THE HISTORY AND CAPABILITIES OF DEEP ROVs

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ABSTRACT

The following paper will discuss the history of Remotely Operated Vehicles (ROVs) and, in particular, their use in the deep ocean, which will essentially address depths beyond 10,000 feet. The present status of their use and future projections will also be addressed.

INTRODUCTION

The importance of using unmanned vehicles to gain knowledge of the ocean was underscored by a National Research Council study (NRC, 1996)), which put forth many recommendations directed toward achieving that goal. Shortly after that study the MTS Committee on Remotely Operated Vehicles completed a two-and-a-half year effort to publish a book on CD-ROM titled "Operational Effectiveness of Unmanned Underwater Systems" (Wernli, 1999), which provides a detailed examination of ROVs, AUVs and other remote systems. As discussed in that book, the use of deep water ROVs offshore continues to increase, and will expand even further in the future. This paper will summarize those capabilities and provide a projection of where the technology being developed will lead us in the future.

HISTORICAL PERSPECTIVE

Whether one identifies the beginning of the ROV by the development of Dimitri Rebikoff's POODLE in 1953, the PUV (Programmed Underwater Vehicle) Luppis-Whitehead Automobile torpedo developed in Fiume (then in Austria) in 1864, or the first wire-controlled torpedo co-invented by Sims/Edison in 1891, it has to be agreed that ROVs have come a long way. They have matured from early, unreliable systems, to vehicles capable of probing the ocean's depths, down to the magic 20,000-foot (6,096-m) barrier and beyond.

Initially, the US Navy had the missions that required unmanned vehicles, and accordingly, provided the financial backing to break down some of the technological barriers (Wernli, 2000. Ultimately, through technology developed in the US Navy’s R&D centers and through cooperation with industry, Navy financed vehicles broke the 6,096-meter barrier in 1990—not once, but twice. The first tethered ROV to reach the depth was the *CURV III* vehicle. Operated by Eastport International (now Oceaneering Technologies Inc.) during that time for the US Navy's Supervisor of Salvage, *CURV III* reached a depth of 6,128 meters. Then, less than a week later, that long sought record was again broken by the Advanced Tethered Vehicle's record dive to 6,279 meters. The *ATV*, developed by the Space and Naval Warfare Systems Center, San Diego, was transferred to SUBDEVRON5 (Submarine Development Squadron Five—formerly the Submarine Development Group) Unmanned Vehicle Detachment in San Diego. Because of a downsizing of navy capabilities, the ATV was transferred to the Scripps Institution of Oceanography where it is now used for oceanographic research.

The celebration of the depth records achieved by the US was short lived, however, as Japan stormed onto center stage with a series of excellent vehicles topped by the *KAIKO*. The *KAIKO* not only took over the record for the deepest dive, but obliterated it, reaching the deepest point on Earth in the Mariana Trench—10,911.4 meters—in 1995. A record that can be tied, but never exceeded (at least not without a shovel).

These previous records are a tribute to engineering design and human determination, but the ability to reach a given depth means little if one cannot perform meaningful tasks while there. To this end, the offshore industry can be given credit for moving ROV technology from the days of lost vehicles bobbing away on the waves to the present level of maturity and high reliability. In the early days, an ROV operator was happy just to get his system back on board safely, but today, modern ROVs work round the clock offshore, logging thousands of hours without a system failure. The work class ROVs that are supplying this reliable capability—the offshore workhorses—will be discussed in the next section.

THE WORKHORSES

There are several classes of ROV. They range from small low cost vehicles that are used for shallow water inspection and work tasks, through light work vehicles that cover a variety of tasks, up to the primary work class vehicle, that is used to accomplish most of the unmanned vehicle work offshore.

Work class vehicles can be broken down by depth capability and horsepower, with the majority of them being used for current deepwater operations to 3,000 meters. With new requirements such as subsea tie-in operations on deep-water installations and the transportation of very large diverless intervention systems, this class of ROV has become very large, powerful and capable of carrying and lifting large loads—thus the term "heavy work class vehicle" has been adopted by the industry. These vehicles may stand over 2.4 m tall when a tool package has been installed underneath the ROV. Such heavy work class vehicles typically have a 100-250 horsepower range and a through-frame lift capability up to 5,000 kg—the distinguishing feature between medium and large ROVs. The vehicles range in weight (without work packages) from about 2,000-6,500 kg. Schilling Robotics UHD (Ultraheavy Duty), figure 1, is an excellent example of a heavy work class vehicle.

Figure 1. Schilling Robotics UHD

Table 1 (Michel) provides an estimate of the number of commercial ROVs based on a recent survey of operators.

Work Class ROV systems operating worldwide	
Oceaneering International, Inc.	200>
Subsea 7 (ex Halliburton/Subsea)	120
Sonsub (Division of Saipem)	59
Fugro (ex Thales/Racal)	36
Technip (Coflexip/Stena)	35
Canyon (Division of Cal Dive)	27
Stolt (Stolt/Comex/Seaway)	19
Others- Approximate number of specialty systems, plus systems operated by smaller companies. New contractors could increase the totals by as many as another 30 systems (Source: Drew Michel interviewing contractors)	75
Total Systems	571

Table 1. Commercial Work Class ROVs

Will the industry ever require vehicles that can reach beyond 3,000 meters? Essentially, the die has been cast, and as oil exploration goes deeper, it will continue to be supported by ROVs. Tasks for ROVs in support to deepwater pipelines, and oil and gas exploration and production, continue to increase in both depth and complexity. The exploration water depths in the Gulf of Mexico have more than doubled during the last two decades. With the recent escalation in oil prices, and the subsequent increase in the price of gas at the pump, the competition between oil companies will force the extension of their research and drilling into deeper waters. And, as the oil and gas reserves are depleted, and offshore operations reach well beyond 3,000 m, you can bet that the ROVs will be there to support the effort. As the next section will verify, depth is no longer a limit. And, when combined with the reliability of today’s workhorse vehicles, the technology will be there to perform the tasks when needed.

DEEP WATER ROVS

Although working to depths of 3,000 m is no small task, doubling that depth imparts a heavy toll on the overall system design. In particular, the added size and strength requirements of the umbilical can force the overall system beyond that which your average offshore operator can handle. One interesting aspect in deep ROV design is that, due to the general lower current regime encountered in deep water, these vehicles tend to require less power to fight the current, which aids the designer in keeping the umbilical diameters as small as possible.

Search and Recovery Missions

Search and recovery missions using ROVs is dominated by government/military establishments, primarily due to the magnitude of the problem, and the desire for the recovery of objects from any ocean depth. The magic number for the operational depth of such systems has always been 6,096 m, the depth that covers 98 percent of the ocean floor. Since search primarily involves semi-autonomous vehicles and towed systems, while recovery requires tethered ROVs, they will be discussed separately in the following sections.

Search

Underwater search was initially performed by towed systems, and still is in many cases. These vehicles, such as Scripps Institution of Oceanography’s *Deep Tow*—one of the first such systems—carry the necessary sonars, photographic equipment and other sensors required to locate everything from lost torpedoes and aircraft up to ships such as the *HMS Titanic*. The Woods Hold Oceanographic Institution, which has been instrumental in locating long lost objects on the seafloor (*ARGO*-I lays claim to the discovery of the *HMS Titanic*) now operates the *ARGO*-II towfish. The *ARGO*-II is a near-bottom towed vehicle—towed at altitudes of approximately 3 to 15 m above the seafloor—designed to operate to depths of 6,000 m. Its powered tether utilizes fiber optics to downlink controls to various subsystems and data sensors, and uplink digital data in both image format and as data-streams.

Towed systems have proven their worth many times over, however, they are inefficient if taken in the context of today's technology. On the plus side is their ability to carry large sensor suites that are operated with unlimited power duration because of the tow cable. On the negative side is the requirement to turn the ship each time another pass over the search area is required. For a 6,096-m system, the time to bring the vehicle back on the proper track is extremely high, especially when compared to the time that the vehicle is actually on track searching. Studies have shown that the search time can be reduced by an order of magnitude if the cable is eliminated and a semi-autonomous vehicle used. Both the French and the US Navy followed this approach when they decided to develop the *EPAULARD* and the Advanced Unmanned Search System (*AUSS*), respectively (both are now retired). This technology is now resident in the commercial industry, and companies like C&C Technologies are using AUVs in support of offshore search and survey operations. C&C Technologies’ *Sea Surveyor*, based on the Kongsberg *Hugin* AUV, has reliably performed survey lengths that are reaching an equivalent distance of three times around the world.

Recovery

The reason that one searches for an object is generally a desire to work on or recover it. For the military, it is usually the latter. Military aircraft and systems are continually falling into the world's oceans. When that happens, the military, regardless of the country, has a significant desire to recover the wreckage, or at least the most critical portions of it. To provide that ocean-wide capability, the military has developed the technology base necessary to field full ocean depth—6,096 m capable—ROVs.

Several programs in the US Navy have addressed deep ocean recovery technology. Assuming the vehicles are available to reach the deepest ocean realms, the tools and techniques to recover lost items from such depths also had to be addressed. The result of these programs, augmented by technology developed for offshore oil field operations, has provided the capability to recover most desired items from the ocean floor.

However, because of the advances in the commercial ROV industry, the deep ocean recovery capability in the US Navy has essentially been transformed to contractor support. Phoenix International, Inc. has the support contract with the Navy through 2011, where their fleet of two *Remoras* (6,000 m) and two Schilling UHDs (3,500 m) provide an excellent capability. They have an additional 3 Schilling UHDs on order. Whereas the military broke down the technological barriers in deep ROV development and also deep ocean search by AUVs, there is no longer a need for the navy to maintain the systems in house; they can be acquired under contract from the commercial sector when needed.

Deep Ocean Research

Unlike the stagnation in deep ROV development in the military arena, the use of ROV technology for deep ocean research is growing dramatically. Technology has moved forward significantly since the early expeditions of the *H.M.S. Challenger* during the 1870s, when deep sea researchers first collected comprehensive samples of life in the deep ocean. Today, there are several methods to obtain data on benthic communities—from trawls to manned submersibles and unmanned undersea vehicles. Although trawls have their benefits, they don't provide the real time *in situ* observations available by the other methods, and in many cases, they damage or destroy the environment they are investigating. Many scientists still prefer manned submersibles, however, they are becoming rare, with existing systems, such as the US Navy's *Sea Cliff* and *Turtle*, having been taken off line due to funding constraints. Thus, ROVs will provide the primary means of extending the researcher's reach into the depths, allowing the real-time acquisition of such deep-sea knowledge in the future. Today's technological sophistication of ROVs and camera sleds allows the biology and ecology of deep-sea habitats and organisms to be efficiently studied. Their ability to obtain high quality photographic and video documentation of dive sites in previously unobtainable locations provides the scientist with a wealth of data. The remainder of this section will discuss the unique capabilities and problems of some of the ROVs being developed or used for scientific research today.

Most ROV systems presently performing deep ocean science missions for the oceanographic community have been based on industrial systems that are adapted to scientific missions. One such example is MBARI's first ROV, *Ventana*, built by International Submarine Engineering (ISE). Even though its ancestors reach into the oil patch, MBARI's *Ventana* vehicle, a *Hysub* ATP-40 with upgraded cameras, sensors, sampling gear and telemetry, has been successfully conducting a variety of scientific investigations in and near the Monterey Submarine Canyon since 1988. *Ventana* preserves most of the reliability and ruggedness typical of hydraulic ROVs, but lacks the quiet operation and the fine control capabilities of more advanced ROVs, particularly those with electric thrusters. These concerns have led researchers to develop vehicles such as WHOI's *Jason* and MBARI's new *Tiburon* ROVs, all-electric vehicles configured specifically for scientific research.

The first deep ROV in the United States designed from the outset to support oceanographic science missions is WHOI's *Jason* vehicle (now upgraded to the *Jason II*). This 6,500-m system has completed science missions that include surveying a deep dumpsite and geological surveys at hydrothermal vent sites on the Juan de Fuca Ridge, along with ancient shipwreck investigations in the Mediterranean Sea. *Jason,* figure 2, is designed for detailed survey and sampling tasks that require a high degree of maneuverability. It weighs about 3,675 kg in air, and is neutrally buoyant at depth. The vehicle is equipped with six brushless DC thrusters designed to provide a force in any of *Jason*'s axes, and uses electric motors for its pan/tilt and manipulator, thus avoiding the need for a noisy and less efficient hydraulic power system.

Figure 2. *Jason II* ROV

The *Jason* vehicle usually operates below the *Medea* vehicle during deeper missions. *Jason* is connected to *Medea* by a neutrally buoyant cable 20 mm in diameter and approximately 35 m long. The vehicles work together to provide lighting for each other in a fashion not commonly available in other submersible systems. The dual vehicle ROV system uses *Medea* as a wide area survey vehicle, which functions as a precision multi-sensory imaging and sampling platform. Medea weighs 544 kg in air, is negative in water, and is maneuvered by controlling the surface ship's position within a dynamic positioning reference frame. *Medea* is configured with a silicon intensified target (SIT) black & white camera for terrain identification and visual location of Jason when both are operating.

Many of the concepts applied to Jason have been adopted by MBARI in the development of a new ROV dedicated to scientific missions—the *Tiburon* (Newman)**.** The mission requirements for the *Tiburon* ROV (figure 3) have driven most of the design decisions and the overall configuration of the system. The primary location for MBARI's research is in the Monterey Canyon, where the 4,000-m capability of the *Tiburon* will support investigations of geochemical processes, physics, geology and biology. The need to make observations of marine organisms imposed the requirements that acoustic noise and water disturbances be minimized and that a zero light emission capability be provided. The ROV also had to minimize acoustic emissions and disturbance of the water around the vehicle to minimize impact on the environment and avoid interference with acoustic devices. Missions for which the *Tiburon* is designed include:

- Instrument placement, retrieval and support.
- *In situ* experimentation.
- Ecological studies and observations (midwater and benthic).
- Sampling and light coring.
- Surveys of environmental parameters.

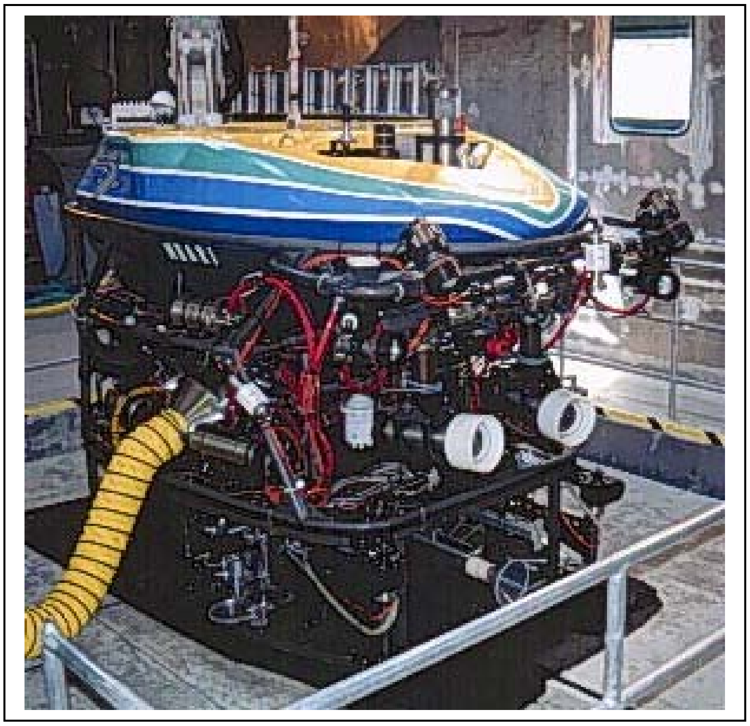

Figure 3. MBARI's *Tiburon* ROV

Several companies or institutions are presently developing electric ROVs. One firm, Schilling Robotics, in Davis, California, US, is pushing the envelop with a totally new class of all-electric ROV called *Quest*. Its incorporation of a new digital communication system, and electric ring thrusters with only one moving part each, provides an efficient design useful is applications from oceanography to offshore oil.

The United States is not the only country developing such advanced research ROVs. The Japan Marine Science and Technology Center (JAMSTEC) and MITSUI Engineering and Shipbuilding, Ltd., has developed a family of Dolphin ROVs for scientific missions and for recovery of the *Shinkai* manned submersibles. The *Dolphin* 3K, a 3,000 m ROV, has been used for geological and biological research operations and JAMSTEC has recently added the 3,000 m capable *HYPER DOLPHIN*. More recently, Japan has completed the development of the *KAIKO*, which has reached the deepest part of the ocean—10,911.4 m in the Mariana Trench.

Whereas reaching a depth of 6,000 meters in the ocean was a tremendous feat by an ROV, the giant leap made by Japan in reaching a depth nearly twice that is truly phenomenal. The *KAIKO* is a two vehicle system: the launcher, which connects to the ship via the 12,000 meter electro-optic primary umbilical and also handles the 250 meter secondary cable to the vehicle, and the free swimming vehicle that can operate around the launcher within a 200-m radius (Tazaki). During vehicle operations, the *KAIKO* launcher normally hovers at a point 100 meters above the sea floor.

The *KAIKO* has three mission modes. The first is to survey the ocean floor down to a depth of 6,500 meters by towing the system, which carries a side scan sonar and a sub bottom profiler on the launcher. This provides the capability to conduct sea floor topography and investigate the stratum beneath the sea floor. The free-swimming vehicle can use its TV cameras for precise survey of the sea floor.
The second mission is to extend the sea floor survey down to full ocean depth. In this case, the launcher is not towed, but hangs below the ship (depending on the current profile) while the vehicle performs a precise survey of the ocean floor. And, the third mission is to provide a rescue capability for the *SHINKAI* 6500 manned submersible.

The *KAIKO*, which quite fittingly means “trench,” completed its ultimate dive to the bottom of the Mariana Trench on March 24th, 1995. After a three hour trip, the vehicle reached the sea floor at 11º22.400’ N and 142º35.550’ E, where it conducted some research and left behind a “calling card” sign for future visitors. Unfortunately, in May 2003, on its 296th dive, the *KAIKO* was operating in the Nankai Trough at a depth of 4,675 m when the secondary tether snapped. The secondary ROV was lost. JAMSTEC has decided to replace the vehicle, but in the meantime, the *UROV 7K* has been modified to operate with the remainder of the system, figure 4.

In France, the French Institute of Research and Exploration of the Sea (IFREMER), long a developer and user of systems for deep exploration, operates the 6,000-m ROV for scientific missions named *Victor* 6000. The deep ROV is designed to make optical investigations and to carry out local missions that include imagery, implementation of instrumentation and the sampling of water, sediments and rocks. The *Victor* 6000, which was developed for IFREMER by ECA S.A., has a depth capability of 6,000 m and a 1,320 lb payload capability. The all-electric vehicle uses a 2,200 lb depressor that connects its 300 m neutrally buoyant tether to the 8500 m umbilical.

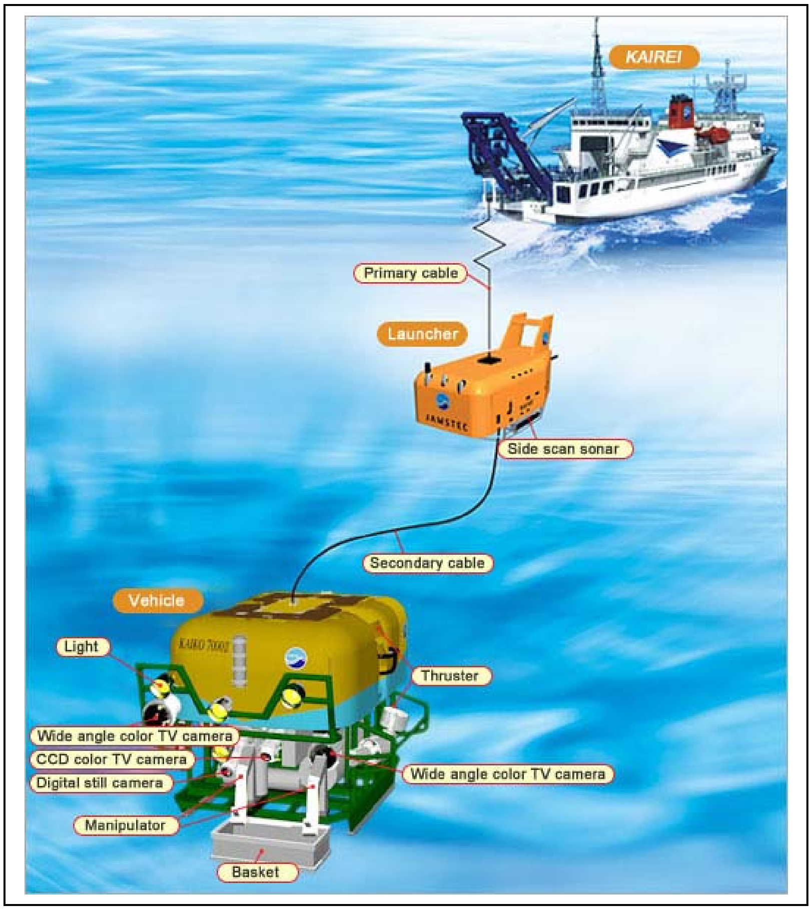

Figure 4. Japan's *KAIKO - UROV 7K*

Korea has joined the deep-ROV field with the development of the *Herime* ROV by the Korea Ocean Research and Development Institute (KORDI). *Herime* is a two vehicle system, with the launcher and ROV, similar to the *KAIKO*. The 6,000 m capable deep-sea vehicle will conduct scientific research of the ocean environment, and perform oceanographic surveying, deep-sea sampling for geology/geophisics and biology, and underwater structure maintenance. Recent tests in the Philippine Sea successfully reached a depth of 5,775 m.

And, last but not least is China. The Underwater Engineering Laboratory, Shanghai Jiao Tong University, is also pursuing the development of deep-sea research ROVs.

THE FUTURE

From the past to the present, the capability and applications of ROVs have continued to increase. They have evolved from unreliable and expensive systems to highly reliable workhorses (albeit still expensive) that are continuing to set operational records offshore. Where will ROVs go in the future? Looking into the crystal ball and trying to focus on the future of deep water ROVs is blurry at best. However, some interesting observations can be made:

- The offshore industry will focus on ROVs to work down to depths beyond 3,000 m as the market requires. The technology is there to go as deep as necessary.
- Vehicles will become simpler, and the equipment they mate and work with underwater will become more complex.
- All electric ROVs and work systems will reach maturity and increase in number.
- The requirement, and need, for deep ocean exploration and research will increase.

Is there a trend here? I believe so. The ability to perform heavy duty work at full ocean depths has been proven—future applications become a design and finance problem. The trend that advancing technology is underscoring is a movement toward advanced semi-autonomous ROVs—capable systems that will have the ability to perform meaningful tasks to full ocean depths. Systems that will carry their energy with them, possibly recharging on the ocean floor, and communicate with the surface via ultra-small fiber optic umbilicals or acoustic modems. Such ROVs will still be able to perform complex tasks through the ability to mate with pre-installed underwater structures and equipment, or with other work packages sent to the ocean floor when required.

For example, Cybernetix of France, has developed a hybrid system, *Swimmer*, figure 5, that combines an ROV and an AUV. The AUV can fly to a remote offshore site and mate with the structure where it can acquire power and command and control. At that point, control can be turned over to an operator on shore or on a platform elsewhere, and the ROV can be used to perform underwater tasks. When the job is complete, the ROV can be recovered and the AUV can then transit to the next location without support from above.

Figure 5. Cybernetix's Swimmer AUV/ROV

Ultimately, there will be fixed installations where tethered and autonomous vehicles alike will perform their tasks, without the umbilical tied to a ship floating above. The number of work ROVs for offshore applications will continue to increase in the future. However, just as the bottom line has driven manned submersibles to the shore, the bottom line will drive the deep ROVs of the future toward miniaturized tethers, and semi-autonomous operation. Although the time line cannot be established with clarity, one projection can be confidently made—tethered, autonomous, and semi-autonomous ROVs will become abundant in the world's oceans in the decades to come, playing an ever increasing role in offshore operations, defense, and the understanding of Mother Earth.

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