

Remote Control of Unmanned Undersea Vehicles

Dr Henry Robinson

Dr Alison Keary

H Scientific Ltd, U.K.

INTERNATIONAL UUV SYMPOSIUM

International Unmanned Undersea Vehicle Symposium

April 24-28, 2000

Viking Hotel

Newport, RI 02840

Abstract

This paper overviews the latest advances in our research and development programme in undersea vehicle control. The paper describes a powerful remote control and monitoring system for both undersea and surface vehicles. The system is based upon a set of self-tuning autopilots for transit, waypoint following, and four modes of dynamic positioning. The system is flexible, allowing the user to adjust the link bandwidth usage down to minimal and even zero during a mission. The dynamic positioning system provides four types of automatic hover control, including a minimum-power mode. Self-tuning applies to all control modes, and this allows the vehicle autopilot parameters to be adjusted automatically even when the vehicle dynamics are altered, e.g. after picking up or dropping a payload.

This approach to remote control is powerful, since it minimises operator workload by providing a high-level interface. The vehicle mission can be altered at any time using a graphical mission-planning screen which includes an electronic chart of the mission area. The new mission parameters are automatically downloaded to the vehicle and low-level vehicle control is performed by the on-board autopilot, leaving the operator free to concentrate on high-level decisions.

The paper outlines how the system can be adapted to suit a variety of vehicle configurations, by setting up the vehicle parameters on a simulator and then downloading a configuration database to the vehicle unit.

The paper presents both simulation results and some initial sea trials data.

Introduction

The use of autonomous and remotely operated vehicles for subsea measurement and monitoring as well as other tasks, is a rapidly growing field. Recent surveys of remote-controlled underwater vehicles¹ list over 90 manufacturers and about 300 vehicles, which are used for a wide range of tasks including rock dumping, mine hunting and destruction, payload testing, survey and inspection, and cable burying.

One of the key technologies which underpin this field is that of remote vehicle control. It is vital that a vehicle should be capable of proceeding accurately to a target area; manoeuvring within that area to fulfil its mission; and returning equally accurately and safely to base.

A very real challenge, in the subsea environment, is the limited bandwidth available for telemetry and remote control. Since electromagnetic techniques are effectively out of the question in many cases, or require the use of an umbilical cord of some sort, telemetry and remote control

often require the use of acoustic methods of data transmission. Acoustic techniques, however, become limited in range as the frequency is raised, or in bandwidth as the frequency is lowered. This places limits on the data rates and distances that can be accommodated using acoustic telemetry.

This paper introduces the remote control autopilot which has been developed for AUV / ROV application and describes the configuration methodology to produce a generic remote control autopilot. The results from simulations and sea trials are discussed.

Overview of the remote control autopilot

The system is separated into the remote control operator workstation and the autopilot, shown in Figure 1. The low-level control of the actuators and control surfaces is performed either wholly or in part by the autopilot which is located on board the vehicle. The operator workstation, which may be located on land or on a support vessel, is used to plan missions, to send high level commands to the autopilot on the mission, and to monitor the progress of the vehicle. The workstation and autopilot communicate via a low bandwidth link. This system, combined with an efficient serial data protocol, reduces the data traffic between the workstation and the autopilot.

The system is designed to allow the autopilot algorithms to be configured to control the particular arrangement of propulsors and control surfaces on the AUV. The autopilot therefore provides a commercial off-the-shelf system (COTS) which can supply remote control function on a generic basis. The configuration methodology utilises the AUV simulator which was developed during this programme.

The system incorporates a new range of self-tuning autopilot algorithms, including heading and speed control; track keeping (waypoint following); point and area hovering with and without operator-imposed heading setpoint; controlled drift and rotation on a hoverpoint or within a hover area; together with roll, pitch and depth control.

The system was developed on PCs, using the Windows operating systems; the remote control panel runs under Windows while the autopilot algorithms, on the vehicle, run on an embedded processor. A full vehicle simulator allows the system to be tested and modified to suit different vehicle configurations.

The functional components of the system are described in more detail in the following sections, together with the development of an AUV simulator.

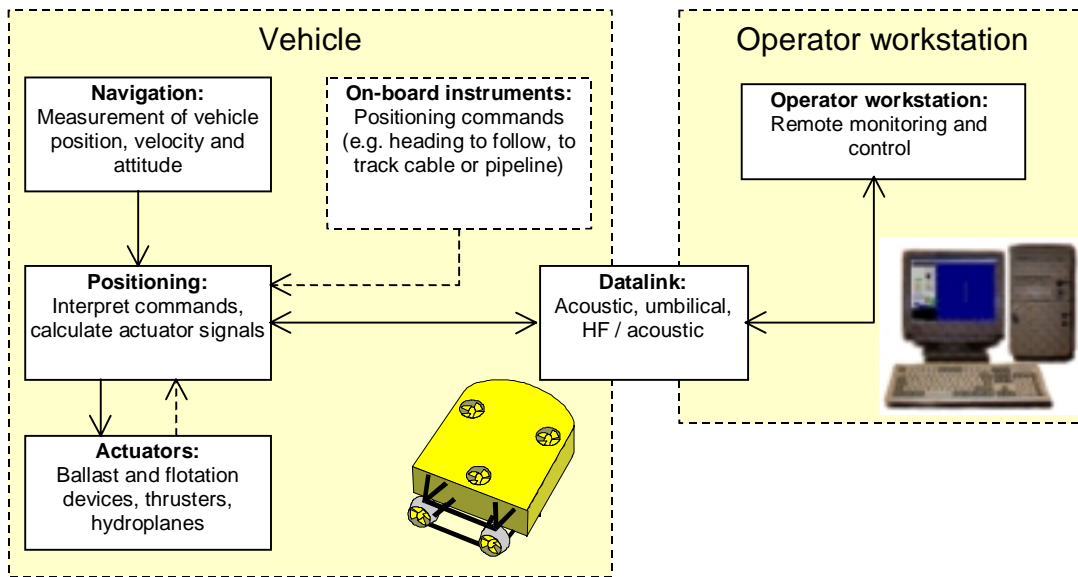


Figure 1: Block diagram of the navigation and positioning functions

Autopilot

The autopilot, located on the vehicle, receives commands from the operator workstation. This is combined with the navigation information from onboard instruments, such as velocity sensors and inertial navigation system (INS) and converted into control signals for the actuators and control surfaces.

The system uses a closed loop controller to control the position and speed in six dimensions, namely three linear, and three angular degrees of freedom. While this might seem a daunting task, in practice it can usually be solved by means of several separate controllers. For instance, separate controllers may be used to regulate the angle of roll and pitch angle.

Determining the connections between the autopilot outputs and the vehicle actuators is a relatively simple task on a surface ship: there is usually one actuator which moves the rudder, which in turn controls the yaw rate and heading. However, on an underwater vehicle, control may be more complicated. For example, in the case of a vehicle equipped with two thrusters mounted aft, and two horizontal hydroplanes near the front, yaw and heading are controlled by differential thrust; and forward hydroplanes control the vehicle attitude. This problem is addressed by defining relationships which translate the fundamental force requirements into actuator control signals using a model of the vehicle configuration. These conversions are carried out in the Control Allocation Module (CAM). The relationships do not need to be exact, since inaccuracies are effectively eliminated by the closed-loop nature of the control system. A slight

mismanagement of the yaw-roll interaction, such as might occur when turning at speed, may give rise to a slight rolling motion; this roll, detected by the on-board sensors, causes the controller to generate a corrective roll signal, which restores the vehicle attitude. This robustness is an important feature of the autopilot, because the behaviour of the actuators (including cross-coupling effects) is usually dependent on the vehicle speed.

The autopilot algorithms have the capability to self-tune, in which they learn the vehicle response characteristics and self-adjust the control parameters to achieve rapid, precise control without over-shooting. The self-tuning algorithm adjusts the controller to near-critical damping, by performing a series of manoeuvres during which the autopilot issues a series of control signals and the vehicle responses are measured. The procedure is comparatively swift, and depending on the size and control characteristics of the vehicle, takes of the order of a minute or two to complete. The heading controller, for instance, is tuned by performing a short manoeuvre involving a zigzag and straight-line sections. Variants of this self-tuning process are used for tuning the speed control, forward and lateral position control, roll and pitch and hover controllers.

The ability to self-tune is an important feature of a generic autopilot unit, making the system applicable to a wide variety of vehicles. Self-tuning may reduce the commissioning period by many hours and even days. It is also a useful feature for any craft which is apt to alter its characteristics, for example by collecting or dispensing a payload or by being fitted with a new scientific instrument; or even in the event of an actuator failure.

Autopilot algorithms have been developed for the following modes of control in the horizontal plane: heading following, waypoint following, hovering, either on a setpoint or within a defined area, and low-speed movement relative to a datum. Altitude and attitude control is superimposed on these; this may be achieved using an independent roll and pitch control algorithm to keep the vehicle at a given depth setpoint, within a prescribed range. The setpoint may be continuously updated using data from an altimeter, if it is required to follow the seabed at a fixed distance.

Any of these modes may be implemented using an autopilot system, a remote-operated manual system, or a combination of the two.

The ability to hover, or to travel at low speed, is an important requirement for many AUV and ROV missions. This needs to be possible in still water and in the presence of currents. The control system provides four hover modes, which are characterised according to whether the vehicle heading is determined by the operator, or set by the controller in such a way as to minimise propulsive power. The hover modes are further classified into point-hovering and area hovering algorithms.

The choice of vehicle heading may be crucial if the vehicle is attempting to hover in the presence of a significant current, in which case, a considerable power saving may be achieved by hovering either into-tide or down-tide. Hovering into-tide is generally preferable as the propulsors and control surfaces are operating in their most efficient regimes and any disturbances, which may interfere with the operation of sonar, optical or other sensors on board, are minimised.

Figure 2 is extracted from the mission planning and monitoring display and shows the electronic chart with waypoints, hover area and danger areas.

The point-hovering algorithm may appear to be the obvious choice in many situations, but it may not be the most energy-efficient algorithm and may result in unwanted oscillations about the setpoint. This may result from continual and cyclic or random disturbances such as those encountered close to the sea surface in appreciable sea states, a non-optimal configuration for a controller or actuator, or erroneous fluctuations in the reported vehicle position. Under these conditions, an area hovering algorithm may offer a substantial saving in power usage by the propulsors and other actuators and offer acceptable performance in terms of accuracy. Under certain conditions, the actual position variations may actually be smaller than those obtained using an equivalent point-hover algorithm, because, in the presence of errors in position fixing, the area hover allows the vehicle to remain relatively undisturbed while the point-hover algorithm drives the vehicle to and fro in response to each erroneous position fix.

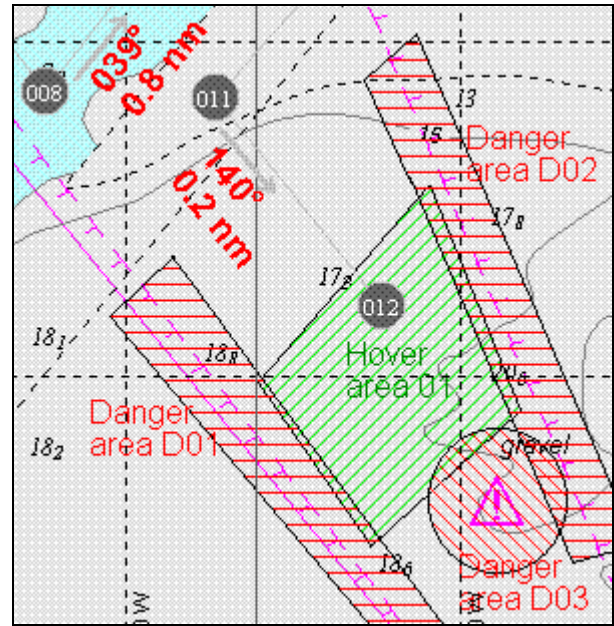


Figure 2: Vector chart overlaid with waypoints, a hover area and danger / avoidance zones

Remote control workstation

The remote control workstation provides the operator interface which can be used to configure the autopilot for a particular vehicle and to control the vehicle and monitor its performance.

The configuration data, used in the autopilot to translate high level commands into machinery controls, is obtained using the AUV simulator to model a particular arrangement of actuators and control surfaces. This is downloaded to the autopilot and may be refined using self-tuning manoeuvres.

Given the wide range of mission profiles which has already been mentioned, it is necessary for the remote control system to be as flexible as possible. This is achieved by providing a range of control commands. These include the lowest level (“set actuator A to position X”); an intermediate level, such as “joystick” control, such that the joystick movement is translated into a combination of actuator signals in such a way as to produce the desired vehicle movement; and high level commands such as a heading and speed setpoint, or a series of waypoints to be followed. In this last case, the instruction includes specifying the action to be performed at the last waypoint, such as “hover on last waypoint” or “continue on extended track segment” or “hover within predefined area”.

Using this combination of low, intermediate and high level commands, it is possible to achieve almost any sequences of manoeuvres, within the constraints of

available power and the configuration of the vehicle and its actuators. A “standby” command, for example, may be used to leave the vehicle parked or hovering within a predefined distance of the current position, to await further instructions; a joystick may then be used to manoeuvre the vehicle so as to bring instruments to bear on a target; and a “return home” or “Track X – execute” command may bring the vehicle back for recovery at the end of a mission.

As well as the fully automatic or fully manual control modes, it is useful to allow hybrid modes; for example, driving the vehicle under manual thruster control with automatic heading, while an attitude controller maintains a level roll / pitch attitude. Any of these combinations are allowed simply by switching the appropriate degrees of freedom between automatic and manual on the control panel.

Remote control datalink

An efficient remote control protocol was developed, using a query-response methodology. The remote control station may request any navaid, actuator or setpoint information, either as a single message or as a continual update stream for monitoring. Equally, the remote control station may download waypoints or other control directives. The protocol has been shown to be robust; the data link may be disconnected and reconnected at any time and the autopilot and control station recover to a normal running condition with no operator intervention. The remote control system allows the underwater vehicle to be controlled manually, or by sending a set of commands to the autopilot, while monitoring the position and vehicle status on a graphical display on the remote control workstation. The communication uses only a modest bandwidth, leaving as much bandwidth as possible for other on-board instruments. The protocol also lends itself to multiplexing of the control data with other signals. This structure provides for error checking and positive confirmation that each message has been received without errors – a necessity in the underwater environment, particularly over extended distances. A watchdog facility is also a key feature of the system, allowing the vehicle to execute a predefined manoeuvre or sequence if no intelligible messages are received within a predefined period, so that the vehicle will for example return to a recovery location following failure of the datalink.

Within the vehicle, the remote control system supports NMEA 0183 standard interfaces. This is communication

interface designed for navigation instruments, which makes it possible for the autopilot and remote control system to use a standard electrical specification and a standard communications protocol. The protocol defines sentences and sentence structures for passing data such as heading, position, waypoint, as well as commands, between navigation sensors, Electronic Chart Display and Information Systems (ECDIS), autopilots and the like.

Development of generic system

Many key components of the AUV / ROV are available off-the-shelf including thrusters, actuators and powerplants, and navigation devices and systems. One of the difficulties of developing a fully generic autopilot system which would be applicable to most, if not all vehicles, lies in the range of geometries of the vehicles. For example, vehicles may be highly streamlined and designed to cover large distances in a level attitude, while others are designed for manoeuvrability, including the ability to hover in almost any attitude relative to a datum. The various geometries not only give different hydrodynamic lift and drag forces, but they also imply different ways of achieving positional control – heading may be controlled, for instance, by hydroplanes (rudders), differential thrust or by vectored thrust. The infinite variations of possible geometries and configurations make it difficult to envisage a single, generic autopilot or autocontroller system.

The process of calibrating the autopilot algorithms for a particular vehicle configuration is achieved by modelling the vehicle with the AUV simulator. The location and type of thrusters and actuators can be defined in the model, together with the vehicle geometry, and this can be used to produce the set of functions which generate the relationships between the fundamental force requirements and the actuator control signals. Having configured and tested the vehicle using the simulator, the application to a real vehicle is achieved by downloading a configuration file across the serial data/command link.

AUV simulator

An AUV simulator was developed and used to test the autopilot control algorithms. The simulator comprises an AUV vehicle model, which calculates the motion of the vehicle in response to the actuator controls, subject to currents and random fluctuations, the navigational instruments, and the autopilot algorithms.

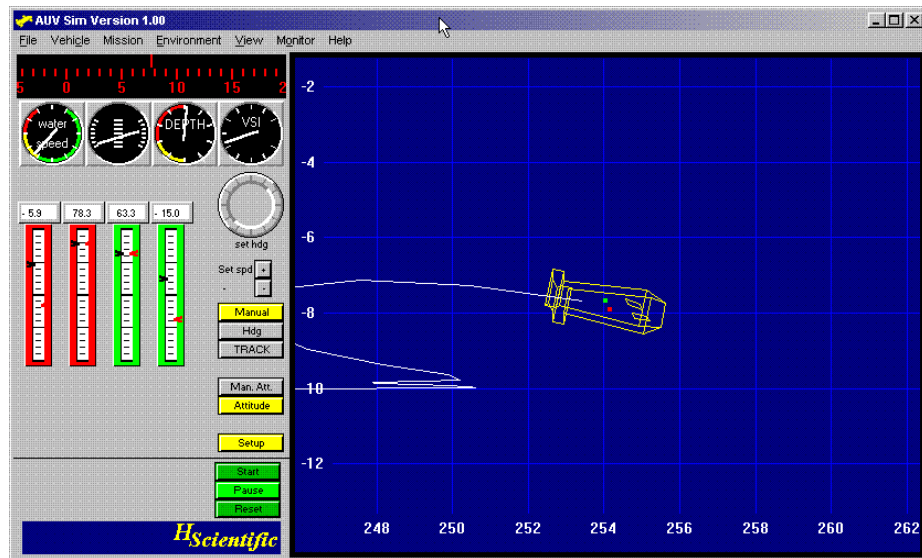
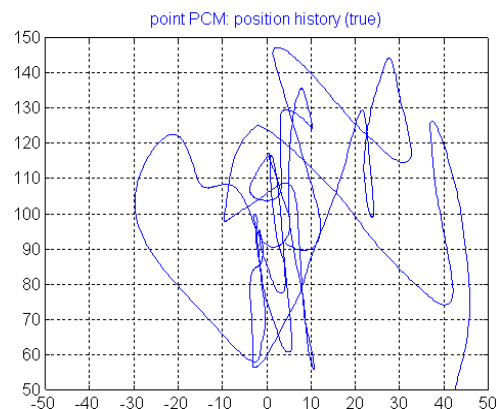
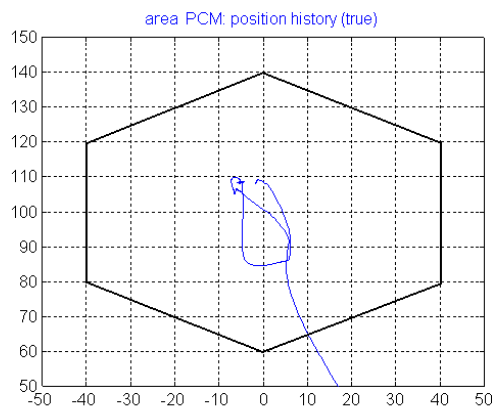


Figure 3: AUV simulator screen

Figure 3 shows an example screenshot of the AUV simulator, showing the simulation of a vehicle with twin aft thrusters and twin hydroplanes. The control console, on the left, shows analogue or digital displays of heading, speed, attitude, depth and rate of descent. A compass rose (greyed out) allows simple heading control using the autopilot. The system shown is under manual thruster control, while the automatic attitude controller has just been switched on. The outer sliders refer to the

hydroplanes; inner sliders control thrust. The axes are labelled in metres from a local datum and hover controls are not shown.

The AUV simulator was used to test the various autopilot algorithms. Figure 4 illustrates the behaviour of a simulated hover exercise using point and area hover; the graphs of machinery activity show clearly how the area hover is much more efficient in its use of energy.



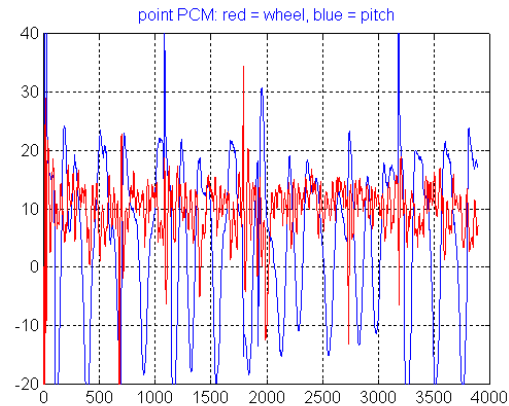
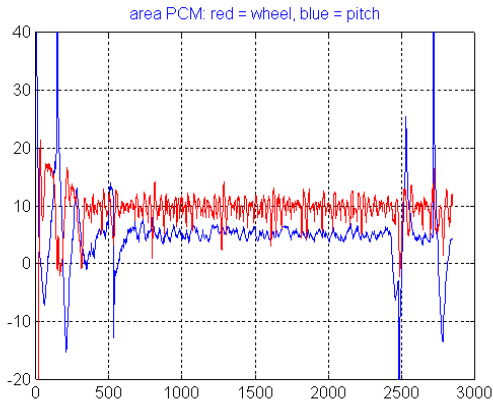


Figure 4: Simulated hover behaviour

The user can configure the vehicle to match the layout and physical characteristics of a particular vehicle, using edit windows to position thrusters and hydroplanes, and to stipulate the physical dimensions, the centre of mass and buoyancy, and the centres and coefficients of drag in various directions of motion including rotation. The vehicle navigation instruments may also be configured, to reflect the instruments on board including the data rates, latencies and error characteristics. Having configured the craft, the user may drive it manually, using sliders to control all the individual actuators and seeing the vehicle responses on the simulator screen. The vehicle motions may be viewed from different angles, so as to observe motions in all six degrees of freedom.

There is a second distinct way in which the simulator can be used in developing and testing the configurable autopilot control system. Consider the situation where the vehicle, and autopilot, is removed from the water (or has not been launched). The remote control station sends commands to the autopilot which translates them into machinery demands. The vehicle response and effect on the navigational equipment, such as velocity sensors and INS, can be modelled by the simulator. In this arrangement, the simulator is connected to the autopilot on the vehicle and used to provide a “virtual” sea trial. The progress of the trial can be monitored from the remote control station, as in normal operation.

The heading autopilot was tested in this way, and was found to work the first time in the “real” sea trial. This result validates the methodology, and demonstrates the time and cost advantages of this development method.

Results from sea trials

Sea trials to test the self tuning autopilot algorithm were carried out with considerable success. The trials vehicle was a surface vessel, 17 metres in length, powered by twin propellers with rudders. The trial successfully

demonstrated the operation of the self-tuning autopilot algorithm; **Figure 5** shows the path of the trials vessel during the heading self-tuning manoeuvre (on the right hand side of the figure). The improvement in heading control is demonstrated by the precision of the subsequent 90° turn. The self-tuning manoeuvre took 2 minutes to complete.

Trials were also performed to test the heading control and the waypoint following algorithms. The performance of the autopilot was further tested by operating the vehicle with one propeller trailing to test the control algorithm in an asymmetric configuration. The remote control protocol was also tested extensively.

The sea trial supported the simulation methodology used in system configuration and testing. This system may likewise be used to assess the system performance with new vehicles.

Following the success of these trials and extensive simulation studies, systems are currently being fitted to semi-submerged vehicles for trials in the coming weeks.

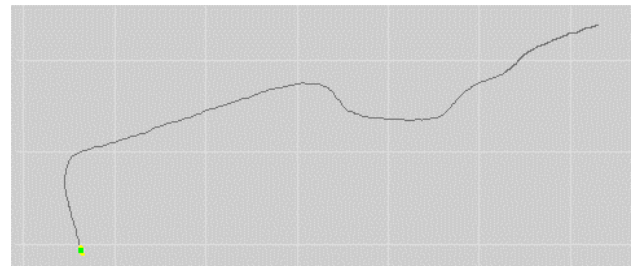


Figure 5: Sea trials record showing self-tuning procedure

Conclusions

This paper has described a control system which is applicable to remote control and monitoring of subsea or surface ROVs and AUVs. The control algorithms are capable of self-tuning, and support heading control, waypoint following, and four hover modes. The remote control system allows the vehicle to be programmed with a set of waypoints and hover points, and allows progress to be monitored using an efficient serial data protocol.

The wide variations of vehicle configurations, mission profiles and their positioning or autopilot requirements, have hitherto made it difficult to envisage a single, generic remote control and positioning unit. This project has shown however, that it is possible to design a generic unit to suit a very wide range of vehicles. By providing a wide range of commands, spanning from the low level, direct machinery signals up to the high level commands using waypoints and hover areas, and an equally wide range of automatic control modes, it is possible to cater for a large proportion of the mission profiles which may be envisaged.

The result is a system, comprising the underwater control unit and the remote control workstation, which is user-configurable for almost any vehicle, self-tuning, and gives the operator a very powerful, intuitive console workstation from which the vehicle may be controlled and monitored.

By developing the remote control and positioning task as a separate, generic and fully configurable unit, it is possible to obtain a fully functioning vehicle, including remote control facilities, from off-the-shelf components.

The control algorithms have been tested using the AUV simulator and through sea trials. The results from these tests have validated the various component features of the system and the development methodology.

References

1. "Remotely Operated Vehicles of the World", 98/99 edition, published by Oilfield Publications Limited, UK.