Precision Navigation Sensors Facilitate Full Auto Pilot Control of Smart ROV for Ocean Energy Applications

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***Abstract* — A Smart Remotely Operated Vehicle, ROV Latis designed as a prototype test bed for operation such as the challenging role of ocean engineering support in wave and tidal energy development is presented in this paper. With state of the art navigation sensors/instruments the vehicle can achieve precision navigation and positioning sub sea and this capability has been utilised within automatic control functionality and autopilot control systems developed and trialed on ROV Latis and not available in commercial ocean ROV technology. This paper describes the vehicle's many novel design features: sensor and control systems, autopilot systems, station keeping, fully automatic way point navigation, rapid auto tuning when ROV configuration or payload is changed, fully automatic fault tolerant thruster control with redundancy. The paper also introduces the transparent ocean immersive augmented reality pilot control environment.**

I. Introduction

Deployment, installation & maintenance of ocean energy devices require use of underwater robots and support vessels, which are also used by other offshore industry e.g. off shore oil & gas. ROVs have thus become the workhorse of subsea operations in many sectors. Some ROV applications require precision navigation and positioning capabilities which can be achieved with (fibre optic gyro) FOG based INS systems. These sensor suites are expensive and often ocean engineering companies will forego use of such technology on cost grounds and use inferior sensor solutions with reliance on piloting skills. For ROVs, both with FOG based INS systems and without, operation of the vehicles remains a very skilled task and the industry is very dependent on the skills of ROV pilots. With the precision instruments however, significant levels of auto control can be developed and thus with autopilot functionality and advanced real-time visualisation, ROV operations can be made significantly less dependent on the skills of ROV pilots and the range of tasks that can be successfully undertaken is expanded.

This paper describes a Smart Remotely Operated Vehicle, ROV Latis, designed as a prototype test bed for challenging operation environments in the ocean. ROV Latis shares much with other state of the art ROVs as used in ocean engineering and ocean research. The vehicle also has many features not available in commercial ocean ROV technology [1]. With state of the art navigation sensors/instruments the vehicle can achieve precision navigation and positioning sub sea. The navigation sensor suite includes a fiber optic gyro based inertial navigation system with extended Kalman filter integrated with aiding sensors (DGPS while on the surface, ultra short base line acoustic positioning (USBL), Doppler velocity log (DVL), precision depth sensor). Such a suite of sensors, while not ubiquitous, is not uncommon on research or some work-class ROVs. The automatic control functionality and autopilot control systems developed and trialed on ROV Latis are, however, superior to systems provided on other ROVs.

This paper describes the vehicle with many novel design features. The sensor and control systems are described, the autopilot systems in particular are described which significantly deskills operation of such a vehicle in the challenging role of ocean engineering support in wave and tidal energy development. Station keeping, fully automatic way point navigation, rapid auto tuning when the ROV configuration or payload are changed, fully automatic fault tolerant thruster control with redundancy, the transparent ocean immersive augmented reality pilot control environment are described along with other detail in the paper.

II. Smart ROV Latis

A. Features

The main features of ROV Latis are:

1. Modular design with multiple modes of operation,

2. Very high positioning accuracy of ROV in deep water,

3. Semi-Automatic Speed Modes enable robust, stable and accurate ROV Course Following & ROV Dynamic Positioning with simple mouse click,

4. Fully automatic way points navigation with auto-compensation of ocean currents and umbilical drag effects,

5. Advanced 2D and 3D real-time visualisation – providing better situation awareness,

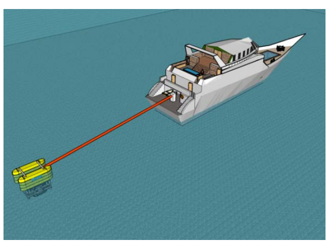
6. Built-in thruster fault tolerance and optimal control allocation for any thruster configuration,

7. Built-in auto-tuning of low-level controllers, providing optimal controller performance, regardless of changes in ROV configuration between missions.

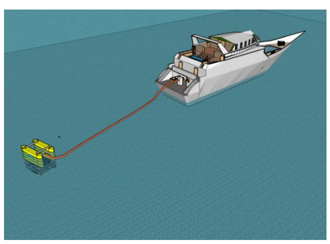
8. Modular software architecture and extensive interface library enable easy system adaptation to any ROV & SHIP in the market.

B. *Operation Modes*

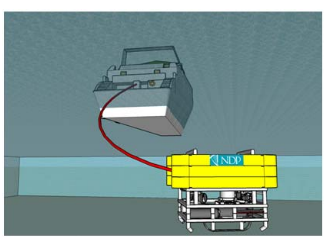
ROV Latis is a vehicle with multiple modes of operation [1]. It can be operated on the surface as a survey platform either towed (Fig. 1a) or thrusted by 4 horizontal thrusters (Fig. 1b) to allow surge, sway and yaw. It can also operate as an ROV fully controllable in 6DoF by 4 horizontal and 4 vertical thrusters (Fig. 1c) or as ROV with submerged tow/holding line for operations in submerged tow or on station in strong currents (Fig. 1d). In these various modes of operation it is used in conjunction with a fibre optic umbilical and winch; the umbilical carrying vehicle power, control and data from sensors and instruments.



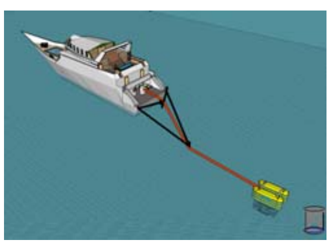
(a) Surface-tow mode.



(b) Surface-thrusted mode.



(c) ROV operation mode.



(d) ROV with submerged tow line in strong currents.

Figure 1. Operation Modes.

C. *Technical Specifications*

Technical specifications are given in Table 1.

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TABLE I. TECHNICAL SPECIFICATIONS

Base Vehicle	
Chassis	Marine grade Aluminium
Payload	100 kg
Max. depth	1000 m
Thrusters	Seaeye SM4 (4H, 4V)
Power supply	11kW, upgradable
Instruments & Navigation Suite	
Multibeam sonar	Reson SeaBat 7125
Sidescan sonar	Tritech SeaKing sonar 325 kHz
Sound velocity probe	Reson SVP-24
INS	ixSea PHINS
Depth	CDL Microbath (Digiquartz)
DVL	RDI WorkHorse Navigator 600
USBL interface	iXsea GAPS
GPS (surface)	CSI-Wireless Seres or Submersible GPS GPRS-6015G
Obstacle avoidance	6 Tritech single-beam echosounders
Cameras	Bowtech Explorer-3K monochrome 2 LCC-600 monochrome Tritech Typhoon colour
Pan & tilt	Bowtech SS-109
Lights	3 Bowtech LED-1600 1 Bowtech LED-800 2 Tritech LED lite
Control System	
Embedded	Digital Logic EBX945 National Instruments Compact RIO
Topside	Control PC Visualisation PC
Control & Visualisation Software	LabVIEW 8.6
Umbilical	
Length	400 m
Diametar	25 mm
Core	6 AC, 4 DC, 8 single mode fibres

D. *Advanced Pilot Interface*

The Advanced Pilot Interface (Fig. 2) presents all important control data to the ROV pilot using familiar graphic controls & indicators. The pilot is able to use a combination of touch display, joystick, gamepad, mobile device, mouse or keyboard as input devices to generate commands, switch operating modes and enable/disable low-level controllers.

Figure 2. Advanced Pilot Interface.

Set points can be entered numerically (e.g. using numeric control fields) or graphically (e.g. moving instrument pointers by mouse). The pilot can also easily switch between manual mode, semi-automatic modes (Follow Desired Speed & Course, Keep Current Position and Go To Position) and fully automatic mode (automatic navigation through way points).

E. *2D Topview Display*

The 2D Topview Display (Fig. 3) shows a top view of the working zone and includes features like auto zoom, nav info display, floating heading indicators, visualisation of way points, real-time visualisation of sensors measurements (INS, DVL, USBL, GPS, etc.), distance & angle measurements tools, ROV-fixed, SHIP-fixed and free Lever Arms etc.

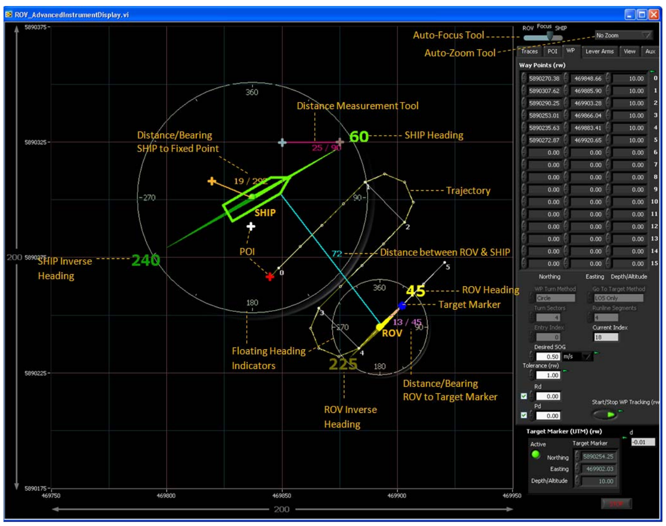


Figure 3. 2D Topview Display.

F. *3D Real-Time Augmented Reality Display*

The 3D Real-Time Augmented Reality Display (Fig. 4) provides 3D real-time visualisation of the support vessel, ROV, ocean energy device, ocean surface, seabed, etc.

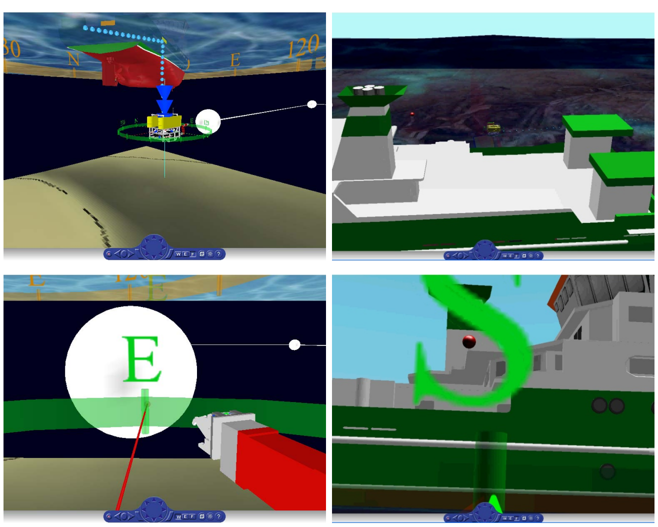


Figure 4. 3D Real-Time Augmented Reality Display.

G. *Control System*

The control system includes fast auto-tuning of low-level controllers, automatic thruster fault detection and accommodation, semi-automatic and fully-automatic control modes, optimal control allocation of thrusters, etc.

The autotuning process of Heave (Depth) and Yaw low-level controllers involves the following steps: (1) Generate self-oscillations; (2) Wait for transient stage to finish; (3) Measure amplitude and period of steady-state oscillations; and (4) Find new values of controller gains using tuning rules. A novel set of tuning rules for underwater applications has been developed, which provides the optimal performance of low-level controllers in the case of configuration changes and the presence of disturbances (waves & sea currents).

In fault-free case, the fault-tolerant control system uses thrusters over maximum-sized attainable command set in an optimal way, minimizing the energy consumption, the most suitable criteria for underwater applications (Fig. 5). In case of thruster faults, the control system automatically accommodates faults, keeping full controllability of ROV for low speeds and providing opportunity for safe continuation of a mission in presence of thruster fault(s).

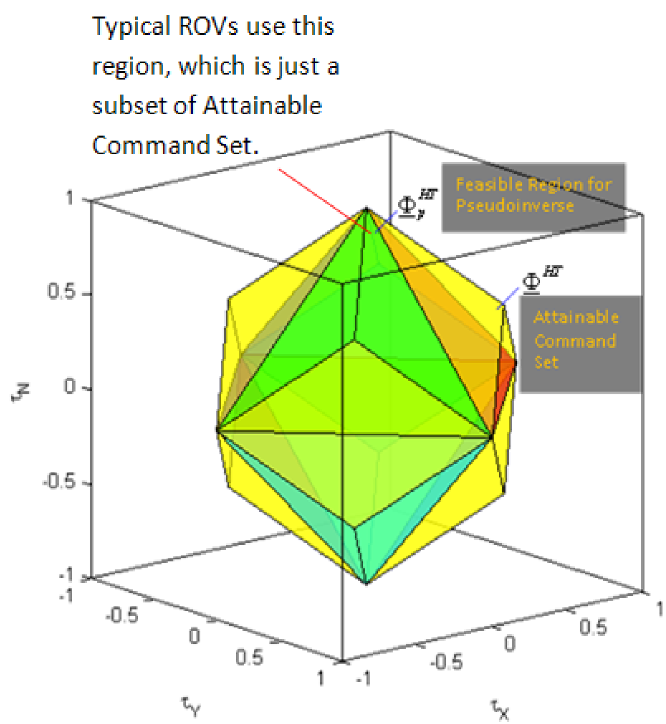


Figure 5. Input control space for X-shaped configuration of horizontal thrusters.

There are two methods implemented for automatic way-points navigation: “Line of Sight (LOS) only” and LOS + Correction”. The “LOS only” Go To Target Method gives good performance in situations where there is little or no ocean current. In this case there is no lateral corrective action generated by controller to bring the ROV on the desired path. Desired course is calculated as a bearing from ROV to the next way-point and heading follows course automatically.

The *"LOS + Correction"* Go To Target Method is used in the presence of ocean currents (Fig. 6). In this case, in addition to the standard LOS algorithm, controllers generate adaptive lateral corrective action to bring and keep the ROV on the desired path.

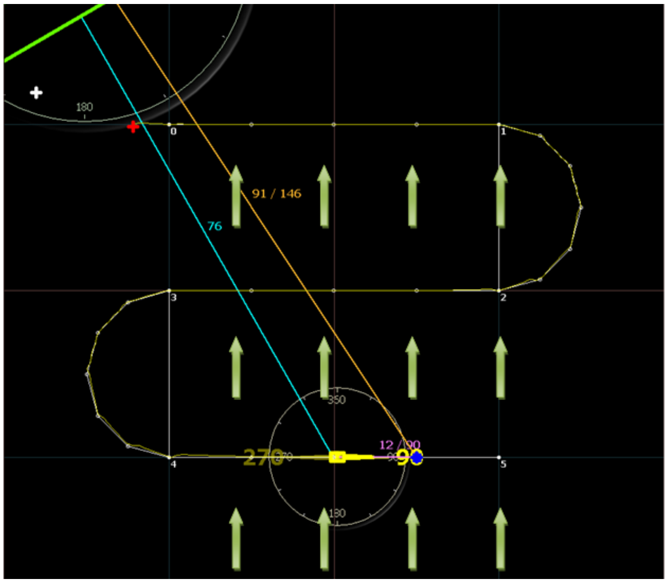
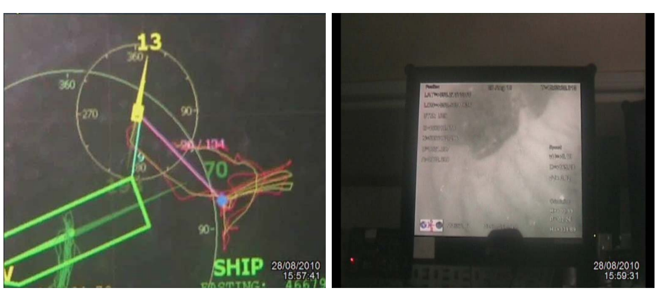


Figure 6. Tracking performance in the presence of northern ocean currents of 0.3 m/s: Go To Target Method = "LOS + Correction".

III. TEST TRIALS

The performance of the overall system has been successfully validated through a series of test trials off the coast of Connemara, in Galway Bay and on the Shannon Estuary onboard research vessels Celtic Explorer, Celtic Voyager and small ship Shannon I [2]. The trials included alignment of INS and DVL, auto-tuning of low-level controllers, infield testing of the advanced 2D & 3D displays, testing of advanced control modes in presence of currents, etc. A selected result is reported in the following.

During the last cruise in August 2010 (ROV Latis onboard RV Celtic Voyager), repeatability test has been successfully performed in Galway Bay. The ROV was flown on a low altitude transect off the sea floor and an easily identifiable reference (a rock with four starfish on its surface) was identified in the ROV pilot camera display. Position & orientation of the ROV were recorded.



(a) 2D Topview Display. (b) Rock used as reference.

Figure 7. Repeatability test.

The ROV was then moved to a new random position (tens of meters away, see Fig. 7a). Recorded position & orientation were used as set points for autopilot, which guided the ROV back to the rock position (see Fig. 7b). This test was repeated a further four times over a 90 minute period with the ROV flying other mixed trajectories between commands to station from new positions and the results of the tests were recorded so that the reliability/repeatability of the auto-pilot could be assessed. After each return the rock was visible in the pilot display in the same position and errors, if present, were not noticeable in camera view. This test proved that there was not any drift in ROV position estimation with (USBL-DVL-Depth)-aided INS after 90-minute period. In addition, this test demonstrated high quality of control system in subsea dynamic positioning.

IV. CONCLUSIONS & FUTURE WORK

This paper described the main features of ROV Latis, the next generation smart underwater vehicle. The vehicle was built as a prototype platform to demonstrate system validity & operability and to prove new technologies developed in the Mobile and Marine Robotics Research Centre, UL. Field trials have demonstrated that the ultimate objective (saving ship time & making ROV operations easier) can be achieved through:

- Improved user interface (advanced 2D & 3D displays – better situation awareness),
- Advanced control modes (enabling ROV pilots with average skills to achieve exceptional results),
- Use of state-of-the-art positioning and orientation instruments (fibre gyro INS), which provide high-accuracy control and navigation data (yielding easier post-processing & better quality of bathymetry data).

Instruments such as fibre gyro INS are expensive; however, in the overall cost of a work-class or light work-class ROV they are not so expensive. Yet, they facilitate the implementation of the advanced control systems described in this paper by providing highly precise position and orientation information in real time. The dividend for including precision navigation instruments is unlocking the possibility of implementing the advanced control and auto pilot systems as described in this paper and implemented on ROV Latis.

Further work will include implementation and test trials of smart technologies (bundled into the ROV Upgrade Kit) on commercial work-class ROV in collaboration with MI SOT, Canada. The project is expected to start at the end of 2011.

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