Enhanced submersible control using the Remote Systems Engine

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SYNOPSIS

As the need to perform complex tasks in ultra deepwater increases, the tools and technology relied upon to perform these tasks in turn become increasingly complex.

In response to this increasingly important requirement, Schilling Robotics has developed a modular control system technology, called The Remote Systems Engine (RSE). The RSE is a collection of hardware and software modules that allow the efficient creation of almost any type of deepwater remotely controlled equipment.

This paper describes the RSE software's command, control, communication, and configuration functions, and emphasizes the innovative architecture that allows precise control of a wide variety of applications.

INTRODUCTION

The Remote Systems Engine™ (RSE) from Schilling Robotics is a collection of hardware and software modules that allow the efficient creation of almost any type of deepwater remotely controlled equipment. RSE components were designed for use on a wide range of remotely operated submersible systems, including subsea process equipment, wellhead management systems, electrical power conversion systems, remotely operated vehicles (ROVs), remotely operated tools (ROTs), trenchers, autonomous underwater vehicles (AUVs), submarines, tow fish, and plows. The Schilling Robotics electric work-class QUEST ROV is an example of a complete remote intervention system constructed from RSE components.

Though RSE components can be used on almost any type of subsea system, this paper focuses on enhanced control features that the RSE makes available to human-controlled underwater vehicles such as ROVs and submarines. The paper describes (1) operational advantages that this advanced control provides, and (2) individual RSE hardware and software components that make this control possible.

ENHANCED CONTROL FEATURES

Benefits of Enhanced Control

For remotely controlled subsea vehicles, "enhanced control" generally refers to system features that provide greater job or task flexibility, provide a safer environment for both operators and equipment, allow greater efficiency, and provide a less stressful environment for operators.

Another aspect of enhanced control is timely and complete access to all pertinent system data. For maximum utility, this data access must be intuitive, and the data must be presented in a form that can be easily understood and easily recorded. Improved data access allows pilots to more accurately assess situation and make better judgments. Complete data access also allows more accurate and efficient troubleshooting when system problems occur.

This combination of specific advanced control features and improved information access augments pilot's expertise to improve overall job performance.

RSE-Based Control Features

The RSE provides the same basic control functions that are available on most submersible vehicles, including:

- Auto depth and altitude
- Auto heading
- Thruster trim setting
- A serial data steam that includes vehicle attitude and status information
- Single-speed cable deployment
- A fixed single-user, text-based user interface

However, the RSE provides many additional control features, including:

- Automatic station-keeping (holding vehicle position constant in three-dimensional space against currents and other motive forces)
- Automatic displacement from a known position
- Four distinct input control modes
- Pitch and roll compensation and control
- Cruise control
- Extremely accurate camera and instrument actuation (pan & tilt units that feature 0.00175-degree accuracy)
- A cable-friendly cable deployment system with proportional input control and three speed ranges
- Topside (remote) hydraulic fluid pressure and flow control
- A data display system that projects multiple data streams (video and instrument data) in a single high-fidelity image on a central 72-inch screen
- Multiple control stations with touchscreen and proportional device inputs
- Intuitive and flexible graphical user interface
- Independent telemetry path for customer-supplied equipment.

Planned enhancements to RSE control functions include:

- Automatic path flying, or “follow mode,” in which the ROV follows a preplanned path using input survey data
- Collision avoidance
- Pitch, roll, and yaw rotation about an arbitrary point
- The ability to perform typical seafloor measurements, in which the operator sets a start point, accurately displaces the vehicle to an end point of a measurement, and records the distance reported from the control system without using sonar targets or other techniques that could introduce inaccuracies or inefficiencies

Station-Keeping and Displacement

For piloted subsea equipment such as ROVs and submarines, the station-keeping and displacement functions allow the pilot to relinquish to the control system many of the tasks related to vehicle position and movement. While these functions are being automatically monitored or performed, the pilot can focus exclusively on other tasks that require human judgment or dexterity.

Station-keeping and displacement are made possible in RSE-based systems by an integrated Doppler velocity log that supplies information to the control system about vehicle position and speed information relative to the seafloor. Advanced DVL sensors can now provide a significant amount of information, including bottom and/or water track velocity, altitude, temperature, heading, tilt, acoustic echo intensity, and even pressure and depth. With the addition of data provided by the onboard motion reference unit, the RSE control system can maintain position in the X, Y, and Z axes.

The benefits of station-keeping are immediately recognized by equipment operators. For example, ROV observation tasks such as drill support require holding vehicle position for hours or even days. Without station-keeping, the pilot must (1) manually control the vehicle throughout the task, (2) to grasp a structure to hold position, or (3) to physically land the vehicle on the seabed. While these options work in many cases, they can also damage the structure being observed, stir up the seabed and thus decrease visibility, or cause the pilot to make errors due to fatigue. With station-keeping, the operator can manually position the vehicle, invoke the auto mode, and release control. The vehicle control system then not only maintains the position of the vehicle relative to the seafloor, but it automatically controls pitch and roll, which is critical to accurately focussing a camera on a specific target or performing a delicate manipulator task.

When an ROV is operating in water currents, typically one operator must be solely responsible for maintaining vehicle position while a second focuses on the task being performed. With station-keeping function, the vehicle automatically reacts to external forces (such as current) to maintain position. Heading, altitude, and position are all maintained automatically, allowing the operator to focus on the task from an exceptionally stable platform.

Low or nil visibility can also result in pilot disorientation. This causes the pilot to at best lose position and spend valuable time reacquiring a target, or at worst allow the vehicle to drift into subsea equipment. Experienced pilots can fly the vehicle and maintain position in low-to-nil visibility using instruments alone. However, this situation is very stressful for even the most experienced pilots, resulting in problematic fatigue levels. Station-keeping allows the pilot to relinquish vehicle control to the control system, eliminating additional operator stress and maintaining position far more accurately and for an unlimited period.

The RSE control system also uses the DVL to support a displacement mode, which allows operators to perform extremely accurate, automatically controlled displacements. The operator can enter a desired displacement in the X, Y, or Z axis, press a button, and watch as the control system automatically moves the ROV in the appropriate direction for the commanded distance. Displacement accuracy is measured in centimeters. Following the displacement, the vehicle reverts to the station-keeping mode, holding position until manual control is resumed or another displacement command is given.

Displacement is particularly important for 2D and 3D mapping (for example, creating video mosaicking transsects), where defined distances must be traversed at a defined, steady speed.

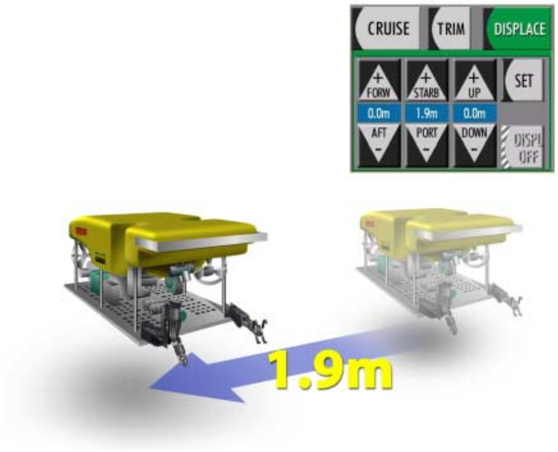

Figure 1 Automatic lateral displacement of an ROV

Station-keeping and displacement provide a number of efficiency and safety features, including:

- Safe operation in low/no visibility conditions.
- Operators are less stressed when losing visibility
- Allows long duration observation without missing an event.
- Lowers wear and tear on the vehicle since the crew is not frantically moving about trying to find a location.
- Removes operator fatigue when flying for long periods
- Displacement allows for repeated accurate movements between locations.

The four different input control modes are:

- Control of thrust – This is the typical form of input control in most submersible vehicles
- Control of velocity – This form of input control allows the operator to control the velocity of the vehicle directly. When the input device is set to zero, the velocity of the vehicle will be brought to zero providing a ‘dynamic brake’.
- Control of position – This form of input control allows the operator to control the set point in the selected auto mode.
- Bottom mode, which uses a unified frame (body and inertial) - This form of input control ignores the pitch and roll of the vehicle and the control system responds like a traditional submersible vehicle. For example, if the vehicle was pitched up and the operator flew forward, the vehicle would move both forward and upward. With bottom mode off, the vehicle would fly purely forward.

Two input locking mechanisms.

- Cruise mode which operates just like a car's cruise control.
- Auto heading full mode which prevents the operator from accidentally changing the heading set point when operating the control input device.

A cable friendly cable deployment system with proportional speed control and three speed ranges to facilitate operator control and provide a safer environment. The top speed of 300 m/minute allows the system to be very efficient. The proportional control used in the lowest speed range provides very fine control of cable position, making docking much safer than conventional single-speed systems. An ROV's tether management system is an example of this cable deployment system.

The pan & tilt units have proportional input and maximum velocity control with programmable set points. Axis-direction swapping for mounting upside down is also provided. The programmable set points make operations with the pan & tilts more efficient.

The system has active pitch and roll compensation that minimizes the pitch and roll response to vehicle movement. The system is also capable of auto pitch and auto roll control where the operator can set the desired angles and have the system maintain those angles.

Hydraulic fluid pressure and flow control from the topside. No need to bring the vehicle on deck to alter either the pressure or the flow in the hydraulic system. This makes the changing of these values much more efficient.

The TheaterView system combines video, graphics, and an information overlay that provides a rich set of information for the operators using a large projected image.

Multiple control stations that are not confined to the control van allowing instrument control and monitoring from remote sites.

The control system typically does not occupy all of the bandwidth available in the telemetry system. This means that a number of ports are available for customer use.

All of these features lead to a safer, more efficient and capable submersible system.

THE COMPONENTS OF ENHANCED CONTROL

This RSE's enhanced control features are made possible by a combination of hardware and software components. Key components include the massively parallel telemetry system, unique thruster control packages, electric rotary actuator, hydraulic valve pack, hard real-time control software, and an intuitive graphical user interface.

HARDWARE COMPONENTS

This section describes some of the hardware items that, in conjunction with RSE software, allow the RSE to perform advanced control system.

The RSE telemetry system is composed of three major components: a surface multiplexer, a single mode optical fiber, and a submersible multiplexer that also distributes instrument power. The surface multiplexer supports 90 serial channels and 24 channels of composite video. Each submersible multiplexer or hub supports 30 serial channels and 8 composite video channels. The serial channels are over-sampled, time division multiplexed, and then transmitted on a carrier. This design yields deterministic, low-latency communication through the telemetry system that provides high bandwidth and quick response.

The RSE provides multiple options for actuation. The most powerful is an electric ring motor, an 11-kW, low-speed, high-torque motor. Because the thruster contains a control unit that 'closes the control loop' locally, thruster response to control commands is very quick and accurate. Position control allows a higher-frequency response than conventional thrusters, providing a stable platform from which to work can be performed.

The electric rotary actuator is smaller, with 250 W of output power. It incorporates local control electronics, and has been used in a range of applications, including camera pan & tilt units and linear actuator assemblies (with the addition of a lead screw). The actuators have four control modes: position, velocity, torque, and trapezoidal. Position mode is used to control latches and ball valves, for example. Velocity mode is used to keep a rotating shaft at constant velocity for long periods. Torque mode allows the actuator to be used as a general-purpose torque tool. Trapezoidal mode provides linear acceleration and deceleration, along with a trajectory generator for movement from point to point. This is the mode used for the pan & tilt units.

The hydraulic manifold has an on-board controller with RS-232 serial control, allowing fluid pressure and flow to be controlled remotely.

SOFTWARE COMPONENTS

Software Overview

Like the RSE's hardware modules, the control software modules are also nonspecific to individual applications, but are specific to software control functions in remotely controlled machines. The software modules contain all the necessary elements for controlling real-time processes.

The RSE software control system is made up of the following major components (shown in **Figure 2**):

- A real-time computer (RTC) for low-latency control
- A server computer to coordinate and distribute user input and system status information
- One or more client computers that provide a touchscreen input device and a highly intuitive user interface

Depending on the application, some or all of these components may be present.

The RTC can be considered "control central," while the server is the user interface "communication central." Both computers have responsibilities for command and configuration, and are connected via Ethernet. All computers in the RSE use Intel Pentium® processors. The server and client computers run Windows NT®, and the RTC runs the VxWorks® operating system.

All subsea communication is controlled by the RTC using Schilling Robotics' SeaNet telemetry system. This system is massively parallel — supporting up to 90 serial devices at one time with no delays or other packetizing artifacts—to ensure minimal delays and signal jitter. Also, devices that are not controlled by the RSE software can be added to the system.

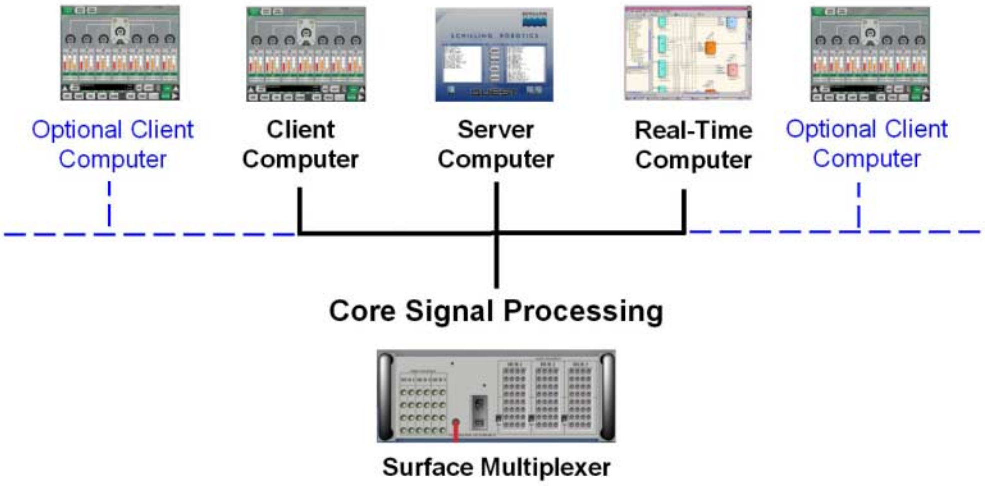

Figure 2 RSE communication diagram

For autonomous systems requiring control but not a user interface, the RTC can be used by itself. In autonomous systems with user interfaces (such as manned submarines), all computers would reside on the vehicle. For tethered systems, the computers would reside in a topside van.

Real-Time Control

One unique quality of the RSE control system is that tethered systems do not require a subsea control pod. All control is done from the surface, eliminating the need for large, heavy, one-atmosphere control pods that use a myriad of different electrical connectors and are vulnerable to seawater intrusion. The RSE surface control is possible because of the massively parallel communication architecture, the use of powerful computers, and the use of distributed control.

Typical submersible devices used today (such as a camera or Doppler velocity log) contains a microprocessor (usually a DSP, FPGA, or microcontroller). This existence of local control inside the device makes it possible to interface with the device at a higher level, allowing control to be done from the surface. For example, there are local processors in RSE control packages for electric actuators and electric and hydraulic thrusters, and these processors close the loop on speed, torque, or position control. Because the topside control unit does not have to close this loop, it can concentrate on preparing the next speed or torque set point.

The massively parallel communication architecture supports 90 serial lines per RTC. The overall control architecture allows use of multiple RTCs, thus supporting hundreds of serial communication lines.

The RTC was designed to be modular, reliable, robust, flexible, precise, and deterministic with low latencies. The Pentium®-based RTC runs the real-time operating system VxWorks®. The operating system's fast interrupt response time and large number of priority levels ensures low latencies. The operating system also supports very fast context switching and a flexible scheduling system.

The RTC includes (1) the data manager, which schedules subsea device polling and activities and provides the information (with low latency) to the rest of the system, and (2) the control section, which implements all complex control algorithms, such as those for thrusters and actuators. These functional components are discussed in more detail below.

Data Manager

The data manager is responsible for all data flow in and out of the RTC. It schedules device controller communications with the goal of achieving deterministic data flow from the submersible devices. The data manager also ensures that no device is ignored or "starved" for data; this is done with a modified version of the "elevator algorithm" which dynamically schedules events as they occur. The data manager forms the bridge between the serial devices and the network-based communications of the rest of the system. Communication throughout the system is achieved using a commercially available, network based, real-time middle-ware product called Network Data Delivery Service (NDDS). This product passes messages between software components, including those on the GUI.

Control Section

The control section uses Constellation®, a commercially available tool that supports both top-down and bottom-up software design using hierarchical, component-based modeling (see **Figure 3**). The Constellation® application's graphical design tools greatly simplify software module construction and implementation. It also provides run-time executives for model execution. In the RSE software, Constellation® communicates with the rest of the software system using NDDS.®

The control system uses mathematical techniques that produce very precise control. The feedback system employs Kalman filters to smooth and stabilize sensor output. The RSE proprietary trajectory generator outperforms simple trajectory generators (such as a fifth-order generator) by orders of magnitude. Reports from the field indicate that the RSE-based QUEST WROV can displace 60 meters with an accuracy of centimeters or decimeters. The control system supports "path flying," where a predetermined path is input to the system and the vehicle follows the path without human intervention.

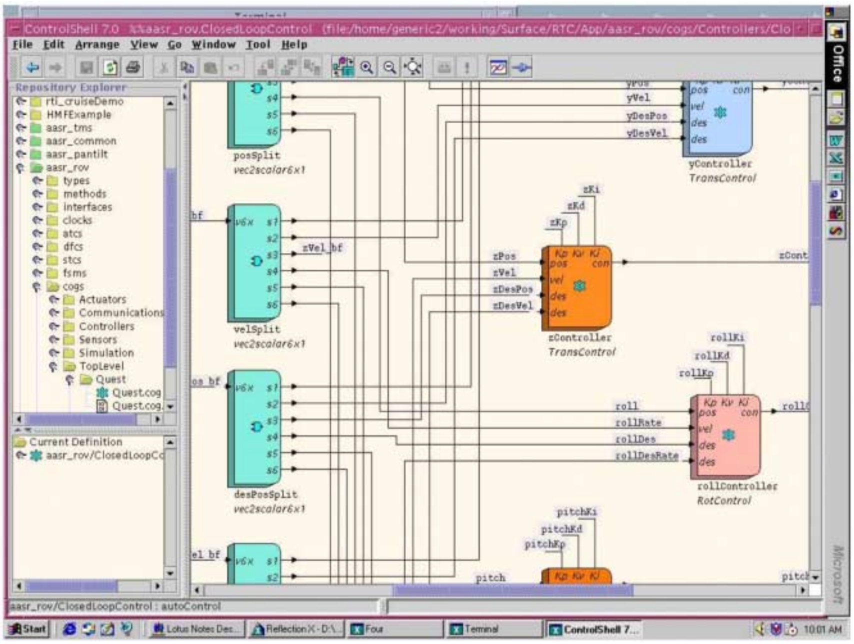

Figure 3 Constellation® screen

Graphical User Interface

The graphical user interface (GUI) is modular, reliable, robust, flexible, intuitive, and visually appealing. Except for the customized buttons, most controls in the interface are commercially available tools.

Buttons on the GUI are critical in achieving a visually appealing, intuitive control system. All buttons in the RSE software are based on a “general button,” with derivatives such as a repeating button, a power button, and a button that can be labeled by the user. This general button was developed as part of the RSE because no commercially available tool provided the required flexibility.

The RSE software GUI is robust, with highly isolated modules monitored by high-level task managers or supervisory software to detect problems and automatically restart software subsystems.

The GUI’s use of distributed control and Ethernet communication allows it to support any number of operating stations, making remote monitoring and control for subsea systems easy and straightforward. This allows engineers and scientists to monitor operations from remote locations on the ship, from a platform, or on shore, minimizing crowding in the control shack or van.

The GUI architecture allows the user to label buttons and ports, and these labels are then used throughout the system. The labels can be changed at any time, and the change is instantly reflected throughout the system. This allows operators or service engineers to quickly locate particular devices, and also eliminates the need to keep separate lists of device locations. This yields a more efficient and safer environment.

User input devices can be dynamically reassigned from one control station to another. Operators do not need to change seats to change system control devices, and left-handed input devices need never be used by right-handed operators. (For example, an ROV pilot can control the flight of a vehicle with one input device, and by simply touching a button, can switch control to another input for manipulator control.) Dynamic input device reassignment also provides redundancy, since a backup or replacement can be easily designated for any input device.

The GUI performs standard event and alarm logging, providing event windows that display the most recent generated event. Events and alarms are also posted to logs. Alarms can be acknowledged or suppressed, and at any time the user can assign a particular audible alarm to sound when a particular alarm occurs. To request that event displays be filtered, the operator can either specify which event types should be included, or specify which event types should be excluded. Event logs can be saved and viewed on Windows®-compatible machines, either as historical records or to help identify system problems.

The GUI uses the server computer to coordinate user activities by taking input from the client computer and other input devices, and distributing this information to the clients and the RTC. The server computer is populated with software modules called agents. Because the client computers lack logic, the server computer’s agents perform all of the user interface logic. At system startup, a simple text file is accessed to determine which agents are needed for the current session. Agents are completely isolated from each other so that failure of one agent does not affect the others. The agents exist within a framework that enforces consistent interface with the rest of the system. This framework also provides tools for frequently used functions, including timers and event loggers. The server computer also supports data logging, ranging from a standard stream of vehicle attitudes and positions to a custom log of fluid flow into a subsea actuator. Trend graphs can also be generated to examine data over time.

Simulation

The RSE includes a simulator module that is similar in architecture to the RTC and that is designed to mimic performance of subsea devices. The simulator is based on real-world models and exact communication protocols.

Simulation allows the software development team to test and verify its work long before system hardware is available, which reduces the time needed to debug software after hardware is available, increases reliability, and lowers costs. Real hardware can also be used in conjunction with the simulator for hybrid testing, allowing evaluation and diagnosis for instruments such as Doppler velocity logs and sonars. The simulator can also inject deliberate errors to test system response to catastrophic errors. Events that might damage real hardware can be tested against the simulator, with confidence in the results. This results in a system that is more reliable than otherwise since the response to catastrophic events can be tested ahead of actual deployment of the system.

The simulator is also a valuable aid for user training, and allows training to be conducted before system integration begins.

SUMMARY

The enhanced control features discussed in this paper provide greater job and task flexibility, allow efficiency gains on the job, provide a safer environment, and reduce the stress on the operators on submersible systems.

The use of local microprocessors in subsea devices and the massively parallel telemetry system provide large amounts of detailed data about all sub sea systems. The system architecture of the RSE provides the operator with the ability to quickly and efficiently integrate multiple sensors, saving time and reducing complexity while increasing capability.

The benefits of the RSE have been demonstrated in the case of the QUEST electric work-class ROV system, and the technology is currently being applied to a sub sea drilling system. Future applications of the technology include AUVs, subsea processing systems, and long-term ocean network installations.

Author Biographies

Jason Stanley is Vice President of Sales and Marketing—Remote Systems for Schilling Robotics. He oversees sales and marketing activities for the Remote Systems Engine™ products and QUEST remotely operated vehicles. Mr. Stanley has 15 years of experience in remote systems operations and manufacturing. He holds a B.S. degree in ocean engineering from Texas A&M University in College Station.

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