AUV Commercialization – Who's Leading the Pack?

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***Abstract* - Taking AUV technology from the drawing board and putting it into commercial practice has been a long and costly process, however, there are several companies that have done just that. Are AUVs ready for commercialization? Have they been successful? Who's leading the pack? Who's buying--military, offshore, academia? This paper will attempt to answer those questions.**

I. INTRODUCTION

AUVs have moved from a state of research and development, through operational demonstrations and have now reached the beginnings of commercial acceptance. This trend can best be exhibited by the commercial operation of AUVs at the end of the last decade. Although there were at least 66 AUVs being developed in 12 different countries, with many being operated by academic and governmental establishments, there were basically no commercially operating systems [1, 2]. This does not mean there were not a few unique AUVs that could be made commercially available if the need was there, or some that were being touted as commercial AUVs although none had been sold. What it does mean is that we are on the cusp of the acceptance curve, and that curve has begun to take an exponential change upward during this year.

Commercial acceptance of AUVs offshore is off to a fast start with the following vehicles being sold or developed for commercial applications: *Hugin* (Norway), *Maridan 600* (Denmark), *AQUA EXPLORER 2* (Japan), *Sea Oracle* (U.S.), *Explorer* (Canada) and *CETUS II* (U.S.). In addition, there are AUVs being used for military applications and other small vehicles being produced by academic institutions. The commercial applications of these vehicles are discussed in more detail below.

II. WHAT IS THE MARKET?

A. Commercial

In the commercial sector, underwater survey in support of the oil and gas sector will initially dominate the market. The offshore market for AUVs has been analyzed in detail by Douglas-Westwood Limited of the U.K. [3]. The future will not only see subsea installations going deeper and covering larger areas of the seafloor, but the number of installations will have doubled between 1998 and 2003; the value of the subsea market will increase from $4.9 billion in 1998 to $11.8 billion in 2003. They envision two main groups of AUVs—a Survey AUV for data gathering and a Hybrid AUV/ROV for subsea intervention.

The survey systems would be used to survey drilling sites and pipe routes, and they could also take in-situ soil measurements and measure seabed currents along the pipeline route. Douglas-Westwood estimates indicate that subsea drilling site surveys typically cost from $150k-$250k for shallow water, with two deepwater sites costing $900k and $1.4 million [4]. Obviously, reduction of these high survey costs can shave a lot off the bottom line. In the case of the Hybrid AUV, cost savings were not projected, however, the fact that floating production systems are supporting extensive undersea networks of wells, flowlines, risers and other subsea hardware, the potential savings for an AUV-based intervention system, operating from the floater itself, could be significant.

Another analysis by C&C Technologies, Inc. showed that the total cost of a deepwater survey could be cut from $707k using a deep-towed system ($26k/day with ship) to $291k using an AUV ($55k/day with ship) [5]. That is a whopping $416k (59%) savings. A similar conclusion was also reached by the U.S. Navy prior to the development of their 20,000 foot Advanced Unmanned Search System (AUSS). Analysis indicated an order of magnitude reduction in full ocean depth survey time could be achieved if an AUV was used. Thus, even considering the cost of transit time, the increased on-site efficiency of an AUV over towed systems is such that the overall cost will come down. Time is money.

The commercial potential of AUVs for offshore survey is projected in a pre-release of data [6] from the upcoming study *"The World UUV Report."* If AUVs meet industry expectations, sales could reach 30 units by 2004 and they could account for 20% of unmanned undersea vehicle (UUV) operations revenue. The majority of this AUV operational revenue, which could exceed a cumulative total of $200 million by the end of 2004, would be in the survey area. Whereas the ROV revenue is projected to increase by about 63% from 2000 to 2004, AUV revenue is projected to increase by 5,500% during the same period. Obviously, someone believes that AUVs have come of age.

B. Military

On the military side of the equation, AUVs have been under development for decades, and they are now reaching an operational status. Their initial fleet application will be for mine hunting, which was also the case for fleet introduction of ROVs. However, in the case of AUVs, they will operate from a submarine and not a surface ship. The U.S. Navy's submarine launched AUV is the Long Term Mine Reconnaissance System (LMRS), which is scheduled for initial operation in 2003.

An AUV similar to the LMRS is being developed by BAE Systems for the Defense Evaluation and Research Agency (DERA) of the U.K [7]. The *Marlin*, a submarine tube-launched vehicle, is scheduled for a series of technological evaluations beginning in April 2001. Programs are also ongoing in several other countries.

A study of the broader scope of AUV mission applications for the U.S. Navy was recently completed by an ASN/RDA chartered study team [8]. The study, which looks ahead 50 years, provides a roadmap for the Navy to use in integrating unmanned undersea vehicles (UUVs) into the battlespace of the future. Critical missions include Intelligence, Surveillance, Reconnaissance, Mine Countermeasures, Tactical Oceanography, Communications, Navigation, and Anti-Submarine Warfare.

The Navy UUV Master Plan incorporates near-term acquisition efforts while establishing the direction for long-term development and technology investment [9]. The U.S. Navy's Office of Naval Research has already applied the results of this plan to direct their future R&D investments, and UUV technology programs exist at most Navy R&D Centers.

C. Scientific

International academic and research organizations are pushing the technology toward useful realization faster than the slow paced introduction into the oil patch or the bureaucratically sluggish military establishment. Because of limited resources and the necessity to launch from small boats or platforms, the academic community must keep vehicles small and economical. Smaller vehicles such as the Woods Hole Oceanographic Institution's (WHOI's) *REMUS*, MIT's *Odyssey*, and Florida Atlantic University's new modular AUV *Morpheus* are showing that cost effective missions can be performed. Small, inexpensive, mass produced AUVs that one can afford to occasionally lose will be the catalyst that pushes operational AUVs from the tens into the hundreds or thousands.

III. WHO'S LEADING THE PACK?

A. Offshore Survey – Now Operating

The leaders will begin to clarify as more operational data is acquired, however, the *Maridan* and *Hugin* vehicles certainly appear to be the first out of the gate.

The AUVs developed by Maridan A/S, Denmark have had many recent successes. The AUVs are an outgrowth of research originally carried out under the EU's MAST research program. This began with the first prototype *MARIUS* (1991-1993) followed by *MARTIN* (1994-1997). The vehicles, Figure 1, which completed over 1000 kms of sea trials, have evolved into their first commercial vehicle, the *MARIDAN 600*. One of the first successes for Maridan A/S was an underwater archaeology survey for the National Museum of Denmark using the *MARIDAN 150* during which the vehicle located and mapped a sunken 12th century ship. The success of this survey was a milestone for their commercial vehicle production. In 1999, the *MARIDAN 200* AUV carried out an autonomous survey off the cost of Nambia for De Beers Marine. Earlier this year it was announced that Hallin Marine Systems of Singapore reached agreement with Maridan A/S to offer AUV services using the *MARIDAN* line of vehicles. Recent announcements indicate that De Beers is planning to buy two *MARIDAN 600* AUVs, which are capable of operating to 600 meter depths and will be used for diamond mining surveys. Plans are underway on the next model, the *MARIDAN 3500* – a deep water survey class AUV – which will hit the waves in 2001. Unofficial costs for a *MARIDAN* vehicle range from $15K-$20K/day with ship, or you can buy one for around $1.5M-$2.0M depending on depth and sensors.

Fig. 1. The *MARIDAN* AUV.

Norway's *Hugin* AUV, Figure 2, was developed and operated by Kongsberg Simrad in partnership with Statoil, the Forsvarets Forskningsinstitutt (FFI – the Norwegian Defense Establishment) and Norwegian Underwater Intervention (NUI). First demonstrated in 1992, the *Hugin* series of vehicles has performed over 100 missions, several of them commercial pipeline route surveys in the Norwegian sector of the North Sea [10]. The *Hugin* vehicle is in routine use by NUI. Most recently, the *Hugin 3000* AUV, a third generation vehicle rated to 3,000 meters, has been purchased by C&C Technologies, Inc. of Lafayette, Louisiana, an international hydrographic surveying company. Delivery of the *Hugin 3000* is expected in 2000.

Fig. 2. *Hugin* AUV.

Japan is also in the running in the area of offshore cable surveys. The *Aqua Explorer* line of AUVs has been under development for nearly a decade by KDD R&D Laboratories. Their latest version is the *AQUA EXPLORER 2* (AE2), Figure 3, operated by Kokusai Marine Engineering Corp. (K-MARINE). The AE2, which recently completed a survey of a buried cable in the Taiwan Strait that exceeded 400 km, is now available for hire in the UK through an agreement between K-MARINE and Oceanscan Ltd.

Fig. 3. *AQUA EXPLORER 2*

B. Offshore Survey – In the Queue

The previous three vehicles (or at least their predecessors) are out there working with quoted day rates or sales prices. But what other contenders are lining up?

Racal Survey Group Ltd's *Sea Oracle*, Figure 4, is the next AUV intended to go into the commercial survey market. A team of Racal and Bluefin Robotics engineers is developing the Sea Oracle. The AUV is based on the *Odyssey* vehicle technology, which has been a real workhorse in the academic sector. Bluefin Robotics Corp. was founded in 1997, based on technology developed at MIT's AUV lab, which owns shares of the corporation. Another stakeholder in Bluefin is the Monterey Bay Aquarium Research Institute (MBARI), which has asked Bluefin to commercialize all the AUV technology MBARI will develop over the next decade [11].

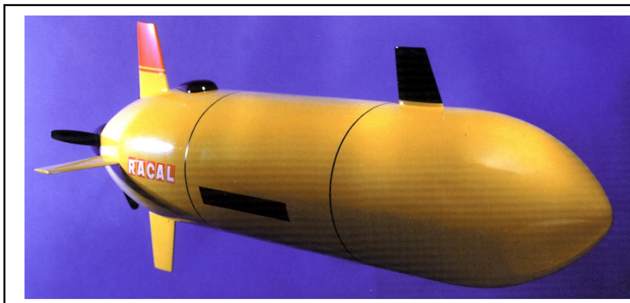

Fig. 4. Racal's *Sea Oracle*

The *Odyssey* vehicles, now at the *Odyssey III* stage of development, have completed thousands of dives worldwide to depths exceeding 3,400 meters. Twelve *Odyssey* vehicles have been built to date. Racal has agreed to purchase two *Sea Oracles* with an option for six additional units. The first vehicle, capable of 3,000-meter operation, is scheduled for delivery by the end of 2000.

International Submarine Engineering Ltd., Port Coquitlam, BC, Canada, developers of such AUVs as the *Theseus* and *ARCS*, is designing a deep water commercial site survey AUV for Fugro GeoServices Inc. Called the *Explorer*, the vehicle will conduct seabed surveys to depths of 3,500 meters [12]. The vehicle is presently undergoing final design.

C. The Other Commercial Players

There are also other vehicles that have been developed and delivered commercially. These vehicles cover size ranges from 3 to 30 feet long.

On the large-scale vehicle end, ISE has the *ARCS* and the *Theseus* vehicles and Perry Technologies has the *MUST*. These vehicles have each performed some dramatic operations including the deployment of fiber optic cables. In the case of *Theseus*, the fiber optic cable was deployed under the ice pack.

Mid-size vehicles include those from the Institute of Marine Technology Problems (IMTP), Russia. Based on their *MT-88* AUV, the IMTP has built and delivered the *CR-01* and *CR-01A* in conjunction with the Shenyang Institute of Automation (SIA) and the Chinese Academy of Science. They have also developed the *OKPO* AUV for Daewoo Heavy Industry, Korea.

Smaller vehicles are commercially available such as the *CETUS II* from Lockheed Martin. The *CETUS II*, the follow-on to the *CETUS* vehicle developed by the MIT AUV lab for Lockheed Martin, is 33% smaller than the original and has a base price of $35K-$45K. Three systems have been built to date for U.S. Navy organizations.

Another small size vehicle that has seen considerable success is the *REMUS*, which was built by WHOI under ONR and NOAA funding. The *REMUS*, with over ten sold by WHOI, and it's understood another five are in production for the U.S. Navy, has a base price in the $175K range.

D. Non-Commercial Scientific

There is also a wide spectrum of operational AUVs that are not necessarily looking at the bottom line. These vehicles, which are used for scientific missions, are amassing impressive track records.

The leader in this area appears to be the Southampton Oceanography Centre's *Autosub*, which continues to complete successful science missions under the funding of the Natural Environment Research Council. After a decade of development and exploration, *Autosub 2* is now in the wings with an increased depth rating to 2.5 km and range up to 1,000 km.

In the US, WHOI's *ABE* vehicle has acquired impressive data and is also going into the *ABE II* phase. Florida Atlantic University has the *Ocean Voyager II* and *Ocean Explorer* series of vehicles and their new modular *Morpheus* vehicles.

JAMSTEC of Japan has unveiled their 9.7-meter long, 1.5-meter high, 3,500-meter depth AUV the *Urashima*. This vehicle will join JAMSTEC's *UROV 7K* AUV/ROV and their Marine Robot *MR-X1* that is under development. The University of Tokyo continues to conduct research with their *R-1 Robot* and has plans to dive on an erupting underwater volcano in the near future.

The vehicles mentioned above are not the only players. There are many other AUVs that are being used by military, academic and commercial organizations, however, those mentioned above are performing the most significant amount of work.

IV. THE FUTURE

AUVs are now at an early stage of acceptance. As they work their way into the phase of operational acceptance on a commercial level, their numbers will grow. Academia is not only using AUVs but also spinning off firms to supply commercial versions. And the US Navy is gearing up to push the technology, ensuring that cost-effective systems are available for use by the fleet in the future.

But the future will hold more than the acceptance of the "standard" AUV, it will begin to see the Hybrid AUV/ROV emerge. Today, the number of all electric ROVs, such as the Quest ROV developed by ALSTOM Schilling Robotics, is increasing. These more efficient vehicles will increase system reliability and eventually provide cost-effective components that will become available for use by AUVs. Along with this will come the fusion of the AUV and the ROV into the Hybrid AUV that is projected by many to be the future vehicle in the offshore oil and gas industry.

The previous information leads to one definite conclusion. The "inner space race" has begun and the leaders of the pack are fighting to see who will be there to capture first prize in the future billion-dollar AUV market.

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