SMART ROV$_{\text{LATIS}}$: Flexible Survey Platform for Surface and Underwater Operations

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Abstract: This paper describes a novel vehicle designed for operation flexibility in high-resolution near seabed survey from shallow inshore waters out to the continental shelf edge. The vehicle can be operated in surface tow or as a thrusted pontoon. With buoyancy module release the vehicle becomes neutrally buoyant and is operated as a survey class remotely operated vehicle (ROV) depth rated to 1,000m. Special features of the system include: deployment interoperability for small inshore boats and larger research vessel; fault tolerant thruster control; novel high frequency short range sonar; onboard computer control enabling real-time disturbance reaction; topside augmented reality system support. The paper includes test results from the off shore sea trials with the ROVLATIS in March 2009.

1. INTRODUCTION

In recent years, autonomous underwater vehicles (AUVs) have been the focus of much research by the academic community (Lapierre and Jouvencel, 2008; McEwen *et al*., 2005; Petres *et al*., 2007; Refsnes *et al*., 2008; Rentschler *et al*., 2006; Silvestre *et al*., 2009; Stutters *et al*., 2008) and major advances have been made in Navigation, Guidance and Control of AUVs. Elements of this AUV technology are now being adapted for use on new generations of ROV. (Bingham *et al*., 2006; Kim *et al*., 2007) describe advances in ROV navigation strategies. (Saul and Tena, 2007; Bingham *et al*., 2006; De Souza and Maruyama, 2007) detail ROV station keeping systems and (Rife and Rock, 2006) detail the design and validation of a control law for the observation of Deep-Ocean Jellyfish with the MBARI Ventana ROV. (Caccia, 2006) describes vertical motion control of the ROMEO ROV using laser triangulation and optical correlation methods. (Negahdaripour and Pezhman, 2006) describe a vision system on an ROV for automated ship-hull inspection, based on computing the necessary information for positioning, navigation, and mapping of the hull from stereo images. Other advanced functionality such as automated fault management; monitoring of system components for faults and automatic fault compensation is also being ported from AUVs to ROVs. (Soylu *et al*., 2007) details a thruster fault-tolerant control systems that will, in the event of a single or multiple thruster failure, reallocate thruster power across the remaining thrusters in order to maintain ROV course/trajectory.

Over the last five years, researchers in the Mobile & Marine Robotics Research Centre (MMRRC) at the University of Limerick have been engaged in science collaborative and engineering led seabed survey projects, including technical - design, integration and offshore support (Grehan *et al.,* 2005, Grehan *et al.,* 2006) and survey operations carrying out detailed survey projects acquiring high-resolution bathymetric, sidescan and video imagery/maps. The team have worked with leased ROVs integrating precision navigation and imaging sonar on the vehicles and ship/topside controls (Grehan *et al.,* 2006). Other activities include development of survey platforms (autonomous underwater vehicles (AUVs), ROVs and pontoons) for high-resolution seabed mapping (Molnar *et al*., 2005, Toal *et al.,* 2006). The team has further developed real-time Virtual Underwater Laboratory (VUL) (Omerdic *et al*., 2006) and real-time high-resolution sidescan sonar simulators (Riordan and Toal, 2008) for use in laboratory testing, training and offshore operations support. The idea to integrate all these technologies into a unique system (MPPT Ring) has been proposed in (Omerdic *et al*., 2008). This paper details work on the development and testing of ROV$_{\text{LATIS}}$, a new 'Smart' ROV with novel physical and onboard technology attributes that extend its capabilities for both conventional subsea ROV survey operations and wide area (surface) survey coverage under tow or self-thrusted. A suite of supporting control, simulation and off-shore operations tools incorporating virtual/augmented reality mission support technologies are also detailed. In addition, a further range of tools developed to assist subsea operators with mission planning, rehearsal, mobilisation, sea operations and pilot/hydrographer training activities are described. Experiences of offshore testing in the ROV$_{\text{LATIS}}$ maiden voyage are then reported.

2. DEVELOPMENT PROCESS

2.1 Design objectives

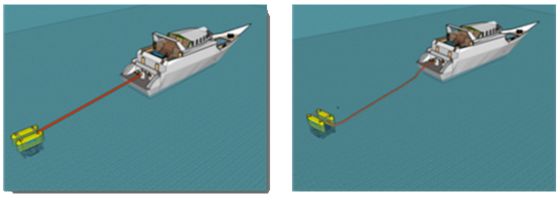
Key design requirements for new platform include the following:

- It should be able to support the core survey suite, including multibeam, sidescan, Inertial Navigation System (INS), Doppler Velocity Log (DVL), pressure (depth) sensor and Ultra-Short Base Line (USBL) transponder.
- It should accommodate both subsea survey activities and wide area (surface) survey activities in order to maximise equipment utility.
- It should be deployable using small surface support vessels, such as tugs, trawlers etc. thus reducing operational costs.

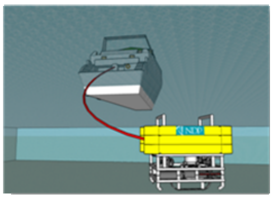
To meet these objectives a hybrid ROV/towed-Pontoon vehicle, ROV$_{LATIS}$, has been designed.

2.2 Initial design concepts

ROV$_{LATIS}$ is a new vehicle with multiple modes of operation (Toal *et al*., 2008).



(a) Surface-tow mode, (b) Surface-thrusted mode,



(c) ROV operation mode.

Fig. 1. ROV$_{LATIS}$ operation modes.

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 (Fig. 1c). In these various modes of operation it is used in conjunction with a fibre optic umbilical and associated winch; the umbilical carrying vehicle power, control and data from sensors and instruments.

ROV$_{LATIS}$ is designed and constructed in modules, allowing for ease of handling in inshore surveys on small boats with small crews. Each component in this modular design (buoyancy modules, upper frame, lower toolskid, etc.) is kept to a two man dry weight lift. The upper frame mounts the 8 thrusters – 4 horizontal and 4 vertical. The lower toolskid frame caries the payload sensors (Fig. 2). In the surface-tow or surface-thrusted modes of operation, overall vehicle buoyancy is maintained strongly positive by 8 buoyancy modules mounted on the vehicle upper frame.

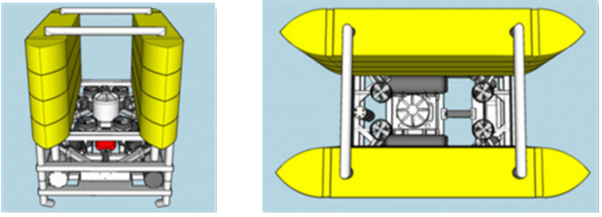


Fig. 2. ROV$_{LATIS}$ design concept.

While in surface-tow mode, a “Quick Release” arrangement allows the two top most buoyancy modules to be detached from the vehicle, reducing overall vehicle buoyancy to neutral or slightly positive. The vehicle can then be operated in ROV mode for submerged survey with control in six degrees of freedom (surge, sway, heave, pitch, roll and yaw). The synthetic foam buoyancy modules are depth rated to 1,000m, while all the other components integrated on the vehicle including payload sensors are depth rated beyond 2,000m.

2.3 Applications

The deployment flexibility of the vehicle design makes it suitable for a number of scenarios such as home land security and survey in harbours, survey in inshore waters from 2 m deep outwards and survey operations in deeper waters to 1000m+. High resolution video and sonar imagery of the underwater environment can thus be acquired in the approaches to and within the confines of a port or harbour. In tight and confined spaces, where a boat and tow cannot operate, the vehicle can be operated from a boat at anchor or from a harbour wall and manoeuvred under thrust for inspection of the undersides of boats/ships, harbour walls and the harbour bed. ROV$_{LATIS}$ provides the full compliment capability of high-resolution ROV survey, including multibeam & sidescan sonar, magnetometer, sub-bottom profiling and high resolution camera imaging.

2.4 Technical specifications

Technical specifications are given in Table 1.

Table 1. ROV$_{LATIS}$ – Technical specifications.

Base Vehicle	
Chassis	Marine grade Aluminium
Payload	100 kg
Max. depth	1000 m
Thrusters	Seaeye SM4 (4H, 4V)
Power supply	11kW
Instruments & Navigation Suite	
Multibeam sonar	Reson SeaBat 7125

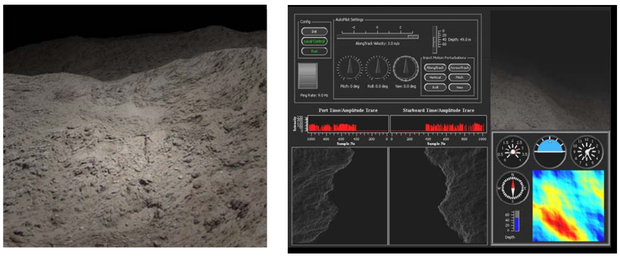
Sidescan sonar	Tritech SeaKing
Sound velocity probe	Reson SVP-24
INS	ixSea PHINS
Depth	CDL Microbath (Digiquartz)
DVL	RDI WorkHorse Navigator 600
USBL interface	iXsea GAPS
GPS (surface)	CSI-Wireless Seres
Obstacle avoidance	6 Tritech single-beam echosounders
Cameras	Bowtech Explorer-3K monochrome 2 LCC-600 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
Umbilical	
Length	400 m
Diametar	25 mm
Core	6 AC, 4 DC, 8 single mode optical fibres

3. MISSION SUPPORT TOOLS

To support mission planning, rehearsal, mobilisation, sea operations and ROV pilot and operator/hydrographer training, the MMRRC have developed a suite of hardware and software tools, which can be used stand-alone or as part of a fully integrated ROV survey operation system. In this section these tools are described in more detail.

3.1 PULSE-RT

PULSE-RT is designed to provide real-world representative sonar (sidescan and multibeam) and video imagery down to centimetre scale resolution on survey sized terrain maps at survey ping rates (Riordan *et al.*, 2006). Using a performance-optimised computational engine by way of a multi-resolution mesh abstraction framework, the sonar simulator is unique in delivering real-time performance on commercial-off-the-shelf PCs. This tool provides a cost-effective method to develop and assess operator proficiency in (1) configuring sonar instruments under varying environmental conditions and (2) classifying features of interest not immediately evident in the incoming data stream. By replacing part of an often prohibitively expensive ship time schedule with the use of immediately accessible desktop PC resources, training can be delivered using a variety of methods, such as ‘virtual’ laboratories, internet-supported teaching, special practically orientated lectures and laboratory courses. By design, the simulation framework is decomposed into a physics module and a visualisation module for each sensor modelled. The physics module performs the numerical computational required to simulate the operation of the sensor in the subsea environment model selected for the current mission. It generates the synthetic imagery seen by the sensor at the position and attitude provided by an input navigation stream, when triggered by an external source. The imagery is formatted in the protocol of the modelled sensor and output on the selected port. The visualisation module, in parallel, collects this data for rendering and logging. Visual immersion and increased situation awareness is provided by incorporating the latest advancements in 3D graphics visualisation, to generate a photorealistic real-time video stream through an Augmented Reality Graphical User Interface (Fig. 3.) (Riordan *et al.*, 2008).



(a) Simulated Terrain, (b) Simulator GUI.

Fig. 3. PULSE-RT.

3.2 Adaptive multi-sonar controller

An advanced data-adaptive multi-sonar survey controller has been developed within the MMRRC (Thurman *et al.*, 2007). Patent pending, this new technology dramatically improves survey efficiency and data-correlation by making it possible to acquire multiple sets of survey data simultaneously from different types of sonar operating within the same bandwidth (Fig. 4.). For the first time multibeam, sidescan and other types of sonar can be operated simultaneously from the same position without interfering with each other. This technology is particularly suitable for shallow water ship-based operations or alternatively ROV/AUV operations flown close to the seabed, where a significant increase in survey efficiency is achieved. The controller works by adapting the ping schedule of two (or more) sensors using a novel real-time beam-processing algorithm. The controller uses multibeam sonar to build a digital model of the terrain beneath the ROV as it traverses over the seabed. The real-time algorithm for adaptive ping scheduling then uses this data to predict the ping reception cycle for other sonar, which illuminate the same seabed sector.

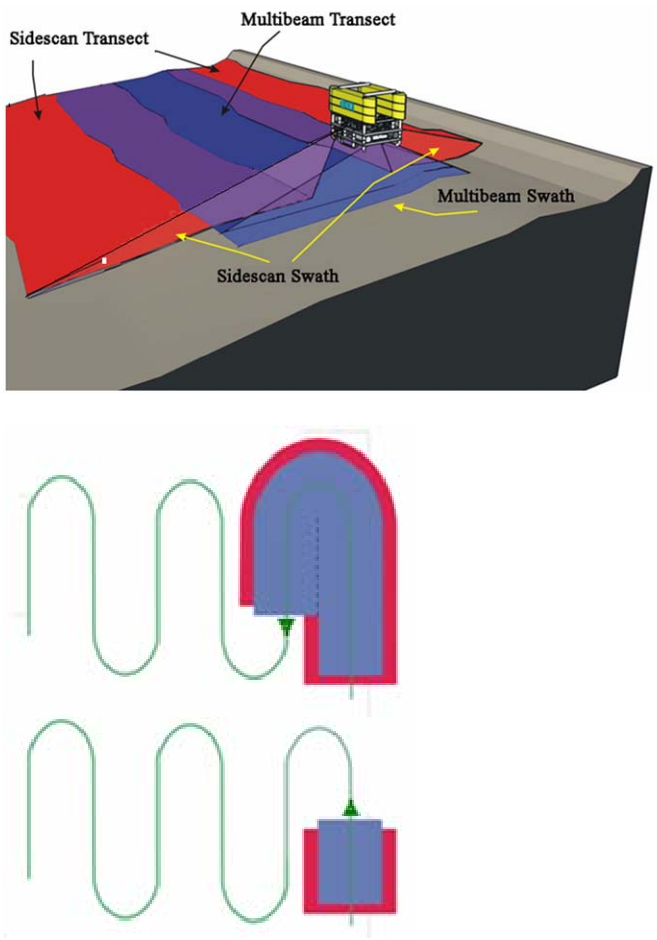


Fig. 4. ROV sonar beams patterns and ensonified seafloor segment based on transect completed.

3.3 *MPPT Ring*

The MPPT Ring is a set of multi-purpose platform technologies for subsea operations, including survey equipment integration, efficient planning & mission simulation, ROV pilot training, ROV fault-tolerant control, enhanced in-mission survey execution, and offline analysis & replay of acquired data (Omerdic *et al*., 2008). The MPPT Ring (see Fig. 5.) symbolically represents the dual character of platform technologies: the inner and outer rings can be rotated/expanded independent of each other, indicating that any technology/module can be transparently interchanged between the simulated and real-world environment. This duality of operation facilitates the application of modern control, modelling and simulation tools in marine technology development. It provides a framework for researchers to develop, implement and test advanced control algorithms in a simulated virtual environment, under conditions very similar to the real-world environment.

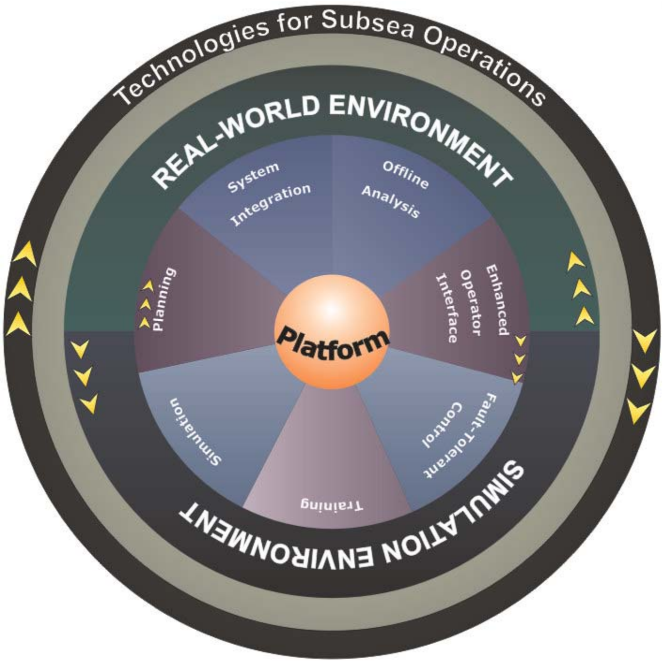


Fig. 5. MPPT Ring.

The key features of the MPPT Ring and the challenges faced by ROV pilots are set out in Table 2.

Table 2. MPPT Ring: Key features and challenges.

Key features	Challenges addressed
Signal-level compatibility between simulated and real-world environment; Open architecture for rapid control prototyping and hardware-in-the-loop development; Real-time vessel and sonar simulators	Easier testing and integration of survey equipment
Survey planning and operation tool ; 3D real-time visualisation of navigation data	Improved ROV route planning and mission rehearsal before mobilisation; Enhancing pilot awareness by incorporating 3D augmented reality tools to assist the mission and to capture pilot, ROV and environmental data to help assess the success of the mission offline later
Advanced, flexible fault-tolerant control system with auto-tuning capabilities; Set of aiding tools for ROV pilots	Automatic steering assist through fault-tolerant control of ROV thrusters

Benefits of the MPPT Ring are listed in the following:

System Integration:

- Check connection and make system integration before mission execution.
- Detect and resolve problems in advance.
- Find optimal positions for onboard equipment.
- Make fast connection with ship & ROV resources and save costly ship time.

Planning:

- Build complex underwater scenarios using an expandable database of objects (ROV and ship models), structures and custom components (moorings, buoys, etc.).
- Prepare mission plan, including routes, trajectories and way points.
- Generate marketing “proof of concept” visualisations.

Simulation:

- Simulate run-time behaviour in normal and critical situations under disturbances (waves, currents, umbilical effect) using full 6 DOF real-time simulators.
- Develop and test advanced fault-tolerant control system with auto-tuning features.
- Use hardware-in-the-loop to evaluate the performance of embedded controllers.
- Simulate system response to different faults (thruster faults, leakage in the wet bottle).

Training:

- Provide real-feel training without exposing personnel and equipment to hazards, while simultaneously saving expensive ship-based training.
- Train pilots to control the vehicle in normal and harsh conditions, including strong currents, waves, thruster faults and system errors.
- Provide interaction with dynamic objects using standard input interfaces.

Fault-Tolerant Control:

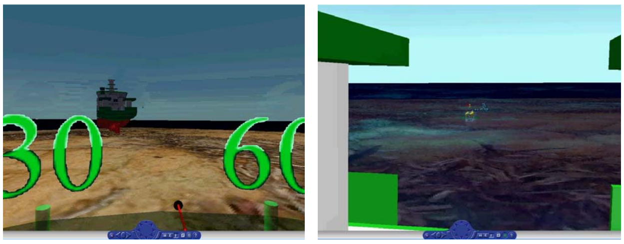
- Provide optimal and robust vehicle control in fault-free case, which minimise control energy cost function.
- In faulty cases detect, isolate and accommodate faults by distributing control energy among operable thrusters and continue missions with minimum loss of performance and manoeuvrability.
- Using a set of aiding tools allow operators to be more concentrated on other tasks.

4. ROV$_{\text{LATIS}}$ – OFFSHORE TEST TRIALS

Off shore trials (survey cruise; CE-09-04) of ROV$_{\text{LATIS}}$ were undertaken off the west of Ireland’s Connemara coastline on 26 February 2009. The vehicle was mobilised using the ship RV Celtic Explorer. The cruise consisted of a day in Galway port integrating and testing ROV and ship systems and 6 days at sea. During the trials all of the ROV’s systems were proved, sensor interoperability was demonstrated and comprehensive vehicle diagnostics were performed. In addition, system identification was performed on the ROV and tuning of vehicle controllers was successfully carried out. A series of pre-planned survey missions were also conducted. These missions were used to trial the operation of the vehicle, the MPPT Ring, ROVs augmented reality topside control and visualisation, multi-sonar controller and use of vision systems for near seabed navigation. Selected survey results are reported here.

4.1 INS/DVL calibration

If a Doppler Velocity Log (DVL) is used as an aiding sensor for a Fibre Gyro Inertial Navigation System (INS), it has to be calibrated with respect to INS, prior to being used for navigation aiding. Speed inputs received from the DVL are measured in the DVL-reference frame without any pre-compensation. These inputs have to be compensated through an INS/DVL calibration procedure by calculating misalignment and scale factor between the INS and DVL reference frames. The INS on the ROV$_{\text{LATIS}}$ is an Ixsea PHINS and the log sensor is an RDI Workhorse DVL. For the purpose of this calibration a local DGPS receiver was mounted on the ROV, which was towed behind the ship in a straight line in shallow water on the surface for approximately 2 kilometres. ROV towing, as seen on the real-time Augmented Reality Display from different View Points, is shown in Fig. 6. ROV & ship trajectories during PHINS/DVL calibration are shown in Fig. 7. After calibration the following values were obtained: Roll and Pitch misalignment: 0° (both instruments are mounted on opposite sides of the same plate), Heading misalignment: -44.654° and Scale factor: 0.1%.



(a) Pilot Camera View, (b) View from ship’s deck.

Fig. 6. Augmented Reality Display: PHINS/DVL calibration with ROV$_{\text{LATIS}}$ towed behind the ship.

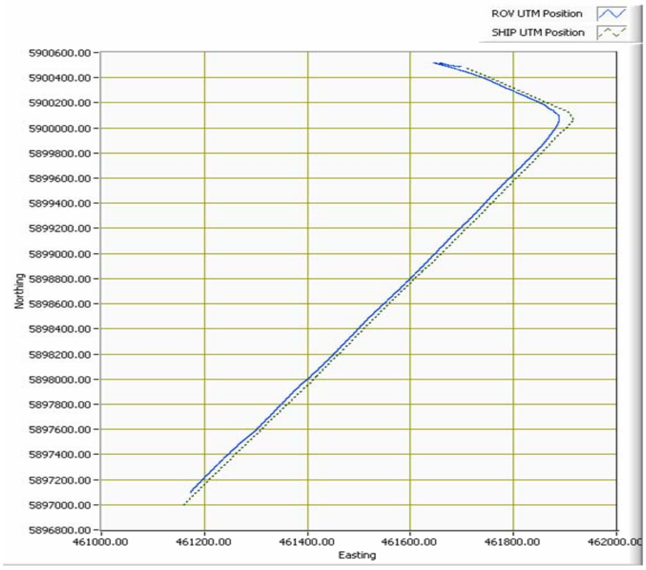


Fig. 7. ROV & Ship trajectories during PHINS/DVL calibration.

4.2 *ROV recovery and navigation accuracy*

After successful PHINS/DVL calibration, the ROV performed a number of dives with different mission objectives. In one of the missions, performed at night, the ROV spent approximately 1.5 hours in the water at various water depths within DVL bottom track range. Estimations of ROV position (obtained from PHINS & USBL (Ixsea GAPS)) and ship position (obtained from DGPS) are shown in Fig 8. DVL, USBL and depth sensor were the only available navigation aiding sensors while the ROV was submerged (Stage 1). Due to a firmware problem USBL was unable to receive pressure measurement feedback from the depth sensor mounted on the ROV, which would have improved navigation estimates by resolving multipath problems i.e. this information could help USBL to pick the correct position from multiple solutions. For this reason, it is possible to notice "jumps" in the USBL estimation of ROV position. However, USBL data was not available during surface operations (Stage 2), so PHINS relied on DVL aiding alone. DVL aiding was lost once the ROV was lifted out of the water and recovered to the deck (Stage 3). From the point of recovery, PHINS was left operating on deck without any aiding sensor. Drift of PHINS position estimation is illustrated in Stage 4.

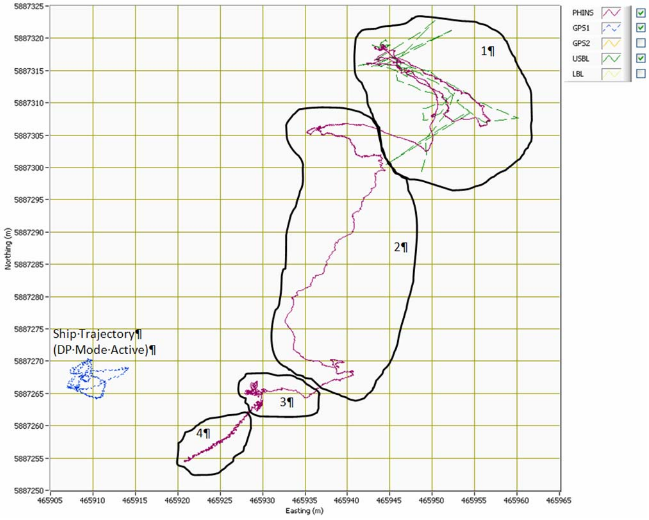
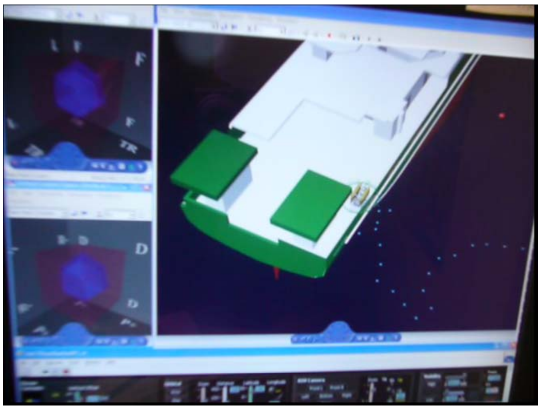


Fig. 8. ROV & Ship trajectories during recovery.

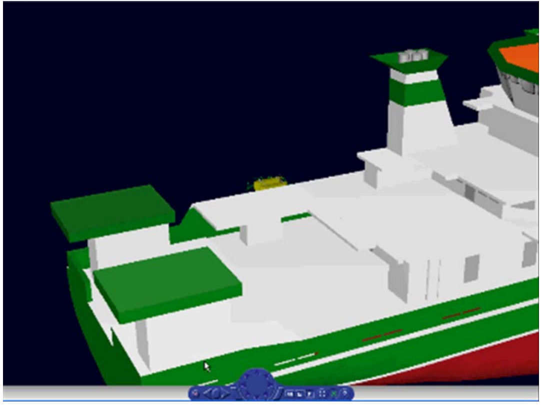
(a) Real ROV on the deck,



(b) Augmented Reality Display inside Control Cabin.
Fig. 9. Recovery after night mission.

(a) Initial position,

(b) Drift after 3 minutes,



(c) Drift after 6 minutes.
Fig. 10. PHINS drift in position without any aiding sensor.

In order to demonstrate navigation accuracy, two images were captured on the deck at the same time. The first image (Fig. 9a) displays the position of real ROV on the deck, after recovery from the water (Stage 3). The second image (Fig. 9b) is captured at the same time inside the Control Cabin from the Augmented Reality Display. The position and orientation of the vehicle on the deck in both images illustrates high navigation accuracy immediately after recovery. However, since PHINS was left operating without any navigation aiding sensor, it started to drift. Fig. 10 shows ROV initial position and position drift after 3 and 6 minutes, respectively.

5. CONCLUSIONS

This paper has presented a novel survey platform, the ROV$_{LATIS}$, developed for flexible operations from the beach to 1,000m+. The ROV$_{LATIS}$ system differs from other survey class ROVs of its size in a number of key areas. It offers multiple modes of operation, allows for both large area survey data to be collected in shallow water (using vehicle in surface tow mode at boat velocities) and detailed high resolution survey at low-altitude (using vehicle in ROV mode flown close to the seabed) to be collected using a single instrumented platform. In addition, ROV$_{LATIS}$ affords intelligent vehicle navigation guidance and control functionality such as thruster fault accommodation and sophisticated control functionality for marine disturbance compensation to enhance vehicle performance during routine survey operations such as transect following at fixed altitude. The systems engineering approach to concurrent development of ROV$_{LATIS}$ has been carried out simultaneously with the development of advanced offshore mission support augmented reality tools, simulation for training and multi-sonar controller technologies. The development of mission support technologies in parallel with the physical vehicle design and construction has had many benefits for the overall system design, optimisation, inter-operability and integration. Furthermore, the vehicle system architecture also affords a high degree of flexibility for vehicle control and payload expansion. In final summary, ROV$_{LATIS}$ is a 'Smart ROV' and has been designed to serve as the host platform for proving new technologies developed in the Mobile and Marine Robotics Research Centre.

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