range of possibilities that a student team has shown to be feasible and achievable (with almost no financial resources), and second, to look to Collegium members to define a few difficult, challenging, and demonstrably needed "real" measurement/inspection problems that might be solved with a robot submersible. Such a challenge could provide Sea Grant researchers and students with the basis for designing, building, and testing prototypes of a more sophisticated vehicle, perhaps in collaboration with interested industrial partners. The goal would be to provide a prototype of a new system or family of systems that could be profitably produced by the industrial community to more economically serve the ocean industry.

2.0 UNTETHERED ROBOT SUBMERSIBLES

2.1 Background.

Some of the technology for untethered robot submersibles is already well-advanced. Torpedoes, for example, have been in use for many years. However, torpedoes do not provide a useful model for commercial uses because they are designed to accomplish a single specific mission and they are not recoverable once the mission is completed.

A robot vehicle called UARS (Unmanned Arctic Research Submersible System) has been designed to carry out ice profiling missions and was reported in the literature in 1972. The system was developed by the Division of Marine Resources and the Applied Physics Laboratory of the University of Washington with funds from the Advanced Research Projects Agency of the Office of Naval Research. UARS is 10 feet long, weighs 900 pounds in air, and has a depth capability of 1500 feet. It can travel at 3.7 knots for more than 10 hours. The main batteries are silver zinc. The description of the vehicle implies that it is controlled remotely using a coded acoustic pulse train.

Another robot submersible is being developed in Japan by a combined government and industry group. This ambitious system is designed to measure and process oceanographic data. It includes a robot vehicle, a data buoy, and a shore-based processing center. This robot submarine, called the OSR-V, is nearly 16 ft. long, weighs 2.75 tons, and can travel at 4 knots. The maximum operational depth is 820 ft. The propulsion motors are driven by 100 volt, 140 ampere-hour, silver zinc batteries.

The OSR-V will be used to collect oceanographic data. At regular intervals, it will rise to the surface and radio data to an anchored buoy, which in turn will transmit the data to a base station. During the intervals between data collection, the vehicle remains quiescent at the bottom. It uses a minicomputer for system control and data collection.

The development plans for the OSR-V called for the first proposed operational run in the fall of 1975. We have not received further details on the proposed run. Details on the state of development of the data buoys and other components of the system were not available.

As nearly as we can discover, these two systems are the only commercial untethered robot vehicles available.

With the continuing development and decreasing cost of microprocessors, the major cost item of computer-controlled vehicles has become very inexpensive. Furthermore, the standard solid state LSI (large-scale integration) chips and cassette recorders available for data systems suggest that very small, inexpensive, robot submersibles could be designed and developed. These small robots could provide highly mobile instrument packages that could be deployed from and recoverd by very small vessels, thus substantially reducing the logistic costs of data acquisition.

2.2 The MIT robot submarine.

The MIT robot submarine is an inexpensive, versatile vehicle that has been designed, constructed, and tested by a group of MIT students under the direction of Professor A. D. Carmichael. The material and hardware costs of the vehicle are less than $3,000. The MIT robot uses a minicomputer specially designed and built for this project, and very simple sensors in the autopilot.

The vehicle is substantially smaller and lighter than either the half-ton UARS or the 2.7-ton OSR-V. It is about 8 feet long, 15 inches in diameter, and weighs about 250 pounds in air. It has a range of about 15-20 miles at about 3 knots and has a maximum depth capability of 200 feet. The robot submarine has the following main components and systems:

1. pressure hull and streamline fairing
2. propulsion system
3. control surfaces and servomotors
4. electronic control and supervisory system
5. control software
6. data collection and storage arrangements systems
7. tracking systems

The vehicle is free flooding with the critical components housed in PVC tubes, which form the pressure hull. There is a streamlined fairing over the pressure hull comprising a fiberglass nose and tail and a cylindrical aluminum center body.

The energy source is a 96-ampere-hour, 12-volt automotive-type lead/acid battery that has been modified to operate at the ambient water pressure. The battery powers a small dc motor that is coupled to the propeller through a reduction gear box.

The submarine is equipped with bow and stern control surfaces to control the depth, attitude, and course. The fins are actuated by small servomotors driven by servoamplifiers.

The autopilot, which is supervised by a minicomputer, has a commercial pressure transducer to sense depth, a compass to maintain course, and a simple, damped pendulum as the pitch sensor. The minicomputer was designed to provide supervisory control of the autopilot and to supervise the collection and storage of data. The computer has a 4K by 16 bit memory. The computer has input/output interfaces to the autopilot, to sensors, and to shore-based equipment. When the computer is being instructed before an operational mission, an optical coupling system is used to read course and depth instructions into the computer memory. The optical coupling avoids the need to unseal the robot and circumvents the problem of making and breaking electrical connections in the presence of seawater.

Figure 1 (page 7) shows 2 views of the robot submarine.

Software has been developed to facilitate the operation of the computer in the submarine. This software design has permitted the development of simple operating programs for robot missions. These operating programs allow the vehicle to travel on prescribed, sequential courses at preset depth and at the same time to make scientific measurements and record the data in memory or on magnetic tape.

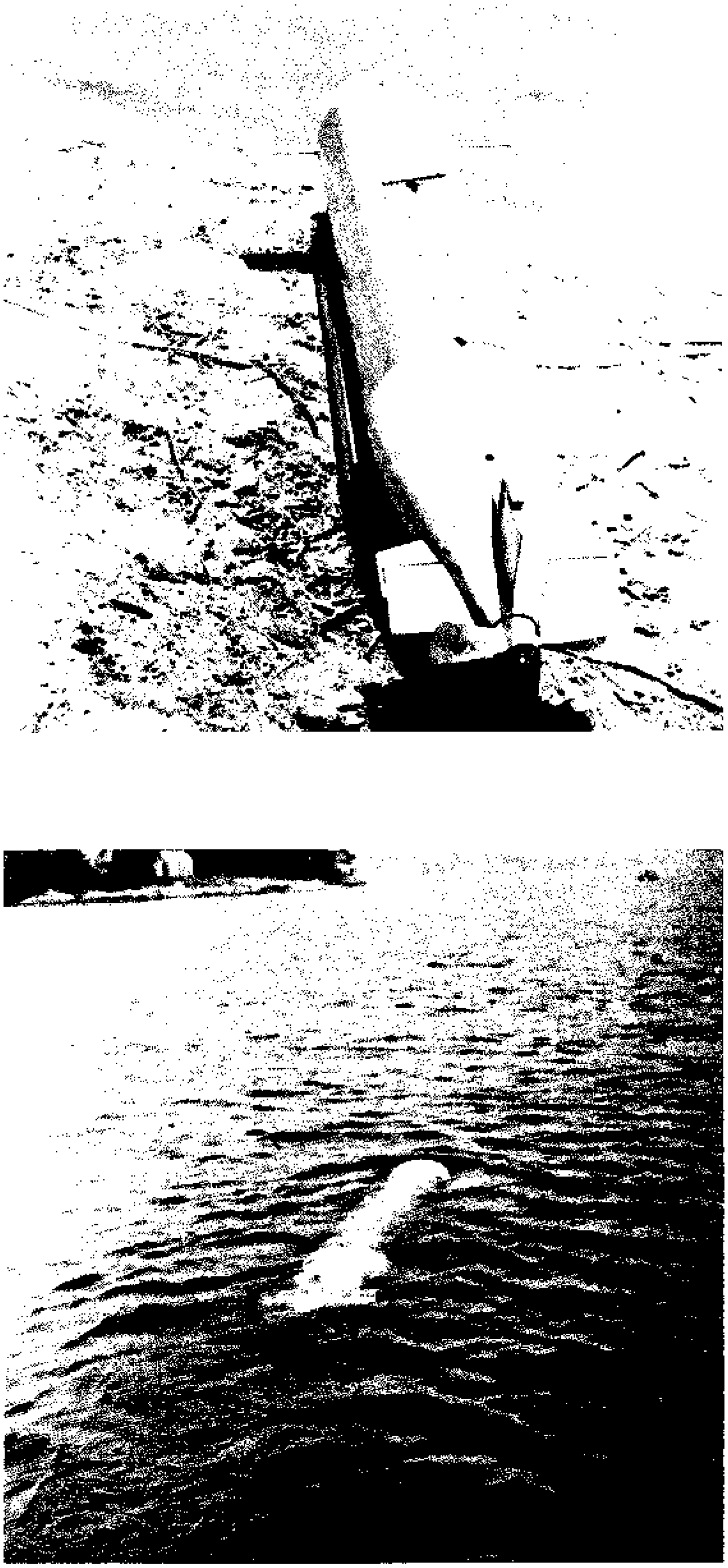

FIGURE 1

MIT ROBOT SUBMARINE

3.0 CONSTANT DEPTH FLOATS

3.1 Background.

Robot submersibles, such as those discussed in the previous section, are useful for applications requiring controlled mobility. Another type of untethered submersible, called the Swallow Float, can be useful in situations where self-propulsion is neither necessary nor desirable. The Swallow Float is an instrument used for tracking deep ocean currents. It is designed to sink to a prescribed depth in the deep ocean and to send out a sonar signal that enables a ship to track it. The body of the Swallow Float is designed to be less compressible than water and when properly ballasted it sinks to its design depth, where it is neutrally buoyant; it remains at that depth and moves with the body of water. Since it requires no energy to remain at its prescribed depth, it can operate for many years until it fails structurally or the battery power for the sonar pinger is exhausted. It is the nautical equivalent of a radiosonde balloon.

Swallow Float is a passive device in the sense that its fixed mechanical design determines the depth at which it "floats." It is a useful design for depths of the order of 1000 meters. To obtain precise control at shallow depths (a few feet to a few hundred feet), active floats must be used. An active float has a sensor and servo package to compensate for environmental or system changes that tend to change the depth of flotation. It can also be programmed to change depths at prescribed time intervals under internal or external control. In essence, a modern constant-depth float can be considered a robot submersible without propulsion.

Active floats for tracing streamlines in the deep ocean have been proposed. These floats use various methods for changing their displacement or their weight in order to control depth. One such system, the Autoprobe, uses compressed air to provide a controlled change in displacement in order to maintain constant pressure (1, 5). In another system the weight of the float was varied by selectively pumping overboard either a light or heavy liquid in order to control depth. This is very similar to letting out sand or gas to make a free balloon rise or fall, as is equally sluggish (2).

3.2 The MIT Constant Pressure Float.

MIT's Constant Pressure Float was developed to provide a constant depth float for shallow (i.e., about 10 to 100 feet) water operation. The design uses a pressure sensor to determine pressure depths. The output from this sensor drives a servocontrol system that changes the displacement (i.e., volume) of the float to maintain the preselected depth. At the operating depth, the servosystem controlled depths to about ± 1 1/2 inches. The float is shown in Figure 2 (page 10).

A precision pinger circuit in the float is synchronized with a clock in a base station recorder to track the float. A signal from a pair of precisely located hydrophones is used to derive range and azimuth information. The float has been operated with an additional pinger signal (hydrophone) that is delayed with respect to the navigation signal by a time proportional to depth. Thus, the actual depth can be compared at the base station with the programmed depth.

FIGURE 2

MIT CONSTANT PRESSURE FLOAT

The float is operated by first setting the desired depth. Two hydrophones and the recorder are placed into position. The clock in the recorder and float are synchronized. The float is then released from a designated site where it sinks to the preset depth. It then floats along with the water flow. The position of the float is continuously tracked with the recorder. At the end of the prescribed operating time it rises to the surface and is recovered.

The purpose of the constant pressure float is to follow a body of water and to trace out a streamline. The track of the float is precisely in "plan view" but it does not follow vertical movements of the water. However, in most practical applications, it provides an excellent approximation to a streamline.

3.3 Applications.

In a number of different situations, untethered constant depth floats can be used advantageously instead of fixed or towed instrumentation. First, when flow is too slow or irregular for an array of fixed conventional current meters to be useful, a float with accurate tracking can be used to provide precise velocity vectors and particle paths.

Second, a few floats can be utilized to define main streamline patterns in a body of water, for example, surrounding the outlets from a power plant. The main streamlines so obtained can be useful in determining optimum locations for fixed instrumentation for longer term monitoring or for defining flow fields more fully.

In a similar way, a float can provide an accurate calibration of flow direction and velocity to check anomalous or unexpected results from fixed instrumentation.

Third, for a large class of problems--particularly those concerned with environmental measurement and analysis--such properties as temperature, turbidity, chemical concentrations, and/or biological conditions in a flow field are of concern. Suitably tracked floats with appropriate sensors and data recording packages can measure the diffusion or dispersion of the relevant properties along streamlines leading from the source.

In summary, untethered floats, drifting at fixed or preprogrammed varying depths can define flow fields and physical, chemical, or biological properties associated with the flow field. The requisite tracking instrumentation and data-sensing recording techniques are all straightforward, state-of-the-art, and relatively inexpensive. Compared with towed or fixed instrumentation, logistic costs and total system costs can be low.

4.0 FUTURE DEVELOPMENTS AND MARKETS

4.1 Vehicle developments.

MIT's project reports on the robot submersible (3,4) indicate that the prime purpose of the MIT vehicles was to give the students experience in all facets of designing and constructing a complete system. The project was viewed as an exercise in synthesis, as opposed to analysis, to which the students responded admirably.

Clearly, a vehicle with vastly extended capabilities could be designed and constructed, making use of subsystems and components commercially available today. We outline here some of the directions that developments could take to further enhance the utility and marketability of this class of instrumentation systems.

1. Power and propulsion: As noted earlier, the MIT vehicle uses a common lead/acid automobile battery to give a range of about 20 miles. The size and weight of the vehicle could be cut in half and operating speeds would be increased by taking advantage of more efficient batteries, such as nickel cadmium batteries, decreasing the range to about five miles, and using a more efficient propulsion system. The result would be a highly mobile instrumentation system weighing 75 to 150 lbs. The system could easily be launched and recovered from very small boats for near-shore use in the ocean, or in lakes and rivers. Uses might include the monitoring of thermal effluents of power plants, detecting pollutants, and providing survey capabilities on very short notice with minimal necessary logistic support. Alternatively, a large oceanographic vessel could deploy a small fleet of

robot submersibles to carry out simultaneously a large number of measurements over a large area.

2. Depth capability: If the PVC pressure hull and instrumentation compartments were redesigned using stronger materials, a vehicle of the same weight, dimension, and operating range could be built to have a much greater depth capability, to perhaps 2500 ft. Such a vehicle could cruise at a fixed depth, follow the bottom over the entire continental shelf, and/or carry out preprogrammed vertical profiles while surveying a body of water.

4.2 Navigation/guidance systems.

The present navigation/guidance system of the MIT vehicle is based on compass heading and distance traveled. Since the system does not detect drift or currents, the vehicle will not return to "home" in a moving body of water when programmed to follow a closed course. Thus, while the navigation system is a computer-controlled, "closed-loop" system with respect to the vehicle, it is "open-loop" in the sense that the system does not continuously check its position with respect to the outside world.

A closed-loop navigation system, through which the vehicle's position is continuously compared to its desired or programmed position, is essential. The detected difference between the desired position and the actual position could be used as a feedback signal to steer the vehicle back to the desired position on the programmed course. A number of systems available today could achieve the desired results.

For much more sophisticated robots, inertial guidance systems would eliminate the need for external signal sources or transponders to previous location data. From the viewpoint of logistic support and operational simplicity, inertial guidance is an ideal system, albeit an expensive one.

For less complex and less expensive systems, a pair of transponders would provide adequate external reference points by which the onboard computer could constantly determine the vehicle position with respect to the transponders. A coded sonar signal from the vehicle would interrogate each transponder, which in turn would send confirming signals back to the vehicle. The time delays between sending the interrogation signal and receiving the confirming signals provide sufficient data for the onboard computer to compute vehicle position with respect to the transponders.

An even simpler and less expensive system would use two fixed sonar transducers with clocks synchronized with respect to each other and with respect to the onboard computer clock. Such clocks, divider circuits, and the "ovens" required for frequency and time stability are standard components used in industrial data acquisition systems today. They are readily available, rugged, precise, and inexpensive. Such a clock-based system has the additional advantage of requiring only a passive "listening" sonar transducer aboard the vehicle. It need not have the power, oscillators, and amplifiers required to send a signal to the transponders.

4.3 Sensor packages.

The present robot incorporates only a pressure transducer, a temperature sensor, and "fail-safe" leak and over-pressure detectors. A collision avoidance sonar has been designed and simulated, but is not yet operational. Some investigations are presently being carried out to consider the feasibility of adding a photographic camera. Biological sensors, hydrocarbon detectors and similar sensors clearly can be added as required.

An onboard computer coupled to the various sensor packages _and_ to the navigation/control system provides a powerful package that has profound implications for the potential capabilities of the robot. Such a robot has the capability to decide where to go on the basis of the information it receives about its environment.

For example, a modest extension of the collision avoidance sonar would allow the robot to follow a trawler at sea while photographing the trawl net in order to improve our understanding of fishing techniques. Similarly, such a robot could be instructed to find, follow, and photograph an undersea pipeline for undersea inspection.

4.4 Communications.

Although many operations can, in principle, be carried out completely under control of the robot's computer, the operator of the vehicle generally wants and needs immediate information (as near real-time as possible) about what the vehicle sees and senses. The operator can then make decisions about how the vehicle should alter its course or activity and instruct the robot what to do next. For example, in trying to define the shape of a thermal plume, the most efficient procedure might be to direct the robot to travel along an isotherm rather than to have it proceed on a fixed grid. To find the source of a thermal plume, the robot could be directed perpendicular to an isotherm, i.e., in the direction of the maximum increase in temperature. In both cases, the operator directs the vehicle on the current real-time data acquired by the vehicle.

This kind of experimental approach, which is powerful and highly desirable, requires a two-way communication link between the robot and the experimenter. The communications link carries data from the vehicle to the operator and carries control commands from the operator to the vehicle. Those who have read the Collegium Brief on Telemanipulators (January, 1976), will recognize this material as being another example of Professor Thomas Sheridan's concept of "supervisory control," in which an intelligent automaton is supervised by a human to achieve an efficient division of labor.

Communications between the robot and the operator must be by sonar if present-day technology is to be used. For sending sensor data from the robot and for sending control signals to the robot, the power and bandwidth requirements for distances consistent with the range of the robot do not appear to be very difficult or taxing technical issues. A very real and interesting technical challenge is raised when considering the desirable capability of sending video pictures back from the robot to the vehicle so that the operator can "see" what the vehicle is doing and where it is.

Signals in the megahertz range are needed to transmit real-time video-pictures. In sea water, higher frequencies are attenuated faster than lower frequencies, so trade-offs between range and frequency would be required because of limited available acoustic power on the robot. Sending real-time video pictures is not practical. However, high resolution pictures can be transmitted over a limited bandwidth by decreasing the rate at which single pictures or frames are transmitted. For example, with a 50 kilohertz bandwidth, about one picture could be transmitted every twenty seconds.

This "slow" single frame rate is very fast compared to taking a picture, retrieving the vehicle, and later developing a film. This "slow" system would be very useful for inspecting structures, examining sunken or damaged objects, surveying pipelines, etc. One could also use this capability for carrying out detailed, photographic inspections, the slow video being used for locating the object to be photographed and for aiming and focusing the cameras. This slow frame system would also be useful in directing surface-controlled grappling hooks. No doubt many more applications will occur to the reader.

4.5 Mechanical tools.

One further step, given a limited capability of seeing beneath the sea, is to consider putting on primitive mechanical tools or telemanipulators. Sophisticated telemanipulators and inexpensive robot submersibles are a contradiction in terms, but simple tools for picking up samples from the ocean bottom or attaching light lines to sunken objects are entirely feasible.

5.0 SUMMARY

A class of intelligent, semiautonomous robot submersibles has been shown to be a feasible and effective extension of man's capability to measure beneath the sea. The work at MIT and elsewhere should be viewed as an indication of potential capabilities rather than an end in itself. By improving the vehicles and their sensors and communication systems, and by adding some form of video or sonar capabilities, oceanographers and offshore developers can investigate the oceans and inspect and survey beneath the sea by "remote control." The offshore oil business could employ divers and manned submersibles more cost-effectively when they are needed and rely on small inexpensive robots for the simple tasks.

The market success of tethered, self-propelled devices, like the Hydroproducts RCV-125, which is a remote controlled vehicle carrying a sophisticated video-camera system, attest to the utility of the general concept of remotely controlled vehicles under the sea. An obvious next step is to eliminate the need for a tether by making the vehicle more intelligent and independent.

Professor Carmichael and his students are planning to design and build a new robot. Comments and suggestions from interested industrial organizations would be useful in this effort. Correspondence in this regard may be addressed to the MIT Sea Grant Program.

6.0 REFERENCES

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7.0 APPENDIX

The summary report below was submitted to Collegium members following a meeting on June 14, 1976, which was held to discuss the Opportunity Brief with interested representatives of industry.

SUMMARY REPORT

DATE: Collegium Workshop, June 14, 1976

TOPIC: Opportunity Brief #5
Untethered Robot Submersibles

Professor Carmichael reviewed the work on which the brief was based and the design constraints (primarily dollars, which is a good education for the students) and design objectives (primarily education of students).

The constant pressure floats and robots were demonstrated by the students and made available for detailed inspection by the members. Current and future developments were outlined by Professor Carmichael. A reprint of an Oceans 76 (Marine Technology Society/Institute of Electrical and Electronics Engineers, Inc.) paper was handed out. It is available by calling us.

The interactive session centered on two closely interrelated areas:

(1) markets and applications

(2) changes in design and capabilities

Markets. A primary application of the robot submersible is as a vehicle for transporting sensors of various kinds over a predetermined path at fixed or variable depths. Environmental or oceanographic surveyors who must continuously sample temperature, salinity or other chemical distributions over a large area are representative markets, as noted in the Brief. The advantages of a robot compared with the present practice of towing and instrument package, will be realized only if the robot can travel at least four knots and, perhaps 8 knots, at depths of about 500 feet or more.

The consensus was that such operating conditions make towed bodies less and less attractive, because of long cables, high tension, and large drag and the resulting expensive logistical problems of supporting long, strong cables (see E. C. Brainard, II, OTC 76 paper #2575, for example).

A second group of applications discussed at the Workshop related to needs for location, inspection, and/or identification of submerged objects such as cables, pipelines, sunken vessels, or offshore structures. The markets are offshore industries, such as oil, gas, and telephone companies.

While detailed maps and charts identify locations of pipelines and cables, the correspondence between the maps and "reality" may be low, either because the pipeline or cables moved after being laid and/or because the precise location was not known when they were being laid. In addition to locating the pipelines or cables, a robot could inspect them using video, photography, hydrocarbon detectors, or other specialized sensors.

An interesting variant in the second group of applications is a small robot with upward looking sonar to detect surface and sub-surface ice ridges. It would operate under ice and would aid ice breakers in finding paths of least resistance. The market would be the U.S. Coast Guard and Navy and oil companies operating in the Arctic.

Design Changes. The two groups of applications imply distinctly different directions for design changes. The first group requires higher speed, greater depth, and larger payload to provide for more sophisticated sensors, data acquisition systems, and data storage facilities. A capability of towing sensors such as magnetometers or by hydrophone may be implied also.

The second group of applications, search and inspection, implies a vehicle with much different capabilities. First, it must be able to transmit information about what it "sees" or senses, and about its own location to human operators on a control ship or an offshore structure. In turn, based on information received, the operators may want to focus cameras, turn on a video tape recorder, instruct the robot to drop a sonar beacon, and so forth. In short, a wide band (1 KH_z to 50 KH_z) communication system is implied. Speed is not so important, but control of speed, attitude, and position is very important. Hovering may be required, for example.

Use of such a wide-band sonar communication system would permit the operator to see periodic "snapshots" of what the robot is "seeing" and would greatly extend the capabilities of man on the sea's surface to get detailed, permanent records of pipelines, structures, and wrecks beneath the sea.

The development of robot continues. We invite your comments and suggestions about specific capabilities that might be useful to you as Collegium members, either from the viewpoint of potential future product developments on your part, or as a tool for tasks which you need accomplished.

Please call or write at your convenience or stop in to see us when you are in the area to let us have the benefit of your views.