DYNAMIC POSITIONING CONFERENCE

September 28-30, 2004

Sensors

Dynamic Positioning and WROVs: A Productive Union

Richard Gross

Schilling Robotics, Davis, California U.S.A.

Return to session directory

Abstract

Dynamic positioning (DP) has been used by surface vessels for over 20 years with great success. No one can now imagine doing typical oil field construction work from a vessel that lacks this capability. DP has also increased the capabilities of AUVs. However, DP has generally not been used on commercial work-class remotely operated vehicles (WROVs), though several research organizations (such as Woods Hole Oceanographic Institution) have implemented DP on their ROVs. Implementing DP on a WROV produces the same effect that DP has in other realms: improved safety and efficiency.

This paper describes the DP system of the Schilling Robotics Quest WROV. The paper discusses real-world WROV tasks that have been performed with Quest, and notes the benefits provided by the union of the WROV and DP.

Specifically, the paper discusses:

- The characteristics of a DP-capable WROV control system
- DP implementation on the Quest WROV
- Use of DP to perform typical WROV tasks
- The future of DP on WROVs

Characteristics of a DP-Capable WROV Control System

In this paper, DP refers to a vehicle control system with the following characteristics:

- Using its own propulsion system and sensors, the vehicle can remain stationary (within a radius of a decimeter in x and y about the set point) for an unlimited time. (However, the maximum power of the propulsion system is a limiting factor in compensating for ocean currents.)
- The vehicle can accurately displace (move to) another location in the x, y, and z axes, and upon arriving at the new location, can remain stationary. Furthermore, the vehicle can perform this displacement while in an arbitrary yaw orientation.
- The vehicle can automatically follow a set of way points created either statically or dynamically. An example of a statically created way point path is a preplanned path using survey data. An example of a dynamically created way point path is pipe or cable tracking.
- The vehicle can accurately report the distance and vector between two points on or near the seafloor.
- The vehicle can adjust the DP set point using a proportional input device. This “rate mode” allows the pilot to fly normally until he nulls the input device, at which point the vehicle automatically holds position.

Figure 1 In station keeping, the system's ability to withstand currents is limited by the propulsion power of the WROV

DP on the Quest WROV

To perform DP, the Quest WROV control system uses sensors, a control model, and actuation equipment.

Sensors

DP on the Quest WROV is built around a Doppler velocity log (DVL), which supplies information about the WROV’s velocity relative to the seafloor. The DVL also supplies altitude and water velocity information. The standard DVL used is the RD Instruments Workhorse 1200, which pings at 1200 kHz . The update rate to the control system is about 9 Hz and varies slightly depending on the range to the seafloor. This DVL has a range of about 35 m; other models with lower ping frequencies have a greater range.

Space considerations prevent the DVL from being mounted at the vehicle's center. Instead, the DVL is mounted on the centerline but near the vehicle front, and software is used to remove the translational components generated by yaw movements so that the DVL appears to the system to be at the vehicle's rotational center.

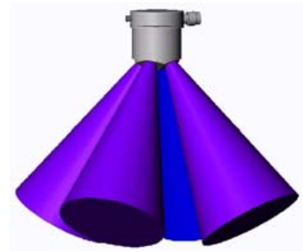


Figure 2 A Doppler velocity log provides data for dynamic positioning

The system is augmented by a motion reference unit (MRU) that provides pitch and roll angles; pitch, roll and yaw rates; and x, y, and z accelerations. The MRU is a Crossbow 700CA model, and is sampled at 40 Hz. The pitch and roll angles are used to correct the range data supplied by the DVL, and to provide the basis for the body-to-inertial-frame transformation. The currently fielded Quest systems use simple filtering, but do not integrate data from the different sensors. The current version applies Kalman filters to the sensor suite, and this appears to provide significant benefit in simulations and pool tests.

Control Model

Numerous models are available for controlling both position tracking and trajectory tracking of robotic underwater vehicles.[1] These models include Linear Control- PD and PID, Nonlinear with Exact Linearization, and Nonlinear without Linearization. The last two also have adaptive models. The Quest WROV uses the PID model with further modeling of the actuation system, but no attempt is made to model the drag, Coriolis force, or buoyancy force.

The Quest WROV uses a body-frame-to-inertial-frame linear transformation based on the angles supplied by the MRU. The control system sums all the forces acting on the system and creates a resultant thrust vector. The system uses an affine transformation that decomposes the resultant thrust vector into the components that are used to drive individual thrusters. The system uses a thrust-to-speed transformation, ensuring that each thruster supplies the correct amount of thrust.

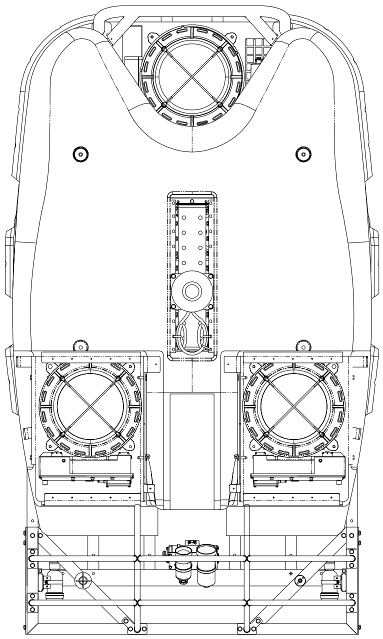
The control system uses closed-loop control of both position and velocity. The former is commonly used. The latter can be used to apply a dynamic brake to the system, such as when the pilot nulls the input control device. The control system also provides pitch and roll compensation, producing a very stable platform. The system incorporates some *a priori* knowledge, such as knowing that the vehicle will pitch up when commanded forward. The system injects a force to counter this pitch moment, keeping the platform stable under hard accelerations.

The system also uses a proprietary trajectory generator based on velocity tracking. Field testing and field reports indicate that the vehicle tracks very well, never deviating more than ±1 m from the desired path in cross currents. Field reports also indicate that the trajectory generator is accurate, performing moves of 60 m or more within a decimeter of the desired destination.

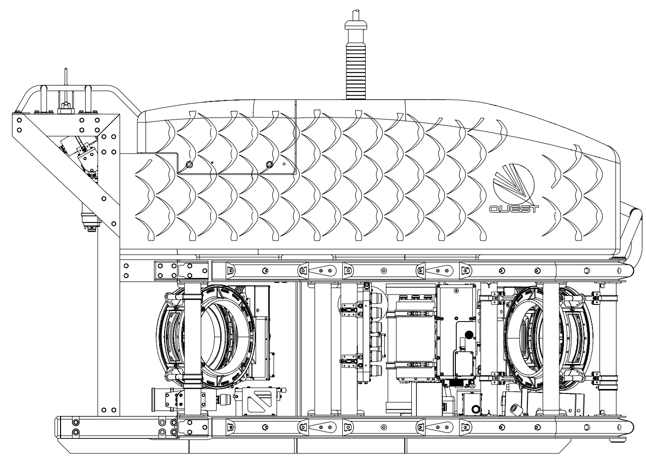
Actuation

Both the electric Quest WROV and the Quest Ultraheavy-Duty hydraulic vehicle use seven thrusters, four mounted laterally and three mounted vertically. The vertical thrusters provide both vertical movement and dynamic control over vehicle pitch and roll.

[1] David A. Smallwood and Louis L. Whitcomb, "Model-Based Dynamic Positioning of Underwater Robotic Vehicles: Theory and Experiment," *IEEE Journal of Oceanic Engineering*, Vol. 29, No. 1 (January 2004).



Top View (vertical thrusters)



Side View (horizontal thrusters)

Figure 3 Thruster placement in the electric Quest WROV

Both the electric ring thruster used on the Quest and the hydraulic thruster used on the Quest Ultraheavy-Duty vehicle are updated at 20 Hz. Both thruster types have local electronics that close the speed/thrust loop. The electric motor controller on the ring thruster has an acceleration rate of over 2500 rpm/sec/sec, allowing quick changes in speed and direction. The hydraulic thruster has a custom speed sensor and local control over the thruster pressure and flow, and uses a feed-forward scheme to ensure quick response to speed changes. The electronics can also null any bias that may develop in the motor.

Typical WROV Tasks

WROVs generally perform three types of work: observation, intervention, and construction. In these categories, DP assists with many tasks, including:

- General operations
- Performing manipulator work close to a subsea structure without having to stabilize by grabbing onto the structure
- Accurate deployment and retrieval of subsea equipment
- Accurate grid searches and surveys
- Operation of subsea manifolds using remote energy sources
- Easy interception of down-lines and loads by holding relative position and moving up and down
- Maintaining position during deployment of heaving loads that disturb the seafloor (causing poor visibility)
- Maintaining position during lengthy observation tasks
- Maintaining position and camera view while waiting for infrequent events

General Operations

Sometimes DP is useful simply to give the pilots/operators a break, as illustrated in the following field note:

> *I just wanted to add another similar but common use of the station keeping. We often use it to just hold the vehicle in place while the operators are busy stowing or deploying the manipulators or tooling. They can concentrate on getting the ROV in or out of operating mode while not having to manage the ROV position at the bottom. Or even checking other things like the sonar, survey screen, tether or TMS, all distractions that can cause the operator to lose sight of the work location.*
>
> *We often use the pan and tilt camera to stow the manips, so you can be distracted from the work site while doing this. The station keeping takes the difficulty out of staying in place at the job site, while concentrating on other ROV tasks and operations.*
>
> *Some operators cannot multitask, so DP allows them to single task and hence provide good quality operations.*

Stabilizing the WROV Without Grabbing Onto a Structure

WROVs are fitted with at least one manipulator, and most have two. One of these manipulators is frequently used to grab onto a subsea structure to maintain the WROV's position, typically while work is performed with the other manipulator. This stabilizing technique can result in a variety of problems:

- In high-current conditions, the grabber arm can damage the subsea structure or itself.
- Many older subsea hardware systems were not designed for grabbing, and provide no convenient attachment point.
- The grabber does not hold the WROV still, but rather acts as a pivot point while the rest of the vehicle responds to forces exerted by the manipulator or currents.
- Subsea structures often have multiple valves with limited spacing between them, requiring exceptional vehicle stability to avoid accidentally bumping other valves with the manipulator.

DP makes close-quarters work much easier by providing a stable platform without the use of a grabber arm, as related below:

> *Quest 3 recently completed work for [client] on the Gunnison Spar project in May aboard the Cal Dive MSV Intrepid. StationKeep was effectively used to perform manipulator-intensive operations on a PLEM [pipeline end manifold] in 3,800 fsw. No ROV manipulator grab points were available on the PLEM, so StationKeep was engaged approximately 1 meter from the valve panel.*
>
> *Manipulator operation included hot stab work and operation of sensitive subsea valves. Valve spacing was tight and the manipulator operator was directed realtime by the client representative to operate a particular valve without touching any other valves. If any adjacent valve was "bumped" it would open and nullify the test. StationKeep provided a stable ROV platform, enabling the operator to successfully operate*

Figure 4 The Quest WROV on the Gunnison Spar

Figure 5 DP is useful for manipulator intervention near closely spaced valves

valves and engage hot stabs as directed by the onboard client rep. StationKeep basically enabled critical path operations on the vessel and platform to be successfully completed in real time...

Accurate Deployment and Retrieval of Subsea Equipment

Equipment (such as a transponder array) is often deployed on the seafloor before a task is begun. Generally, the WROV operator knows the desired locations for this equipment before the vehicle is deployed. Since Quest's DP is relative (that is, the system does not currently have GPS-like knowledge of absolute position), survey data and surfaced-based locating equipment can be used to pinpoint the first location. Once the WROV is at this location, it can use the DP displacement function to place the other equipment. This placement is much more accurate than placement performed using surface-based techniques, particularly when the subsea equipment is being placed at great depths. Also, retrieval time for the placed items is greatly reduced; instead of searching an area for the equipment, the pilot uses surface-based techniques to find the first location and then uses displacement to retrieve the remaining equipment. This technique works even when visibility is very poor.

Making "Hot Stab" Connections

A common task for an WROV is to connect via a "hot stab" to a subsea structure that requires power (either electric of hydraulic) to be transferred to it from a remote source. Electrical power can come from a subsea umbilical (often connected to a oil platform), while hydraulic power typically comes from the WROV's hydraulic supply.

Figure 6 A typical hot stab device
Photo courtesy of Canyon Offshore Inc.

When hydraulic subsea tooling must be operated using the WROV's hydraulic power, a probe (called the hot stab) is connected to the WROV's hydraulic supply through a valve pack. The hot stab is mounted in a socket on the WROV frame. The preferred way to perform the connection is for the operator to first stabilize the WROV, use a dexterous manipulator to remove the hot stab from the socket, and then maneuver it into to a similar socket on the subsea manifold. Once the connection is made, hydraulic operations are controlled through the WROV's valve pack.

This operation is much more difficult when the ROV cannot be stabilized. The manipulator arm holding the hot stab must be frozen into position at the front of the WROV, and then vehicle propulsion is used to carefully fly the hot stab into the socket. If the pilot overshoots the connection, the manipulator is exposed to the full inertial force of a 3-ton WROV.

In hot stab operations, station keeping is clearly a valuable asset for stabilizing the WROV. Even though newer subsea tooling frames often have an "ROV-friendly" handle that the WROV's grabber arm can grasp to steady the vehicle, DP provides superior stabilization for delicate operations.

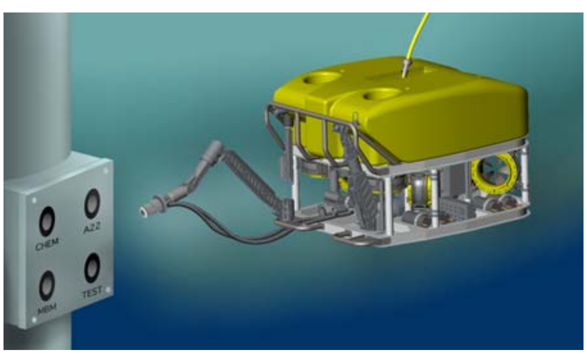


Figure 7 When the WROV is stabilized with DP, the manipulator can insert the hot stab

Accurate Grid Searches and Surveys

The displacement feature allows the operator to perform extremely accurate, automatically controlled movements. The pilot can enter the desired displacement in x, y, and z or can enter a distance at a particular heading. The vehicle then moves in the appropriate direction for the commanded distance, with accuracy measured in centimeters. Upon arrival at the new location, the vehicle maintains position until the pilot commands another displacement or invokes manual control. The pilot can set a maximum velocity for the displacement.

With this capability, the WROV can make searches and surveys with accuracy similar to an AUV's. Unlike an AUV, however, the WROV with its telepresence can easily and quickly change the task's parameters based on what the pilot encounters in his search. For example, if an AUV is programmed to search for an anchor that has been dragged off position, it must first fly cameras in a preprogrammed search pattern, and then a human must review the resultant video. However, if a DP-capable WROV performs the search, it can conduct same an extremely accurate grid search of the area, but the pilot can monitor the camera view in real time and terminate the search as soon as the anchor is found.

Interception of Down-Lines and Loads

In construction work, WROVs are frequently used to guide a surface-deployed cable to a desired location. This task normally requires the WROV to meet the cable coming down from the surface at a position about 25 m above the seafloor. The pilot uses a manipulator to grab the cable. The pilot then flies the vehicle down to the seafloor and searches for the cable's intended destination. This search can be very time consuming, particularly when visibility is poor.

With DP, however, the pilot can first locate the desired location for the cable, enable DP, and then displace upwards to 25 m above the seafloor, maintaining the same x, y position (see Figure 6, next page). Using sonar, the pilot finds the cable and calculates the distance and heading from the WROV's location. Using displacement, the pilot commands the vehicle to move for the calculated distance, and grabs the cable with a manipulator. The pilot then reverses the previous displacement to move laterally back to the cable's desired location, and displaces down to the seafloor to arrive at the cable's destination point. All this can be done when visibility is very poor, a typical condition in seafloor construction zones.

Maintaining Position During Deployment of Heaving Loads

WROVs are often required to monitor pipeline touchdowns, providing visual confirmation that the pipeline is being laid in a clear, planned location. This task is relatively easy when visibility is good. However, visibility is often compromised when the surface vessel heaves, causing the pipeline to surge and stir up sediment. Deploying DP can greatly reduce crew stress in such a situation; by maintaining a known, safe distance from the pipe, the operator doesn't have to worry about letting the WROV collide with the pipeline, or letting the vehicle or its tether drift under the pipeline. Instead, the crew can focus attention on the camera and sonar views of the touchdown point.

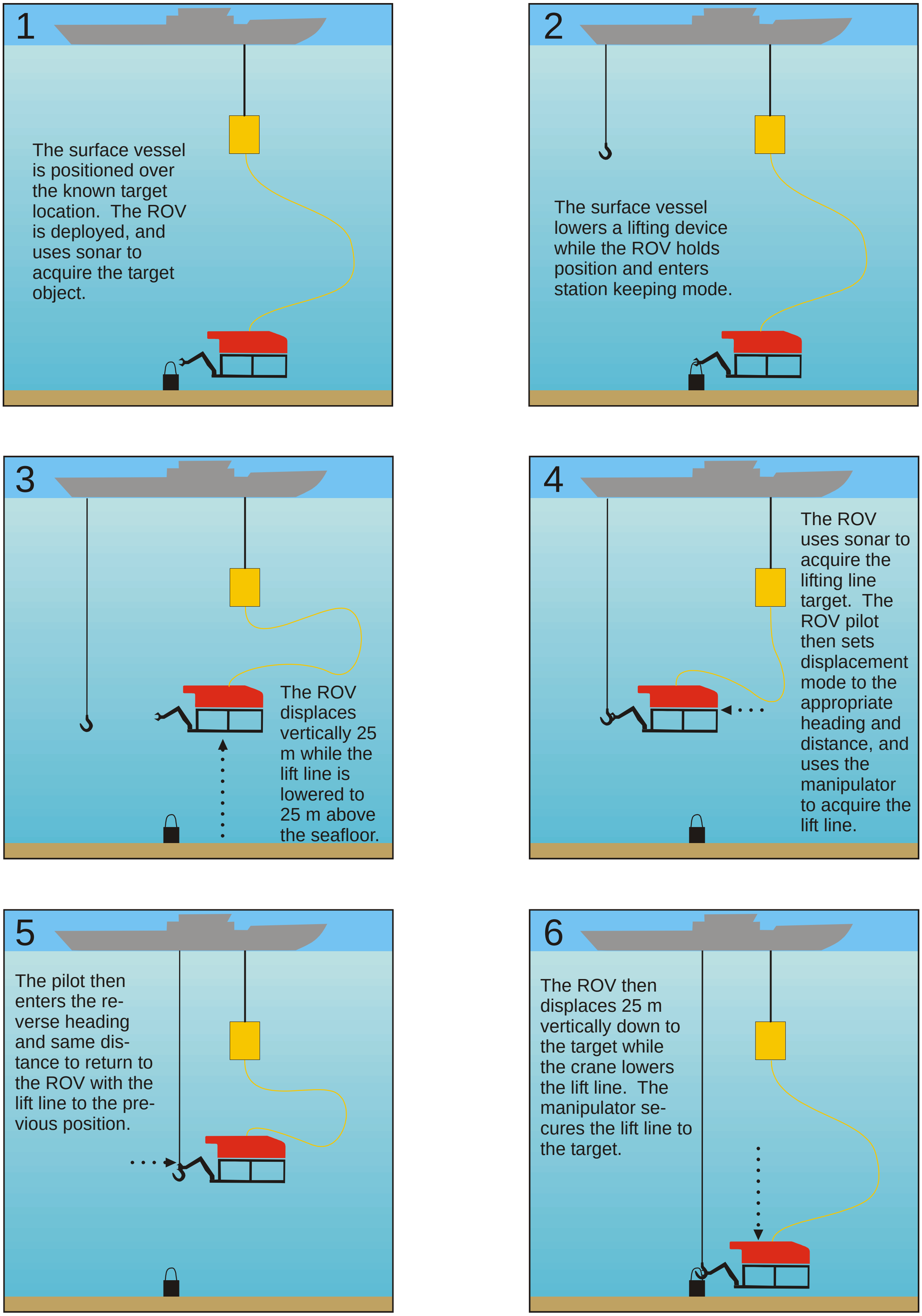


Figure 8 DP assists with down-line tasks

Maintaining Position During Lengthy Observation

WROVs are commonly required to maintain position and observe a task site for hours and even days at a time. (One such oil field operation is called "spudding in.") A note from the field explains:

> *On this job supporting drilling operations, station keeping comes in very useful when we start a new well as they drill open hole and the ROV has to monitor the drill shaft and entry to the casing at the seabed for any gas returns, just in case they were to hit a shallow gas pocket. This is critical as a large amount of gas could sink the rig. So the ROV is on station for 1-3 days during this operation monitoring the well, this period they call "spudding in". Visibility can be affected here and station keeping just holds you in place until it clears up again and you spot the drill bit. When visibility is low you confirm that you are holding location with station keeping by using the sonar. So it is used here to keep the ROV close to the drill bit and watch for gas. It makes it easier on the equipment too, as you are not thrusting all about the place once you loose visibility and try to return to the well. It has the thrusters just ticking over holding station. As you can see, a drill bit spinning very fast in front of you is a scary thing, a tether and ROV killer, so panic can set in if visibility is lost. But with station keep nerves are relaxed, you monitor location with sonar and don't drift anywhere you don't want to be.*

Maintaining Position and Camera View

When new wells are drilled, the well operator has the casing cemented in place. Usually, the top of the casing is above ground and the WROV must be several meters off the seafloor to see the top of the casing. In this case, a pilot cannot use a standard technique for keeping the WROV still (putting the vehicle on the seafloor and applying downward thrust). Instead, the pilot must maintain position while looking at the top of the casing, waiting for the cement to reach the top. With DP, the pilot focuses on viewing the cement overflow, not on holding position. Because this task takes at least several hours, it results either in a stressed crew (without DP) or a "relaxed, ready-for-the-next-task crew" (with DP).

Another example of this type of work comes from the field:

> *Another great benefit is that we usually have to monitor some return port or latch indicator from minutes to hours, while the rig crew operates some valve or equipment.*
>
> *Usually the camera is zoomed in to look at this specific spot waiting for change, so the ROV operator must hold station. Now "free flying" or on "Auto's" with the zoom right in on a spot is very demanding for the pilot to give a good picture. A small movement on the ROV is a big movement in the camera frame. But with station keeping, the stress is taken out of the operation, the camera is held right on the spot it needs to be. The client is happy when he see the change, in that one second that you just waited an hour to see. With free flying, you can miss that quick change if you are not on the ball.*

The Future of DP on WROVs

What does the future hold for DP on WROVs? We envision much more integration with existing technology to provide new capabilities.

Absolute DP

To achieve absolute DP (instead of the relative DP currently used on the Quest WROV), a vehicle-mounted transponder could allow the loop to be accurately closed with the position of the vehicle relative to the surface vessel.

Multi-WROV DP

For tasks that require two WROVs working cooperatively, DP could increase vehicle coordination. A master controlling computer would be required for communication with the vehicles' control systems, to issue joint commands and incorporate vehicle feedback to coordinate the work task. This feature would be useful in tasks such as jumper installation, where the WROVs on the ends of the jumper would know where they were in relation to the seafloor, the jumper, and each other.

Midwater DP

DVLs are a limiting factor in WROV DP because they can be used only within 100 m of the seafloor. Achieving DP for the rest of the water column will be challenging, since a transponder's accuracy and update rate may be insufficient for an accurate and reliable DP system. New technologies may be required to support DP for midwater tasks.

Vision-based dynamic positioning could provide significant benefits, as could sonar-based precise local positioning systems.[1] However, there are frequently no fixed reference points in mid-water, and the lack of visibility would make it difficult for a vision based-sensor to work. Fusing transponder technology with other technologies via Kalman filters might provide adequate performance.

Another possibility for midwater station keeping involves fiber optic inertial navigation systems (INS) that integrate information from gyros and accelerometers. These systems have been used successfully on AUVs, and could be adapted for WROVs. An onboard microprocessor is typically required to process the INS information, and some units have Kalman filters that adjust for navigation errors caused by combining various sensor inputs.

The U-PHINS, an INS for AUVs developed by Ixsea-Oceano, appears to be a good candidate for midwater station keeping for WROVs.[2] The unit includes three fiber optic gyros, three accelerometers, a real-time calculator, and a Kalman filter. In conjunction with ultrashort baseline (USBL) sonar and long baseline (LBL) sonar, the U-PHINS should provides adequate data for midwater DP. U-PHINS can also incorporate GPS information from the vessel, allowing absolute DP.

Position Storage and Recall

A DP system that could store and recall positions and automatically displace between those positions could be very beneficial to WROV operation. The integration of sonar with the DP system could allow the pilot to designate a destination on the sonar system, and the vehicle's control system would then use the vector and distance to displace to the target. However, any system for automatic displacement would require the addition of a collision avoidance system.

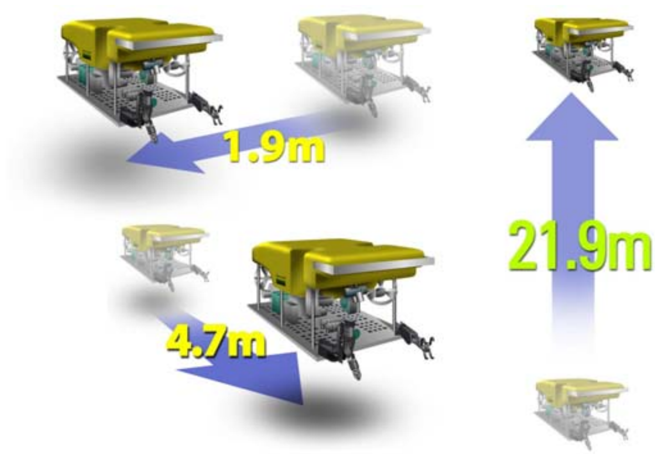


Figure 9 Automatic displacement would further enhance station keeping in WROVs

[1] Yves Chardard, Pierre Marty, Erich Luzi, and Robert Baker, "The Hybrid AUV/ROV Swimmer: A Cost-Effective IMR Alternative," *Conference Proceedings, Underwater Intervention 2004*.

[2] Thierry Gaiffe, "U-PHINS: a FOG-Based Inertial Navigation System Developed Specifically for AUV Navigation and Control," *Conference Proceedings, Underwater Intervention 2002*.

DP for WROV Tools

DP in the WROV would be enhanced by similar capability in the vehicle's tools, such as manipulators and pan and tilt units.

In the case of manipulators, simple dynamic control of the position and orientation of the end effector would make it a more effective tool for the WROV. For even great effectiveness, WROV DP and manipulator DP could be integrated. For example, a laser pointing device could designate a target, and the vehicle and the manipulator could coordinate vehicle propulsion and arm joint movement to fly the end effector to exactly the correct location and in the correct orientation.

DP techniques could also be used to control cameras and their pan and tilt systems. For pan and tilts, the point to track would be designated by a laser pointing device, and the vehicle control system and the camera's pan and tilt system would work together to keep the set point in the camera's view.

Summary

Using DP on WROVs has proven to save significant time on a large variety of tasks, and also creates a much safer environment for the equipment. It also significantly reduces operator fatigue, leading to fewer mistakes in vehicle piloting. We believe that DP on WROVs will soon become standard. One message from a WROV superintendent states:

> *For many years, ROVs have been fitted with automatic systems for holding heading and depth, and these have become accepted as minimum requirements. Due to the advantages that "Stationkeep" offers in improving the efficiency of ROV operations, it is felt that this too could become a standard feature required by operators and clients in the future.*

The use of DP on WROVs is not limited to the oil and gas industry; science and military vehicles would similarly benefit. A field note by a science user states:

> *I just wanted to let you know that yesterday's dive went very well. We actually stuck a sensor package right into the heart of a black smoker vent. It was incredible, and it was also possible because station keeping worked extremely well. Even with cable drag and a boat that couldn't hold station to within 100 meters, we were able to hold the Quest on site for several hours.*

A researcher returning from a month-long science expedition in the mid-Atlantic states:

> *Once you experience this type of controllability for an ROV, it becomes what I consider a new benchmark, or standard for scientific vehicle functionality.*

We believe that DP on WROVs will revolutionize the performance of many subsea tasks and provide better value for WROV owners and users.

Acknowledgements

The author thanks Chris Legg, Greg Engemann, Dave Kelman, Jason Stanley, and Chris Grech for their input.