Innovation and Operation with robotized systems

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Abstract: The presentation will summarized state of the art of underwater vehicles in the different domains of applications as, offshore, military and oceanographic business. The present paper is a focus which reports on the status of French Institute for Sea Exploitation (Ifremer) new Trends in underwater systems as an illustration of research in the underwater robotics domain applied to oceanographic applications. It will focus on recent innovations, improvements and operational references of the Remotely Operated Vehicle (ROV) "Victor 6000", of the Autonomous Underwater Vehicles (AUV) "Aster" and "Idef" and some hints about RandD in the domain of Advanced Intervention AUVs and fleet coordination.

Keywords: autonomous vehicles, remotely operated vehicles, manned submersibles, underwater vehicles

1. INTRODUCTION

Underwater Vehicles are used in a wide range of applications and sectors offshore, military, oceanography, coastal works, in shallow water and deep sea. In term of “real applications” it is common to say that with more than 5000 operational systems, the underwater robots are the more developed “intervention and survey” robots for “real works”.

The vehicles are dedicated to inspection, survey or intervention tasks with telemanipulators and tools. From manned submersibles to complete unmanned autonomous systems the panoply is large.

Remotely Operated System have been build during the Oil Boom last three decades, with very mature industrial applications and robust technologies, with an acceleration of the requests and technological offers, as the depth increase in offshore developments. From first small observation ROV initially built for diver assistance, to modern medium size and heavy work class ROVs equipped with manipulators and tool sleds all the components of such versatile systems are to day reliable and on the shelf components. The only problem remaining with ROVs is the fact that they are linked to ships, which are dimensioning in term of operation costs (much more than the ROV itself).

Since ten years, with a growing need of surveys (pipe line, sites, under ice investigation…), the optimization of the cost of at sea operation have pushed the research for new systems which are to day arising as “the solution”, for rapid environmental assessment in the military sector, or economically very competitive (reduction of ship cost) for example for Pipe survey.

On the RandD size, the optimization of operational cost, and new requirements as under ice applications, or long term monitoring of sites and infrastructures on the seabed, push labs and industrial partners to investigate the new domain of Inspection and Intervention AUVs.

The presentation will integrate a state of the art and review of all this technologies, and will use reference to the fleet built and operated by Ifremer, in which all the systems are existing. Manned submersibles, ROVs, AUVs for survey, inspection and intervention.

For more details on the state of the art aspects readers can consult the professional reference review [Douglas Westwood 08].

Ifremer has been engaged in the development of underwater technologies since the beginning of the 1970s and in the operation al use of underwater systems within the European oceanographic fleets. Development of the deep sea ROV Victor 6000 and a complete upgrade of the well-known manned submersible Nautilus in 2000-2002 are some of the major activities undertaken recently by Ifremer, as well as numerous reference in the field of autonomous underwater vehicle for survey task but also for complex autonomous telemanipulation tasks.

Manned submersibles have been pioneers in the field of operational access to the deep sea for science for 20 years. Along with the Shinkai 6500 from Jantec in Japan and with the two MIR vehicles from Russiaia, Ifremer’s Nautilus is capable of diving up to a depth of 6000 m. It was overhauled
in 2000-2002 and is currently available for science investigations with 1600 operational dives already conducted.

*Nautilis* (see Figure 1) is mainly dedicated to oceanographic investigation but has also been used for archaeology, for example to dive on the wreck of the *Titanic*, and on oil spill reduction, for example on the wreck of the Prestige off the coast of Galicia. It’s a very flexible tool for complex unknown underwater environments. However, *Nautilis* is not ideally suited for surveillance, especially when it is important to optimize the cost of collected data, or when the conditions are not consistent with the use of a heavy deep sea system. Ifremer has been developing a new generation of underwater vehicles with an emphasis on autonomous vehicles.

In the context of deep water technologies, numerous projects have been conducted recently with European partners for offshore applications. This effort started with the development of the supervised AUV *Sirene* [Rigaud, Semac, Drogo, Opderbecke & Marfia, 1999] that was designed for accurate launch and deployment of a benthic station. The prototype was built by Ifremer for depths up to 4000 m and has demonstrated progress in precise autonomous positioning and tracking using Kalman filter techniques, robust acoustic range-estimators, chirp communication and noise reduction technologies, as well as electro-acoustic-compatibility. The technology developed in *Sirene* was applied to the *Swimmer* research and development project in collaboration with Cybernetix for the offshore industry [Chardard & Rigaud, 1998]. This hybrid AUV, which was based on the *Sirene* vehicle, carries a classical ROV and was designed to dock on a preinstalled bottom-station linked by a permanent umbilical to the surface. Once docked, the *Swimmer* "Shuttle AUV" deploys the ROV using the established link with the surface, through the permanent field umbilical. Over and above the *Sirene* technologies, the autonomous docking concept was demonstrated using an innovative, integrated high precision positioning system (Figure 2).

The successful development of *Swimmer* was followed by an ambitious prototype AUV that was built in collaboration with Cybernetix, Hitec-Horton, and Herriot Watt University. This is the *Alive* intervention AUV (Figure 3), the first AUV equipped with manipulators. The vehicle is able to dock with grabbers on a typical offshore ROV panel in an acoustically supervised mode. This project demonstrated innovative robust optical and acoustical dynamic positioning and sensor based docking, proven at sea in real conditions [Perrier & Brignone, 2004].

Beyond these technological advances, the need for a more classical survey AUV has arisen within Ifremer scientific programs, mainly dedicated to environmental survey, in the field of physics, chemical analysis, living resources survey, or risk assessments for geophysics (slope instabilities and seismic surveys). This has led to the establishment of an operational program based on a fleet of coastal survey AUVs. With respect to the ROV *Victor* 6000, the system has been in operation since 1997 and has been intensively used for multidisciplinary science cruises all over the world. The vehicle is in permanent evolution. A new high resolution mapping module has been designed. This scientific tool skid is dedicated to "optical and acoustical mapping" at limited altitude for very high resolution "multi-modal" mapping.
2. VICTOR 6000, REMOTELEY OPERATED VEHICLE

Victor 6000 is a scientific electrical ROV entirely dedicated to deep sea scientific studies. Victor 6000 has achieved numerous oceanographic cruises in the Atlantic, Arctic and Pacific oceans. More than 340 dives have been carried out from L’Atalante, Thalassa, Pourquoi pas? and Polarstern research vessels. Victor 6000 the deep sea remotely operated vehicle (see Figure 4) is rated to reach 6000 m depth, e.g., 97% of the ocean depth. The vehicle is part of a global system built of subsystems, "scientific module" (tool sleds), winch and cable, dead weight and umbilical, positioning subsystem using acoustic ultra short base line (USBL) techniques, and all software for data and dive management.

- The vehicle itself includes specialised servicing equipments dedicated to propulsion, video surveying, lighting, remote control, navigation and tele-manipulation. The positioning is carried out by an ultra short baseline system “POSIDONIA”®.
- The toolsleds or modules composed of a frame located under the vehicle where most of the scientific instruments are installed.

Since 10 years, Victor 6000 is proposed to scientists with a “basic sampling” toolsled, which includes a retractable drawer, sampling tools and temperature probes. Since 2 Years Victor 6000 is proposed with a second innovative toolskid dedicated to high resolution mapping of the sea bottom, with acoustical and optical devices.

Figure 4 : Victor6000 on R/V Polarstern and Victor6000 on R/V Atalante

In 2005 The system will be soon equipped with a second module dedicated to high resolution mapping of the sea bottom, with acoustical and optical devices.

Figure 5 : The new High Resolution Survey Module

A deep record dive at high latitude (79°north) has been reached in the Molloy Deep at 5550 metres. The performance obtained till 2004 during 3500 hours of work/survey (+ 500 hours transiting between sea surface and ocean bottom) near the seafloor are contributing significantly to the observation and the monitoring of the deep benthic ecosystems in various environments of the mid-oceanic ridges and the continental margins.

For the video mapping, the ROV Victor 6000 is equipped with a vertical camera. The survey of video mosaicking is carried out at an altitude of about 3 meters, to ensure a good image quality. As the camera aperture is 60°, the video mosaicking coverage is about the same as the altitude. This means that, in our case, the mosaic width is approximately 3 meters. In addition, geo-referencing is provided on-line by measured or estimated data from navigation including USBL and dead-reckoning. For on-line working purpose, the speed of the ROV is 0.3 m.s⁻¹ maximum and the images used for computation are 352*288 pixel size.

The new High Resolution survey module is build to manage optical and acoustical high resolution mapping at limited altitude with the ROV. A new high dynamic cooled CCD camera (Pelletier effect based) have been designed for optical mosaicking.

Caracole cruise :
The Caracole cruise took place in 2001 on the ship L’Atalante with Victor 6000. It aimed at mapping at a high resolution the carbonated mounds on the continental margin off Ireland. For this purpose, a micro bathymetry survey was done and was completed by video mosaicing and sampling. Fig. 4 presents one of the results obtained during Caracole cruise. Victor 6000 has surveyed an area and videos were transmitted on-line to MATISSE. Geo-referenced mosaics have been produced and embedded into the GIS where high resolution bathymetry survey have been superposed (Fig. 6). The difficulties in optical mapping arising from varying altitude, lighting conditions and navigation accuracy are clearly visible.
This cruise took place during the summer of 2003 in the North Atlantic Sea and the North Sea. Video mosaicing has especially been carried out during the second leg on the Håkon Mosby Mud Volcano (HMMV). This volcano is located in the Northwest of Norway at about 1250 meter depth. It has a diameter of around 1 km and the purpose was to get an accurate overview of the whole volcano. For this purpose, lots of measurements were carried out, particularly chemical measurements, micro bathymetry and video mapping (Figure 7).

Complete mapping of the volcano area could not be achieved given the limited coverage of color video on the seafloor. The objective of the video survey is to produce significant samples distributed over the area.

The recent MoMARETO cruise (Sarrazin et al. 2006) illustrate the Victor 6000 capacities. It took place on three hydrothermal fields of the mid-Atlantic ridge. The main objective of the cruise was to study the spatial and temporal dynamics of hydrothermal communities colonizing the MoMAR zone, located on the Azores Triple Junction. Most of the dives were centered on Lucky Strike, two other vent fields, Menez Gwen and Rainbow, were also visited.

On Lucky strike the challenge was the high-quality bathymetric mapping on chaotic and rough terrain with active hydrothermal edifices, fields of pillow lava, typical lava lake structures, fissures and cracks. After several mapping from 90 to 30 meters altitude survey, a reference dive at 8m altitude have been conducted to couple the micro-bathymetric survey with OTUS mosaics. The data acquired give important insights on bottom texture and structure and permitted mapping of vent faunal habitats in the vicinity of active sites. A complete coverage of the Tour Eiffel edifice was done (80m x 120m). The survey around this 10-m high structure was particularly tedious and several additional passages were needed to complete the data set. A first image mosaic mapped the distribution of faunal assemblages around the structure. This small-scale survey took 4 hours of bottom time (Figures 8,9,10).
Figure 8: The center of the map is occupied by a MMR "Reson SMF 7125" map. The area covered is 1000m x 500m for a resolution of 1m. The lava lake is visible in blue and is surrounded by several active hydrothermal structures. In contrast, the background shows the previous up-to-date map of the area, obtained from the ship. The area covered was 4000m x 4000m for a resolution of 50m.

Figure 9: A zoom on Tour Eiffel hydrothermal structure with MMR "Reson SMF 7125". Area 150m by 100m, DTM = 0.25m. The sulfide edifice is 11m high.

Figure 10: Raw mosaic of black and white OTUS images giving an optical view of Tour Eiffel.

3. AUV: ASTERX AND IDEFX

The various fields of physical oceanography, marine geological resources, fish stock evaluation, natural risks assessments, etc., in the continental shelf and margin regions, all linked to socioeconomic demands, are fueling the need for more detailed surveys. The analysis of scientific requirements, collected from several French and European oceanographic institutes, led to the specification of a 600 to 800 kg, 3000 m depth-rated, modular vehicle with more than 100 km range capabilities and around 200 kg payload capacity. For coastal applications this vehicle would be operated by a limited crew from small (<30 m) non specialized boats/or vessels of opportunity. The final objective of this program is to establish an operational fleet able to quickly mobilize for environmental survey, for example on non-forecasted events (meteorological events, seismic activity, accidental pollution, etc.). Another goal of the AUV program is to combine AUVs with ROV operations on a classical cruise.

The two sisters AUVs named AsterX and IdefX are 4.5 meters in length with a diameter of 0.69 meters. Depending on the payload the weight is between 600 and 800 kg in air, with a diving depth of 3000 meters. The cruising speed is between 0.5 to 2.5 meters per second. The AUV is capable of carrying various payloads in its payload sections for a wide spectrum of applications [Ferguson, 2000][Rigaud et al, 2004].

- Typical classical payloads have been design for:
- Current profiling and physical-chemical parameter measurement
- Sonar imaging for fish-stock evaluation
- Bathymetric sonar, sub-bottom sounder and side-scan sea-bed investigation

Figure 11 illustrates the vehicle general arrangement
The use of such an AUV in coastal areas dictates rules for usage, and an evaluation of operational risks. This has led to select a basic operational scenario, in which the vehicle will surface only if an escort vessel is able to manage the security on the sea-surface. In other cases the vehicle will not be permitted to surface without acoustic contact with the escort vessel and will remain underwater, or ultimately lie on the bottom and wait for the escort vessel to command it to surface. For this reason, sophisticated acoustic communication and relocation functions have been included.

From February 04 to June08 AsterX and IdefX have been used for 220 Days at sea on 28 campaigns:

- Max depth reached 2500m
- Max distance in one dive 74km with one surfacing
- Mean Operational team 2 or 3 people
- Mobilization from 10 different vessels. The Figure 12 shows an underwater high resolution map (EM2000), built and overlaid on another original map built from the ship hull mounted sonar (Simrad EM300). This (1*1m square pixels) map is built with the AsterX cruising at 3 knots over the terrain at 60 meters altitude from the bottom in a very rough terrain, from 300m depth to 1000 depth. The followed trajectory crossed the lines perpendicularly, climbing with a pitch in order to keep the vehicle axis parallel to the mean slope and descending at constant attitude. Here, the cost of mapping has been optimized, in terms of time of survey (18kms in line 4 km2 covered in less than 3 hours, First level map built on the ship 30minutes after the end of the dive). This result is an illustration of the data cost optimization, by minimization of the needed ship time versus the survey time.

Recently a new acoustic subbottom profiler has been developed for offshore business survey, and also for high resolution mapping of the first meters of sediment layers. The Echoes 10000 AUV echo-sounder is a co-development from iXSEA with Ifremer, it operates in a frequency band from 1.5 to 6kHz. The Figure 14 shows some results with this new innovative device.
The main interest in AUVs is related to the cost optimization at sea, with running modes related to No-ship or Ship (size) reduction scenarios. Ultimate views are now to manage the possibility to speed up and secured surveys and/or interventions with several vehicles (homogeneous or heterogeneous fleets).

4.1. General overview

Three current EU or national (ANR) funded projects allow to carry on research work:

- GREX (EU-FP6): communication and mission coordination between several underwater vehicles;
- CONNECT (ANR): network architectures for heterogeneous vehicle fleets;
- FEEDNETBACK (EU): control of vehicle fleets through networks with heterogeneous communication channels.

The vehicle control architecture is designed to provide a powerful but safe framework for studies and future operational use. The vehicle control computer (VCC) is the standard controller of the AUV; it ensures the basic system functions by operating: sensor data collection, low level control loops, automat level mission control, operate alarm response security system. The VCC accomplishes and supervises the automatic execution of the mission as it is programmed before the dive. The NEMO® software allows the management of those functions.

The fault detection and response system within the VCC will continue to guarantee the security of the system.

This control architecture ensures that new, possibly application-specific algorithms for mission re-programming do not affect the security of the vehicle; failures in such algorithms can lead to dives that do not fulfill the objectives, but they can not cause failure of the security management. This separation in the functional hierarchy is important since mission re-programming algorithms can change from one field application to another.

Software tools exist for the development/definition and the management of the rule sets. The architecture allows simplified qualification of new defined vehicle behaviors.

4.2. Fleet coordination

With new products coming up regularly in the field of acoustic data links, we are experimenting the vehicle to vehicle communication, with coordination between the AsterX AUV and a smaller autonomous test bed vehicle, which is an Hovering Type AUV, called VORTEX.

In a first approach, the scenario is given by similar dive plans, which in order to be executed in a coordinated way, require the faster AUV AsterX to enter in a wait spiral phase and to resume it’s track on the completion of an acoustic handshake between both vehicles.

More complex mission scenarios with applications like are also tested:

- An autonomous surface relay following the AUV track and ensuring a communication channel;
- Coordination of vehicles on a simultaneous dive in order to optimize complex missions;
- AUV data monitoring and mission re-programming through stationary vehicles (ROV), observatories; etc.

Figure 15: two-vehicles coordinated mission
5. CONCLUSION

We are still on a learning curve with AUVs. Developments are ongoing and yield higher levels of autonomy and behavioral robustness at sea. For example, high level programming mission preparation systems, named Mimosa® and PSE®, are being improved for mission building and high level, fault tolerant control.

With operational ROV, data fusion of acoustical and optical maps based on concurrent mapping localization techniques with data fusion technologies is underway. This is still an open research activity in terms of signal processing and considering the development of new sensors and subsystems. Other research activities based on 3D optical reconstruction with non calibrated stereo are also underway, with a first demonstration of a stereo head installed on the Victor manipulators for a cruise on the Atlantic ridge during the 2006 summer to map hydrothermal vents and cold corals [Sarradin et al., 2004].

In parallel, permanent research and development on heterogeneous systems (AUVs/ships/autonomous surface systems/underwater observatories) and on autonomy in all the components (energy, positioning, navigation, control) are conducted with regular benchmarking and integration of mature components on operational underwater systems, with a permanent feedback from operations at sea.

REFERENCES


