The Application of Autonomous Underwater Vehicle (AUV) Technology in the Oil Industry – Vision and Experiences

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Key words: Autonomous Underwater Vehicle, AUV, Seabed Mapping, Swathe Bathymetry, Sub-bottom Profiling.

ABSTRACT

BP has been contracting commercial services using a survey class AUV to collect sidescan sonar, swathe bathymetry and sub-bottom profiler data at proposed oilfield development locations in the US Gulf of Mexico and the UK sector of the North Sea. In the deep-water Gulf of Mexico the surveys were conducted at proposed field facilities locations and along proposed pipeline routes in water depths ranging from 500 to 2300 metres. In the North Sea surveys were conducted on the continental shelf in water depths between 80 and 120 metres.

This paper will review the expectations we had of AUV technology before these surveys, contrast these expectations with our experiences during the surveys, and indicate directions in which we wish to see AUV technology develop.

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1. INTRODUCTION

The search for offshore hydrocarbons has taken the oil industry into increasingly deep water. Over the past decade activities have gone beyond the continental shelf in the Gulf of Mexico, off Brazil, West Africa, north west Europe and the Mediterranean Sea. Oil is now being produced from fields in 1000m water depth, with field developments in progress in double these depths.

Traditional hydrographic survey technology has struggled to keep apace with these trends. The water column between surface and seabed significantly degrades the resolution of data. Deployment of sensors closer to the seabed requires an increasingly long tether. These long umbilicals have made deep-water surveys less productive, with costs almost exponentially proportional to the water depth. It became inceasingly obvious to us that applying the traditional vessel-mounted and towed sensor techniques of the late 20th century required a radical change in deeper water.

Autonomous Underwater Vehicles (AUVs) are not new. They have been used for oceanographic studies and for military purposes for several years. But, to we users of commercial survey services, it seemed that most work had concentrated on the vehicles themselves rather than on the use of such vehicles in surveying and site investigation. Never-the-less, the deployment of AUV-bourne sensors appeared to have the potential to solve the problems of accurately surveying deep-water sites.

In the late 1990's BP surveyors and site investigation specialists vigourously persued the technology and its application to oil industry requirements. In 2001 we conducted our first commercial surveys using the technology. This paper outlines our experiences, contrasts them against our previous expectations, and suggests future directions.

2. OUR VISION IN THE 1990'S

2.1 Our marine site survey requirements

Site surveys supporting offshore oil and gas facilities emplacement are intended to map all features that may impact the proposed structures, with particular emphasis on natural or man-made hazards on the seabed or in the subsurface. Surveys typically consist of bathymetry, insonification through sidescan of the complete area of interest, very high resolution profiling of the shallow subsurface and, for locations at which wells will be drilled, imaging of the subsurface through high resolution multi-channel reflection seismic techniques. Seabed sampling and coring may also be required, to provide ground-truth to the seismic data. The relative importance of these techniques varies from site to site depending upon geology and proposed facility, but often the sum of the whole is greater than that of each of the parts and careful integration of all data is required.

In deep water, traditional exploration seismic techniques will often provide imaging of the shallow geology adequate for well design. Then the key sensors for site surveys are those needed for production facilities foundation design, that is a very high resolution profiler (in the frequency range 1 to 10 kHz), sidescan sonar and swathe bathymetry. Of course it is of limited value to have data from these sensors without a clear understanding of its location, so accurate navigation, both relative to a predefined plan and an absolute record of actual location, is essential.

2.2 AUV Capabilities

Our review of AUV capabilities confirmed the potential of the technology in two areas:

- as a replacement for conventional ship-bourne hydrographic survey tasks.
- as a replacement for conventional tethered Remotely Operated Vehicle (ROV) tasks.

We recognised two significant limiting factors. Firstly, batteries. Limitations in battery power restricted either endurance or the sensors that the vehicle could carry. Secondly, vehicle navigation and control. Whilst all of the navigation components, in particular inertial systems, were available and all of the sensors were in existance, they had not been integrated into a commercial autonomous vehicle before. But with existing technology the concept of a ”survey-class” AUV seemed feasible. Together with our technical colleagues in a sister oil company, we drafted and promulgated within the industry an outline specification of requirements **–** see Appendix A.

3. EXPERIENCES

BP does not own or operate AUVs. But we now have many months of practical use. We have seen two systems:

- the Hugin 3000 AUV built by Kongsberg Simrad of Norway and owned and operated by C&C Technologies, a survey company based in Lousiana, USA. BP used this system for several months in the Gulf of Mexico in water depths to 2300m.
- the Maridian 600 AUV, built by Maridan a/s of Denmark and owned and operated by De Beers of South Africa. This system was operated in the central North Sea in conjunction with Gardline Surveys of the UK, in water depths between 80 and 120m.

Both of these systems carry swathe bathymetry, sidescan sonar and chirp profiler as payload sensors.

3.1 Key findings

To end-users the vehicle is a means to an end; it is the data collected which is of primary interest to us. The key learning from both of the systems we have used is the significant improvement in data quality. We anticipated this in deep water, especially in contrast to surface-mounted sensors. But the Hugin 3000 AUV is delivering better quality data than we have seen from deep-tow systems using similar sensor suites over the same area. And we see improvements in data quality in shallow water too, from the Maridan system. We attribute this to the improved stability that the AUV platform provides, to the co-location of the sensors (thereby removing relative positioning problems) and to the repeatability of the navigational capability. The latter allows improved line to line positioning and better mosaicing of seabed imagery. In our 1999 requirements statement, written at a time when crude oil prices in real terms were at a thirty-year low, we emphasised the need for cost savings. These are of course always welcome, but we are now more focused on the vastly-improved data quality. The justification for accepting no cost decrease is the ability to see features that may be significant to our understanding of the potential hazards in the area that we would otherwise not be able to see, thereby providing detail for improved design and installation of facilities. There is no turning back.

This superb data was not delivered without teething problems. These AUV's are complex beasts, with a dozen acoustic systems having to work in close proximity without inteference.

Safety is of great concern to BP. Both the C&C and De Beers launch and recovery systems and processes are well thought out and safe. But for recovery both rely on grappling for a rope released by the AUV. Sea state is the limiting factor for launch and especially recovery. The challenge for all AUV operations in North West Europe is to allow safe launch and recovery in up to 6-metre seas at any time of day or night. And for the De Beers vehicle, the unwillingness to recover in darkness is a severe impediment to its usage by the offshore oil industry.

The interplay of launch and recovery capabilities with vehicle endurance will be a crucial factor in the commercial sucess of AUV systems. The longer the mission endurance, the less frequent the dependency on a weather window for launch or recovery. Conversely, the more frequent the need for AUV handling operations, the more weather sensitive the system will be. And a greater proportion of time will be taken with unproductive descent and ascent.

The 4.5-hour endurance of the De Beers Maridan vehicle is a serious problem for oil industry operations. In contrast, over a 6-month period in the Gulf of Mexico with the C&C Hugin 3000 system we were averaging dives of just under 40 hours.

3.2 AUV Autonomy

The Hugin 3000 system as currently used by C&C strictly is not autonomous, but untethered. That is, untethered in the physical sense: there remains an acoustic tether (actually, with this system, multiple acoustic tethers). There are advantages and disadvantages to this. Without the ability to receive external navigation from a seabed transponder or transponder array, Hugin 3000 is dependent upon positioning input from a vessel-mounted ultra-short baseline positioning system (USBL) to limit inertial navigation system drift to within acceptable margins. A mother vessel to provide this input is therefore required. But the presence of the mother vessel allows for continuous monitoring of AUV control and payload systems. This provides assurance that the system will return with adequate data, and in the C&C/Hugin case provides for more than a minimum of quality control information allowing for provisional data interpretation and mission replanning.

The disadvantage of this tight acoustic tether is that it demands a dedicated vessel to support. There is a cost associated with that. In contrast to the Hugin operations, once the Maridan system had been deployed, its mother vessel was able to carry out vibrocoring operations until the AUV required revictalling. The Maridan system does have an acoustic link to verify that sensor are on or off, but this does not provide any assurance that adequate data is being acquired.

The way forward is to build flexibility into the AUV control systems, to allow autonomous operations but also to have control and real-time quality control capabilities when required. For the Hugin system, this will require improvements to the AUV navigation system to remove its dependence upon USBL input. For the Maridan system, significantly greater mission endurance is a must. For both, the launch and recovery weather window must be extended.

4. THE FUTURE

The first commercial AUV systems applied to surveying are with us now. Other vehicles and their similar payloads are on the way. These systems can all follow pre-programmed missions, and have a (largely untested) collision avoidance capability. Their payloads are bathymetry, sidescan sonar and profiler. They make ideal foundation geophysics packages. However they do not address other areas of oil industry requirements where, with further development, there is potential for the AUV technology to be applied. Other potential applications include:

- environmental inspection
- engineering inspection.
- underwater engineering intervention.

Inspection is undertaken using sonar, photography and physical measurement. Intervention currently uses tethered remotely operated vehicles (ROVs) for valve manipulation, component replacement, etc.

4.1 Inspection AUV

An industry need is the ability take photography for confirming seabed features - important for environmental assessment of an area. If we find areas that may contain deepwater corals, brine lakes or natural seeps we would like to take a look at them without having to bring in another vessel with an ROV.

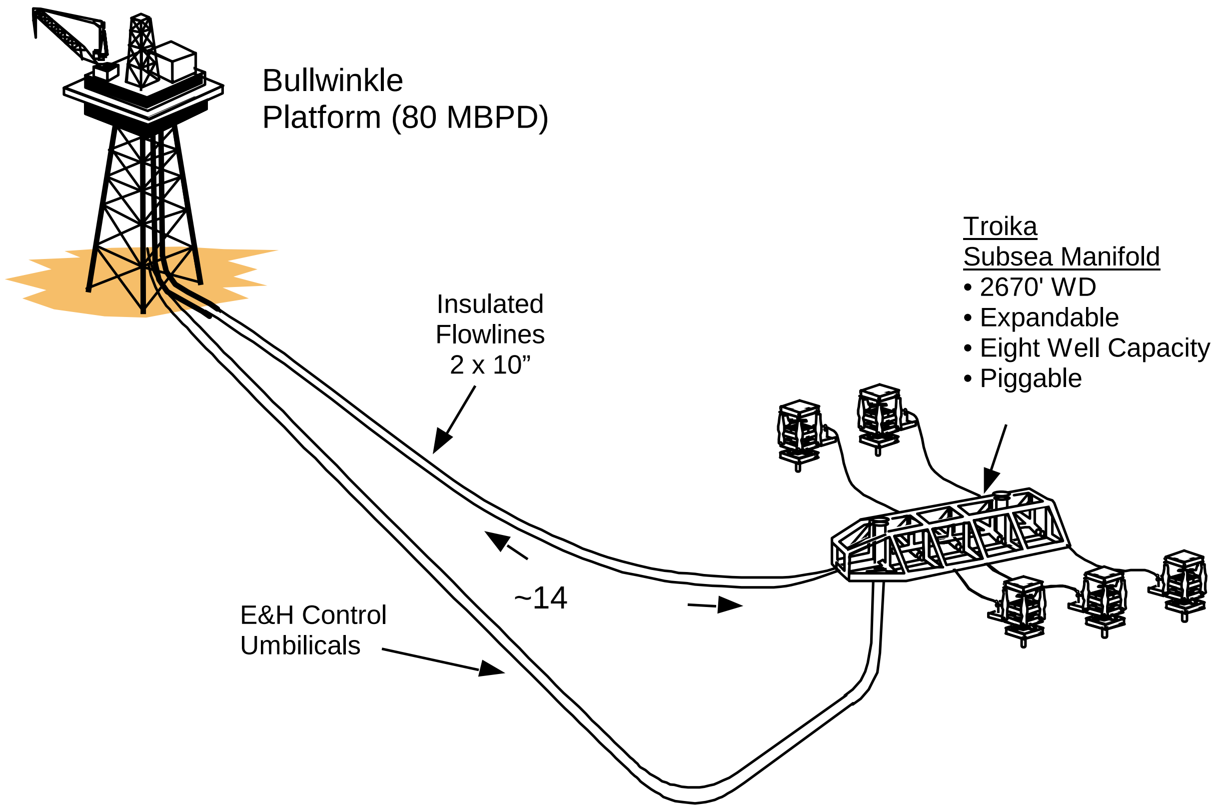
The industry also requires the ability to inspect submarine pipelines and cables. If the position of these are accurately known, then, within the navigation limits of today's survey AUV's, sonar inspection is possible. In the general sense, today's navigation capabilities are not good enough. The collision avoidance systems remain untested for deployment adjacent to seabed hardware. Our current knowledge of facilities locations is not to the sub-metre level required for inspection. And AUV positioning has yet to reach these accuracy levels. We believe that the way forward is to have real-time automated interpretation of the payload sensors such that they can interpret the position of the vehicle relative to the facility, and for there to be a real-time feedback of this to the vehicle navigation system so that the vehicle is placed in the optimal position for further sensing.

4.2 Hybrid AUV-ROV

The maintenance engineering potential of AUV technology is beyond the scope of detailed analysis in this paper, but worthy of a brief mention, if only because the potential savings to one operator alone have been calculated at $50 million per year. ROV umbilicals have the same disadvantages as deep-tow survey systems – limited in excursion, prone to entanglement except in open locations and a physical drag in the water column limiting productivity. But for engineering applications they bring important advantages. Power can be supplied from the surface and is not a limiting factor. So, with appropriate manipulators on the vehicle, intervention with subsea hardware is possible.

Increasingly the oil industry is moving towards limiting the number of production platforms installed, and instead using technical advances that allow for seabed wellheads to be tied back to a central connection. See the figure below for a schematic diagram.

The concept of a hybid AUV-ROV would be ideal in these circumstances. A free-swimming AUV could be housed at the central production facility and despatched to any of the distant seabed production facilities when required. There it would latch with a docking station containing a reeled control umbilical which would have connections back to the control centre built into the seabed facilities. It can then operate as an ROV, with all of the advantages that entails.



4.3 Engineering class AUV

When there has been a quantum leap in power technology and ROVs can become self-sufficient in this respect, the intervention-class AUV will have arrived. To us this remains a distant prospect, but more possible than appeared to be the case five years ago.

5. CONCLUSION

Survey class AUVs are emerging technology, but with us today. They are delivering a limited but important suite of data of tremendous quality. We expect to see their capabilities increased in the very near future through the real-time integration of sensor interpretation with the vehicle control system, bringing a pipe and cable inspection capability. Hybrid AUV-ROVs are coming. An autonomous intervention is a possibility. All these capabilities support the business need of the offshore oil industry.

APPENDIX A

Survey AUV – Oil Industry Requirements

A.1. The following outline specification for a survey Autonomous Underwater Vehicle (AUV) has been prepared by BP and Shell to encourage development of 'industry standard' vehicles. Appropriate specifications are required to encourage 'fit for purpose' survey AUVs. Over specification of AUVs may delay their introduction, hamper their transportability and delay acceptance by the oil industry, as it will add to the AUV cost and delay their development. However these 'fit for purpose' vehicles should preferably be capable of later expansion of specification.

AUVs should be considered for suitable survey operations in all water depths, ranging from nearshore and shelf (possibly a large market) to deep ocean (a more limited market).

It is likely that there will be uses for minimum payload survey AUVs, as well as more flexible AUVs capable of later expansion.

Survey AUV requirements are listed below, divided into essential and preferred requirements.

A.2 <u>Cost Reduction</u>

It is expected that survey AUVs will significantly reduce engineering/installation costs by provision of very high quality survey data. However, for the industry to readily adopt these vehicles, survey AUVs must reduce survey costs compared to conventional surveys (or be at least comparable). To encourage rapid development, the industry should aim to <u>significantl</u>y reduce survey costs by the use of survey AUVs. To ensure significant cost reductions, the following are required: -

- Highly efficient operations (rapid line turns, fast survey speed, limited weather dependence).
- High reliability.
- 'Fit for purpose' vehicles - not over specified for the task but capable of scope expansion.
- Capable of safe operation (including launch/recovery) in sea states of greater than 2 metres.
- Preferably capable of safe operation (including launch/recovery) in extreme sea states.
- Endurance of at least 24 hours, preferably 48 hours.
- Capable of deployment and recovery from low cost support vessels.
- Low recharge time or multiple AUVs (one operating, one recharging).

A.3. <u>Support Vessel</u>

The type of support vessel will dictate survey costs. Waiting for full AUV autonomy may delay introduction of Survey AUVs. Although full autonomy is desirable in the longer term, <u>at present it is likely that a support vessel will be required to support and partly (or fully)</u>

position the AUV.

- Support of the AUV must be possible from vessels of opportunity
- Vessel may undertake simultaneous operations (e.g. multi-channel high resolution seismic or shallow gas surveys).
- It is preferred that multiple AUVs operate from a single support vessel. This will require a level of autonomy by the AUV.
- Safe onboard battery storage and charging arrangements.

A.4. Survey Speed

- A preferred cruising speed of at least 4 knots.
- Navigation and maneuvering control between speed ranges of 2-6 knots
- Preferably capable of maintaining survey speed in high current environments (up to 3 knots).

A.5. Flexible launch/recovery

Launch and recovery of the vehicle should be carefully considered, as it will impact upon both cost of the operations and safety aspects of AUV operations.

- Capable of launch/recovery in sea states of greater than 2 metres.
- Preferably capable of launch/recovery in extreme sea states.
- Capable of launch/recovery from a variety of support vessels.
- Preferably capable of launch/recovery from a moving vessel.
- Minimal human intervention for launch and recovery for reasons of safety.

A.6. Depth Capability

Survey AUV depth requirements will depend upon international survey portfolios. Careful analysis is required of AUV costs for various water depths compared to this portfolio. It is suggested that a survey AUV that can operate in water depths of up to 3000 metres should be adequate for most oil industry applications in the medium term. However, there will also be applications for AUVs in shallower and deeper waters. It is likely that cheaper AUVs for operations in shallower waters will create their own niche markets.

A.7. Air Transportable

- For international acceptance, the AUV package should be air transportable including batteries.

A.8. Payload

- Sub-bottom profiler – preferably optional seismic sources for different geology.
- Side Scan Sonar – 100 and 500 kHz options.
- Bathymetry – Preferably Swathe echo sounder.
- Temperature/salinity or conductivity measurement.

- Precise depth sensor.
- Collision avoidance system.
- Heading, pitch, roll, yaw sensors.
- Navigation – see below.
- Preferably, RDI Acoustic Doppler Current Profiler
- Preferably capability to install additional payload sensors.

A.9. Navigation

3D Navigation of the AUV is required. Survey AUV navigation requirements are: -

- Mission programming to follow a pre-determined survey grid loaded to the AUV.
- Mission positioning accuracy of 10 to 40 metres.
- Data positioning accuracy of 5 to 20 metres.
- Capable of utilising position updates from acoustic positioning e.g. USBL or LBL systems transmitted from the support vessel, seabed beacons or some other source.
- Preferably capable of utilising position updates from GPS when on the sea surface.
- Doppler velocity log capable of operations over a variety of seabed soils.
- Dead reckoning during short periods of loss of navigation data.
- Collision avoidance logic.

A.10. Flying Height

- Survey AUVs must be capable of operating at a variety of flying heights above the seabed.
- The minimum flying height will be controlled by requirements of the 500 kHz side scan sonar.
- Capable of maintaining a fixed survey altitude over a rugged seabed terrain or maintaining a constant depth as the terrain changes.

A.11. Data Supervision and Quality Control

To ensure integrity of acquired data and mission alteration.

- Variations to the AUV mission shall be possible from the support vessel.
- As a minimum, the survey AUV shall be capable of self-checking and cessation of operations if systems are non operational.
- The AUV shall preferably transmit status flags to the support vessel. Sub-sampled raw data is the preferred status flag.
- To ensure data integrity, it is preferred that a significant amount of sub-sampled raw data is transmitted to the support vessel.

A.12 Data Logging/Storage

- Compatible with the endurance of the Survey AUV when operating all survey sensors at their maximum sample rate.

- Data logging frequency compatible with the survey sensor.

A.13. Time Synchronisation

- All sensors including navigation shall be precisely time synchronised at all times.

A.14. Integrated Packages

- Payload sensors shall not interfere.
- Simultaneous operation of multiple Survey AUVs is preferred.
- AUVs shall be capable of operations in environments with acoustic noise (coherent or random).

A.15. ‘Nice to Have’ (not essential)

- Capability to add additional sensors.
- Visual capability (video/stills).
- Magnetometer.
- Hydrophone for use with other acoustic sources.
- Capability to dock into a ‘garage’ and download data/recharge.

BIOGRAPHICAL NOTES

David Bingham

Dave has a BSc in surveying from University of Newcastle upon Tyne, UK. After working as a hydrographic surveyor for Decca Survey and Sonarmarine, be joined BP in 1980. He has been involved with offshore survey and positioning activies in the Far East and North West Europe.

Tony Drake

Tony joined BP's Survey and Cartographic department in 1977 after graduating from the University of Nottingham with a degree in civil engineering. He has been involved in onshore and offshore survey and positioning activities in support of exploration and development projects that have been undertaken in many countries around the world

Andrew Hill

Has a BSc in Maritime Studies and an M.Sc in Marine Geology and Geophysics. After leaving university in 1982 he joined Geoteam UK Ltd in Aberdeen, subsequently moving to A/S Geoteam in Oslo, Norway in 1984. He joined BP in 1988 as the High Resolution Geophysics specialist. He is now BP's Survey and Site Investigation Global Network Leader. Andy is a member of the Society of Exploration Geophysicists, Joint Chair of the Gulf of Mexico Geohazards Forum and a member of the Society of Underwater Technology's Offshore Site Investigation Committee. He has written and presented numerous papers on various aspects of hydrographic and geophysical site investigation in Europe and America.

Roger Lott

After graduating from the University of Newcastle upon Tyne, UK, with a degree in Geography and Surveying and working as a land surveyor in Jamaica, Roger joined BP in 1973. He is a Fellow of the RICS and of the Royal Geographical Society, member of the Hydrographic Society and Institute of Navigation. He is a past Chairman of the FIG-IHO Advisory Board for Hydrographic Surveying, Chairman of the European Petroleum Survey Group geodesy committee and a member of FIG Working Group 5.5, Reference Frames in Practice.

In 2000 the authors were awarded a BP Innovation Award for the introduction of Survey AUV Technology to the industry.