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Lead Authors for this deliverable: **Jean Francois DROGOU, Lorenzo BRIGNONE, Volker RATMEYER**

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Executive Summary

This document describes the existing systems and development activities related to training and simulation in scientific underwater operations. The overall aim is to reach interoperability on the European and international scale for telerobotic hardware development and operational procedures as part of today's challenges in marine science.

The example of the simulator platforms developed at IFREMER and MARUM is described in detail to provide a view of the state of the art and evaluate perspective integration plans.

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Training and Simulation

Author(s): Jean Francois Drogou,
Lorenzo Brignone,
Volker Ratmeyer

Abstract:

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1.0   Introduction

The increasing demand of remotely and autonomously operated underwater vehicles and platforms whithin marine sciences during the last few years has strong implications for both, the requesting scientific community, as well as the technology-hosting and operating institutions.

The expertise needed ranges from detailed technical understanding of platforms, vehicles, tools and sensors, to enhanced abilities of planning the complex, technology loaded missions and expeditions. The goal of training should be the assurance of a quality work at a comparative level between all participating operators and scientists, allowing the missions and their associated science tasks to be carried out successfully over long term deployment periods.

Needs are now evolving for facilities, which can setup such dedicated training and testing environments, including tools like vehicle simulators and dedicated hardware installations such as hydraulic test stands or water tanks capable of hosting large vehicles and systems for underwater testing.

Both IFREMER and MARUM are currently developing virtual mission training and testing facilities, with different detailed objectives but with the overall common goal to gain highest possible mission efficiency and preparation quality, and to enhance compatibility. Attempts are currently being evaluated for both training setups - in situ object manipulation training as well as procedural training in virtual environments, rather than utilizing valuable scientific dive time while at sea. Proposed setups may include both approaches and allow the definition of scenarios with all physical constraints implemented, including vehicle dynamics, ocean environment dynamics (including weather, currents and real bathymetry), and object creation versus virtual manipulation up to a very high level of detail. Among commercial systems some exist which already fit to existing platforms, minimizing the need to develop the virtual vehicle base before being ready to use in a training or test mission.

In a final stage, such a training facility could be designed as a full virtual tele-operations control environment available for virtually testing and training on several kinds of platforms, such as deployments, vehicle interactions, object intervention, mission planning and GIS based post processing. In the European context, access could be organized for regular training courses and mission testing and would be available for operational crews and - increasingly important - to scientists.

Manipulation training stands

Manipulator training is essential for many kinds of operations. For intervention training, however, it is expected that the proposed standardization of specific hardware such as connectors, handles and tooling, similar manipulation tasks will emerge to maintain the periodical service at different sites and structures. This again will allow a certain repetitive training scheme to be worked out i.e. as expert courses, and to be shared between different manipulation systems on existing ROVs or other remotely controlled devices.

Virtual operations training and testing.

In addition to the manipulation task itself, underwater intervention needs to be comparable on a higher level. This may implement operational procedures from underwater vehicle piloting and navigation, over large-structure localization and handling, to ships positioning and wire-guided tool deployments from surface. Today's computer technologies allow the setup of virtual environments including the above components and can be used to design, test, verify and train operational procedures of such intervention especially in marine science. In addition, the specification of a certain software platform for underwater simulation could allow a virtual "accommodation and guidance" throughout the process of technical development of observatories and platforms. This in mind, observatory structure development would be able to gain experiences from virtual in-situ handling already during the CAD design phase, and thus help reduce the risks of expensive design errors and later incompatibilities. Versions of such virtual simulators are already in use/under further development at IFREMER and MARUM.

2.0 Terminology

AUV	Autonomous underwater vehicle
ROV	Remotely Operated Vehicle
DVL	Doppler Velocity Log
VCC	Vehicle Control Computer
SCC	Surface Control Computer
DOF	Degree(s) of freedom
STR	Système Temps Réel
GIS	Geographic Information System
USBL	Ultra Short Baseline
UDP	User Datagram Protocol
LAN	Local Area Network
WAN	Wide Area Network
TMS	Tether Management System
LARS	Launch And Recovery System
HDTV	High Definition TV

3.0 Applicable documents

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4.0 Present State of actual Work: Description of existing simulation and training platforms

4.1 Description of platforms existing at IFREMER

The Underwater System Department at IFREMER has been involved for decades in the development of both manned and unmanned (tethered and autonomous) systems for scientific oceanographic exploration. These include the manned submersible NAUTILE, the scientific ROV Victor 6000 the Asterx class of survey type operational AUVs and a number of R&D based endeavours such as the AUVs SIRENE, SWIMMER and ALIVE.

Since the very beginning a key enabling element within this development work has been the integration of comprehensive simulation platforms to help verify the integrity of communication interfaces within the different modules. In some cases the role of simulation platforms has risen above merely development necessity to become a comprehensive and interactive tool for personnel training purposes. In these cases, the scope of such platforms has been limited to IFREMER needs however a widening of the exploitation perimeter is nowadays envisaged in order to integrate with similar tools from other European players in the underwater intervention scene.

4.1.1 Asterx AUV simulator

The AUV simulator platform has been custom developed to reproduce the core elements of the hardware and software architecture that realise the backbone of the operational AUV of the Asterx class.

The main objectives of this implementation are:

- To enable validation of software developed for the realtime and payload modules

- To enable operation of the core AUV modules in a simulated environment

- To allow testing and use of all AUV piloting modes, manual and autonomous mission

- To provide a training platform for the operators

The overall architecture of the AUV simulation platform is presented in figure 1. The key feature of the platform is the integration of four core hardware/software complete modules identical to the ones used within the operational vehicles. These are the Vehicle Control Computer (VCC), the Surface Control Computer (SCC), the MIMOSA operator console and the Triade payload computer.

The VCC and SCC are exact clones of the hardware and software counterparts integrated to the operational AUV, running the QNX 4.2 operating system and the ACE vehicle controller provided by the vehicle manufacturer (the Canadian company ISE). IFREMER has purchased

the development tools and rights of the AUV control software, therefore all evolutions and modifications of the original code are normally first tested on the simulation platform prior to operational deployment.
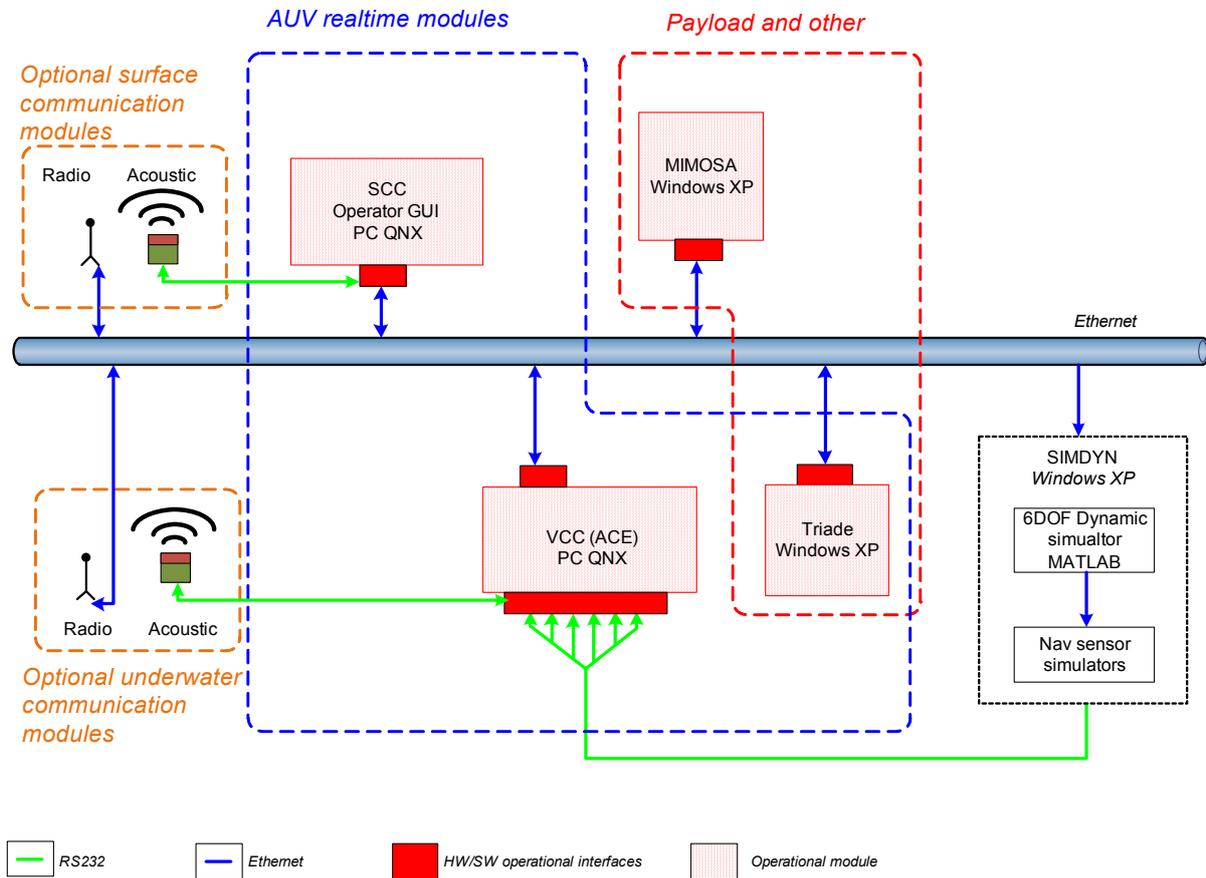
Figure 1. Overall architecture of the AUV simulation platform

The MIMOSA operator console and the Triade payload computer are software modules installed on dedicated Windows XP machines that differ only from non crucial hardware elements compared to the ones used in the operational system. MIMOSA is the mission planning and dive monitoring tool developed by IFREMER for planning and tracking purposes and available commercially.

The Triade computer is a Windows based PC which is integrated within the AUV's main pressure hull and provide host functionality for several payload specific software modules, including the diagnostic and reactive control software suite NEMO-PSE.

As shown in Figure 1 all of these "operational module clones" exchange data through the same interfaces as used in the real system. This involves using the set of network messages, coding and decoding modules, syntaxes and refresh rates which are identical to the real time operational system. This is a key factor in ensuring that all modifications introduced to the original system are compatible with the core communication backbone.

It is important to notice that communication via Ethernet is the nominal communication mode within SCC and MIMOSA as well as within VCC and Triade, as these pairs of modules are located at the same positions within the vehicle architecture, namely the *surface station* and the *onboard station*.

Ethernet is used in the communication between *surface* and *underwater* stations in debug mode only as the vehicle is fully un-tethered during operational deployment. Ethernet is therefore not considered to be the nominal communication mode between surface and underwater stations however the interfaces used within the simulation platform are the same used in the real operational case. In addition to that since the hardware of both VCC and SCC are identical clones of the operational systems, pairs of acoustic and radio modems can be connected to the two computers thus recreating a complete and realistic implementation of the operational architecture. It should be noted that the vehicle's acoustic modems can be configured to work and exchange data outside the water.

Radio and acoustic modems do not feature as the standard equipment integrated to the platform mostly due to practical and cost considerations; for this reason they are considered as *optional* modules from the point of view of the simulation platform. The spare units from the operational vehicles can be connected to the platform for specific testing and validation work, notably de development and tuning of acoustic communication protocols and data compression schemes.

As stated before the VCC used in the platform is an identical copy of the operational system from both hardware and software point of views. In order for this realtime module to operate in a simulated environment, the SIMDYN or *Dynamic Simulator* module has been created and integrated to the platform. The role of SIMDYN is to provide the real time VCC system with a set of linear and angular velocities and positions that are compatible with the actuation setpoints that VCC generates and sends to the original actuators. These are mainly 5 movable fins and one thruster motor which are not included in the simulation platform Their recreated effect though is taken into consideration through a complex 6 degrees of freedom simulator which is run on SIMDYN.

The dynamic simulator includes several modules each computing the force and torque components for the main identified mechanical phenomena affecting the dynamic behavior of the vehicle, notably:

- Hydrostatic forces: weight and floatability
- Actuator forces: thruster motor and movable fins
- Hydrodynamic forces: lift and drag
- Apparent forces: angular and linear inertia, Coriolis and centripetal forces

The 6DOF simulator is run on a MATLAB Simulink dedicated program. This is been developed from a well reputed modeling principle (see Thor Fossen "Nonlinear Modelling and Control of Underwater Vehicles") and accepted simplified models for actuators and

hydrodynamic forces. The performance of the theoretical simulation has been subsequently fine tuned using dynamic data logged on the real vehicle in order to reduce the gap between simulated and measured behavior. This has yielded a simulated non-linear and continuous model of the vehicle that suits remarkably well the real time system.

The MATLAB module within SIMDYN generates linear velocities and accelerations from the state of actuation sent by VCC to the actuators.

A real environment simulator has not been integrated to the AUV simulation platform as the need hasn't yet arisen. In order to validate the sensor interfaces and effectively close the real time loop, the information from the MATLAB simulator are sent to individual navigation sensor simulators. These read the velocity and acceleration values and integrate them within data packet messages that reproduce the syntax and protocols used by the vehicle's navigation sensors. These include:

- Paroscientific depth sensor
- IXSEA PhINS inertial and attitude navigation unit
- RDI Workhorse Doppler DVL
- Altimeter
- GPS

Some environmental constants are defined in SIMDYN in order to complete the computed sensor output. These include for instance water temperature and salinity, seacurrent velocity and orientation, simple bathymetry defined as water column height as a constant or continuous function of the position.

Since the dynamic data is encoded following the exact syntax of the messages sent by these navigation sensors, the VCC software can fully run in closed loop within the simulated environment.

It must be however noted that the working characteristics of a large number of low level hardware modules that normally are interfaced to VCC has not been reproduced within the platform. These include:

- Water alarm sensors
- Ground default sensors
- Battery voltage and current drain measures
- Actual position feedback from actuators (motor rpm and aileron position).

These can be reproduced at software level within VCC itself, in order to validate the performance of control and diagnostic behavior rules.

With the aid of the simulation platform the vehicle operators can be trained to perform several basic operations in the exact way they would with the real vehicle. For this scope, the operator

would use the vehicle's piloting GUI provided by the SCC module as well as the tracking view in MIMOSA.

The basic actions that the operators can be trained to do with the simulator are:

1. **Manual piloting:** the vehicle can be piloted by entering a speed or rpm setpoint for the main thruster and setting setpoints for the main closed loop controllers (heading, velocity, altitude and depth).

   As a result of a manual piloting command received from SCC, VCC would generate the corresponding actuators setpoints. These are used by SIMDYN to compute velocities and accelerations, turned into navigation sensor measurements sent by the sensor modules to close the loop.

2. **Mission planning and execution:** the operator can create a mission profile on the provided MIMOSA computer, subsequently upload the file as in the real case to the VCC computer through the Ethernet network and finally launch the execution of the autonomous mission through the operator GUI. As a consequence the realtime VCC would decode and execute the mission as in the real vehicle, using data provided by SIMDYN to update its position and compute the new setpoints for the low level control loops.

The AUV simulation platform is un invaluable tool for both training and development purposes as it integrates a mix of real time core modules from the operational vehicle and a set of simulated modules to allow loop closure. It is important to remark that due to the fact the actual vehicle's real time control is used, it is not possible to run the simulation other than in real time. It is therefore not possible to apply a gain to the time variable and run simulations at in accelerated or slowed down modes.

Finally, the simulation of the actual payload sensors would be too complex and out of scope for the development training objectives of the AUV simulation platform. However all communication exchange between VCC and the target modules is reproduced and can be monitored on the Triade payload computer.

4.1.2 ROV Victor simulator

During the major overhaul of the Victor 6000 ROV, it was decided to invest in a comprehensive simulation platform to be designed and implemented. The overhaul targeted the complete redevelopment of the vehicle electronics and IT architecture, as well as several other subsystems after the completion of the first 10 years operational life cycle.
At first, the objective of the simulation platform was to enable validation of the several modules that compose both the surface and underwater computing system installed on Victor. This was deemed necessary as the vehicle operational planning didn't allow to access the hardware for integration and testing before the very end of the overhaul. At early stage the simulation platform also served as test mock up to validate several design and architecture ideas in order to identify the definitive configuration.

The technical objectives of the simulation platform are broadly listed as follows:

1. to recreate to its closest the hardware and software architecture of the real vehicle
2. to simulate by software all equipment that could not integrated to the platform for practical reasons (i.e. lighting systems, actuators, low level digital and analog signal acquisition)
3. to simulate the dynamic behavior of the vehicle and generate navigation sensor messages complying with the real case (syntax and physical communication protocol)
4. to simulate the overall deployed system: ship, depressor and vehicle in a simulated environment where realistic trajectories are subject to physical constraints (i.e. sea current, cable length and sea surface and bottom).

To date the Victor simulation platform represents the most complete and comprehensive tool of its sort available at IFREMER. It has successfully supported the *phase 1* of its intended contribution, i.e. to support the development work related to the overhaul. It has now entered *phase 2* and *3* as it plays a major role for validating all technical evolutions before operational deployment as well as to support the continuous process of operator training and skill consolidation.

The Victor 6000 simulation platform follow similar principles employed for the implementation of the AUV simulator. The major difference lies in the number of simulated subsystems which matches the far larger IT architecture of the ROV compared to the simpler AUV. A further difference is identified in the level of detail that has been adopted in the case of the Victor simulation platform which is under many respects higher than the AUV.

The overall architecture is summarised in Figure 2 where a similar color convention to the one used to depict the AUV simulator is adopted.

Once more the core element of the vehicle are reproduced either using the real vehicle's hardware and software modules or by simulation.

At the heart of the simulation platform lies the vehicle's own realtime computer and control software (named STR or "Système Temps Réel"). This is a QNX based industrial PC where the control software developed from the core modules provided by the ACE kernel of the ISE company. In terms of validation, integration tests and training it is crucial to reproduce exactly the same hardware and software setup as in the operational vehicle. For this reason exact copies of the operator tactile GUI and piloting console are integrated to the STR computer. The piloting console (see Figure 6) groups all buttons, joysticks and sliders found in the vehicle piloting van, as well as the hardware and software modules used for acquiring, filtering and pre-treating the analogue signals. These are then converted into Ethernet UDP coded messages sent to STR.

The operator controls the simulated vehicle exactly as the real system by interacting with the provided GUI and console. These command inputs are interpreted by STR and the corresponding action on the vehicle controller, the actuator or other peripheral module is dispatched using the operational interfaces (RS232, RS422 or UDP).

At the receiving end of such signals are three comprehensive simulator modules: SIMETSYS, SIMDYN and SIMENVI which have been custom developed by IFREMER to suit the platform's needs.
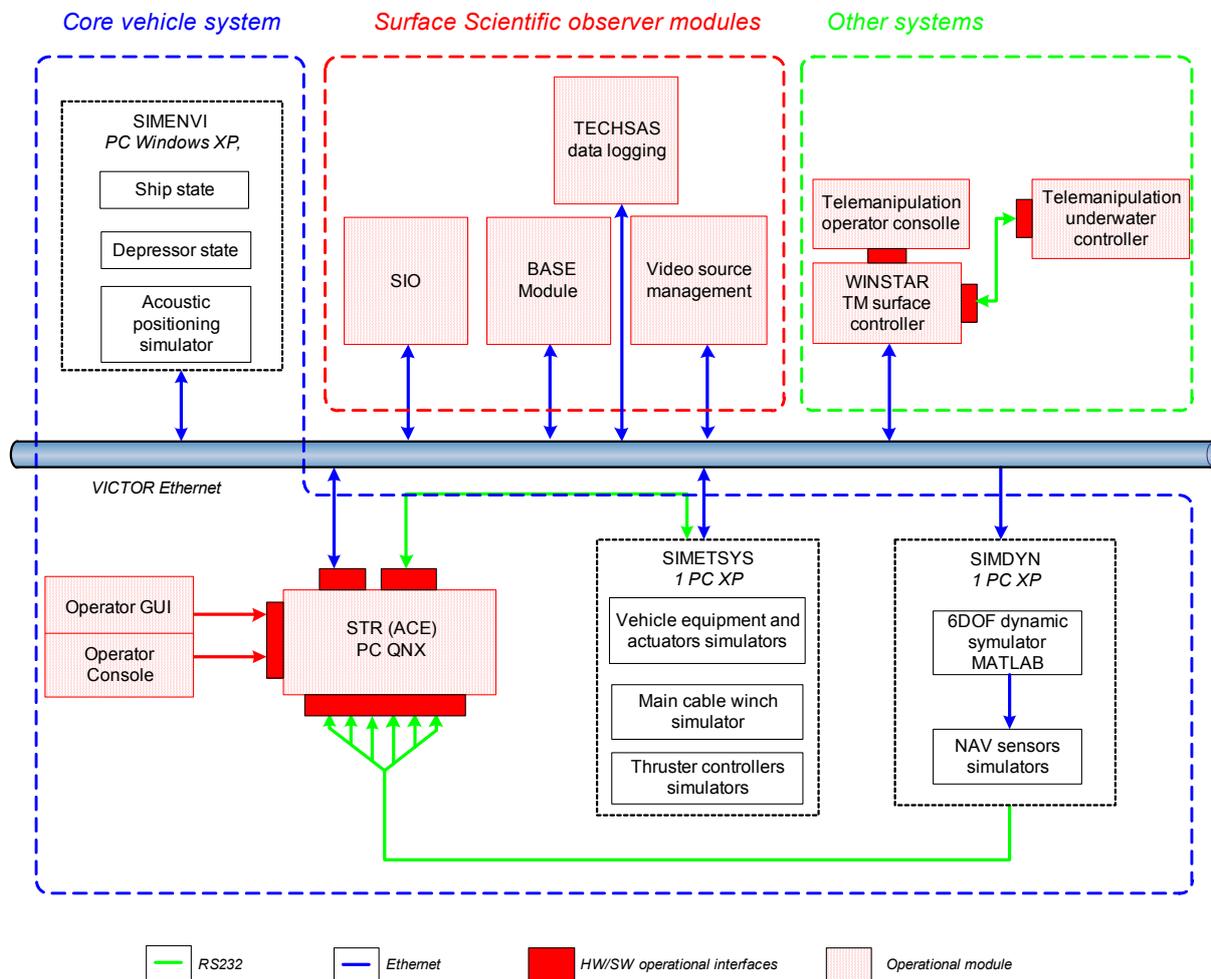

Figure 2. Overall architecture of the Victor simulator platform

The acronym SIMETSYS stands for "SIMulation ETat du SYStéme" or "system state simulator". It is composed by a number of applications developed mostly using Labview® that allow to reproduce the behavior of several subsystems such as:

- the thrusters power driver boards;
- the main winch control system;
- the power distribution relay switches, both for the main and payload circuits;
- the hydraulic compressor pump unit;
- the low level digital acquisition boards (ground fault sensors, water sensors,…).

These simulation modules are designed to interact to the STR and implement the same communication protocol of their real counterparts.

The individual modules are provided with dedicated software buttons that the operator can activate interacting with mouse clicks in order to generate events such as the occurrence of a water alarm or the loss of communication with a thruster power driver board. This is used to generate simulated faults and verify that the event is handled as expected by the STR.

The simulated thruster power drivers are software modules that receive thruster commands by STR and translate them into a coded message packet sent to the SIMDYN simulator. SIMDYN or "DYNamic SIMulator" is similar in principle to the one used in the AUV simulation platform, and is designed to compute the 6DOF dynamic model of the ROV.

The resultant force and torque components affecting the dynamics of the vehicle are computed from the following physical models:

- Hydrostatic forces: weight and floatability

- Actuator forces: thruster motors

- Hydrodynamic forces: lift and drag

- Apparent forces: angular and linear inertia, Coriolis and centripetal forces

The integration of the non-linear model running in MATLAB Simulink environment yields the rigid body velocities and accelerations, which are then in turn converted into navigation sensor data packets by a series of dedicated software modules. In the case of the Victor ROV vehicle the following sensors modules have been developed:

- Paroscientific depth sensor

- IXSEA Octans attitude measuring unit

- RDI Workhorse Doppler DVL

- Mesotech Altimeter

The internal architecture of SIMDYN is schematically represented in Figure 3.
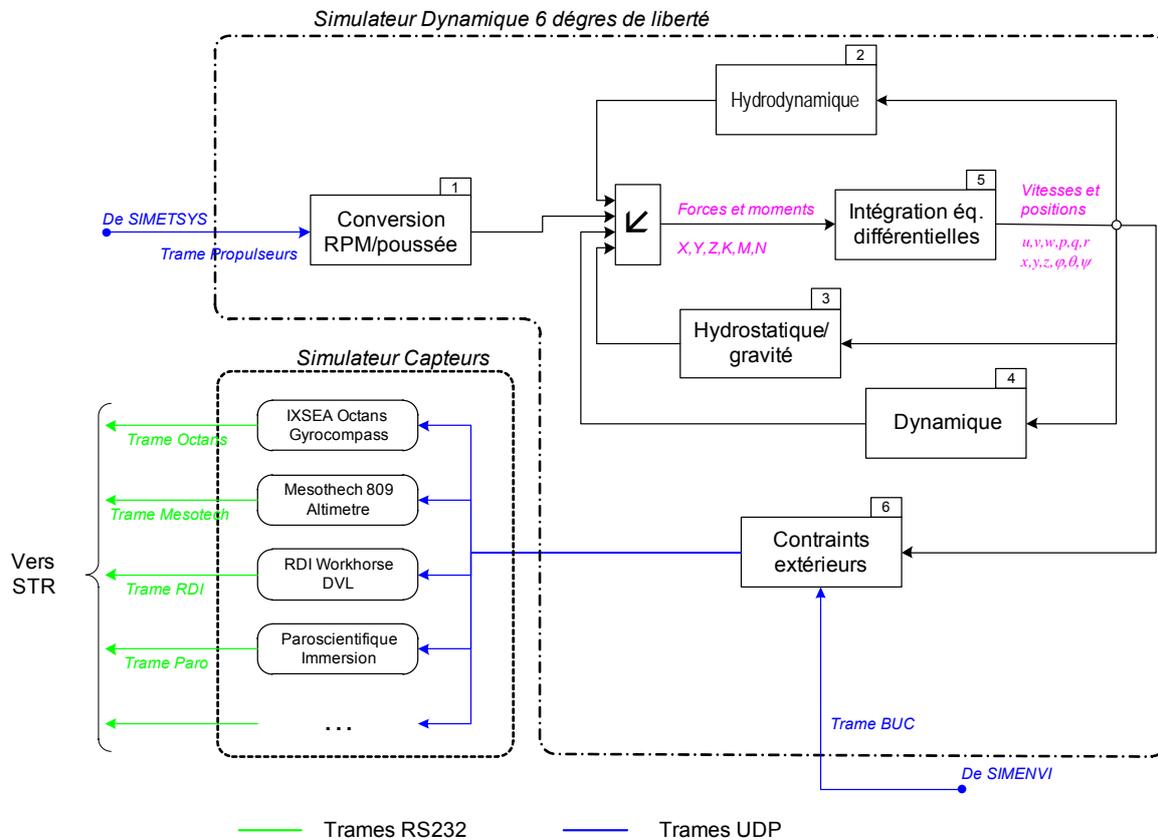
Figure 3. – Internal architecture of the SIMDYN 6DOF simulator

The third major simulation module in the platform is named SIMENVI and acts as a general environment simulator where all the mobile vehicle trajectories are computed and subject to physical constraints. This represents an important step further compared to the AUV simulation platform and is an identified necessity given the nature of the ROV operations that cannot be realistically simulated without considering the ship and the underwater depressor. In the real case mobiles are connected through cables, notably the main cable between ship and depressor and the light cable between depressor and ROV. This poses a series of constraints in the dynamics of the three considered mobiles see Figure 4, which is computed by SIMENVI in the following manner.

In the simulated environment the ship can be given a heading and a displacement velocity (that can be zero). The depressor is located at a depth given by a simplified model of the cable whose length is computed from the actuation commands sent by STR to the dedicated simulator in SIMETSYS. If the ship is moving, the depressor will follow its trajectory once the cable model computes that all of the slack has been taken in and the cable is tought.

The ROV is free to move following the actuators commands and the dynamic response computed by SIMDYN, as long as its linear distance from the depressor does not exceed the maximum length of the light cable (*d*). This length is set by a configurable parameter; the nominal value matches the case of the real vehicle which is 300m. When the light cable is under tension, the vehicle displacement is constrained to the sphere defined by the length of the light cable itself. In this configuration all computed velocities are projected to the

tangential plane α defined by the ROV position, the depressor position and the length *d* (see Figure 5). If in such condition the depressor is towed by the ship, the ROV is as well towed.
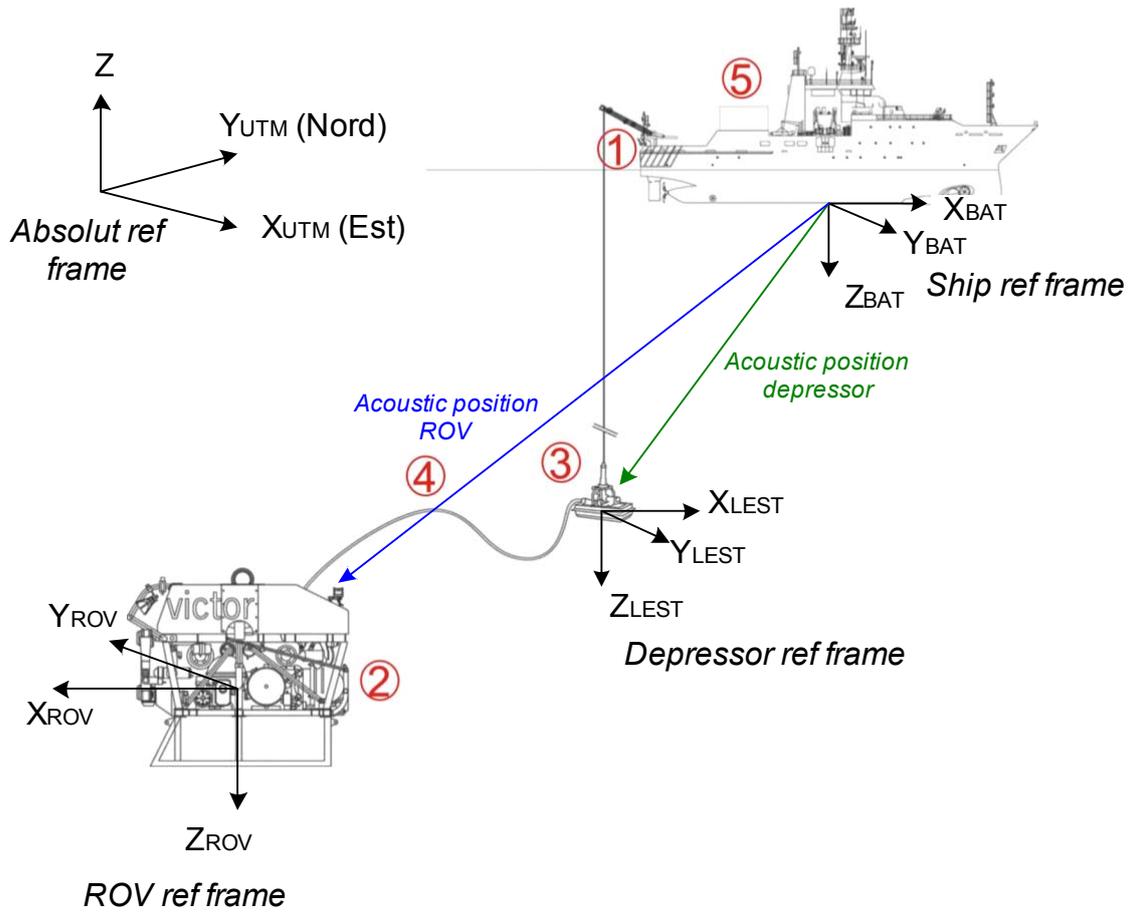

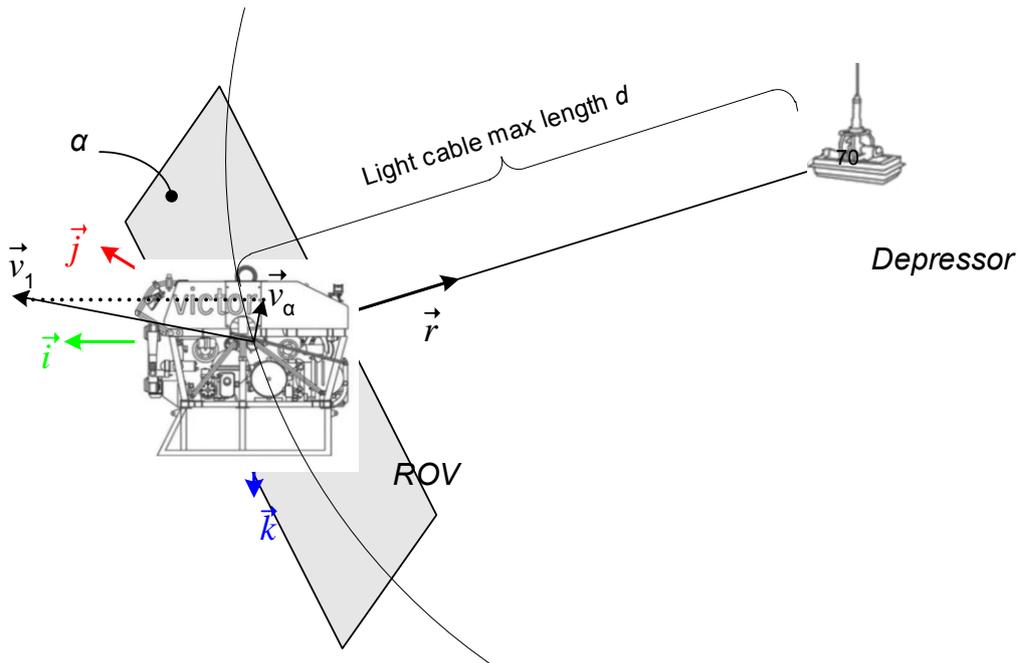**Figure 4. Simulated mobiles and reference frames**

Figure 5. Physical constraint application to ROV velocities when light cable is in tension

The platform also includes the exact copy of a number of operational modules found in the Victor 6000 ROV system, such as the mission planning and tracking software MIMOSA2, an evolution of the original MIMOSA software that implements new functionalities, including the management of the commutation of the video sources and the monitoring of distributed data logging. MIMOSA2 also feature a new multi operator architecture, allowing several "observer" applications to be run in parallel to the main "pilot" application.

The following series of photographs summarize some of the key elements of the Victor ROV simulation platform discussed above.

Figure 6.   Platform Implementation: PC and network switches rack (left); Operator control displays (top right); operator piloting console (bottom right)

4.1.3 Tele Manipulation training

The VICTOR 6000 Remotely Operated Vehicle is fitted with a six degrees of freedom hydraulic manipulator to perform underwater teleoperation tasks such as tool handling, sampling, dexterous manipulation and action on subsea equipment, etc…

Figure 7. The Victor 6000 ROV and its hydraulic manipulator

The manipulator is operated from the surface control room using a set of dedicated control devices (joysticks, master arm, digital screen) by the operator who only relies on 2D video feedback from the numerous on-board video cameras. Despite the large numbers of cameras used on the ROV, the different points of view available do not give to the operator the 3D sense of the underwater scene. Thus tele-operating the manipulator for tasks that require precision, motion stability or repeatability is a challenge that pilots overcome by experience.

Figure 8. Subsea tele operation phase with video feedback in the ROV control room

In order to support and prepare pilots to their work at sea, an inshore workshop has been setup and fully equipped.

The tele manipulation workshop is composed by the same equipment found on Victor : a six degrees of freedom hydraulic manipulator whose geometry is very close to the one installed

on the vehicle, the same control devices, video cameras and operational environment found in the ROV control room.
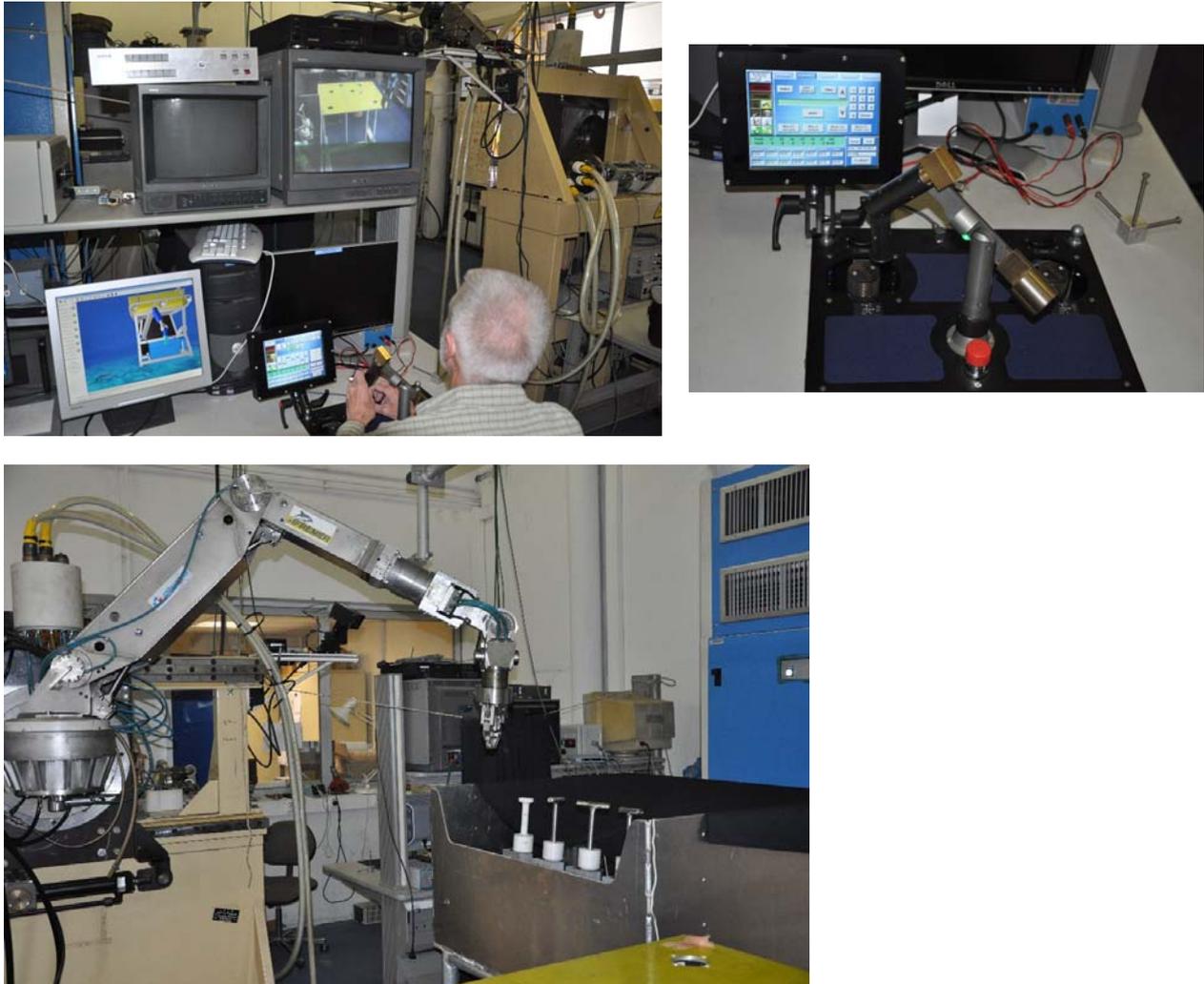
Figure 9. The tele manipulation workshop reproducing the Victor equipment: Operator training on a "hot stab" operation (top left); operator console (top right); 7 axis hydraulic manipulator (bottom)

In the workshop, the pilot is immersed in similar operational conditions as on Victor; he has no direct 3D view of the scene, but has instead only 2D video cameras feedback. Lighting conditions also close to the ones present in real situation can also be adapted to recreate different environments.

The same grippers, sampling tools and tools basket are used in the workshop in order to make the pilot feel the real difficulties encountered in real operations. Manipulating tools, feeling and handling the arm configuration in the constrained space of the vehicle front side, sensing the precision of the manipulator displacement, are some of the components the pilot can learn through training in the workshop. Tasks as complex as possible can be proposed for training, giving pilots experience they will exploit further during real at sea operations.

A dedicated tool rack has been for instance recently implemented for training "hot stab" connector plugging tasks typically found in the offshore industry.

The telemanipulation workcell can be connected of the IFREMER network to the Victor simulation platform (see Figure 2) in order to validate the exchange of data between the telemanipulation controller and the vehicle controller (STR).

4.2 Description of platforms existing at MARUM

4.2.1 Hydraulic ROV Manipulator Training-Stand

Since 2008, a dry hydraulic manipulator training stand is installed at MARUM, Bremen. The installation consist of an Schilling Robotics ORION7PE telerobotic manipulator system, a hydraulic power unit, camera boom with two pan/tilt cameras and an operators control station. Arm and camera setup are designed as a replicate to the installation on the MARUM-QUEST ROV, providing a similar perspective of views on the arm via seperate video feeds, comparable to those at the ROV's original pilot console (Figure 10).

Figure 10. Hydraulic Manipulation Training Stand at MARUM, Bremen. The easy to use setup allows regular pilot exercise, training of 3D perspective viewing with 2 adjustable 2D camera feeds, and design support or optimization of complex tools (shown is a pressure tight sampling system istalled in the sample-drawer of QUEST).

The stand is used for a number of purposes, ranging from telemanipulation training over tool development and prototype testing, to maintenance training on the complete arm system. All

tasks provided high value for the preparation of scientific cruises and are applied regularily during cruise preparation. In addition, the training arm serves as original replacement part in case of a fatal failure of the ROV installed arm. This, however, was only once the case since installation.

Training prooves regularily to be invaluable for pilots due to the continuously installed possibility of use. Procedures and special handling tasks can be repeated without technical risks and can be communicated easily among trainees and pilots and between scientists and pilots. Efficiency of manipulative tasks on the ROV as significantly improved over the last 3 years due to a great acceptance of such possibilities by MARUM pilots.

4.2.2   Virtual AUV and logfile player for post-mission vehicle behaviour analysis

Visualisation and replay of recorded vehicle attitude data can be very helpful to identify inconsistencies or failures in mission plans and logical dependencies of autonomous underwater vehicles. Due to the nature of AUVs, a realtime supervision of the ongoing mission is very limited, mostly only via few acoustic status requests and with the underwater position fixes via i.e. USBL navigation. Inexpected changes of behaviour, mission interruption or unusual high energy losses are only few issues which are very hard to resolve after recovery.

To adress this, a 3D mission player was developed at MARUM to display all possible data available for the AUVs attitude, setpoint controls and sensors after the cruise on a virtual AUV model (Figure 11). Replay of mission includes the possibility to overlay positions on bathymetric data. Control values of thrust, rudder planes and sensors are displayed simultaneously in relation to the AUV's logged feedback values and can help to identify possible control errors or malfunctions.
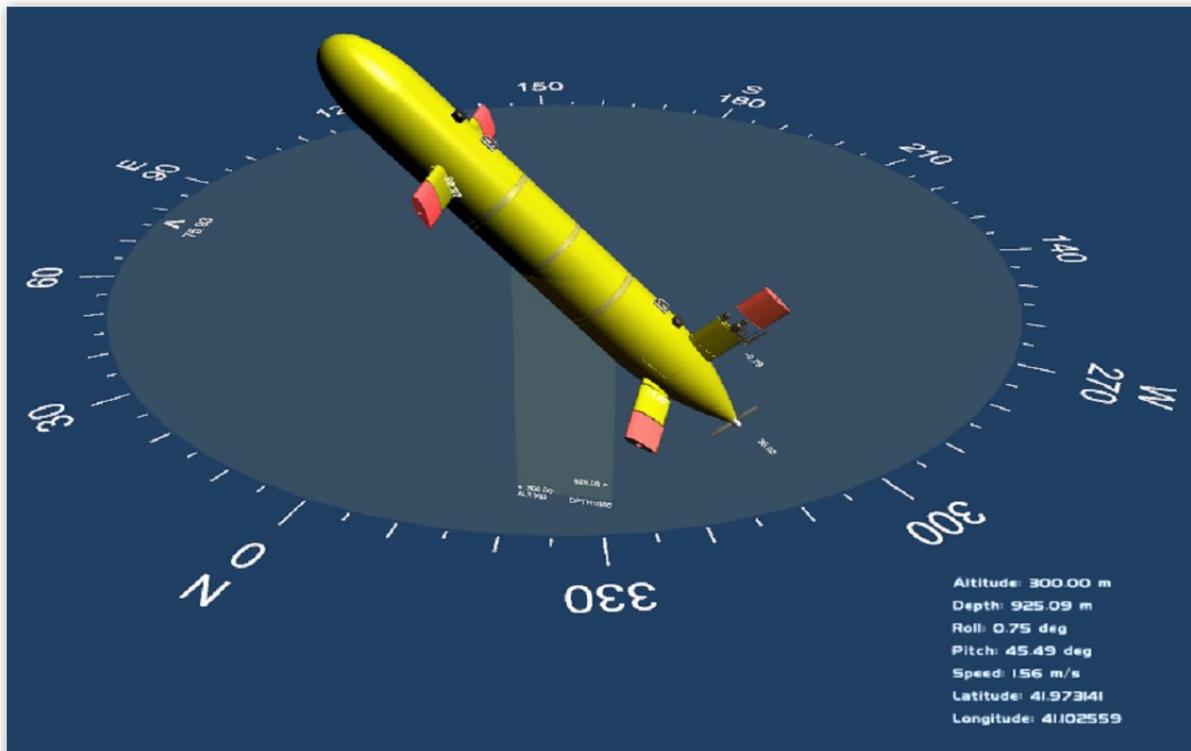
Figure 11. AUV SEAL Mission Player displays setpoints (red) and feedback (yellow) values of the thruster and planes, plus vehicle attitude, speed and navigation. Data are retrieved from the AUVs internal logfiles after mission end and can be played in realtime or accelerated.

Attitude data and depth/altitude values help to evaluate the vehicles center of mass / center of gravity relation, which often can be cause for unusually high energy consumption or even mission cancel. 3D visualisation helped especially at sea to gain time when failures need to be resolved fast and efficiently. This way, crews become easily able to visualize and intuitively understand a number of individual data records displayed simultaneously during mission replay.

The Software setup currently consists of 3 programs :
- SEAL mission player (streams AUV logfiles via UDP)
- SEAL virtual AUV (receives stream and displays AUV model and data)
- POSIVIEW GIS data player combines timetags of mission player and position fixes and displays on bathymetric maps

4.2.3 ROV Software Simulator for pilot training and procedure testing

Scope

Due to the nature of mobile missions for the MARUM QUEST 4000 m ROV, very often the system is at sea or on transport to worldwide changing locations. Thus, a training facility is needed to overcome these substantial time gaps where hands-on experience could be gained by pilots, trainees, technicians and also scientists in charge of adapting tools or planning future missions. A software simulation, installed into a hardware environment comparable to the original ROV control van, was found to be a valuable solution. A first beta release is now available, providing the video distribution of virtual underwater inages, USBL and DVL navigation, object manipulation and a realistic vehicle control console.

Goal

Major aim of the simulator is the training of cooperative operations, rather than configuration or improving control algorithms of the original vehicle. Thus, major attention was payed to the design of a realistic user interface, including a partial replic of the commercial Schilling Robotics (manufacturer of the ROV) control system as well as a number of functions enhancing graphical outputs. These range from particle dynamics, light falloff functions, optical camera view calculations to realistic manipulator and object collision modelling.

Based on a state-of-art commercial 3D graphics engine and including a portation of the open-source physics library « Newton Physics » (http://newtondynamics.com) the MARUM QUEST ROV Simulator provides a networked simulation platform with high end graphical display and correct physical collision models, directional forces and gravity/buoancy modelling. Fluid modelling and hydrodynamics, however, are not implemented into the current version.

The simulator is designed as a client-server architecture, providing multiple clients each with different functions to run the virtual ROV, control system, manipulators, or watch an operation as an observer, all inside the same software (Figure 12). Networking can be performed over LAN and WAN networks.

The setup allows a true coordinative operation training, where pilot/copilot tasks, navigation and observation can be shared and be coordinated within the same virtual environment. Where single control functions of a typical ROV could be trained also without such a setup, dependencies of decisions and realistic workshare of tasks can hardly be trained otherwise than during a real mission. Such training tasks include the basic navigation and apraoch, underwater intervention with one or more manipulators, umbilical and TMS handling, launch and recovery, video mosaicking flight or future ocean observatory installations and maintenace with dedicated and well-defined procedures. The software takes care of these cooperative tasks and allows a realistic pilot / copilot workshare training.

In addition, it aims at the potential of innovative networked digital communication, which is discussed in chapter 5 of this report.
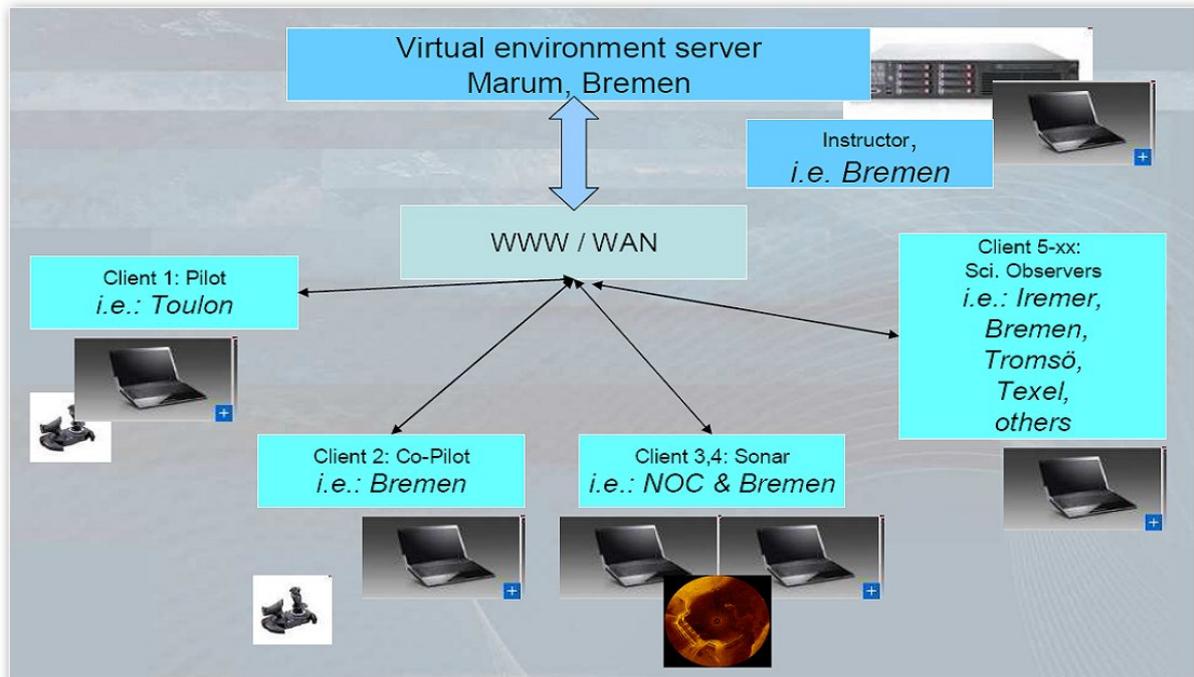
Figure 12. Schematic of networked workshare within the MARUM ROV virtual environment, with clients running different taks remotely.

Functionality

The following functional groups are available within the software :

1) Vehicle Control :
   a. Touch Screen based control clients with major control functions for thruster power, autopilots, ports switching and hydraulics. Further screens will follow to provide failure simulation and vehicle health.
   b. Joysticks provide direct control inputs for thruster, pant/tilts, multiple cameras zoom, lights
   c. All control values for thruster power and vehicle movement forces can be also applied using a telnet client for instructors use.
   d. Wire and LARS controls via telnet
   e. As a development plan, the software will be developed further to be controlled via the real QUEST control system software, and feedback into this with virtual data and status

2) Manipulator Control :
   a. General hydraulic functions can be accessed via control system touch screen pages.
   b. The 7 function ORION Manipulator can be controlled via an original Schilling Hardware MCU (Master Control Unit), serial protocol, or via mouse, joystick or telnet.

c. The 5 function RIGMASTER Manipulator is controlled via touchscreen or Joystick

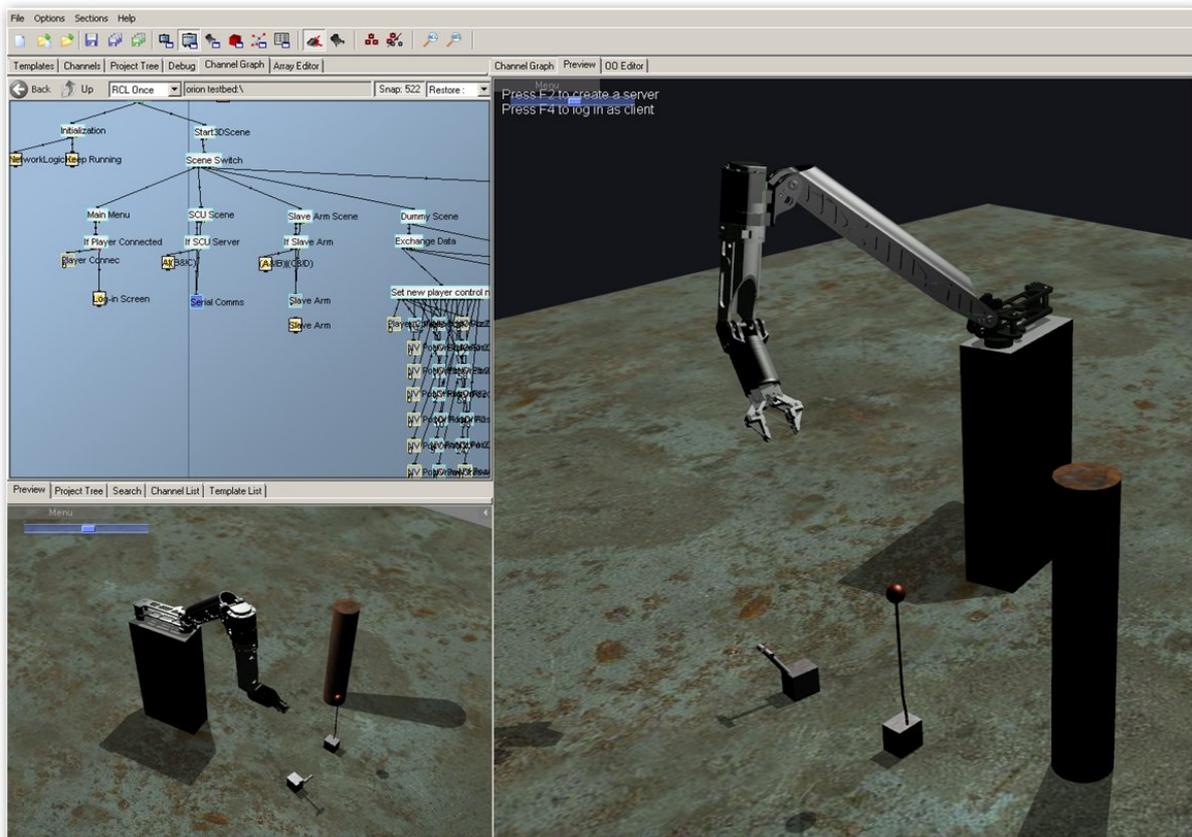d. For both manipulators, a separate stand-alone desktop simulator was developed (Figure 13)

Figure 13. Stand-Alone desktop MARUM ORION 7P Simulator with training collison objects (t-handle and rope)

3) Environment Control Environmental forces can be applied from the instructor via telnet or via the dedicated instructor client (planned). They include
   - 3D current velocities and directions
   - drag effects on wire and vehicle
   - gravity effects (i.e. sample loading, center of gravity affect, bouancy losses)

   a. Underwater visibility effects can be applied or changed (particles, bubbles lights, light falloffs, shadows, turbitity)

   b. On dedicated spots of interest, media textures can be affected to display projections of underwater video from the real life (i.e black smokers, corals, fish, gas bubbles)

4) Navigation and data IO :
   a. Attitude (Crossbow), heading (TCM2), depth (Paroscientific)and altitude data are streamed via UDP, TCP or serial RS232

b. USBL position data are streamed via UDP and TCP, i.e. as POSIDONIA format

c. DVL (RDI workhorse.1200 kHz) data are streamed as PD3 via UDP, TCP or serial RS232

d. Event data are available on custom formats (such as triggers, collisions, approaches, ray-collision checks (planned))

e. A virtual sonar is not yet implemented, but planned.

5) Virtual underwater video functions :

a. Up to 8 camera views can be displayed simultaneously on a 1920/1080 HDTV screen in a tiled window (equivalent to the QUEST ROV video projection setup (Figure 14).

b. Up to 16 cameras can be adressed and positioned on the ROV

c. Up to 4 cameras can be positioned freely in the virtual environment and used for observation of training or « filming » and documentation

d. Each camera view can be configured for optical calibration of the field of view and zoom, and for a number of visual effects such as color, contrast and brightness, gamma, pixel resolution, aspect ratio, blur and turbidity

6) Object interaction and collision dynamics :

a. A realistic object interaction includes collision detection, collision type, inertia, masses and buoancy, friction, and rope dynamics

b. Objects can be moved and transported, grabbed, released and deployed from the virtual ROV or any dedicated host object (i.e. virtual observatories)

c. Objetcs can be imported from major 3D construction or design programs such as 3D Max, Solidworks, Autocad, Maya, or others

d. Assignment of collision models to imported objectsis possible, yet non automatic so far.

7) Networking :

a. The software is set up for multiplayer use, that means multiple clients can interact with the same environmental simulation server

b. Each client can choose/be allowed to act as
   - full ROV control client
   - limited control client
   - Manipulator control client
   - Observer
   - Instructor

c. Clients can either be run as stand-alone-executes, or within a web browser (needs plugin)

d. Currently, only one controllable vehicle per server is allowed. This can be changed in future releases if needed.
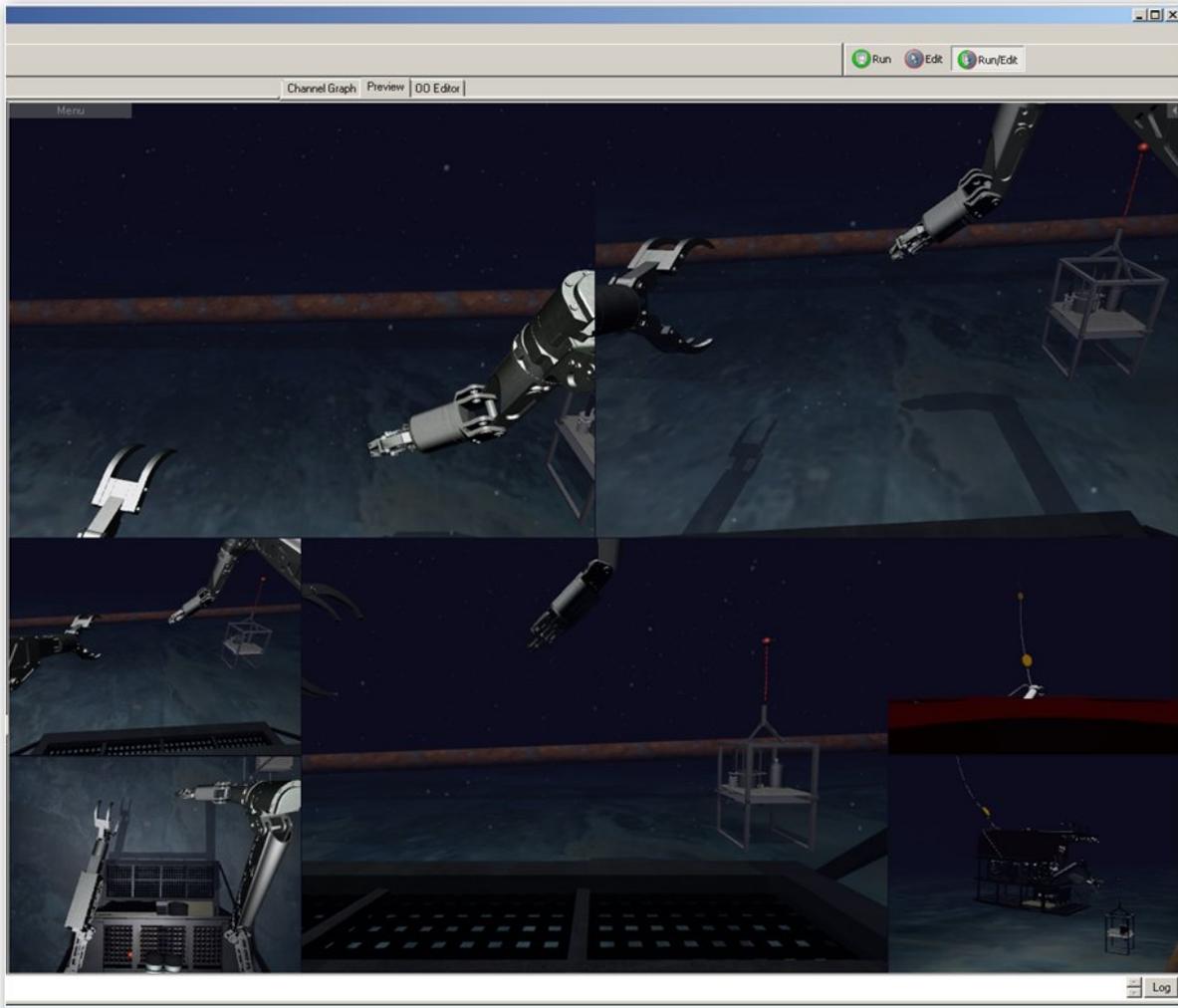
Figure 14. : Tiled projection view of 7 main cameras equivalent to QUEST ROV control van. Trainees gain almost all visual information available during real flight, and are able to exercise cooperative tasks for manouvering, camera control, and 2 manipulator control at the same time.

8) System Setup :
   a. Windows XP, VISTA or 7
   b. State of art accelerator graphics card (ATI or nVIDIA)
   c. Despktop version or Multiple PC Version
   d. MARUM installation will be inside a 20' ROV control van with 2 pilot stations, navigation and data screens, 7F Manipulator Master Console, HDTV Projection and Instructior / Observer station
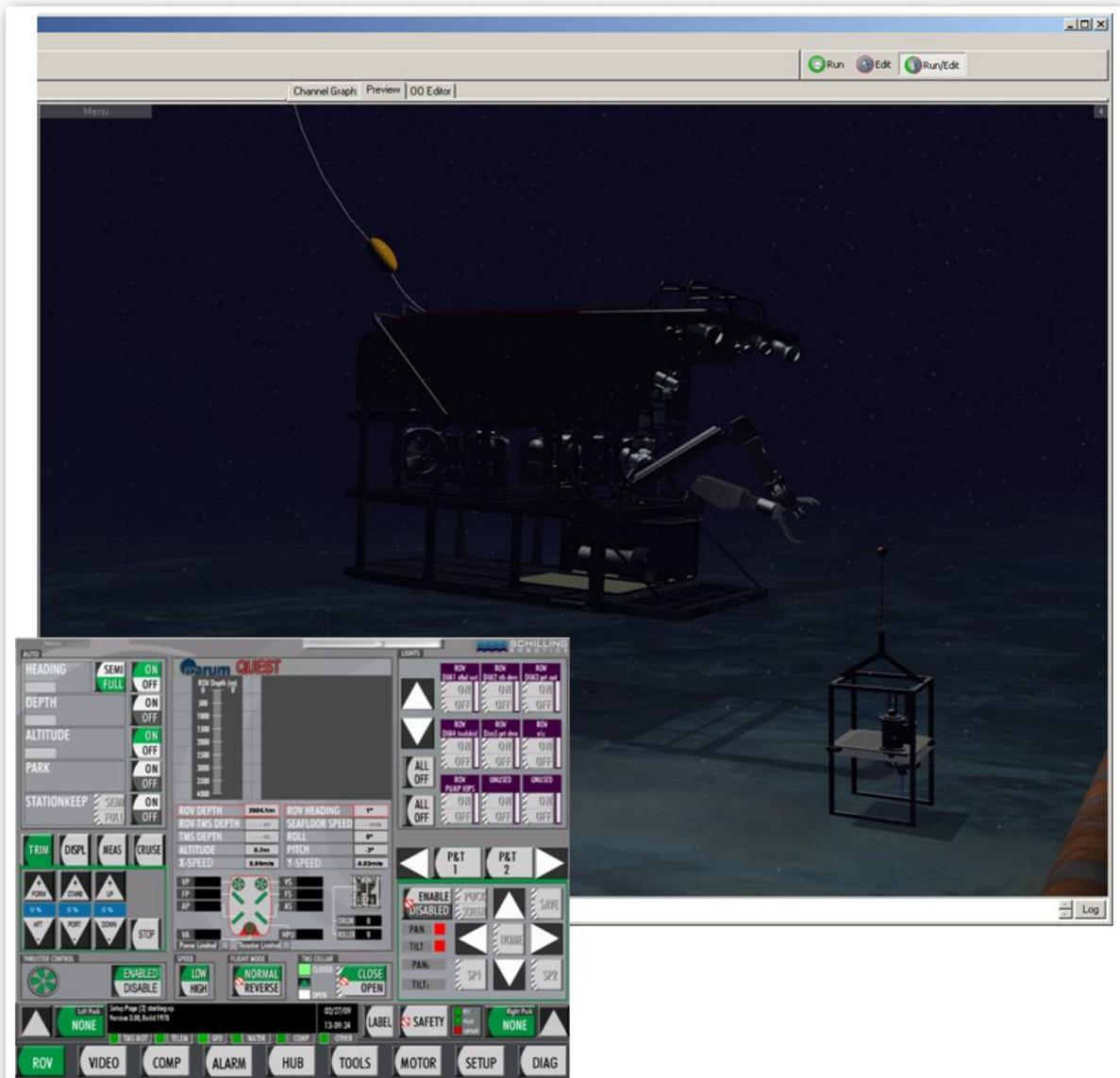
Figure 15. Observer view of the virtual QUEST approaching a science object for recovery. Pickup with 2 arms, and 2nd client for touch screen based piloting of the ROV.

4.3   Industrial simulator solutions

Although not reviewed in the scope of this workpackage, we found there is only a very short list of serious ROV simulation software solutions existing within the industrial market for oil and gas exploration and offshore ROV services:

- GRISIM VROV Simulator (in use for Schilling Robotics, Oceaneering, and other companies)
      (http://www.grisim.com)

- Perry Slingsby VMAX
      (http://www.vmaxsimulator.com)

- General Robotics DEEPWORKS
      (http://www.generalrobotics.co.uk)

5.0 Outlook: The potential of training and simulation in cooperative scientific underwater operations

5.1 Future scientific needs

Although a high level of experience for telerobotic underwater installation and maintenance already exists in Europe, expecially within IFREMER and the participating institutions, future work will even more rely on cooperation and share of expertise to a higher extent than it does today.

Installation, maintenance and recovery of observatory installations, complex sensor deployments and recoveries, vehicle payload exchanges and hybrid vehicle developments are some demanding tasks emerging from current and near-future scientific initiatives. Increasingly, international scientific projects relying on these technologies will run over several years with longterm goals, and probably will not be served with vehicles and platforms solely operated by a single group.

This fact already requires a common understanding of i.e. dedicated intervention schemes at a given structure, or a standardized underwater hardware interfacing, to ensure the same quality of operation between different systems and crews. To achieve such a common understanding, training becomes a relevant issue to address the procedural component of using different systems among similar environments and deep-sea installations.

5.2 Application of networked simulation

Todays software development frameworks are highly adapted to the different needs of networking. This is also true for both scientific simulator systems presented within this report. We propose, that for future operational planning as described above, these possibilities can be of enhanced value.

A first attempt to further develop such an approach is undertaken within the MARUM ROV Simulator. As a server based software, clients are able to log into an ongoing operation and either share data, or visual impressions from different perspectives, or take control over the vehicle, manipulator arms or handling systems.

This said, it is a short step towards the vision of simulation as a somewhat "broadband" interactive whiteboard, where ideas, experiences, and - most important - real procedures can be communicated between operators in realtime. Even if these operators are located in different institutions or countries, they can demonstrate what they develop or plan to execute later at sea. Such communication would allow precise understanding and at the same time cooperative training of procedural tasks, which are often not easy to share. First testing of such functionality will be available in 3rd quarter of 2011.

5.3   Scientists and Student training

Simulated underwater environments allow mission specific training and procedural testing, and thus also help scientists in charge of such missions to gain a higher level of understanding. Because all tasks discussed here are by definition dedicated to marine science, overall mission planning and scheduling of increasingly complex, technology loaded expeditions requires higher levels of such operational awareness than only few years ago. Examples for operational constraints are specific task durations, payload limitations or environmental dependencies such as currents and weather. With the increasing use of remotely controlled vehicle platforms, observatory installations, real-time data networks and autonomous instruments, scientists increasingly need to have access to operational training to become prepared for realistic estimations of technical capabilities, needs of enhanced cruise planning, and finally decisions and design calls of large-scale scientific deep-ocean infrastructures in future.