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**DYNAMIC POSITIONING CONFERENCE**
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**DP Innovation**

# Dynamic Positioning of Underwater Vehicles (tethered or not)

*Jonathan Davis,*

*BP America*

*Dr. Ioseba Tena*

*SeeByte Ltd. (Scotland)*

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## Introduction

Remotely Operated Vehicles (ROVs) are now the tool of choice for any subsea operation. Typical tasks are mapping, observation, installation, inspection, maintenance and repair. Many different types of ROV have been developed and adapted for different tasks. The basic components of an ROV remain common. These are the frame, buoyancy, control system, propulsion system, tether management system and deployment (and recovery) system. Recent advancements have seen the introduction of Autonomous Underwater Vehicles (AUVs) for certain tasks. These systems are essentially, ROVs with no tether. Their components are frame, buoyancy, control system, propulsion system and deployment and recovery system. Figure 1 shows a typical ROV and AUV.

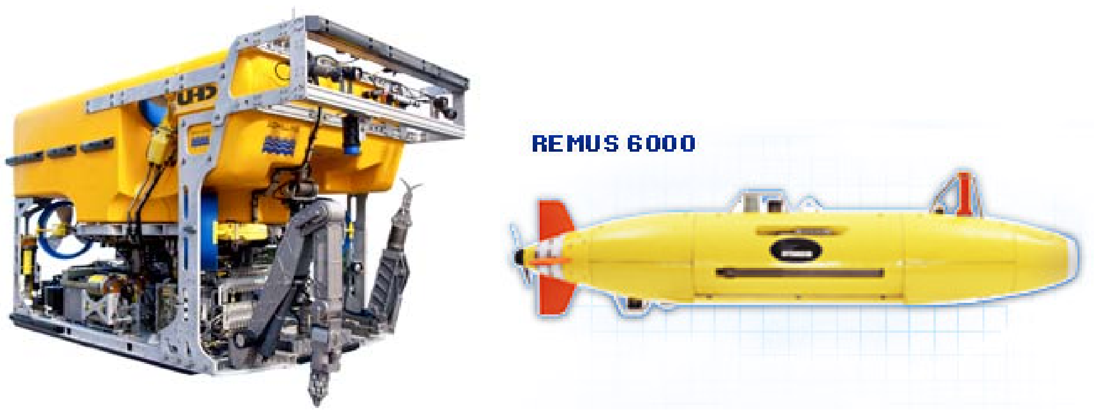



FIGURE 1: Typical ROV and AUV.
*Pictures courtesy of Hydroid and Schilling.*

This paper will describe the application of a Dynamic Positioning (DP) system to an ROV and an AUV. As with any dynamic positioning system, the nature of the vehicle or vessel receiving the system determines the nature of system implementation.

## Typical Dynamic Positioning System Components, Vessel vs ROV, AUV

ROV and AUV dynamic positioning systems have largely developed from vessel based dynamic positioning technology. As a result, many aspects of the system have strong similarities to vessel based dynamic positioning systems. The following paragraphs will explore the similarities and differences.

A vessel dynamic positioning system consists of the following components:

1. Computer – single dedicated computer to perform DP function only. Most systems typically have more than one computer to provide redundancy.
2. Control Console – this provides information to the system operator and allows the input of required vessel movements.
3. Position Reference System – to provide real time feedback regarding actual vessel position i.e. is the vessel located where the DP system operator has specified.

4. Heading Reference System – to monitor vessel heading and verify it is maintained according to DP system requirements.
5. Environmental Reference System – sensors are used to measure wind, waves and current to determine the forces that each place on the vessel and allow the DP system to modify power levels to compensate. This information is also important to the system operator in order to determine the optimum position for the vessel e.g. bow pointed into the direction of wind.
6. Power System – the operation of the power generation system is critical to vessel DP operation since different levels of thrust will require different levels of power. These changes can be significant and rapid, requiring fast delivery of significantly more power. Power generation is monitored as well as power supply to all DP control system components, since a failure in any one of these areas could cause a loss of vessel position.
7. Propulsion System – the propulsion system is used to move the vessel according to DP system requirements. It is important that direction and power levels of thrusters are monitored to ensure that they are performing as required.

Depending on the nature of the operation and associated risk of DP failure, several position, heading and environmental reference systems may be input into the DP system for redundancy.

The following table shows the challenges faced when trying to implement a dynamic positioning system according to the above conventional, vessel based components.

| Vessel DP Element | ROV | AUV |
|---|---|---|
| Computer | Located on subsea vehicle and/or the control van. Continuous communication between both computers. | Located on vehicle only.<br><br>Communication from offline surface computer on intervention request from operator. |
| Control System | Control interface in surface control van. Near real time control of all functions and sensors. | Onboard vehicle. Control system can be set to follow a pre-defined mission. Some AUVs now functioning with greater intelligence, making control adjustments onboard the vehicle. |
| Position Reference System | Relative motion sensors present on vehicle. Absolute position available at surface. Absolute depth and altitude available in the ROV (The ROV must also control this axis). | Relative motion sensors available on vehicle. Absolute position updates from acoustic beacons are also possible if these have been setup prior to mission In shallow waters AUV can also obtain GPS fixes by surfacing. Absolute depth and altitude available in the ROV (The AUV must also control this axis). |
| Heading Reference System | Available – typically single sensor. Variable accuracy and performance (flux gate to | Available. AUVs used in the oil and gas business will normally be fitted with INS system. |

| | | |
|---|---|---|
| | spinning mass gyro) | |
| Environment Reference System | Minimal sensors may have a Sound Velocity sensor present. | Larger AUVs will normally carry sound velocity sensor. |
| Power System | From surface, no local backup. | Local power source, limited in duration, minimal redundancy. |
| Propulsion System | Several thrusters positioned around vehicle frame. | Minimal thrusters, normally smaller than ROV thrusters around vehicle if hover capable or a single thruster at the back if torpedo shaped. |

## Implementation of an ROV based Dynamic Positioning system

### System Design:

As the table above shows, design of an ROV based DP system must be different to a vessel based system. Probably the main difference is the availability of positioning and environment sensor information. The position and heading reference systems of the DP system are therefore the major difference between a vessel based system and an ROV based system. The reference systems must then be designed to operate with positioning information typically available onboard an ROV. The main requirements for absolute position information are:

- Heading
- Speed / distance moved
- Altitude and Depth

It is also possible to derive position information from relative position sensors. The main example of this is sonar, where the ROV can be positioned relative to a subsea sonar target (pipeline, manifold, riser etc.). This method can be thought of as a subsea fan-beam system.

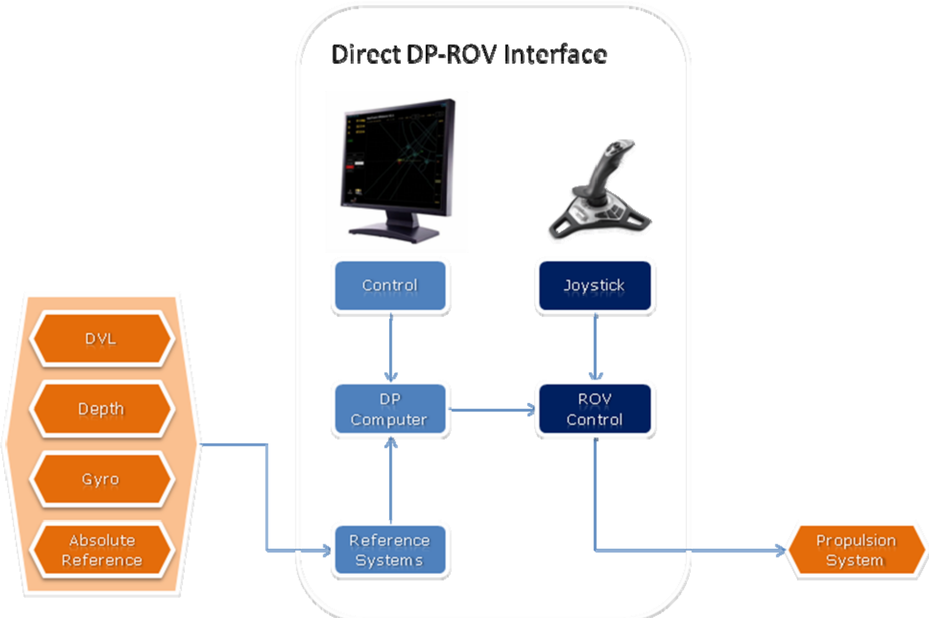
The reference systems integrate data from various sources and fuse it to provide position, attitude and commonly also rate vectors. A conventional navigation sensor suite will consist of a Doppler Velocity Log for (altitude, speed and distance moved), a gyro (typically a north-seeking gyro, for heading) and a depth sensor. It may be possible to integrate other navigation sensors, although this will depend on sensor availability onboard the vehicle. No inputs are taken from environment sensors. It is assumed that changes in the local environment will have a direct impact on the position of the vehicle. Hence, the effect of the local environment is measured indirectly.

During operations, the DP system continuously monitors ROV position, heading, altitude and depth and feeds this back into the DP control algorithms. This allows continuous adjustments to be made until the ROV reaches the required user defined ROV set point. The DP computer module monitors vehicle position and responds to requests, by calculating the necessary thruster settings to achieve new positions.

The DP computer can interface directly through to the ROV control unit or alternatively it can interface to the ROV joystick. By interfacing directly to the ROV control unit the DP computer can be made more responsive (this is a typical configuration when controlling highly dynamic systems such as fighter planes), but a failure on the system risks compromising the actual performance of the ROV. Interfacing to the joystick essentially makes the DP computer module an automatic pilot. It also makes it highly modular and can be easily made to work with new ROV units. This mode of interfacing is preferred when retro-fitting to existing ROVs.

### System Implementation:

As discussed above, the system can be interfaced directly to the ROV thrusters or to the ROV joystick. There are some advantages and disadvantages of each approach. Interfacing directly to the ROV thrusters ensures minimal delays and that the ROV will respond to new positions or position corrections as quickly as possible. This level of interface also requires the control system to be embedded within the ROV control system. To embed a DP system within the ROV control system requires considerable co-operation and is rarely achievable, due to intellectual property concerns. In reality, ROV operations rarely require fast response times in terms of vehicle position and hence this tends not to be an issue in real operations.

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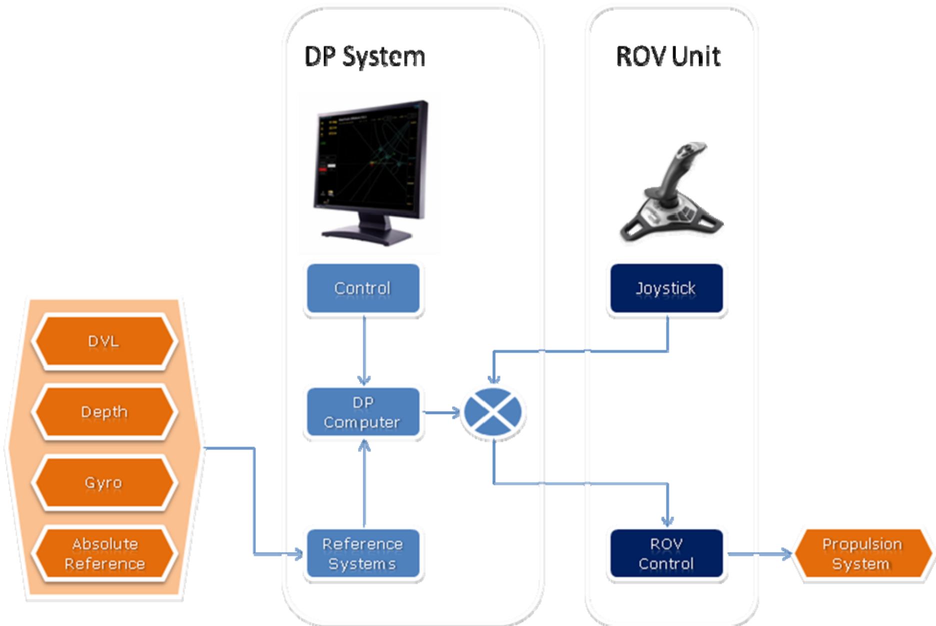
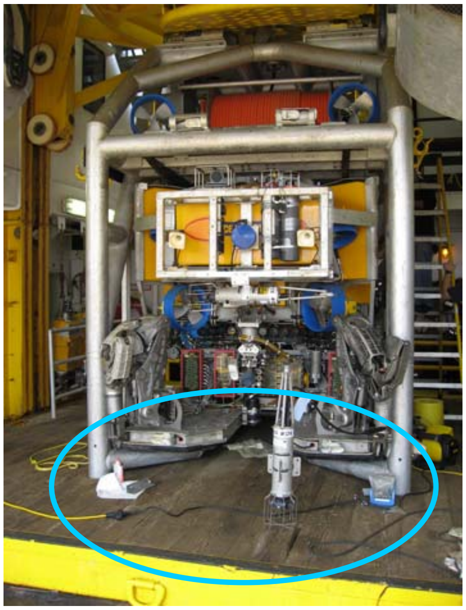
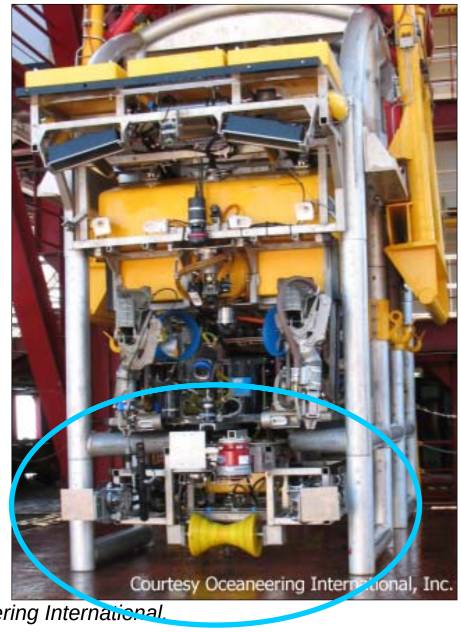
Interfacing through the joystick allows the DP system to control the vehicle through the replication of joystick commands to the vehicle control system. This approach allows full vehicle DP capabilities. For this mode of operation to work well, the DP system must be aligned to the vehicle control system. This is achieved by tuning the system to ensure that joystick commands match the required movement of the vehicle. If changes are made to the control system, these must be also considered in the DP system. This has the potential to impact the performance of the DP system which is operating without knowledge of this change. In order to explain this, consider that the ROV is operating under DP control and working well. The ROV operator then changes the ROV control system settings to reduce all thruster power levels to 50% and neglects to input this information into the DP system. As a result, the DP system will continue to issue joystick commands, which now result in movements with 50% less power. Hence, the system will become less responsive and in some cases may not be able to hold the ROV on station.




A key part of system implementation is the understanding of the host ROV system and its normal mode of operation. As a result, considerable time is spent with vehicle operators to understand this. One example which could affect system installation is variable vehicle payloads. Consider an ROV being deployed with a tooling package. The dynamics of the ROV with and without the tooling package will differ considerably. Under these circumstances, DP system tuning would typically be performed with both configurations.






*Pictures courtesy of Oceaneering International.*

*Work Class ROV in Garage with and without sensor skid (weight 500 lbs).*

**Installation and field proving:**

As part of the installation process a good strategy will generally follow these steps:

- Simulation: the inputs and outputs to the Dynamic Positioning System are simulated under laboratory conditions prior to deployment. This step ensures an efficient installation.
- Dry-installation: all the navigation sensors and the joystick are integrated to the system and all the different components are tested in dry conditions. The engineer checks that the input and output signals are as expected.
- Wet Testing of Position and Heading Reference Systems: it is important that the data from the navigation sensors is aligned with the Dynamic Positioning system. A series of tests are necessary to ensure that this is the case. Errors in the alignment will result in erratic behavior. It is also important to note that human operators often learn to work around navigation sensors with systematic errors. Errors in the sensors must also be identified and any problems must be solved.
- Vehicle Tuning: once the system is ready run the auto-tuning routines that ensure that the requests from the joystick commands are met by the Dynamic Positioning system. The ROV axes are tuned in sequence.
- Sea Acceptance Test: this is carried out by the engineer on-site. All the functionality of the Dynamic Positioning system is carefully tested and the outcomes are documented. Each unit is thus certified to work within the specified parameters.
- Offshore Trial: the system is exposed to standard offshore operations to ensure that it is operating as expected. The Dynamic Positioning system stores log files with relevant parameters. These can be used to analyze the performance of the

system as it performs the trials. The offshore trial can be compared to an FMEA audit. The main purpose of the trial is to understand and quantify the DP system capabilities and limits during normal operations and in failure conditions. This process is critical in order that the DP system can be used safely and effectively in operations.

A good DP design process must carry out a careful study of the system's failure modes: these include breakdown and/or errors of the Dynamic Positioning System, breakdown and/or errors of each of the modules, errors on the input signals from each of the sensors and the joystick.

Importantly, such failures should not compromise the performance of the system. Mitigation of the failures modes and effects must include careful design of defensive software and routines for handing the ROV in manual control to the operators in an easy and safe manner.

As part of the Sea Acceptance Test the time and distance that the ROV would travel if the Dynamic Positioning system lost control and manual control was handed back to the operators must be quantified. At top speed the distance travelled by the ROV should be no more than 0.5 meters.

## Implementation of an AUV based Dynamic Positioning system

### System Design:

The fundamental difference between an AUV and an ROV or vessel is the lack of connectivity. By definition, an AUV has to operate as a standalone, with no real time and online intervention by an operator.

Most AUVs have a Dynamic Positioning core that allows it to follow waypoints along a mission trajectory. How they get there and how they behave once they arrive is heavily influenced by their design. A torpedo (cylinder) shaped AUV with one propeller at the back and with fins is not capable of keeping station over a known position and it must instead loiter by moving around in circles. New generation hovering AUVs share similar design aspects to ROVs and their thruster configurations allow them to maintain station over a fixed position. As with ROVs, AUVs have position and heading reference systems and modular DP computer (though these terminology is not always shared by everyone in the industry). These modules perform the same core functions as those of the ROV. The computer drives the AUV towards its goal and the reference systems provide an estimate of the position and heading.

The AUV must also have an autonomous Control System embedded onboard to pilot the AUV from the start of the mission, through the different waypoints to the end of the mission.

In conventional AUV missions the system travels through a list of absolute coordinates. Although recently tools have been developed that allow AUVs to keep station relative to static or moving structures. With these tools the AUV no longer just moves through a series of coordinates, but it can detect and track structures in its path and then travel relative to those structures. Thus when tracking a pipe using a side-scan sonar, the AUV can maintain a constant distance from the pipe. When tracking a riser with a forward-look sonar, the AUV can travel up-and-down the riser and orbit around it. With these tools the Dynamic Positioning system is a true Dynamic Positioning system as it can maintain station relative to other dynamic objects.

**Installation and field proving:**

Installing and field proving an AUV Dynamic Positioning system, including advanced tools, benefits from a careful de-risking process. SeeByte and BP have ample experience on this front having successfully de-risked and demonstrated various stages of different AUV programs. The final process should include the following phases:

- Simulation: all inputs and outputs are simulated in a laboratory under realistic conditions to ensure ease of integration. Faults are also simulated to ensure that the system can cope with unexpected failures. Simulations can also be run using legacy data sets pertaining to some of the components.
- Hardware-in-the-loop: real hardware elements can be tested in isolation and as part of the whole system by integrating them to the simulation. These tests raise the confidence on the system. The hardware-in-the-loop experiments lead towards the final integration of all the components.
- Tank Tests: tank tests can be carried out for each component in isolation, as part of a more realistic hardware-in-the-loop exercise, and for the whole system. The tank tests should be used to characterize the performance of the system in a controlled environment. These tests are an essential part of the de-risking process as the control of an AUV is done by the AUV itself. It is important to pay particular attention to the control system itself and also to ensure that the AUV can react to failures in components in a predictable and safe manner.
- Onshore Tests: Onshore tests can be carried out in lakes, coastal or harbor environments. A good onshore test area will be free of sensitive obstacles, but provide a good realistic environment to test all of the system components. The onshore tests should be used to trial each module in isolation by disabling other components and providing synthetic measurements instead (for instance testing a pipe following module can be achieved by simulating the output of the pipe tracker). Onshore tests should also test the performance of the whole system.
- Onshore Demonstration and Acceptance Tests: The onshore demonstration phase is a realistic exercise following real concepts of operations where the AUV is made to carry out a real mission. The outcome of this phase is a platform that will require minimal offshore testing.
- Offshore Tests: Offshore tests are an essential part of the de-risking process. At this stage they form part of a verification process rather than the development

and implementation. They tend to show up small functional issues as the system is exposed to offshore operators as opposed to real faults with the system.

- Offshore Demonstration: The offshore demonstration is a real operation in real conditions. The demonstration if successful confirms the operational capabilities of the AUV and its modules.

When considering the failure modes of an AUV Dynamic Positioning system the designer must include, as with ROVs, breakdown and/or errors of the Dynamic Positioning System, breakdown and/or errors of each of the modules, errors on the input signals from each of the sensors and he must also include possible breakdown and/or errors of the Control System.

As with ROVs such failures should not compromise the performance of the system. These should also be mitigated through a careful design of defensive software. However unlike ROVs, AUVs have no operator to fall back to. Thus the AUV must be programmed to deal with failures and in case of complete software breakdown the AUV must be equipped with the mechanical means to surface in a predictable manner. The failure modes become safe and predictable as the AUV is de-risked through the different phases from simulation to offshore demonstration.

## Operational performance improvements possible with Dynamic Positioning Systems

As with all sectors of the offshore oil and gas business, the ROV business is experiencing significant growth. Successful ROV operations face a number of challenges as detailed below:

- High demand for services
- More complex requirements and missions for vehicles
- Dilution of experience and skill

These factors combined, provide perfect synergy for the effective deployment of subsea dynamic positioning systems. The best use of the system is to assist the pilot with small controlled 3 dimensional vehicle movements, fixed offset movements, or station keeping. The ability to station keep has particular advantages, particularly in a complex work environment where the pilot is expected to analyze data from numerous sensors prior to making the next vehicle move, or when operations are required with the manipulator and pilots need to focus on the manipulator operation, not holding the vehicle on location. Fatigue in these cases could result in longer missions and in the worse of cases the vehicle and onboard systems could be damaged.
To the authors' knowledge manufacturers have not published efficiency figures. Experiments carried out and recorded by BP and SeeByte were published in 2007 and shown below.

| | SeeTrack Offshore (DP System) | Typical Pilot |
|---|---|---|
| Transit 17m | 50 sec | 120 sec |
| Manipulator | 120 sec | 1200 sec |
| Docking | 120 sec | 300 sec |

The results show that the system can provide significant improvements in conventional ROV operations.
The system can also be used to fly the ROV following a pre-determined trajectory. This can be of significant use if needing to carry out a survey or if moving the ROV long distances to a pre-determined position. During these types of operations, the ROV is typically required to maintain constant speed, pitch, roll and heading in order that the highest quality data can be acquired. The use of a DP system in this type of operation offers significant advantages.

AUVs have already proven that they can offer significant time savings and improve data acquisition in site surveys and seabed mapping applications. In the oil and gas sector, the application of AUVs requires the AUV to complete a pre-defined mission. Changes can be made to this mission through communications to the vehicle and interrupting and re-programming the mission. To extend the application of the AUV beyond survey and mapping applications, the control system must be capable of adapting a mission. Trials to date have been undertaken to prove that this is possible. In many cases, this requires the AUV to be programmed with various sub-missions which will be implemented on detection of certain conditions. A good example is pipeline inspection, where the AUV can be programmed to follow a pipeline and record data along the pipeline route. The AUV can be programmed to complete this mission at a normal survey speed. If any anchor scours are detected adjacent to the pipeline route, the vehicle can be programmed to break off from the route, circle back 500 feet and resume survey at a slower speed and lower altitude (allowing higher resolution data to be recorded).

## How can we apply this technology?

### Smarter manipulator operations

Many ROV companies have now implemented ROV DP systems, particularly into their subsea construction vehicles. At this time, the most common requirement for these systems is to provide station keeping during operations, especially manipulator operations. ROV manipulators are operated relative to the vehicle and at the present time, the operation of the manipulator and the ROV are two separate and unrelated functions. For many manipulator operations, this requires the ROV pilot to operate both manipulator and fly the ROV simultaneously in order to place the manipulator on the required point. It would be beneficial in the future to combine these operations into a single task, so that it would only be necessary to operate the manipulator. As a result the ROV control system would be integrated with the manipulator control system in order that the manipulator placement would move vehicle and manipulator from a single control station.

### Higher resolution imagery / data

The ability to better control the ROV as a data and image acquisition platform will allow improvements to be made in resolution and quality. These improvements will result primarily from the stability of the ROV and smoother dynamics of the vehicle (constant speed, rotation etc.).

### Operations in complex environments

ROVs are frequently required to perform complex tasks. These tasks are often located in complex areas. Getting the vehicle to the work location can pose some significant challenges. Consider a crowded subsea environment. Add into this, variable currents, surface movement of the mother vessel and varying visibility.
Once at the work location, the ROV pilot is then expected to maintain vehicle stability and perform the work task. An available ROV DP system can be used by the pilot throughout the operation as a guidance tool or a station keeping tool in order to reduce pilot stress and fatigue.

### De-skill ROV Operations

The introduction of ROV DP systems has widely been seen as a tool which can enable less experienced pilots to accomplish complex tasks with the vehicle. It is important to note that an ROV DP system cannot transform a complete novice into an experienced ROV operator; it does however enable pilots with less experience to perform tasks which would normally require many years of ROV operations.

### Reduction in ROV size

Most work class ROVs in use are fairly large. A number of factors influence vehicle size including propulsion power, payload capacity and tooling power. The use of small ROVs has typically been restricted to visual inspection or “eyeball” operations. As a vehicle is reduced in size, the vehicle becomes much more agile and responsive to operator controls. This can be an advantage, but can also result in lower vehicle stability, especially when coupled with less experienced operators. The addition of an ROV DP system can aid with vehicle stability.

### Take the AUV beyond mapping

Current commercially available AUVs provide an excellent solution to seabed mapping. This is in large part due to the fact that mapping the seafloor is a task which can be pre-programmed. The completion of tasks beyond mapping requires the AUV control system to be more adaptive and be able to respond to the immediate environment. The vehicle can no longer only operate according to a pre-defined track and onboard navigation sensors. The control system is required to also understand seabed infrastructure and its position in relation to this. A combination of absolute and relative position and control is required.

### Intelligent AUV inspection

In order to take full advantage of the autonomous vehicle, a degree of intelligence must be built into the system. This will allow the vehicle to respond appropriately to the environment and to the task. This is an area of particular interest for facility integrity management, where the purpose of inspection is to identify any abnormalities or changes. Once a change or abnormality is detected, more information is required. At this point, the AUV will follow pre-programmed routines to react to the abnormality. These routines could range from returning to host to download information, communicating with host, or returning to site of abnormality to acquire further information. The long term goal of AUV operations is to reduce the amount of on site operator intervention required; hence the importance of the onboard control system and the ability to deliver as much intelligence in decision making as is practically possible.

## Conclusions

The use of ROVs is now widespread in the offshore oil and gas industry. It is rare to go onboard any vessel or rig which does not have an ROV of some kind. In contrast to this, the use of AUVs is still limited and most are installed and operated from a limited number of specialist vessels.

ROV's and AUVs are fundamentally different in that the ROV allows real time operation via umbilical. An AUV on the other hand offers minimal real time control, other than the ability to interrupt the mission. While this difference is obvious, it is an important point when considering the application of DP or control systems to each. To be effective, an AUV control system will always require a greater level of intelligence. In reality, this will require the AUV to be pre-programmed in order that it can respond to a variety of circumstances. This is very much an ongoing research and development area. The successful development and deployment of this capability will draw heavily on achievements with ROV DP.

ROV DP however is now very much a reality, with most ROV vendors and operators having access to some form of DP system. The ROV has always had a number of Auto functions (depth, heading etc.) and to date, the ROV DP system has largely been deployed and viewed as an extension of these functions. To use the system to its full capabilities will require a change of mindset and a move away from the view that it is just another vehicle auto function. As with a vessel DP system, the ROV DP system must undergo a series of performance tests and evaluations before use. These tests are important to determine that the system is performing as intended. They are also however important to quantify the performance of the system so that the operator knows what the capability of the vehicle under DP control is. In the same way that a vessel is required to undertake periodic DP system tests, an ROV should also be required to perform periodic performance assessments. This allows the vehicle operator to understand the capability of the DP system and any issues. It also provides assurance to the owner of the asset where the ROV will operate that the vehicle will perform in a controlled manner. Testing of the ROV DP system needs to occur, but this testing should be kept to a sensible and appropriate level. While it is unlikely that an extensive test similar to that required of a surface vessel will be required, it is important for everyone involved to understand whether the vehicle can hold station to within 3 feet, 10 feet, 50 feet and how this capability will change with changing payloads and environmental conditions. After all, a DP system which holds the vehicle on station to +/- 10 feet will provide no benefit to our operation when we are 5 feet away from subsea hardware.

The introduction of DP systems to ROV operations has been very successful in terms of the initial system implementation and deployment. Based on this success, systems can now be refined and improved to further assist the ROV pilot and extend the effectiveness and efficiency of the ROV.

## References

1) – David Saul, Ioseba Tena, “BP’s AUV Development program, Long Term Goals – Short Term Wins”, Oceans 2007, 2nd October 2007, Vancouver, Canada.

2) Ioseba Tena, “A new ROV DP”, Dynamic Positioning Conference Houston, October 9-10 2007, Texas, US.