PROJECT PERIODIC REPORT

Grant Agreement number: 611373

Project acronym: CADDY

Project title: Cognitive Autonomous Diving Buddy

Funding Scheme: Collaborative project, Small or medium-scale focused research project (STREP)

Date of latest version of Annex I against which the assessment will be made: 08/07/2013

Periodic report: **1st** □ **2nd** □ **3rd** □ **4th** □

Period covered: **from 01/01/2014 to 30/06/2014**

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CADDY

Cognitive Autonomous Diving Buddy

Declaration by the scientific representative of the project coordinator

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate) [1]:

  ☐ has fully achieved its objectives and technical goals for the period;

  ☐ has achieved most of its objectives and technical goals for the period with relatively minor deviations.

  ☐ has failed to achieve critical objectives and/or is not at all on schedule.
- The public website, if applicable

  ☐ is up to date

  ☐ is not up to date
- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 3.4) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 3.2.3 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator: ....

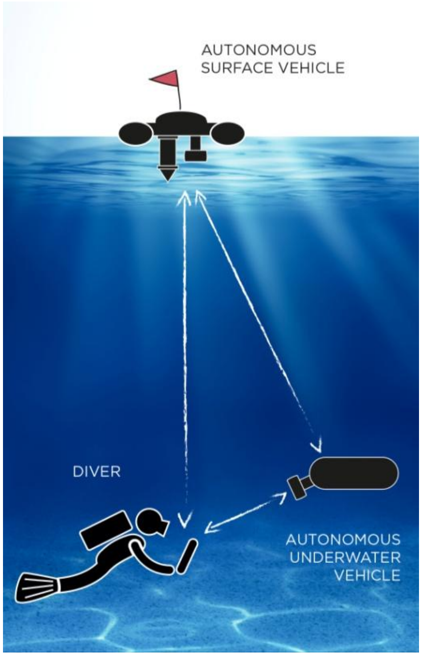
Date: ..../ ..../ ....

For most of the projects, the signature of this declaration could be done directly via the IT reporting tool through an adapted IT mechanism and in that case, no signed paper form needs to be sent

[1] If either of these boxes below is ticked, the report should reflect these and any remedial actions taken.

3.1 Publishable summary

Divers operate in harsh and poorly monitored environments in which the slightest unexpected disturbance, technical malfunction, or lack of attention can have catastrophic consequences. They manoeuvre in complex 3D environments, carry cumbersome equipment, while performing their mission. To overcome these problems, CADDY aims to establish an innovative set-up between a diver and companion autonomous robots (underwater and surface) that exhibit cognitive behaviour through learning, interpreting, and adapting to the diver's behaviour, physical state, and actions.



CADDY concept

The CADDY project replaces a human buddy diver with an autonomous underwater vehicle and adds a new autonomous surface vehicle to improve monitoring, assistance, and safety of the diver's mission. The resulting system plays a threefold role similar to those that a human buddy diver should have: *i)* the buddy "observer" that continuously monitors the diver; *ii)* the buddy "slave" that is the diver's "extended hand" during underwater operations performing tasks such as "do a mosaic of that area", "take a photo of that" or "illuminate that"; and *iii)* the buddy "guide" that leads the diver through the underwater environment.

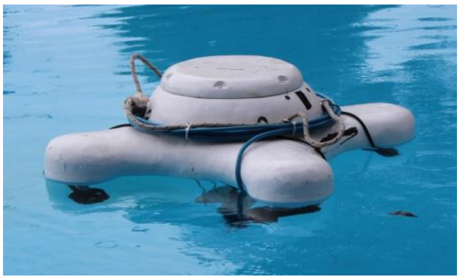
The envisioned threefold functionality will be realized through S&T objectives which are to be achieved within three core research themes: the **"Seeing the Diver"** research theme focuses on 3D reconstruction of the diver model (pose estimation and recognition of hand gestures) through remote and local sensing technologies, thus enabling behaviour interpretation; the **"Understanding the Diver"** theme focuses on adaptive interpretation of the model and physiological measurements of the diver in order to determine the state of the diver; while the "**Diver-Robot Cooperation and Control"** theme is the link that enables diver interaction with underwater vehicles with rich sensory-motor skills, focusing on cooperative control and optimal formation keeping with the diver as an integral part of the formation.

In the first 6 months of the project the partners have made substantial progress in both technological as well as scientific objectives that were set in the project. Here is a short summary of the most important results in the short period of time:

1. **Development of the multicomponent system**

PlaDyPos by UNIZG-FER, MEDUSA$_S$ by IST and Charlie by CNR are the autonomous surface vehicles that have been refurbished to act as the diver's "private satellite". In addition to that, MEDUSA$_D$ by IST and ROMEO by CNR are being modified to serve as the autonomous diving buddy. UNIZG-FER is in the process of finishing their prototype BUDDY AUV, a first autonomous underwater vehicle with an underwater visual interface for the diver.

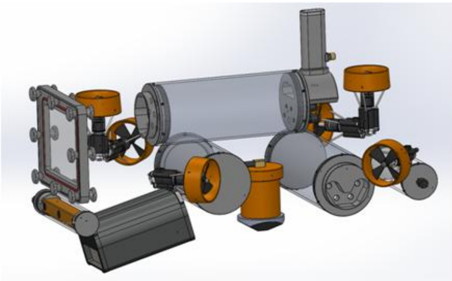
A new set of modems and navigation systems prototype has been developed by UNEW. This system, characterized by small dimensions, initial rate of 100bps and USBL fix repeatability of << 1 degree at update rate of more than 1 fix per second, perfectly fits in the CADDY concept which requires reliable acoustic communication between the diver, buddy and the surface vehicle.



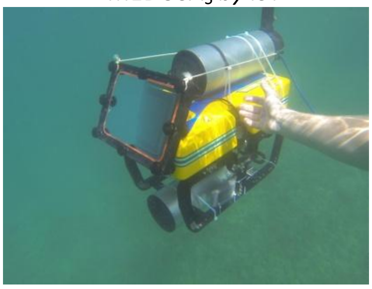
PlaDyPos by UNIZG-FER

MEDUSA$_S$ by IST

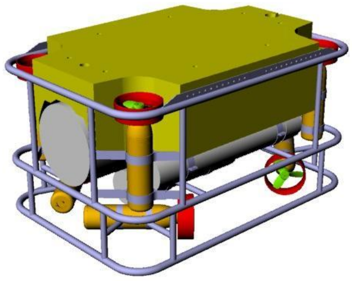
Charlie by CNR



BUDDY AUV components



BUDDY AUV prototype in water



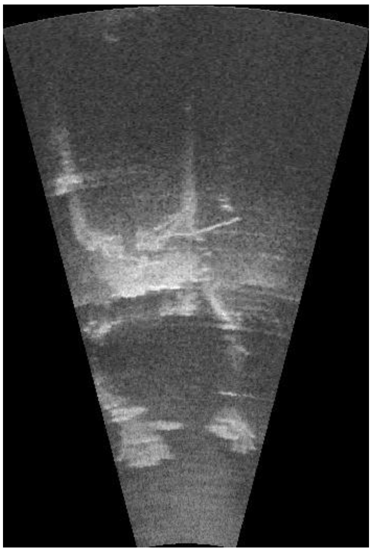
ROMEO by CNR

2. "Seeing the diver" – remote sensing and the DiverNet

We have conducted a large number of experiments in which diver remote sensing techniques such as multibeam sonar, stereo and mono camera were used to record the diver. Further steps will include processing the obtained data to reconstruct the diver pose and/or diver hands

Sonar and stereo camera mounted, filming the diver.

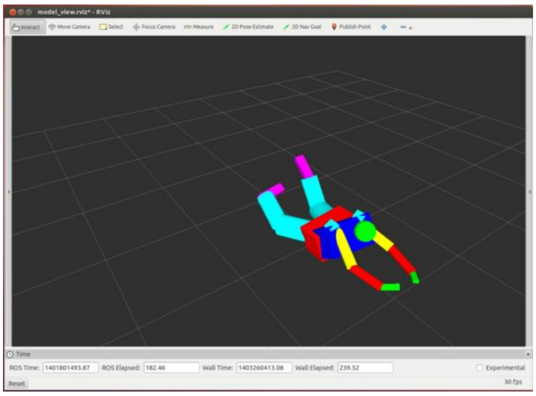
An example of stereo camera acquired diver image.



An example of multibeam sonar acquired diver image.

DiverNet is a specially CADDY designed and manufactured network of inertial sensors that are mounted in the diver in order to reconstruct the pose of the diver. This is the first time a system like this has been successfully developed and tested for underwater use.

Diver with the DiverNet underwater.

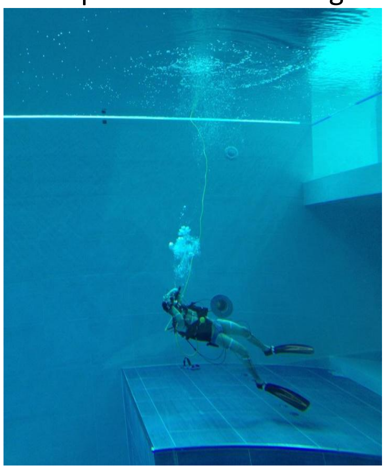


Visualization of DiverNet measurements in a form of a virtual stick-man.

DiverNet mounted on the diver.

3. "Understanding the diver" – linking the posture to emotions

Initial results in the area of hand recognition using vision processing have been obtained. In addition to that, a number of experiments with physiological measurements on divers were conducted by UNIVIE, under the supervision of DAN Europe: emotional breathing, analysis of breathing through the regulator, posture analysis and linking to the persons emotional state. initial results have shown that breathing rate decreases while breathing with a regulator, and that heart speed of change decreases. DiverNet was used to detect diver posture while diving.

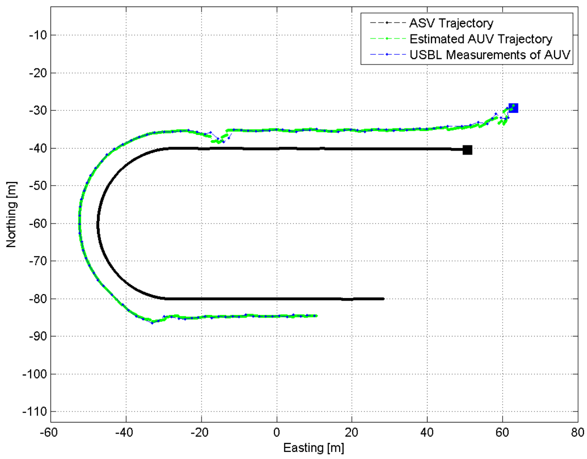


Diver wearing the DiverNet during experiments in Pag, Croatia, and Vienna.

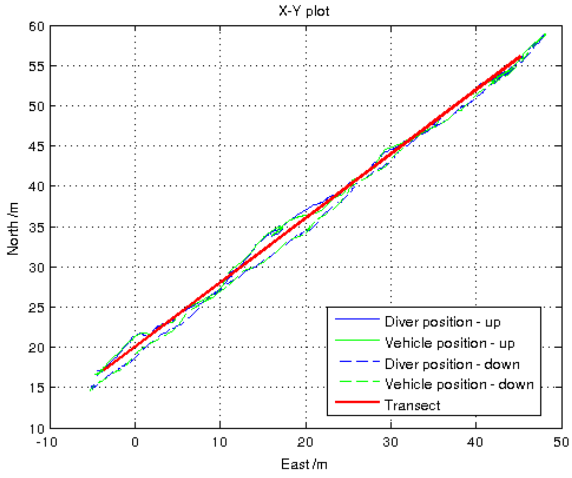
4. "Diver-Robot Cooperation and Control" – tracking, leading and single range localization

Experimental results of two envisioned scenarios were conducted. In scenario 1, AUV in the role of a "buddy guide" has to follow the ASV (autonomous surface vehicle) that is moving in a predefined trajectory. This scenario describes the situation where the surface platform knows the location where it has to take the diver, AUV follows the surface vehicle, and the diver follows the AUV. In scenario 2 the ASV is tracking the diver by keeping its position always above the dive, acting as the divers private satellite. Results obtained in real conditions for both scenarios show excellent performance.

In addition to that, single range localization algorithms were successfully validated in simulations, and are ready to be tested in real conditions.



Plot of scenario 1: leading the diver (AUV)



Plot of scenario 2: tracking the diver

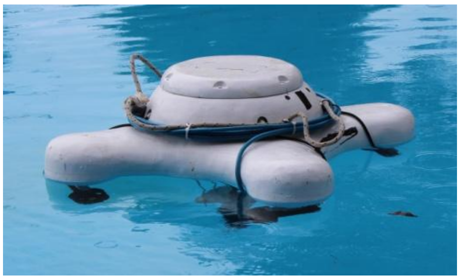
More on CADDY project progress can be found on the website http://caddy-fp7.eu/, and live reports from experiments are available on our Facebook page https://www.facebook.com/caddyproject.

3.2 Core of the report for the period: Project objectives, work progress and achievements, project management

3.2.1 Project objectives for the period

TO1. Development of a cooperative multi-component system capable of interacting with a diver in unpredictable situations and supporting cognitive reactivity to the non-deterministic actions in the underwater environment.

Surface segment: All autonomous surface vehicles (PlaDyPos by UNIZG-FER, Charlie by CNR and MEDUSA$_S$ by IST) have been refurbished to fit the CADDY purposes. In addition to changing the hardware and testing all the developed software (control architectures and mission planners), all partners modified their vehicles to enable ROS-based heterogeneous systems integration.

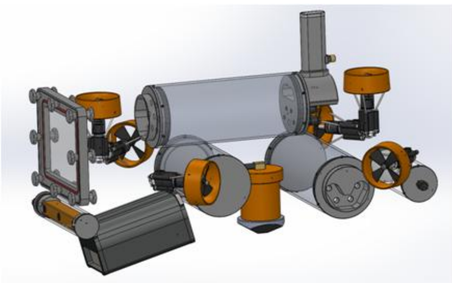


PlaDyPos by UNIZG-FER

MEDUSA$_S$ by IST

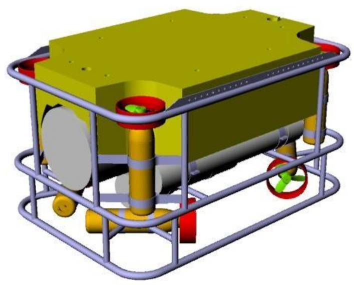
Charlie by CNR

Underwater segment: While UNIZG-FER is almost finished with the prototype of the new BUDDY AUV, CNR has upgraded their ROMEO ROV for the purposes of CADDY project and IST is using their existing MEDUSA$_D$ AUV. The initial BUDDY version was successfully tested during in water trials in Split. BUDDY is the first AUV with diver interface in a form of an underwater tablet.



BUDDY AUV components

BUDDY AUV prototype in water



ROMEO by CNR

Interfacing the diver: A new underwater tablet casing has been designed and produced. The case allows the diver to use commercially available tablets to exchange data with the vehicles.

The underwater tablet case.

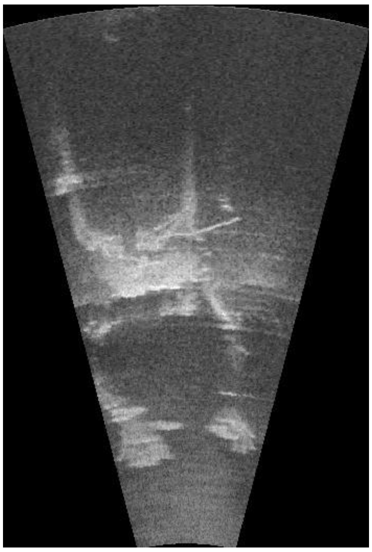
TO2. Establishing a robust and flexible underwater sensing network with reliable data distribution, and sensors capable of estimating the diver pose and hand gestures.

TO2.a. Testing and evaluation of sensors that will enable pose estimation and hand gesture identification in the underwater environment.

Remote sensing technologies such as high resolution ARIS multibeam sonar, stereo camera and mono camera have been tested to evaluate their applicability for diver recognition. A large dataset of diver motions has been acquired during Pag and Padova experiments, and the data is being processed. While the multibeam sonar imagery does not give excellent results for details such as diver hands, it is expected that diver posture at larger distances can be captured. The camera imagery works well at low distances, and we are currently extracting the diver hand point cloud from the stereo imagery.

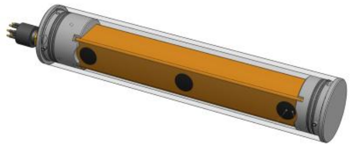
Sonar and stereo camera mounted, filming the diver.

An example of stereo camera acquired diver image.



An example of multibeam sonar acquired diver image.

ARIS multibeam sonar

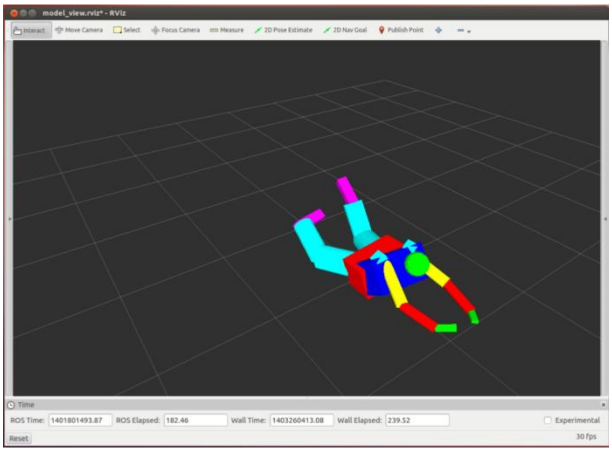


Stereo camera in a custom underwater case

Mono camera in a custom underwater case.

DiverNet is a specially CADDY designed and manufactured network of inertial sensors that are mounted in the diver in order to reconstruct the pose of the diver. This is the first time a system like this has been successfully developed and tested for underwater use. Custom visualization software has also been developed and now, for the first time, real time diver visualization, in a form of a virtual stick-man is possible on the surface. Current version of DiverNet is tethered, while the next one will be wireless. DiverNet also enables inclusion of physiological sensors such as breathing belt, heart rate sensor, etc.

Diver with the DiverNet underwater.

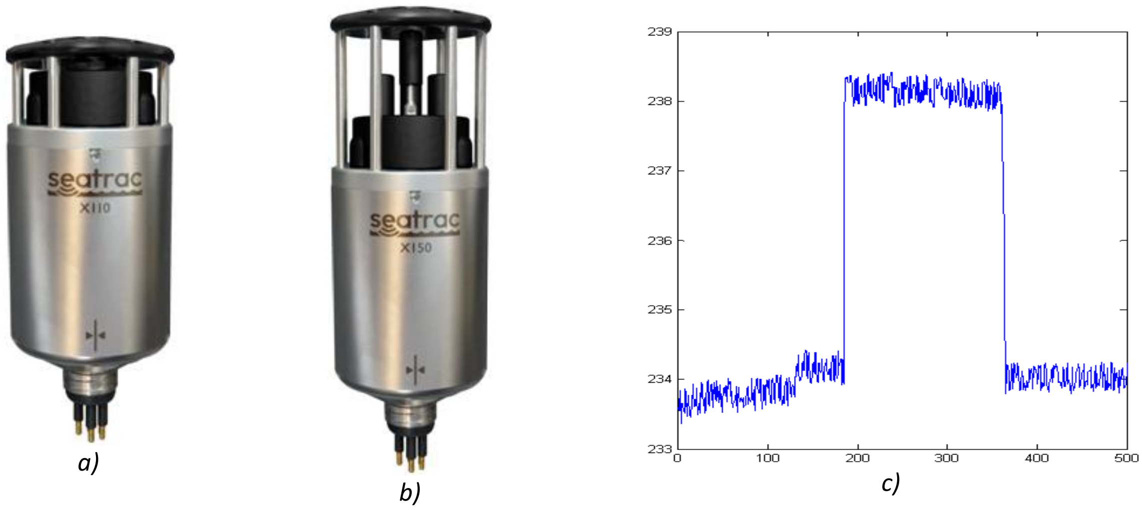


Visualization of DiverNet measurements in a form of a virtual stick-man.

DiverNet mounted on the diver.

TO2.b. Propagation of the acquired data through the network to each agent with strong emphasis on securing reliable data transmission to the command centre for the purpose of automatic report generation and timely reporting in hazardous situations.

New modem and navigation systems prototype hardware, both electrical and mechanical, have been constructed and preliminary tank testing has been conducted. Testing of the initial 100bps modem has been performed through tank testing and successful performance has been demonstrated with variable packet lengths (up to 32 bytes per packet). Initial performance demonstrates USBL fix repeatability of << 1 degree at update rate of more than 1 fix per second.



X110 Modem Prototype, b) X150 USBL Prototype, c) Bearing estimates showing repeatability in two different locations

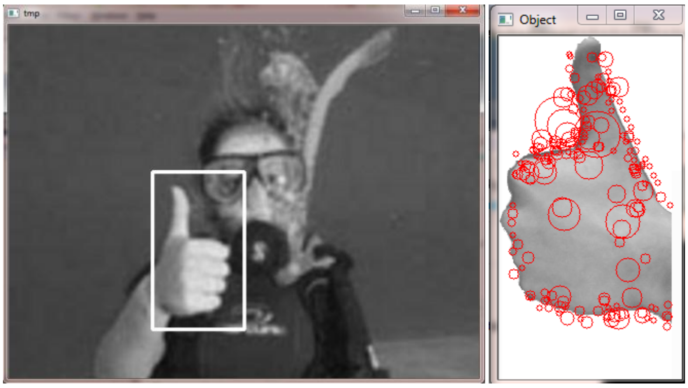
TO2.c. Adaptive learning mechanism for communications scheduling based on the detection of bubble streams produced by the diver.

SO1. Achieve full understanding of diver behaviour through interpretation of both conscious (symbolic hand gestures) and unconscious (pose, physiological indicators) nonverbal communication cues.

SO1.a. Develop efficient and near real-time algorithms for diver pose estimation and gesture recognition based on acoustic and visual conceptualization data obtained in a dynamic and unstructured underwater environment.

In addition to using DiverNet to obtain ground truth data for diver pose, we are working on full diver pose and joint angle estimation using genetic algorithms and a model reprojection based fitness function, which previously showed promising results on monocular thermal images in a safety, security, and rescue robotics (SSRR) scenario.

For classifying detecting diver gestures, we have obtained preliminary results using software implemented in C/C++ and exploiting the OpenCV vision library. For detecting dynamic gestures, hidden Markov models were applied, resulting in a 72% successful recognition rate on a set of 8 gestures. Further improvements are expected.

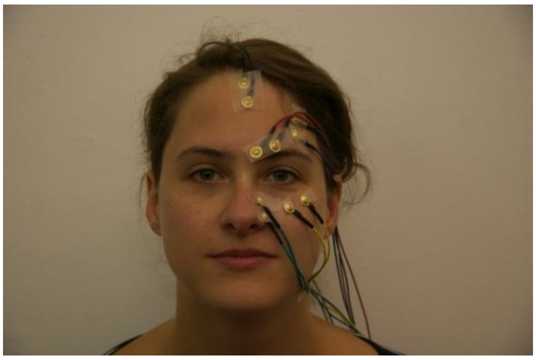


Static hand gesture correctly matched by the system.

SO1.b. Develop adaptive algorithms for interpretation of diver behaviour based on nonverbal communication cues (diver posture and motion) and physiological measurements.

A large number of experiments were carried out in order to better understand diver behaviour. Some are listed here, only mentioning the methodologies used, and some results that were obtained.

1. **Emotional breathing experiments** (Vienna; 99 participants; on dry land). Six basic emotions (amusement, anger, anxiety, disgust, sadness and surprise) were induced by showing the participants pre-validated film clips, after what the participants reported their emotional state via questionnaire. In addition facial EMG electrodes were used to record the activity of several facial muscles.



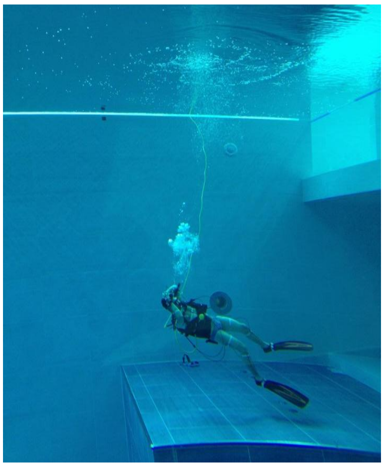
Participant during emotional breathing experiment.

Breathing through regulator experiment.

2. **Breathing through regulator experiments** (Pag, Croatia; 15 participants; on dry land). Participants wore a breathing belt as well as a heart frequency sensor and were filmed with a camera. The results show that breathing rate is significantly lower when breathing through a regulator. In contrast to breathing, heart activity features like speed of changes goes up significantly when breathing through a regulator, and turbulence is lower when breathing through a regulator. On a physiological level this might suggest that

the organism reaches a upper threshold of possible performance when breathing through a regulator.

3. **Internal states and posture experiments** (Vienna; 100 participants; on dry land). Participants were filmed while they were asked by an interviewer to report their internal state in a questionnaire using 18 bipolar adjectives as well as control variables (like sex, body height, age, rating of the interviewer, academic degree and income). This experiment will establish a baseline of how internal states of pleasure, arousal and dominance affect body posture to which results from divers can be compared.
4. **DiverNet experiments** (Pag, Croatia and Padova, all together 22 diver participants). Divers performed a set of tasks while they were recorded with the developed DiverNet and video. The results are still being processed.

Diver wearing the DiverNet during experiments in Pag, Croatia, and Vienna.

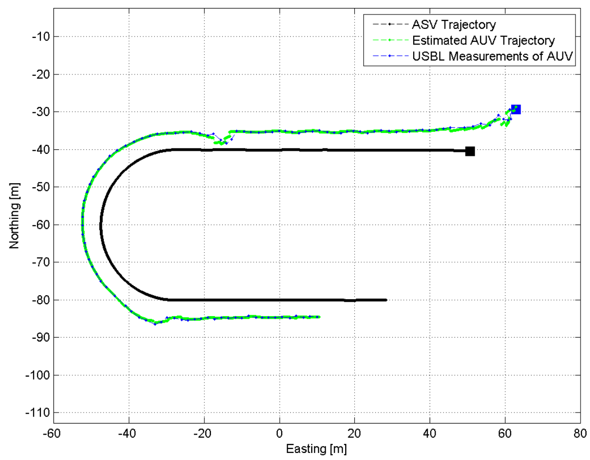
SO2. Define and implement execution of cognitive guidance and control algorithms through cooperative formations and manoeuvres in order to ensure diver monitoring, uninterrupted mission progress, execution of compliant cognitive actions, and human-machine interaction.

SO2.a. Develop and implement cooperative control and formation keeping algorithms with a diver as a part of the formation.

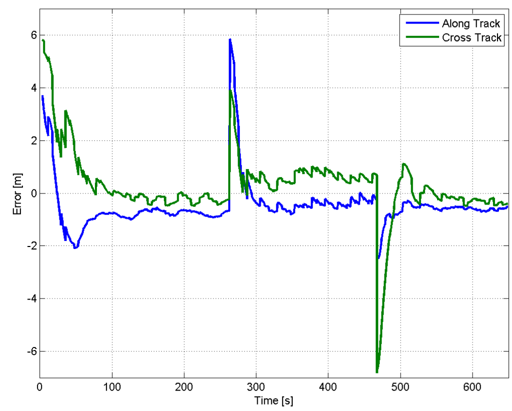
Two scenarios were studied by IST and UNIZG-FER.

<u>Scenario 1:</u> AUV in the role of a "buddy guide" has to follow the ASV (autonomous surface vehicle) that is moving in a predefined trajectory. This scenario describes the situation where the surface platform knows the location where it has to take the diver, AUV follows the surface vehicle, and the diver follows the AUV.

Experiments taken by IST (where AUV is tracking the ASV at a predefined distance, i.e. 5m "to the right" and 17m "behind") show excellent results with tracking errors less than 1m even with only low bandwidth acoustic communication.



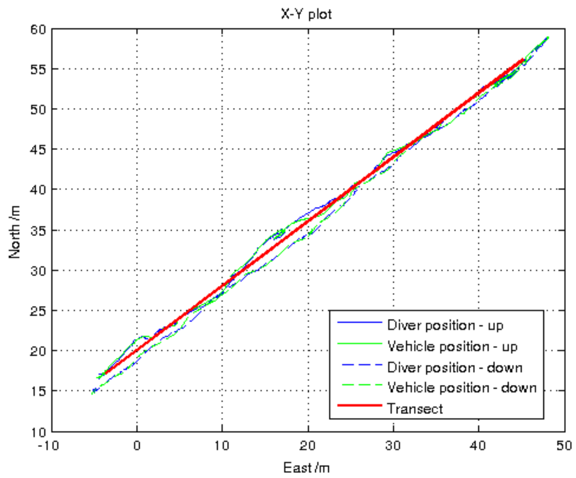
Leader tracking system: *experimental tests with the MEDUSA class of vehicles (ASV trajectory in black; AUV trajectory in green)*



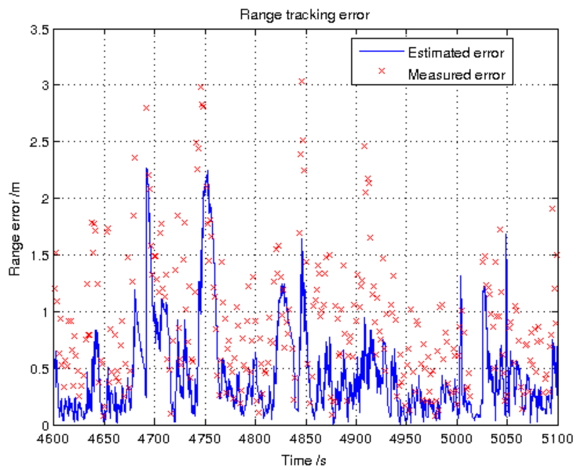
Leader tracking system: along-path and cross track errors.

<u>Scenario 2:</u> The ASV is tracking the diver by keeping its position always above the dive, acting as the divers private satellite.

In the experiments performed by UNIZG-FER, the diver was moving along a straight georeferenced underwater transect while the autonomous platform PlaDyPos was following. Tracking error was less than 3m even with the presence of air bubbles that disturb the acoustic communication channel.



a)

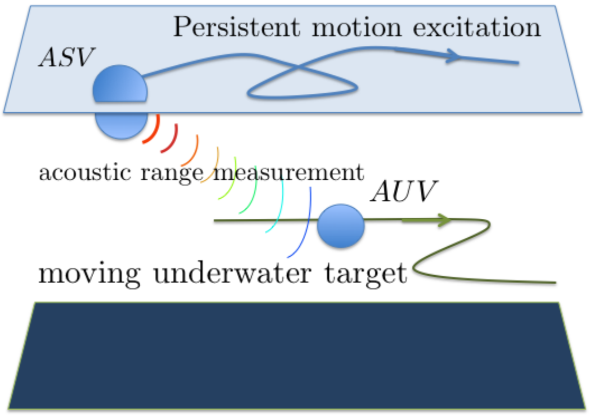


b)

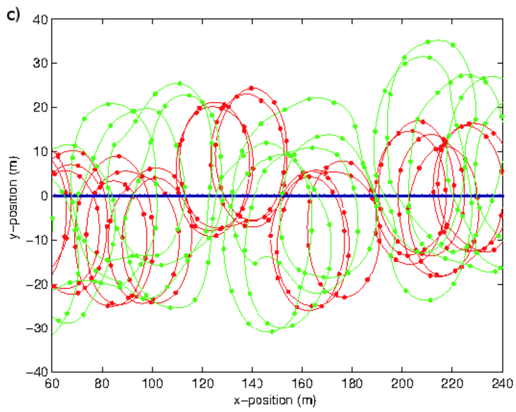
Fig. 4.2.10. N-E plot of diver movement and the tracking range error.

SO2.b. Develop cooperative navigation techniques based on distributed measurements propagated through acoustically delayed sensing network.

Range-only based navigation was successfully demonstrated. In order to eliminate high cost USBL devices, ASVs that have only range measurements from the AUV and/or diver, perform exciting manoeuvres in such a way as to minimize the errors of localization of AUVs/divers. Simulation results are obtained and compared using ASVs that are stationary, performing circular motion, performing motion as to maximize observability of the system (i.e. determinant of the Fisher matrix), and performing motion as to minimize localization error (i.e. by using dynamic programming optimization).



Range Based Localization concept.



An example of ASV path to maximize observability of the system.

SO2.c. Execution of compliant buddy tasks initiated by hand gestures.

SO3. Develop a cognitive mission (re)planner which functions based on interpreted diver gestures that make more complex words.

SO3.a. Develop an interpreter of a symbolic language consisting of common diver hand symbols and a specific set of gestures.

SO3.b. Development of an online cognitive mission replanner.

3.2.2 Work progress and achievements during the period

WP1 Robotic diver assistance system

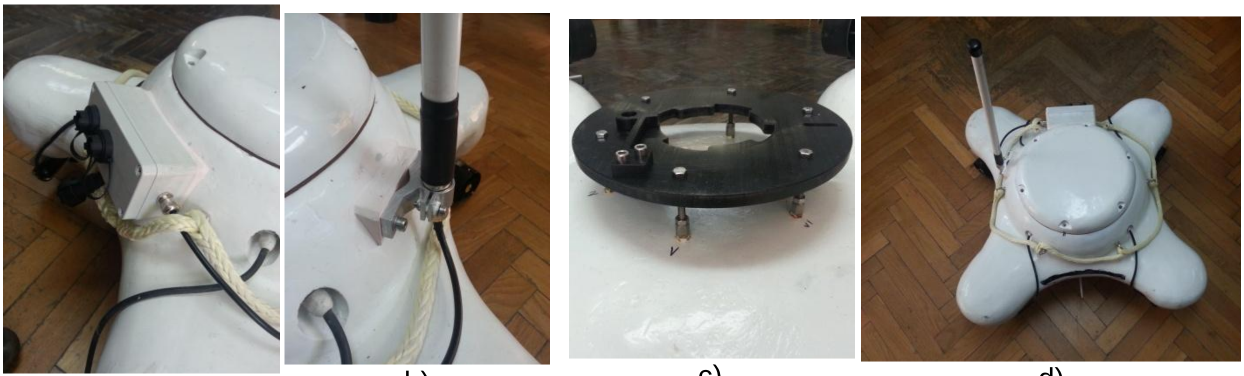
T1.1. The surface segment (UNIZG-FER, IST)

The availability and adaptation of existing/under development surface platforms is described in this section. The main characteristics of the surface vehicles made available by each partner involved in the task, are described in terms of mechanical structure, sensor suites, navigation and guidance abilities, communication systems, integration with the overall framework.

UNIZG-FER efforts are mainly directed on the modification and enhancement of the autonomous surface marine platform, which will be referred to as *PlaDyPos* (short for Platform for Dynamic Positioning, which was its original functionality).

Hardware modifications and refurbishment on the existing surface vehicle include the following items:

- Appendix on the back of the platform for cables (Fig. 1.1.1a)
- Ubiquiti Bullet M2 HP WiFi for platform and ground station (Fig. 1.1.1b)
- Mount for new WiFi antenna on platform (Fig. 1.1.1.b)
- universal mount for USBL and DVL (Fig. 1.1.1c)
- Charging and powering without opening the lid



a) b) c) d)

Fig. 1.1.1. Modifications and refurbishment of the UNIZG-FER PlaDyPos.

The electrical configuration of PlaDyPos is shown in Fig. 1.1.2. The following set of electrical modifications and enhancements have been made: ethernet relay has been added thus allowing the possibility to turn on/off: every motor separately, USBL, DVL, CPU over WiFi from ground station; ethernet switch is added and USB drive for logging; new wiring has been integrated.

Additional activities on the refurbishment of PlaDyPos in immediate future include signalling lights, new paint job, new battery and new motors and drivers.

Since we want to ensure that the platform will follow the diver even at higher speeds, a custom made brushless thruster prototype, shown in Fig. 1.1.3., was created and it will soon be finished. It should work on nominal voltage of 48 V and 3 A current which will give 150 W of power.

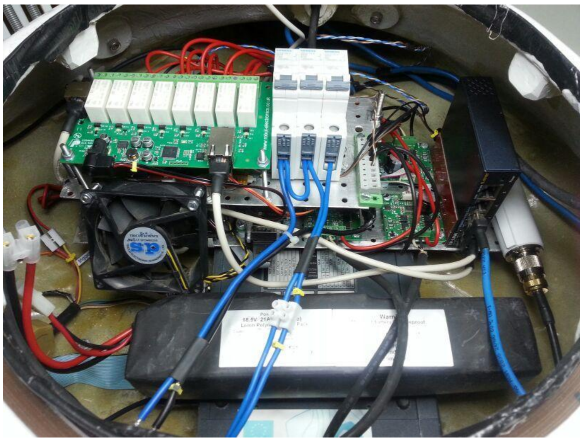


Fig. 1.1.2. Electrical configuration of PlaDyPos.

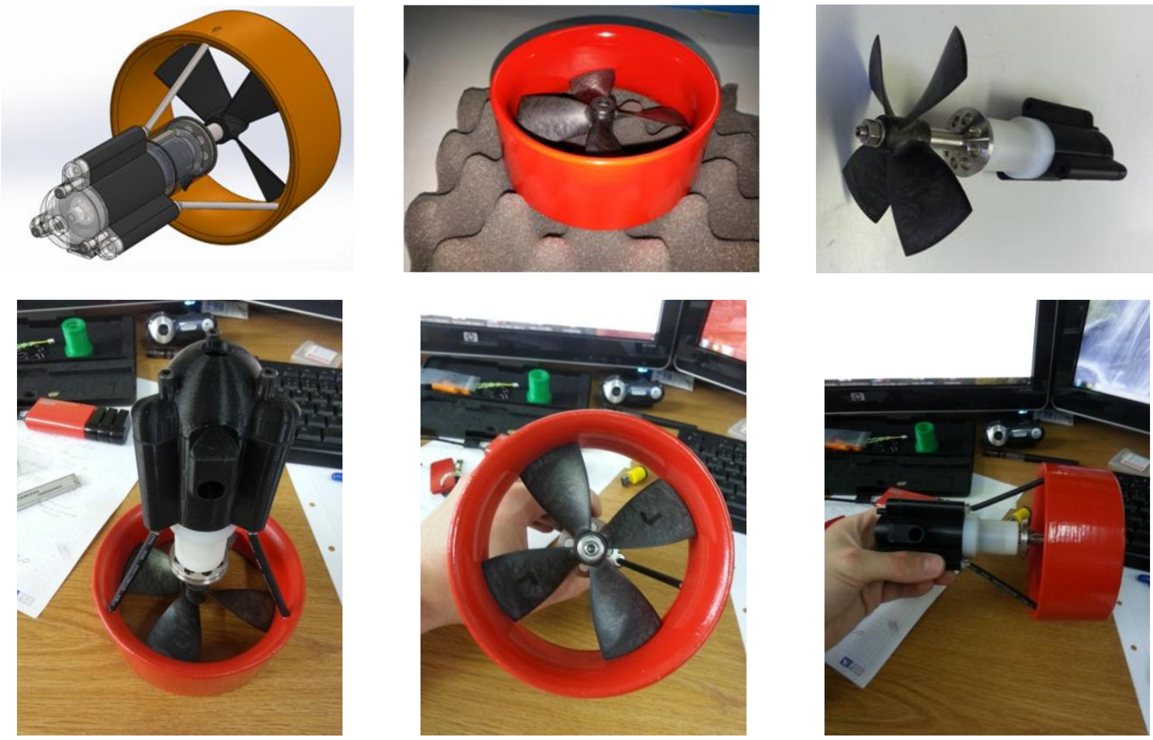


Fig 1.1.3. UNIZG-FER custom made thruster.

Identification:

In order to achieve high quality low-level control, mathematical model of the platform has been identified. Thruster model has been identified using the classical steady state thruster mapping. We have applied the identification method based on self-oscillations to determine the dynamic model of the platform.

Software:

The control structure consisting of low-level controllers, high-level controllers, primitives and mission control has been established and documented. Control structure hierarchy is shown in Fig 1.1.4. Low-level controller and identification extensions have been implemented and pool testing has been successfully performed. State machine for control primitives execution which enables easier building and modifying of complex manoeuvres has been implemented.

Mission is defined as a set of primitives that have to be executed. The primitives that comprise a mission are in fact states in a state machine. The mission control state machine example realized in ROS environments is shown in Fig. 1.1.5a).

Primitives are elementary parts that form a mission. They are uniquely defined by the structure of the low–level and/or high–level controllers that they engage, and a set of inputs.

As it is shown in Fig. 1.1.4, primitives can engage both high–level and low–level controllers. So, for example, the primitive go2point_FA engages the high–level heading controller (heading) in order to face the vehicle in desired direction, and the high–level fully actuated line following controller (LF_FA) which enables following desired line. The first implicitly engages low–level yaw rate controller, while the second implicitly engages the surge and sway low–level controllers. The primitive DP_primitive engages the high–level dynamic positioning controller (DP) in order to guide the vehicle to a desired point, and the high–level heading controller with full actuation (heading) and so on. The list of currently used primitives, their inputs, and high-level controllers they engage, is shown in Table 1.1.1.A

All the primitives were tested on PlaDyPos, surface platform, during Split field trials in June/July 2014. Acquired results show that the proposed control structure ensures bumpless change in commanded signals when mission states change.

Table 1.1.1. List of primitives

Name	Inputs	Controllers
go2point_FA	T_1, T_2, ψ	LF_FA; heading
go2point_UA	T_1, T_2	LF_UA
dynamic_positioning	T_1, ψ	DP; heading
course_keeping_FA	course, ψ	LF_FA; heading
course_keeping_UA	course, ψ	LF_UA

The sensor drivers for the newly acquired Spatial IMU sensors have been custom-developed by UNIZG-FER, and they have been integrated on PlaDyPos.

Testing and performance evaluation of sensors, controllers and navigation was performed on the vehicle in real conditions on Jarun lake in Zagreb.

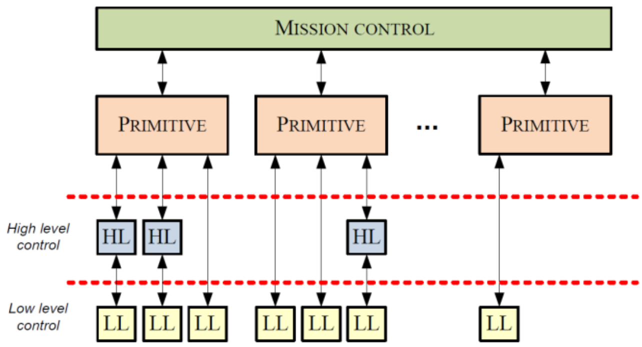


Fig. 1.1.4. Control structure hierarchy.

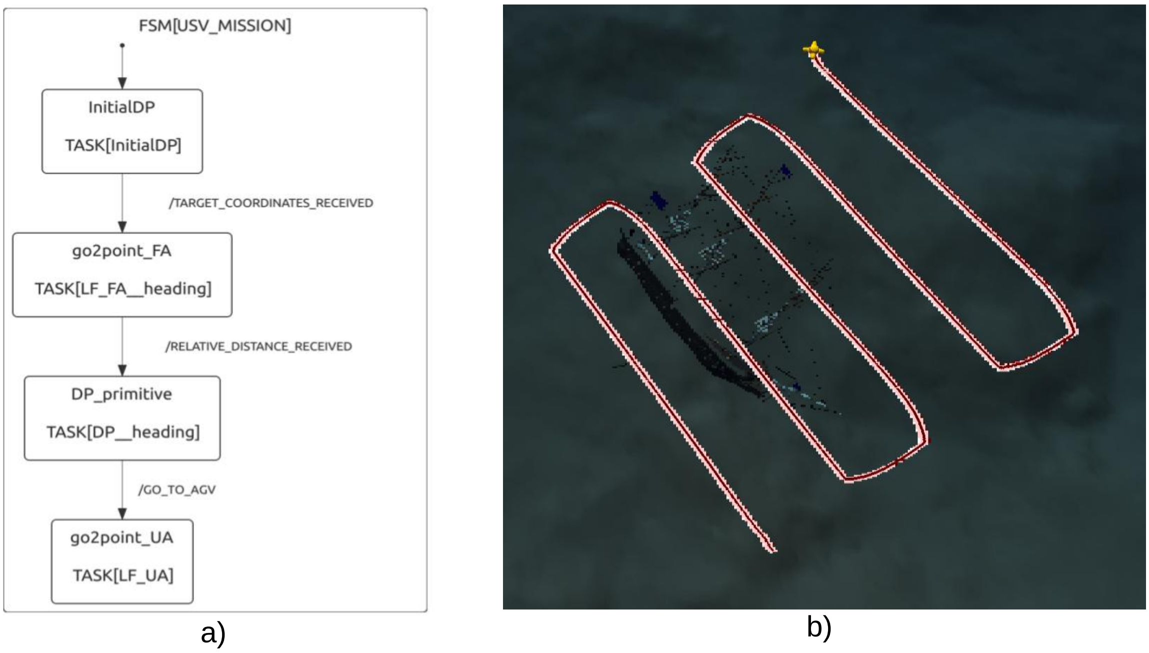


Fig. 1.1.5. a) Example of mission state machine, b) lawnmower mission executed in UWSim.

The Charlie USV (see Fig. 1.1.6) is a small catamaran shape-like prototype vehicle developed by CNR. Charlie is 2.40 m long and 1.70 m wide and weighs about 300 kg in air. The propulsion system of the vehicle is composed of a couple of dc motors (300 W at 48 V), with a set of servo amplifiers that provide a PID control of the propeller revolution rates. In the current release, the vehicle is equipped with a rudder-based steering system, where two rigidly connected rudders, positioned behind the thrusters, are actuated by a brushless dc motor. The navigation instrumentation set is constituted of a Trimble GPS and a KVH Azimuth Gyrotrac. Electrical power supply is provided by four 12 V at 40 Ah lead batteries, which can provide power supply for several hours of operation. The onboard realtime control system, developed in C++, is based on GNU/Linux and run on a single board computer (SBC), which supports serial and Ethernet communications and PC-104 modules for digital and analog input/output (I/O). A commercial wi-fi system provides the communication link, for commands and telemetry, between the vehicle and the remote control station.

The Charlie USV has been upgraded integrating an additional computing board in order to provide an interface with the ROS infrastructure. Moreover a secondary wi-fi system has been mounted on the USV allowing the communication among Charlie and the other vehicles, for the cooperative tasks, relying on the ROS architecture.

Regarding the payload side, the acoustic modem, needed to provide the communication channel for the surface/underwater robots' cooperation, has been mounted on the Charlie USV.

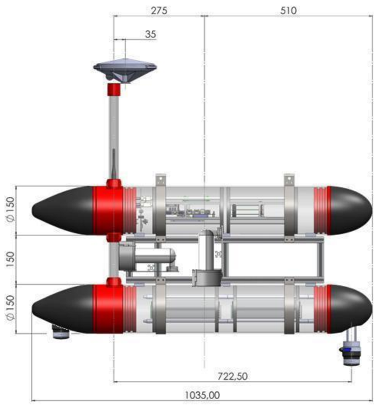
From the software side, the ROS infrastructure has been installed and set up on the secondary computing board. A software wrapper has been developed in order to integrate the custom Charlie control system with the CADDY framework, acting as a gate for command and telemetry dispatch.

Fig. 1.1.6. Charlie USV during operations

IST brings to the core of the CADDY project three autonomous marine vehicles of the MEDUSA-class, designed and built at the Institute for Systems of Robotics (ISR), a laboratory of IST. This class of vehicles was first designed, and prototypes were built, in the scope of the CO_3AUVs FP7 project (ended in January 2012). In the course of the latter project, the MEDUSA vehicles played the role of Autonomous Surface Vehicles (ASVs) in charge of guiding human divers. Since then, the MEDUSA vehicles have been used in the scope of the EC MORPH project to test MORPH Range-Only Formation control and navigation algorithms and to carry out data acquisition experiments.

As part of the effort to afford the members of the CADDY project marine vehicles to test and assess the efficacy of the methods developed for cooperative motion control, the vehicles were upgraded and fully tested, as explained below. *All existing MEDUSA vehicles can be used as ASVs*. In this mode of operation, they are simply referred to as $MEDUSA_S$ vehicles (where S stands for "Surface"). *Two of them have been upgraded in terms of sensors, actuators, power distribution, and control systems to be able to dive and can therefore be used as AUVs*. In this mode of operation, they are referred to as $MEDUSA_D$ vehicles (D stands for "Diver"). This was done in view of the goals to : i) develop and assess, in real operational conditions, the performance obtained with cooperative navigation and control systems for surface and underwater vehicles carrying joint missions (e.g., performing a leader tracking maneuver whereby the CADDY ASV plays the role of leader and the CADDY AUV tracks the trajectory described by the leader), and ii) to evaluate the performance of the navigation and control systems developed to allow for close diver / CADDY AUV interaction. In fact, it is envisioned that from a pure motion control and navigation standpoint, one of the underwater vehicles will act as a proxy for the diver during the first part of the project. Because of the role (as test beds) that the MEDUSA vehicles will play in the CADDY project, the *work done aimed also at adapting the software architecture of both the $MEDUSA_S$ and $MEDUSA_D$ vehicles according to the rules defined by the partner group for heterogeneous systems integration*.

The MEDUSA-class vehicles are approximately 1035 mm long and weigh 23-30 kg (depending on their configuration). The housings consist of two 150 mm diameter acrylic tubes with aluminium end caps, attached to a central aluminium frame. This design allows for a short length and better weight distribution (in terms of metacentric height), therefore the vehicles are easy to transport and launch and have good static stability. The upper body carries the light components, namely a single-board computer, an RTK-enabled GPS receiver, Wi-Fi 802.11 communications, a full navigation sensor suite, and a video acquisition system for an underwater camera. Most of the weight is concentrated in the lower body where the LiPo (Lithium Polymer) batteries and power management electronics are installed. Each of the MEDUSA$_S$ vehicles is propelled by two side-mounted, forward-facing thrusters that yield surge and yaw motion: the vehicle is capable of reaching speeds up to 1.5 m/s. The diving MEDUSA$_D$ vehicles are also equipped with two vertical thrusters for diving purposes.



Height	875 mm
Width	1035 mm
Tube diameter	150 mm
Weight in air	23 kg (Surface), 30 kg (Diver)
Energy	830 Wh LiPo
Endurance	11 h at 1.5 knot
Propulsion System	2 thrusters (Surface) 4 thrusters (Diver)

Fig. 1.1.7. The MEDUSA class of vehicles (MEDUSA$_D$): main particulars

Fig. 1.1.8. The 3 MEDUSA vehicles of IST

At the beginning of the project, the consortium agreed on a unified middleware to facilitate software development and integration. In accordance with this decision, the MEDUSA vehicles were upgraded to the middleware ROS (Robot Operating System www.ros.org), and some new modules were developed. The diagram below illustrate the software architecture adopted for each vehicle. The diagram on the left shows the actual (physical) systems. The diagram on the right shows the structure adopted for Hardware-in-the-loop (HIL) simulations, whereby part of the systems (e.g. true vehicles) are replaced by simulations. The architecture adopted will allow for HIL simulations over the Internet, involving systems developed by the different CADDY partners.

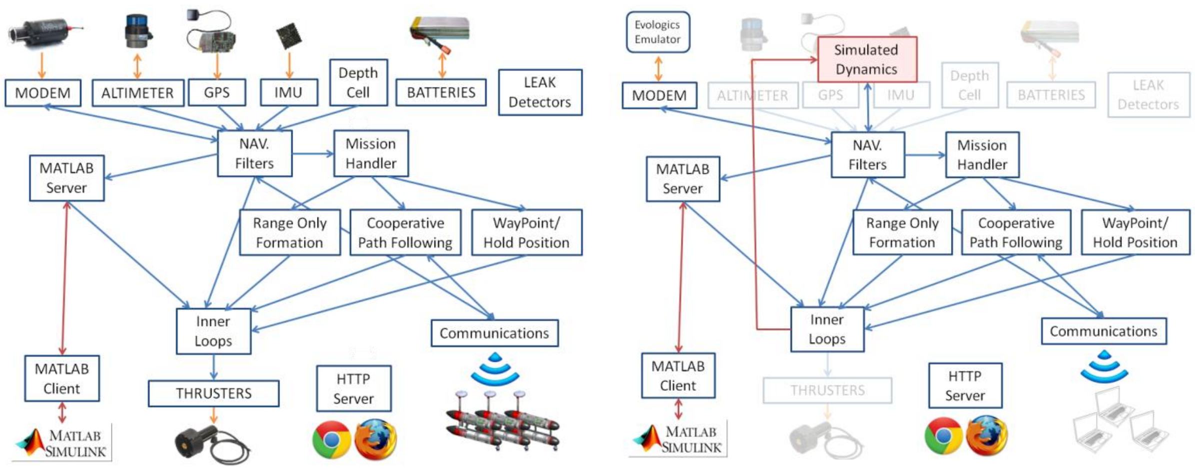


Fig. 1.1.9. The MEDUSA vehicles: Software Architecture (left: physical systems; right: set-up for Hardware-in-the-loop (HIL) simulations).

The following nodes/algorithms were developed (based in part on work done in previous projects) and are here emphasized because they will be helpful during the CADDY project.

Cooperative Path Following (CPF) – algorithms and related sensor/actuation systems responsible for making a group of marine vehicles follow predefined spatial paths while holding a desired formation pattern at a desired formation speed (constant or time-varying, according to a defined speed schedule).

Range Only Formation (ROF) – algorithms and systems for formation control, that is, to make a group of vehicles move in formation by using measurements of the ranges among them.

Waypoint Control /Hold Position (WCHP) – algorithms and systems to steer a vehicle to a given point and to keep its position in a small neighbourhood of that point in the presence of external disturbances such as currents.

Leader Tracking (LT) – algorithms to enable a marine vehicle (follower) to track the motion of another vehicle (leader) by using USBL and other proprioceptive data.

Mission Control - responsible for supervising and activating individual algorithms and systems upon detection of external or internal events.

Shore Console - allows the vehicles operator to visualize and monitor the state of the mission in real time, with interfaces for mission programming, data plotting, and multiple vehicle operation capabilities (see Fig. 1.1.10).

With the purpose of testing CADDY buddy-surface cooperative navigation and motion control algorithms (namely, those involved in the execution of Leader Tracking maneuvers), IST installed Ultra Short Baseline (USBL) units, acoustic modems, and a DVL on two of the MEDUSA vehicles, see Fig. 1.1.11. A description of the algorithms and field test results is available in Workpackage 4.

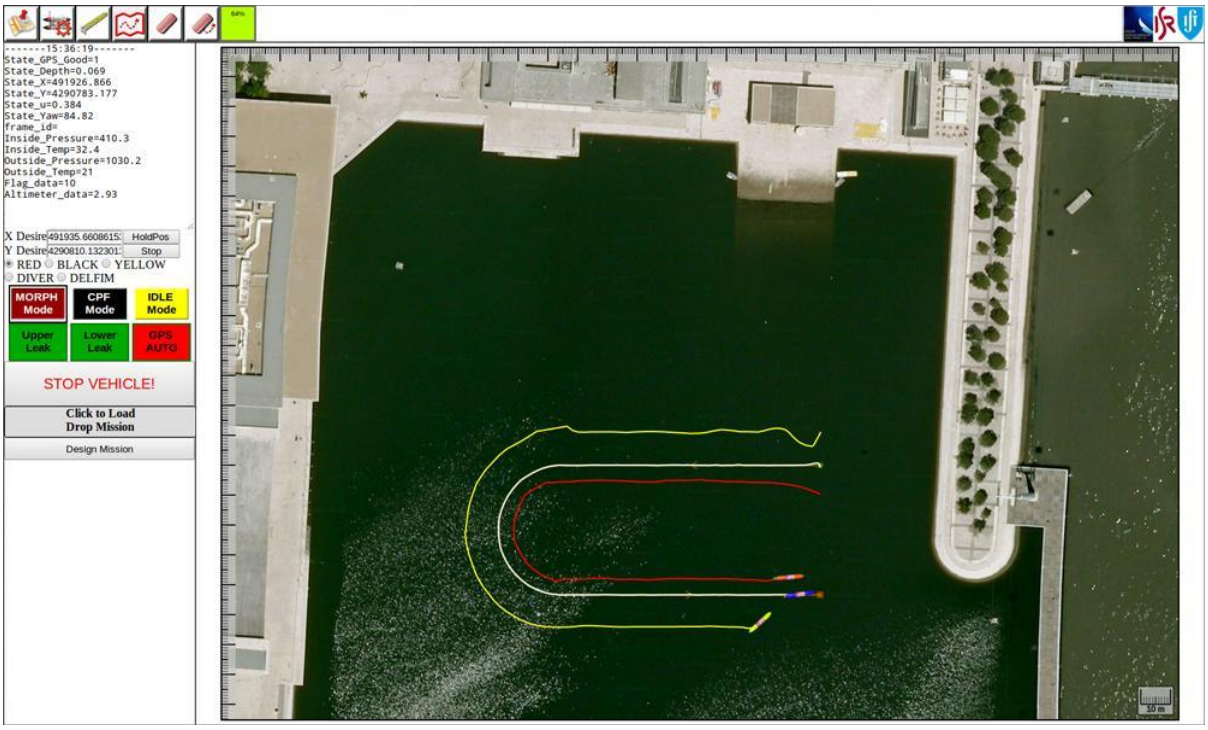


Fig. 1.1.10. Console Print Screen showing two MEDUSA$_D$ vehicles underwater (red and yellow) and one MEDUSA$_S$ vehicle at the surface performing a coordinated maneuver. The black vehicle (MEDUSA$_S$) is the leader, and the underwater vehicles are the followers. Cooperation is done using an USBL installed on the yellow MEDUSA$_D$ using a newly developed algorithm for acoustics-enabled Leader Tracking (LT).

Fig 1.1.11. Two MEDUSA vehicles showing the installation of the USBL units, DVL, and acoustic modems.

The USBL and acoustic modem units, manufactured by EvoLogics GmbH, Germany are property of IST and were brought into the CADDY project to test cooperative navigation and control algorithms at an early stage of the work program. Still during the first year of the CADDY project, the units will be replaced by the new, highly performing communication and USBL systems under development by the University of Newcastle (CADDY partner). Nevertheless, it was judged useful to test the existing units and assess their performance, with a view to better understand the type of performance that can be achieved with navigation and control. The units achieve data transmission rates of 9600 bps, range measurements with a standard deviation of 100 mm, and angular measurements with standard deviations of 5 deg. These figures were computed based on data acquired during experiments conducted at the *"Oceanarium dock",* in Lisbon, Portugal, using one MEDUSA$_S$ vehicle doing path-following maneuvers in the neighbourhood of another MEDUSA vehicle "sitting" at the bottom of the dock on a "tripod", see Fig 1.1.12.

Fig. 1.1.12. A MEDUSA vehicle "sitting" on a tripod, ready to go in the water for USBL calibration purposes.

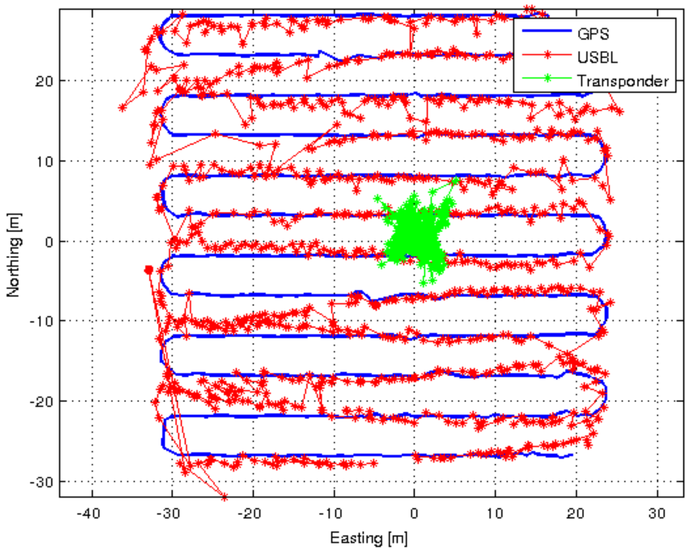


Fig. 1.1.13. USBL data acquired data with two Medusa vehicles

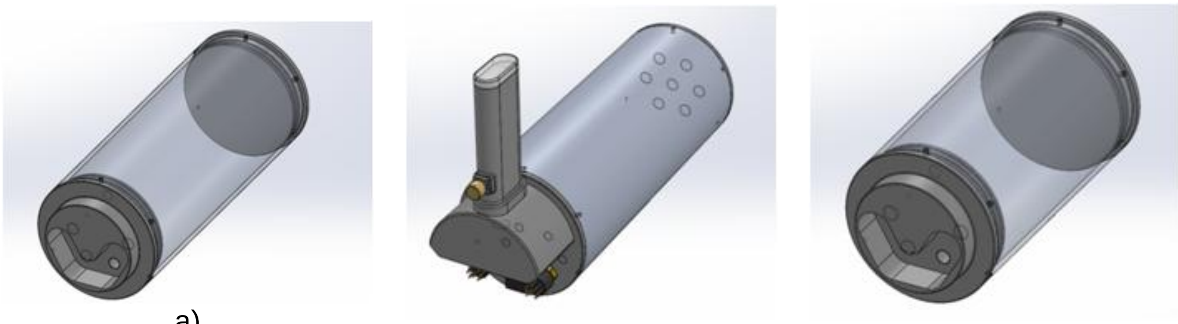
Figure 1.1.13. shows the results obtained during one of the trials with a USBL unit, whereby the stationary MEDUSA acts as a proxy to an acoustic transponder. The "transponder" position estimated by the USBL+GPS of the moving vehicle is plotted in green. Assuming that the location of the transponder is known *à priori* it is possible to calculate the position of the moving vehicle, plotted in red. From the data obtained it was concluded that an accurate attitude unit calibration is needed and the navigation algorithms should handle large periods of time without USBL fixes. Most certainly these periods will be even longer in the presence of air bubbles resulting from the air exhaled by the diver. It must be stressed that the data shown were obtained under very "harsh" conditions: because the maximum height of the water column is approximately 4 meters, acoustic propagation is plagued with severe multi-path effects. The performance of the USBL is expected to improve substantially when the depth of operation increases (and the slant range decreases). Nevertheless, it is important to explicitly address the situation where diving operations take place in very shallow water and to carry out a thorough analysis of the USBL unit that will be provided by the Univ. Newcastle.

T1.2. The underwater segment

The availability and adaptation of existing/under development under-water platforms is described in this section. The main characteristics of the surface vehicles made available by each partner involved in the task, are described in terms of mechanical structure, sensor suites, navigation and guidance abilities, communication systems, integration with the overall framework.

UNIZG-FER is working on the development on the new autonomous underwater vehicle, **BUDDY**, specially designed for interaction with divers. BUDDY will be made of 3 canisters for electronic components. Besides, it will be equipped with high resolution sonar, DVL, stereo camera, low light camera and tablet for interaction with diver. It is equipped with four thrusters in X configuration for horizontal and two for vertical movement. Electronic components will be assembled in rack and will be divided in canisters as follows:

- **Battery canister** - 46.8 V 24.8 Ah battery, 5, 9, 12 and 24 V DC/DC regulators (Fig. 1.2.1a)). Three sets of batteries have been purchased to ensure uninterrupted execution of experiments with the vehicles.
- **Master canister** - fiber optic converter for communication with the surface, ethernet relay board for powering up CPU, thrusters, DVL and acoustic modem (Fig. 1.2.1b))
- **Vision canister** - 48 V DC/DC regulator, Intel NUC CPU for acquisition of sonar and stereo camera image, gigabit switch, ethernet relay board for powering up CPU, sonar and cameras (Fig. 1.2.1c))



a) b) c)

Fig. 1.2.1. CAD model of three canisters comprising the BUDDY AUV.

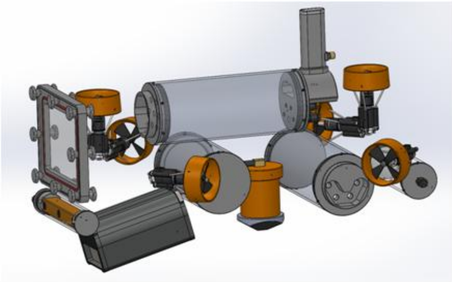
The public procurement of the ARIS Explorer 300 high resolution multibeam sonar (Fig. 1.2.2a)), that will be integrated in the BUDDY vehicle, is finished, and the sonar is available at UNIZG-FER. Fig. 1.2.2b) shows the CAD model of the DVL provided by UNIZG-FER that will be integrated in the vehicle. We performed pool tests for identification and navigation using the DVL sensor.

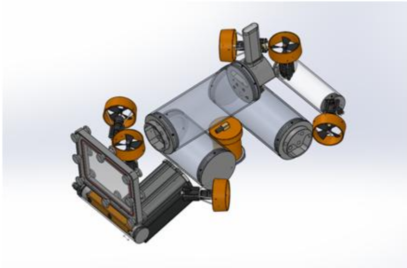
The initial distribution of the canisters, sensors and thrusters are shown in Fig. 1.2.3, in the form of a CAD model. The BUDDY vehicle will be equipped with a commercial tablet in a custom made waterproof casing in order to achieve efficient visual-based communication with the diver.

b)

a)

Fig. 1.2.2 - CAD models of a) ARIS Explorer 3000 and b) DVL.


a)


b)

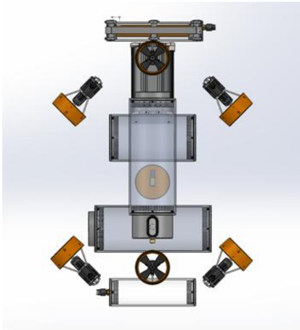

c)

Fig. 1.2.3. CAD model of the BUDDY vehicle.

The first version of the vehicle has been integrated and tested during the summer field campaign in Split (Fig. 1.2.4). We have successfully tested the functionality of the main and battery cylinder. The developed components were mounted on an existing frame (from Seamor ROV). In the next period, extra effort will be devoted to mechanical engineering to complete the design of BUDDY vehicle. It is needed to add and test vision cylinder and the sensors (sonar, DVL, stereo camera, low light camera, etc.). The vehicle will communicate with the surface via 150 m fiber optic cable in non-autonomous mode and acoustic modem in autonomous mode.

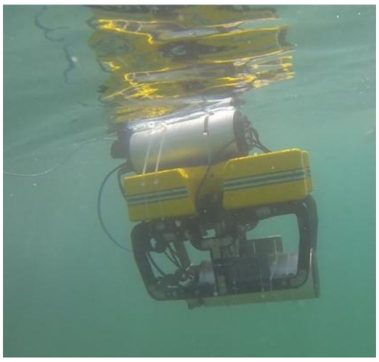


Fig. 1.2.4. First version of BUDDY vehicle

BUDDY AUV safety mechanisms:

In order to ensure diver safety, a couple of safety switches will be mounted on outer shell of the vehicle. Two types of switches are possible:

- **Positive Action Switches** are designed to give a continuous signal when the switch is activated. Various configurations are available including Rotary and Push and Pull (Kill Switches)
- **Proximity Switches** use magnets, either in attraction or repulsion, to open or close an electrical circuit.

After agreement with partners responsible for diver safety, we will converge to the best solution of which type of switches we will use and how many of them is needed to keep divers safe.

The **ROMEO ROV**, developed by CNR, is a fully actuated underwater robotic platform, rated up to a depth of 500 m. The redundant allocation of 4 horizontal and 4 vertical thrusters allows the vehicle to a complete motion capability as well as the hovering skill. The integration of a fiber optic gyro (FOG) for attitude measurement with a Doppler velocity logger (DVL) provides a precise navigation system, needed for underwater operations. The availability of a fiber optic link between the vehicle and the surface control station allows the exploitation of high-rate data measuring devices on-board the ROV, such as cameras, multi-beam or side-scan sonars. The integration of USBL / acoustic modems on board the ROV and the USV provides the relative position sensing / communication between the robotic platforms, allowing the cooperation of the vehicles in the scope of coordinated robotic actions.

The vehicle can be exploited for the initial development of algorithms and preliminary trials.

A 3D representation of the vehicle is depicted in Fig. 1.2.5.

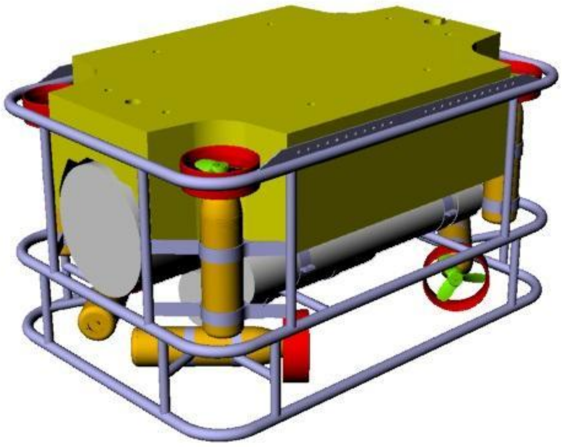


Fig. 1.2.5. 3D representation of the ROMEO ROV

The electronic upgrade of the ROMEO ROV is almost complete and it is focused on the installation of a new computing unit relying on a PCM-3362 Single-Board-Computer complemented by additional I/O boards to provide analog, digital and serial communication channels. Table 1.2.1. reports the number of channel needed and the association with physical devices.

Table 1.2.1. ROMEO ROV channels

Sensor/Actuators/Devices	Dig Input	Dig Output	Analog Input	Analog Output	RS 232 channels
Thrusters	9	16	8	8	0
IMU + GPS	0	0	0	0	1
IFZ camera	0	6	0	0	0
CTD	0	1	0	0	1
PA500 sonars	0	2	0	0	2
Lights	0	3	0	0	0
Temperature	0	0	1	0	0
Batt. Voltage	0	0	1	0	0
Batt. current	0	0	1	0	0

Total	**9**	**28**	**11**	**8**	**4**

A fiber optic link is provided by the ROMEO ROV system for the development & test phases. The tether used for Romeo contains two single-mode fibers and a pair of copper wires used to transfer power from the surface in order to have the maximum possible autonomy. This cable is part of the kit of optical fiber communication system Focal Technologies 903 Video/Data multiplexer.

The system is composed by:
- 1 channel Ethernet 10 Mbps,
- 5 x RS 232 @ 115 Kbps,
- 5 x 422 @ 250 Kbps,
- 4 videocomposite analogic signal channels.

The Romeo's power supply system is constituted by source of batteries charged by a pair of ac/dc converters fed from a 220V AC source through the tether. The battery block is composed of a certain amount of cells Cyclon 2V and 5 Ah. Each block contains 64 cells divided into two parallel 32 placed in series between them, with a total voltage of about 64V 10 Ah. The choice of this voltage is due to the value of the nominal voltage of 60V required by the electric motors mounted in the thrusters.

Romeo can install up to three cylinders (30Ah), one next to the master cylinder and two in the slide, or 1 (only 10Ah) in the case that the slide is dedicated entirely to the payload. Each cell must be charged at constant voltage of 2.45V and constant current to be determined in relation to the charging time, there are no limits of charging current. Then, blocks of 32 cells will be charged at a constant voltage of 78.4V. The value of a cell charge without load is 2.13 V, then each cylinder without load will present at its terminals a voltage of 68.5V. During the discharge the voltage of each cell must not fall below 1.5V, 48V for each cylinder. A brief description of the ROMEO’s Cyclon battery is depicted in Fig. 1.2.6.

The thrusters of Romeo contain a DC brushed motor, its shaft is connected to a tachometer dynamo and in the other side to the propeller through a flexible coupling and a system of dynamic seal with mating-type graphite / ceramics.

The three-bladed propellers were designed to take full advantage of the characteristics of the employed electric motors. Its physical characteristics are the following: weight in air: 8.7 kg; weight in water: 5.7 kg; volume: 3 litters.

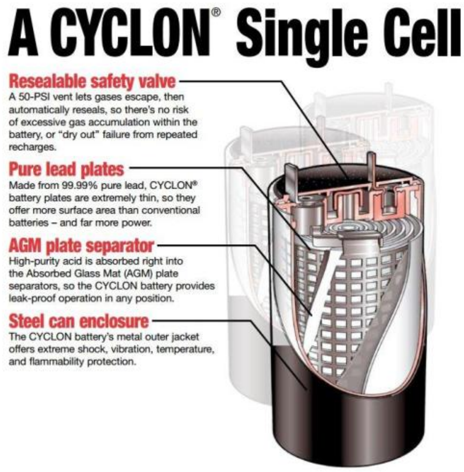


Fig. 1.2.6. ROMEO's Cyclon battery description

The thrust curve is depicted in Fig. 1.2.7.

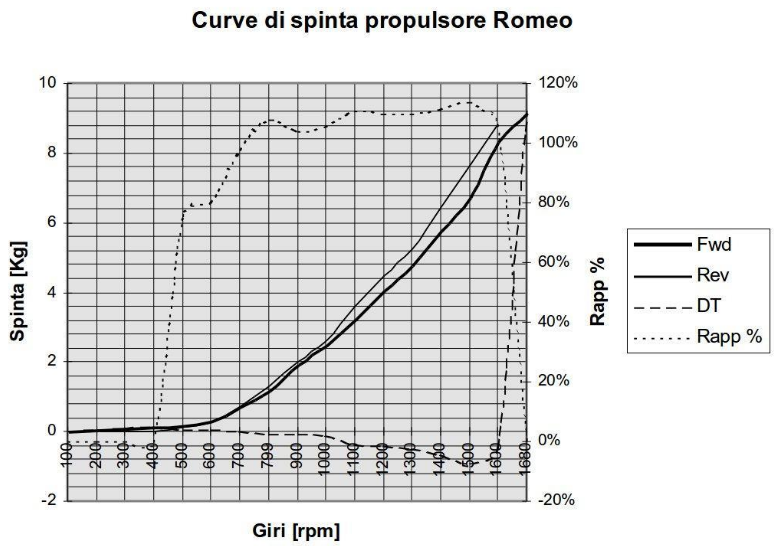


Fig. 1.2.7. Thrust curve

The navigation package is composed by an integrated GPS and Attitude Heading Reference System (AHRS), providing absolute position fix (when surfaced) combined with attitude measurements and IMU-based linear and angular velocity readings. The GPS-AHRS system is a Microstrain 3DM-GX3-35. The ROMEO ROV is also equipped with a Tritech PA200 altitude sensor with a range of 0.7 - 100 m and resolution of 0.025% of the range.

The custom software architecture developed for the control of the ROMEO ROV is linked to a ROS wrapper in order to share telemetry and commands with the other nodes of the framework. In Fig. 1.2.8 a preliminary test of surface and underwater autonomous vehicles cooperation is represented.

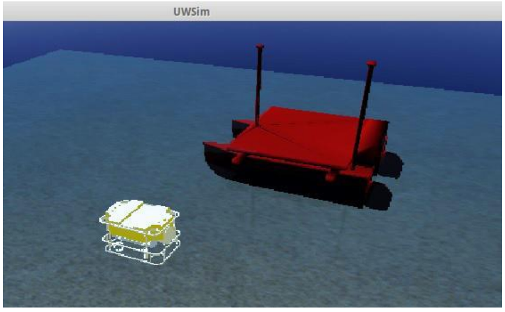


Fig. 1.2.8. Surface and underwater segments cooperation

T1.3. Interfacing the diver to the surface and underwater segments (CNR, IST, UNIZG-FER)

This section provides the description of the dedicated devices needed to interface the diver with the robotic platforms and the main characteristics of the acoustic communication protocols needed to achieve an efficient data link connection among the segments.

UNIZG-FER have developed an underwater tablet case made of Polyacetal (POM-C) and tempered glass. The main purpose of the casing is to hold a commercially available tablet that is used by the diver as an interface to the vehicles. The tablet case is designed in symmetrical form to implement 5 mm thick transparent tempered glass lids onto both sides of the housing (Fig. 1.3.1). This will allow use of the rear camera on tablet, and also due to stiffness of tempered glass, less sagging caused by external pressure. O-ring groove is identical on the both sides and accommodates silicone rubber o-ring seals from 5.7 to 6 mm in section diameter. It will use DIN6336 star-grip M8 threaded knobs for clamping. Rear lid will be fastened and independently sealed with the housing frame via 8 DIN7380 M5 screws with rounded head. All additional brackets, supports and equipment will be bolted to the sides of the frame(holes will be drilled and tapered once all the brackets and extras are defined). For testing purposes 5mm lid thicknesses are used. In this configuration weight of the housing(in air) should be around 3900 grams with tablet and fasteners. This setup is tested successfully at 25 meters.

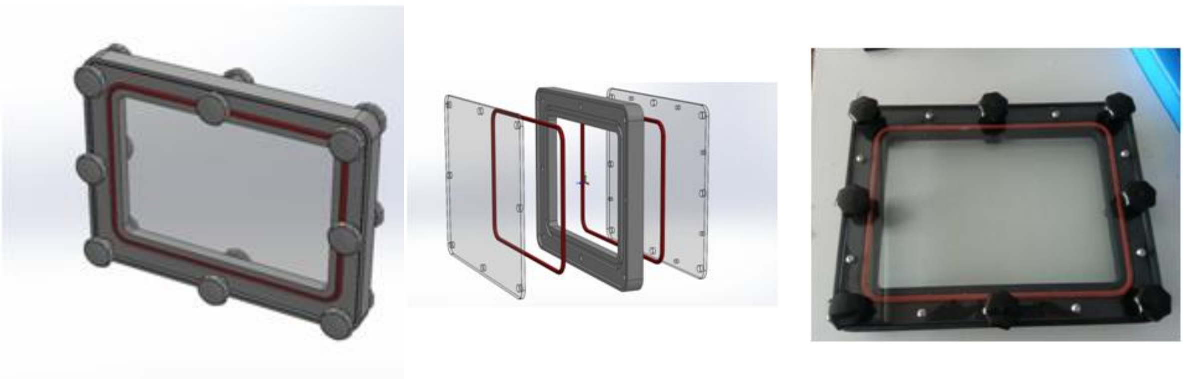


Fig. 1.3.1. Computer model and manufactured tablet case.

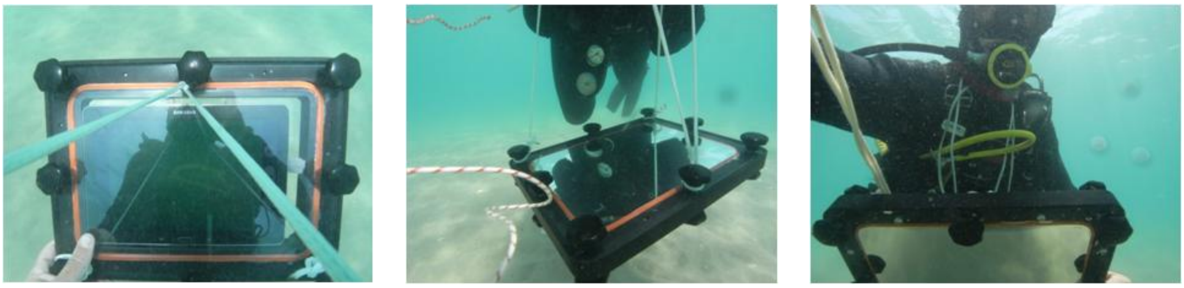


Fig. 1.3.2. First pressure and functionality tests underwater

Works on navigation filter for diver dead-reckoning using the tablet has just started.

The CNR team has been working in the areas that are described below.

Communication protocols

A first draft of the requirements for the communication protocol that will be used in the underwater segments is proposed by CNR.

Given the harsh environment, the scarce bandwidth and the high latency of acoustic links, a very careful use of communication resources is mandatory for the communication between the underwater segments. For these reason, the development of a new custom real-time protocol is being taken into consideration, as well as the use or adaptation of already existing low-level real-time protocols such as ORTE, Open Real-Time Ethernet, an open source implementation of Real-Time Publish-Subscribe (RTPS) communication protocol [1]. The resulting protocol will need to implement and enforce a few requirements, such as real-time performance, priority and quality of service (QoS), platform independence and entropy maximization of transmitted data, while may also provide additional beneficial features such as error recovery of received data and further message compression.

The underwater communication protocol will then need to have the following features.

- *Soft real-time performance*: high priority messages will have to be delivered inside a well defined time frame (ideally on scheduled time) and low-priority messages, even in flooding conditions, shall not delay high-priority messages. The most efficient solution could be to program as much as possible of the protocol's details inside the network driver, to give it the full control of the process of frame generation and reception. This kind of solution, however, is costly and not flexible, so a trade-off might be necessary. The level of real-time performance of the underwater communication protocol should be a performance index of the whole software architecture.

- *Prioritization and QoS*: each message passed to the underwater communication stack must have its own priority tag (usually an integral) that assigns the message to a specific class of service (e.g. 1 = alarms, 2 = diver's and RECUV telemetry, 3 = diver's gestures, …, 10 = environmental data, …, 16 = multimedia content). Then, the priority queuing system generally proceeds to send the highest priority message available, or, in certain conditions and with the purpose of granting a certain amount of queuing fairness, may proceed to send a lower priority message. If any amount of queuing fairness is present, it's impact on soft real-time performance must be assessed.

- *Platform independent*: given the variety of platforms available today, this feature is becoming a true technical challenge. The underwater network protocol must be able to connect a wide range of devices, including SBCs (Single-Board Computers) and mobile devices (e.g. tablets or smart phones) and need to have real-time performance on all of them. This also leads to the requirement of a low memory footprint, especially if the protocol will be partially implemented as a network driver.

- *High entropy*: to maximize the efficiency of the transmission over an acoustic link, each sender must pass to the protocol stack only the minimum amount of symbols needed to represent the data to be transmitted. This means that the sender, who is aware of the meaning of the data that he is about to send, must maximize the entropy (meant as information content) of the message. For example, if a source of information periodically produces a 16-bit value representing the water temperature around the diver, the message will not be coded using 2 bytes. The dispatcher of the message, knowing that the temperature may range from (e.g.) -18 °C to 45 °C, will code the information in a 6-bit field, so that the underwater communication protocol can pack more messages together and minimize the amount of messages (and consequently packet headers) to be sent.

- *Error recovery*: to protect from acoustic noise in the environment (e.g. air bubbles), packets can be padded with checksums or even error recovery codes, such as Reed-Solomon, Low-density parity-check codes or Turbo codes, able to detect and correct multiple random-symbol errors. The use of one of these algorithms, presently used in DVB standard for the satellite transmission of digital television or in 3G and 4G mobile telephony standards, increases the size of the packet, but may prevent the retransmission of a corrupt packet where up to *n* bits are corrupt. The amount of memory and CPU required by the algorithm must be also evaluated before the use of error correcting codes inside the underwater communication protocol.

- *Compression*: to increase even more the entropy of the message that is about to be sent, the underwater communication protocol can make use of one of the many compression algorithms available today. A compression algorithm used as last step before sending the message may shorten low-entropy data such as text strings but will be probably ineffective against data whose entropy has already been maximized by the sender. The use of such protocols may be made subject to the type of message to be sent, and their computational and memory costs must be assessed.

Addressing of nodes

Given that the underwater communication protocol communicates through a shared medium (the water), it may not be necessary to address nodes for each packet sent. For example, high-priority real-time messages may be simply broadcast to all nodes, so that important or continuously updated information is sent to all listening nodes at once.

Conversely, low-priority data should be probably sent to specific recipients only, so some form of addressing of nodes will be necessary. Again, in order to maximize the entropy of the information, a few bits will be sufficient to address all nodes in the system. Particular attention will be given to unreachable nodes, namely nodes that, due to the distance or high noise levels can't be reached directly by the sender. A typical case can be the diver's device unable to directly transmit to the surface vehicle(s): in this case one node (the RECUV) must be used as relay to retransmit the packets between the unreachable nodes.

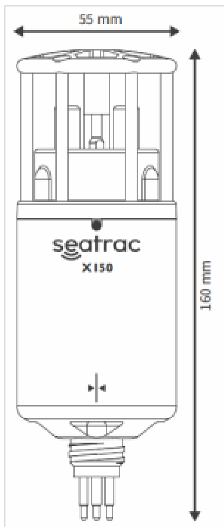
T1.4. Data distribution network

The current focus of task T1.4 has been on the development of the low data rate (100bps) modems and navigation system. To date prototype hardware, both electrical and mechanical, have been constructed and preliminary tank testing has been conducted. The initial design of the ‘Seatrac’ modem utilises a free flooded transducer ring, with a four element USBL array. The enclosure is machined from 316 grade stainless steel and depth rated to up to 3000m. Images of the prototypes are shown in Fig. 1.4.1a) and Fig. 1.4.1b), the X110 model shown on the left is a modem design offering bidirectional communications. The X150 model additionally offers navigation functionality, with the inclusion of the four USBL elements. The dimensions of the USBL, X150, model are shown in Fig. 1.4.1c), the small form factor of the unit is ideally aimed towards the deployment on the diver or ‘buddy’ vehicle. The hardware required to compute an accurate USBL fix is fully integrated into the modem unit, reducing the need for additional topside equipment.

Recently focus has been given to improving the development of the transmit circuitry and transducer design. The new hardware configuration supports higher output power (172dB compared with 167dB) and broader transmission bandwidth (8kHz at a centre frequency of 28kHz). Final developments of a Software Development Kit (SDK) are underway, including documentation defining the ASCII based serial command interface. These tools will be made available to all partners on release of the initial modems.

The acoustic protocol developed for the ‘Seatrac’ modems offers the capability to support varying payload lengths (up to 32 bytes) and the ability to request a USBL position fix on every packet (if required). This enables more flexibility with regards to developing a suitable networking scheme between the ASV, AUV and diver. Current work is focussing on the final development of a suitable USBL calculation algorithms and the incorporation of the internal AHRS sensors to give an accurate positional fix. The delivery of the completed low data rate modem design is planned for Q3/Q4 of Year 1. Further development of higher data rate schemes (1-2kbps) will be planned for the latter half of Year 1 and Year 2.

a)



b) c)

Fig. 1.4.1. X110 Modem Prototype, b) X150 USBL Prototype, c) X150 Modem Line Drawing

To date the following progress has been achieved with regards to task T1.4:

- Firmware for the initial 100bps modem operation has been developed
- Testing of the initial 100bps modem has been performed through tank testing, successful performance demonstrated with variable packet lengths (up to 32 bytes per packet).
- Development and production of modem prototypes (version 2), including mechanical and electronic construction. First production run of 10 modem / USBL pairs completed w/b. 30th June 2014.
- Developed and simulated 1-2kbps Direct Sequence Spread Spectrum (DSSS) scheme.
- Iterative testing and benchmarking of various transducer and USBL element topologies, resulting in the development of an optimal hardware design.
- Integration and tank testing of suitable USBL position calculation algorithms, initial performance demonstrates USBL fix repeatability of << 1 degree at update rate of more than 1 fix per second. Figure 1.4.2. shows the repeatability of USBL bearing during tank testing using attenuated transmitter to produce realistic SNR.

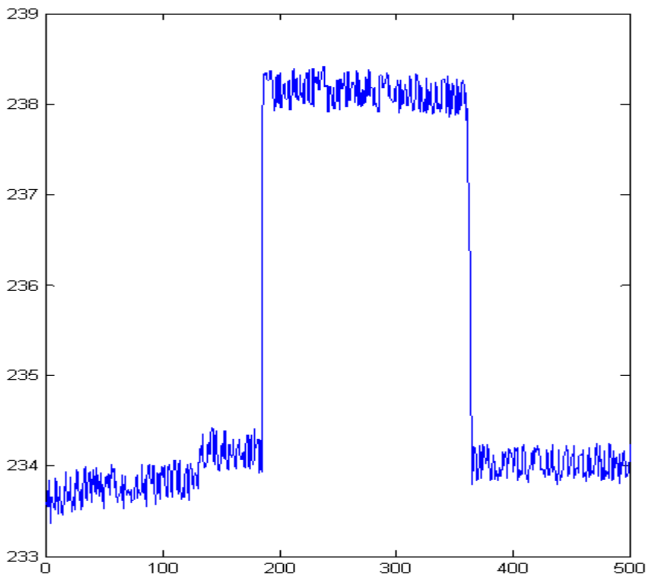


Fig 1.4.2. Bearing estimates showing repeatability in two different locations.

T1.5. Integration, experiments and performance evaluation (CNR, UNIZG-FER, UNEW, IST, JACOBS)

This Work Task will officially start at Month 9. However, due to the nature of required technical development, the partners have already initiated with experiments. Initial brief description of the activities is given.

During the first 6 months the UNIZG-FER team has carried out three field experimental trials in addition to continuous laboratory experiments. These field experiments were crucial for successful integration of the systems, and an important step towards the integration with the partner's vehicles.

- **Experiments on lake Jarun, Zagreb**

Experiments on Jarun lake in Zagreb have been performed to test the DVL and the new PlaDyPos control architecture and modifications.

- **Experiments in Israel, 19-25 May 2014**

These experiments were not charged on the CADDY project. However, we managed to use this campaign to test the PlaDyPos control architecture and performance of algorithms in real life scenarios.

- **Experiments in Split, 20 June - 5 July 2014**

These extensive experiments took place at the venue where the validations trials will be performed. The UNIZG-FER team made preparations for the validation trials and tested the diver tracking abilities of the platform. Structured experiments where PlaDyPos followed the virtual diver, an ROV and the real diver were successfully executed. In addition to that, first trials with the BUDDY AUV were performed. This was a major step towards the completion of the BUDDY AUV.

The CNR team were also engaged in activities related to this task. Given the complexity of the protocol, the simulation must be necessarily conducted in an incremental way, implementing the most important features first (e.g. real-time performance and prioritization) and adding secondary features later in the development cycle. This allows to continuously test critical features, even during the development of other protocol components, to isolate problems and causes and to associate them to the introduction of a particular protocol component.

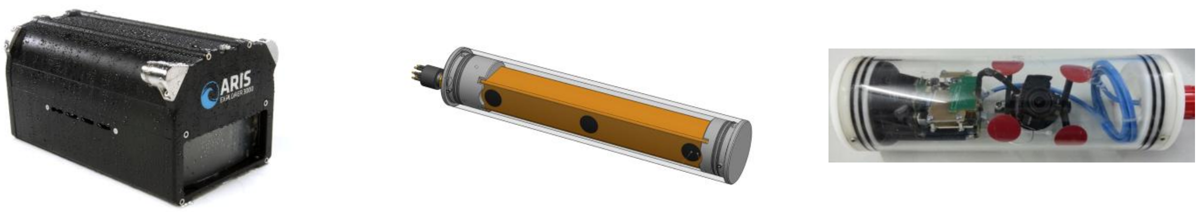
The "environment" must be also added to the simulation incrementally. The simplest approach is to add constant bandwidth and latency constraints first, make them (randomly) dynamic later and simulate the realistic spatial position of the nodes when the development is in an advanced stage. The same approach should be adopted to simulate the sources of noise that may be present in an underwater marine environment.

In order to proceed with the simulation, in the next phases of the project it will be necessary to compile a tentative list of software agents that need to communicate through the acoustic network, the type and amount of data that they need to send and a list of priorities and entropy values for the types of information to be sent. Another element to assess is the amount of multimedia information that could be necessary to the diver to complete its mission: given that the multimedia traffic will have the lowest possible priority, an estimate of this value will provide the highest boundary that the difference between the available theoretical bandwidth and the amount of total periodic high-priority broadcast data might have.

WP2 Seeing the diver

T2.1. Development and integration of diver remote sensing framework

UNIZG-FER have completed the public procurement of the ARIS Explorer 3000 sonar that was shipped to Zagreb in April 2014 (Fig. 2.1.1a)). The underwater casing for the stereo camera has been designed and it is in the process of production (Fig. 2.1.1b)). This is required for the initial experimental data collection in T2.4. The underwater casing for low light camera has also been designed and manufactured (Fig. 2.1.1c)). This camera will be used as auxiliary camera for 2D mosaic, obstacle detection from the rear end or ship/PlaDyPos on the surface. The mentioned sensors will be integrated in UNIZG-FER Buddy AUV.



a) b) c)

Fig. 2.1.1. Diver sensing sensors integrated by UNIZG-FER.

JACOBS have started working on the specification of the diver remote sensing. The framework will be implemented in the Robot Operating System (ROS) easing the integration of contributions.

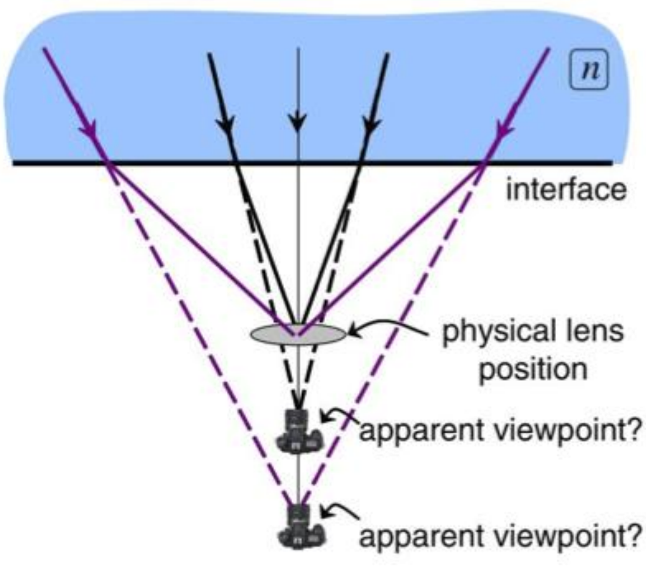


Fig. 2.1.2. Refractive Effects: Different indices of refraction (taken from [2])

First efforts have been made with respect to improvements over the state of the art on handling flat panel interfaces of underwater cameras. Flat glass panels lead to very complex distortions that cannot be compensated with standard camera models. Specifically, though this distortion can seem like usual radial distortion, the actual parameters are dependent on the range of the structure to the camera. In effect, this means that each pixel has a slightly different focal point. This has consequences both for the localization of image content in monocular 2D camera data as well as in stereo 3D – or more precisely 2.5D – range data. An extended camera model, which covers these refractive effects and a reliable calibration method for it, both in the monocular and the stereo case, is hence of obvious interest in the context of "seeing the diver", where the localization and tracking of underwater image content is of high interest. In addition to a literature review, a suitable extended camera model was identified, and very recent work on calibration has been extended to be more reliable. This extension includes non-linear optimization on model parameter estimates and calibration pattern structure, using a novel cost function formulation which is especially fast in the stereo case.

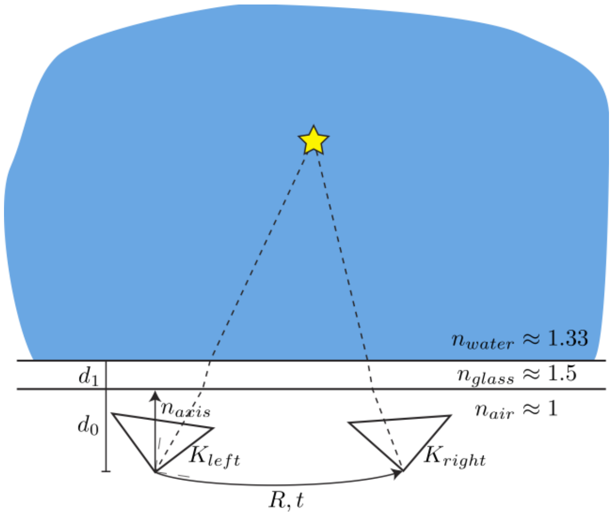


Fig. 2.1.3. Stereo flat refraction model diagram

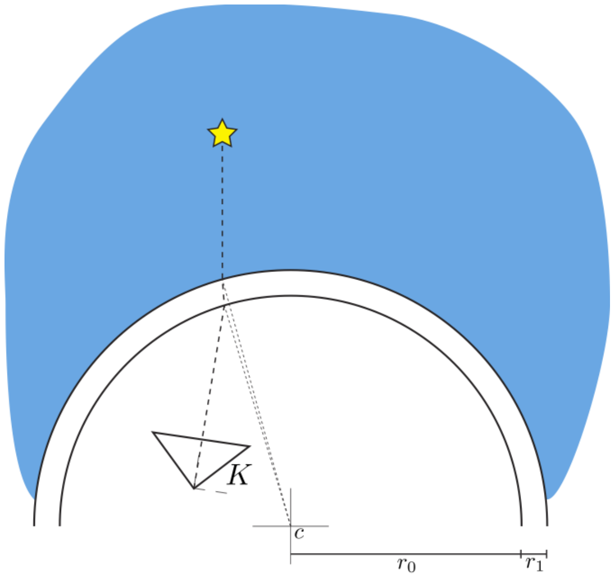


Fig. 2.1.4. Monocular sphere refraction model

In the stereo flat refraction model diagram shown above, the only two parameters that have to be calibrated are n_{axis} and d_0, the normal of the glass pane relative to the left camera and the distance between them. d_1, the thickness of the glass pane, should be know at construction time. Similarly, K_{left} and K_{right} as well as R and t are calibrated with traditional stereo calibration methods in air.

Very preliminary work has been done characterizing distortions from spherical glass domes, as shown in the diagram of the monocular sphere refraction model. Here, r_0 and r_1 are known at construction time, K is calibrated beforehand in air, and c, the center of the sphere relative to the camera, is the only unknown. The closer the camera focal point is to c, the smaller the distortions. Ideally, c is exactly the focal point of the camera, which would in turn mean no refractive distortions at all. Constructing the camera housing such that the focal point is in c entails significant work, and the closer the two, the harder it is to calibrate the exact offset. Thus, the work on calibration has thus far been focused on the flat refraction case.

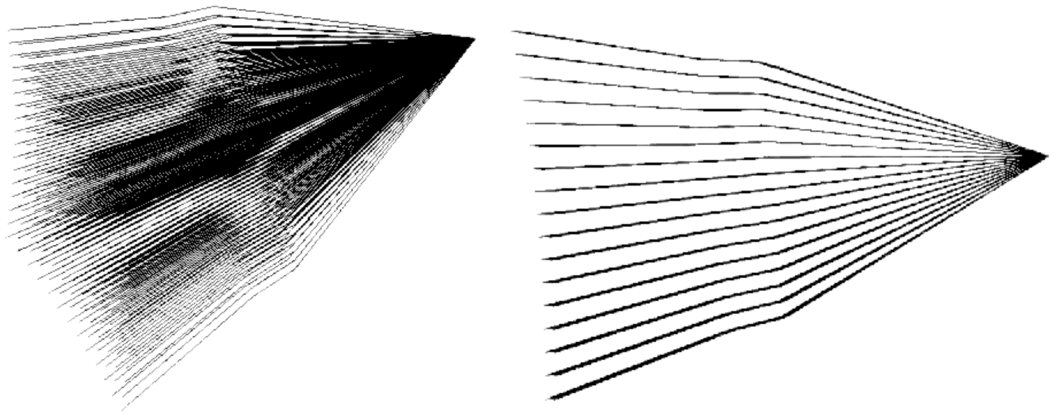


Fig. 2.1.5. Views of a calibrated vector-based camera model

Since the extended camera models are not linear as they depend on trigonometric functions and since multiple focal points exist, it is not possible to use conventional stereo epipolar rectification techniques. Instead, a generalized vector-based camera model has been chosen. Here, each pixel in the camera image has a specific offset and bearing vector associated with it, thus encoding the final view direction in water along the pixel. Current work investigates how this generalized camera model can be used in stereo depth estimation.

Furthermore, development work on the preprocessing and segmentation of monocular video data for diving recognition has started. According software is under development using the standard OpenCV library as well as own developments.

T2.2. Motion compensation and fusion of passive sensors

In order to fuse data from multiple sensor modalities, it is of great importance to have an estimate of the relative locations of the sensors. Fusion is done either a) within on time-step, i.e. the sensors are attached to the same vehicle and are synchronized, or b) across two separate time-steps, i.e. the vehicle moved in between individual sensor observations.

Generally, tracking the vehicle itself is much more useful than tracking the sensors directly, thus for both cases, either the exact mounting pose of each sensor has to be known a-priori, or should be calibrated before the mission. If all sensors are synchronized, a-priori calibration is all that is needed. If they are not, or if multiple views of the same sensor(s) are to be fused, registration methods as well as motion models of the vehicle can be used to compute a relative transformation between vehicle poses at the times in question.

First preliminary work of JACOBS has been performed by testing the performance of a previously developed 6 DoF spectral registration method on stereo range data. Several drawbacks have been identified, and are currently under investigation. Solution approaches include the systematic exploration of the parameter space of the spectral registration method, as well as new signal processing techniques to address specifically the rotation estimation in a more robust way.

T2.3. DiverNet sensor and communication development

UNEW have finished working on the development of prototype DiverNet system. The initial system consists of a centralised processing and acquisition unit, referred to as the ‘hub’, and a selection of inertial and physiological sensors. The central hub utilises a system on chip (SoC) Atmel ARM processor to sample and process each of the sensor readings. In order to supply an immediate system for initial data gathering exercises, planned for early May 2014, the initial prototype utilises a hardwired interface between the sensors and the central hub. Additionally, for preliminary trials the unit communicates with the surface via RS485 over a tethered connection. This format has been agreed to allow raw readings from an increased number of sensors to be gathered and processed in real-time. Future development work will examine the development of a wireless inductive network between the sensors and the hub, along with interfacing the network into the diver tablet and long range communications to the surface via the acoustic network presented in work package 1 (T1.4). A block diagram of the proposed system is shown in Fig. 2.3.1.

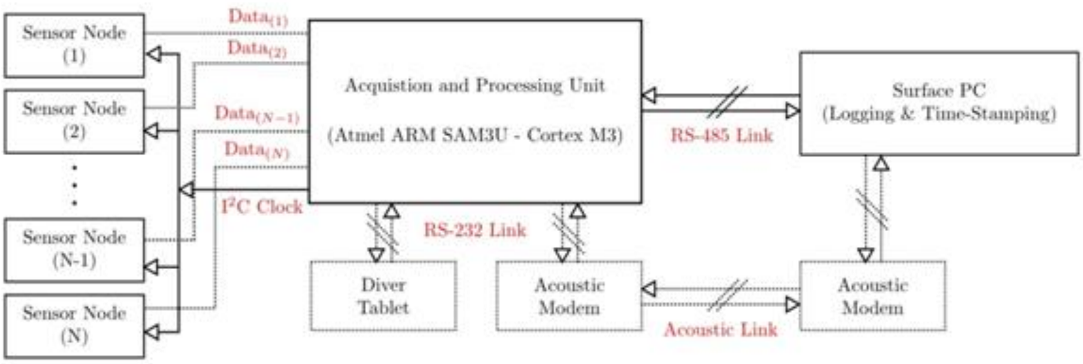


Fig. 2.3.1. DiverNet System Block Diagram (Version 1).

The first prototype PCBs have been received from the manufacturer, pictured in Fig. 2.3.2, and the firmware is currently in development. The mechanical enclosure design has been finalised. The enclosure is machined from 5083 grade aluminium and utilises micro subconn connectors for interfacing with the sensors and surface tether. The design and construction of the sensor potting moulds is currently in development. The final system has been delivered in April 2014.

Fig. 2.3.2. DiverNet 'Hub' Prototype PCB (Version 1): Dimensions 107mm x 40mm

System Specification:

- Simultaneous sampling of up to 20 inertial sensor nodes at a sample rate of 50Hz, (typical operation = 15 nodes).
- Each sensor node consists of:

- 3 axis gyroscope (L3GD20H) – resolution up to 2000dps, 16bit output
- 3 axis accelerometer (LSM303D) – 16bit data output (maximum range ±12 gauss)
- 3 axis magnetometer (LSM303D) – 16 bit data output (maximum range ±16g)
- Tethered surface communication link via RS485 – Throughput of >1MBps over distances of >100m.
- Expandability for integration with alternative physiological sensors via 10 bit and 12 bit ADC interfaces (e.g. breathing belt, heart rate sensors, etc.).
- Additional communication interfaces, USB and RS232, available for connectivity with acoustic modems and local displays (i.e. the diver tablet).
- Central ARM Cortex M3 processor for data acquisition and future integration of on-board data processing algorithms.
- Local removable solid state memory (micro-SD card) and real time clock enabling remote storage and time stamping of data captures (to be supported in future firmware releases).

Software and visualization

UNIZG-FER have developed the software for communication with the DiverNet and for visualization in the ROS environment. Raw DiverNet data is received on the surface via the RS485 link. The data is unpacked and processed by a ROS node. Processing includes transformation of raw acceleration, magnetic and gyro measurements to roll, pitch, yaw attitude. The attitude is additionally filtered by a complementary filter. Attitude measurements in combination with known measuring positions on the human body can be used to measure attitude and positions of the extremities. Data visualization is achieved using the ROS 3D visualization tools, see Fig. 2.3.3..

The human-like model is specified in a Unified Robot Description Format (URDF). The URDF is a XML like format that helps in 3D modelling object with joint and movable parts, i.e. robots. The model specifies 15 characteristic points/joints as defined by UNIVIE to help measure body posture and extremity position. A sample video of the visualization is available online [here](#).

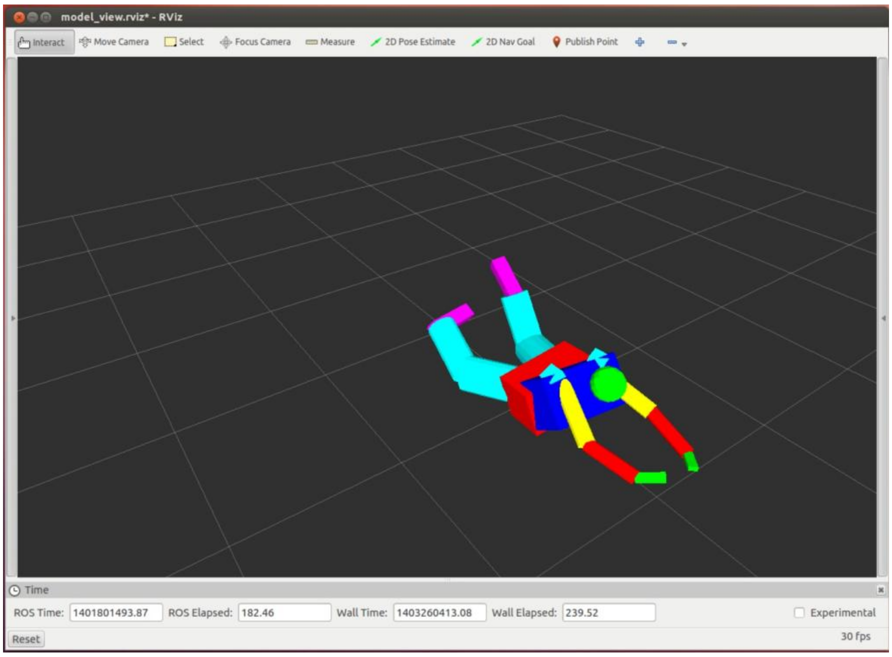


Fig. 2.3.3. 3D reconstruction of the diver posture in ROS RViz

T2.4. Experimental data collection

A number of experiments have been organized by UNIVIE in which other partners also participated. Here is a summary of the activities that were undertaken during the experiments.

1.) Physiological measurements

1.1 Vienna: Emotional Breathing

The aim of this experiment was

- to determine whether/in which way internal states affect breathing patterns and heart rate in humans (without regulator/mouthpiece)
- to validate emotion elicitation through a set of video stimuli by measuring facial muscle activity and reported emotional reaction
- to test the breathing belt/ECG electrodes to be employed in DiverNet (necessary/sufficient sampling rate, …)

Material: 2 Computers, Plasma screen, Sony WebCam, ECG Electrodes, Facial electrodes, ADI breathing belt (UFI Model 1132 Pneumotrace II™), Heart rate sensor (Polar), ADI BioAmp, PowerLab, Video stimuli, Questionnaire (after Rottenberg), Cognitive task (Stroop test)

Procedure: In order to induce the six basic emotions (amusement, anger, anxiety, disgust, sadness and surprise), the participants watched 7 pre-validated film clips, including a neutral film as baseline (Table 2.4.1.). After each clip the participants reported their emotional state during the clip via a short questionnaire. In addition facial EMG electrodes were used to record the activity of several facial muscles (Corrugator; Orbicularis Oculi, Pars Orbitalis; Levator Labii Superioris, Alaeque Nasi; Frontalis, Pars Lateralis) and with it the facial expression of the participant (Fig. 2.4.1., 2.4.2.). The facial muscles were selected according to the Facial Action Coding System (Investigator's Guide) of Ekman to provide an insight into the emotional state of the participant. The breathing pattern was measured with a breathing belt containing a piezo element. In addition the heart rate was recorded via a heart frequency sensor. Furthermore participants were filmed to record their behaviour and to allow identification of artefacts in breathing and heart rate data caused by movements like coughing or yawning. After each film-clip, there was a break of 35s, the questionnaire and a cognitive task that acts as nonemotional distractor to avoid carry over effects. Data collection took place between 03.04.2014 and 09.05.14. All in all 99 participants (49 males, mean age 25,6yrs; 50 females, mean age: 25,1yrs) were tested.

Table 2.4.1. Film-clips for the 6 emotions and neutral with length.

Emotion	Film	Length
Amusement	„baby laughing“ (youtube)	00:00:28
Anger	„Cry Freedom“	00:02:36
Disgust	„Pink Flamingos“	00:00:30
Fear	„Silence of the lambs“	00:03:26
Neutral	„Sticks Screensaver“ (youtube)	00:03:26
Sadness	„Return to me“	00:03:36
Surprise	„Capricorn One“	00:00:49

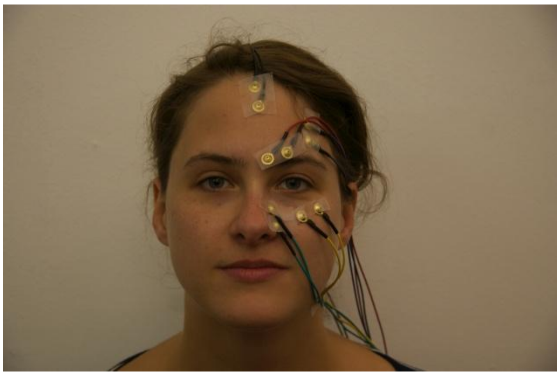


Fig. 2.4.1. Participants with facial electrodes

Fig. 2.4.2. Experimental setup.

Fig. 2.4.3 Experiment control station

Results: We are currently analyzing the collected data and expect to report our results by the end of July. We are testing different algorithms for pattern recognition.

Significance to CADDY: This experiment will deliver a necessary baseline of how emotions affect physiological parameters of humans in their normal ecological environment against which breathing patterns under water with a regulator can be compared. In addition it also allows an estimate of the necessary sampling rates and sensitivity of equipment to be used in the CADDY project.

1.2. Pag: Breathing through a regulator

The aim of this experiment was to investigate the effect of breathing through a regulator on the breathing pattern. As the breathing belt was not yet integrated into DiverNet version 1, the experiment was carried out on land.

Material: Breathing belt, Heart frequency sensor, Video stimulus (screen saver), Sony Digital HD Video Camera Recorder HRX-MC2000E, ADI BioAmp, PowerLab, Air tank, Regulator, Diving mask

Procedure: The participants wore a breathing belt *(UFI Model 1132 Pneumotrace II™*) as well as a heart frequency sensor (Polar) and were filmed with a camera. During the measurements, participants focused on a computer screen with a moving screen saver in order to avoid being distracted. Each participant was recorded for 3 minutes without regulator and afterwards 3 minutes with regulator (attached to a gas tank) and a diving mask. The diving mask inhibited breathing through the nose. See Fig. 2.4.4. for experimental setup. 15 participants (8 men; mean age: 29,1 yrs; 7 women, mean age: 25,0 yrs) were recorded.

Fig. 2.4.4. Experimental setup

<u>Results:</u> : In this comparison we get surprising results. Basically we analyzed time series parameters as developed by Grammer et al (1995) and Koppensteiner and Grammer (2010).

Heart activity was analyzed with the following parameters: Heart rate; General changes over time (expressiveness); Acceleration speed and deceleration speed; Amount of change to max amplitude and to min amplitude; Turbulence – a measure for deviations from regularity.

Breathing patterns were analyzed with the following parameters: Breath rate; General changes over time; Inhalation and exhalation speed; Inhalation and exhalation amplitude; Turbulence.

The differences between the use of a regulator (WR) and free breathing (WOR) are few. Only breath rate is affected by the regulator. Breath rate is significantly lower in the WR condition (Mean breath rate WR: mean = 11,30 breaths per minute; WOR: mean = 14,48 breaths per minute; paired t-test: t = -3,809; p = 0,003). Speed of inhalation and exhalation, turbulence (variation) and amplitude are not affected significantly. Moreover breath rate seems to be individual specific (breath rate WR correlates with breath rate WOR: r = 0,617, p = 0,043). When subjects breath through a regulator the rate of breathing is lower. The other parameters are not affected.

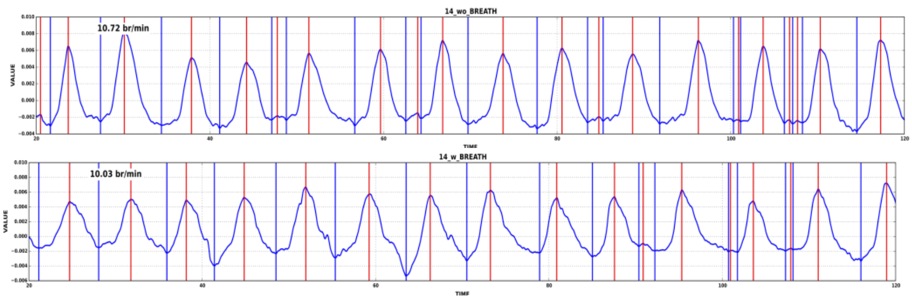


Fig. 2.4.5. Breathing patterns without and with a regulator

In contrast to breathing, heart activity features like speed of changes goes up significantly when breathing through a regulator (WR: 3,27; WOR: 2,61, paired t-test: t = 3,359; p = 0,007, and we find that turbulence is lower when breathing through a regulator (WR: 0,546; WOR: 0,815; paired t-test: t =-2,896; p = 0,016). On a physiological level this might suggest that the organism reaches a upper threshold of possible performance when breathing through a regulator.

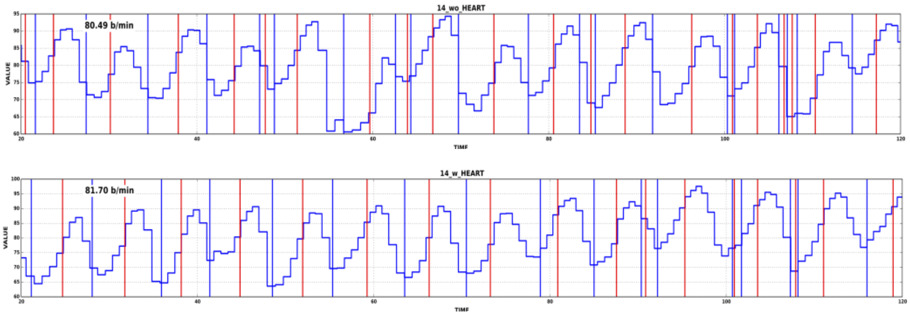


Fig. 2.4.6. Heart rate patterns without and with a regulator

<u>2.) Body Motion</u>

2.2 Vienna: Internal states and posture

The aim of this experiment was

- To determine whether/how internal states (Pleasure-Arousal-Dominance) affect posture in humans
- To determine whether/how well internal states can be inferred from posture by an observer

<u>Material:</u> Sony Digital HD Video Camera Recorder HRX-MC2000E, Computers, Poser Pro (14), Questionnaire (Pleasure – Arousal – Dominance, social factors, age, sex, height, physical activity), EmoSys – Rating study

<u>Procedure:</u> Participants were recruited in the public space of the university. We filmed the participants with a hidden camera (Sony HD Cam Recorder MXR-2000E) while they were asked by an interviewer to report their internal state in a questionnaire using 18 bipolar adjectives as well as control variables (like sex, body height, age, rating of the interviewer, academic degree and income). Once the participant was done, he/she was debriefed and asked to consent to the scientific use of the data. Between the 2nd an 11th of April 2014, 125 participants were interviewed, however, 19 videos had to be discarded, leaving 106 participants (58 women, mean age: 22,5; 48 men, mean age 24,0yrs)

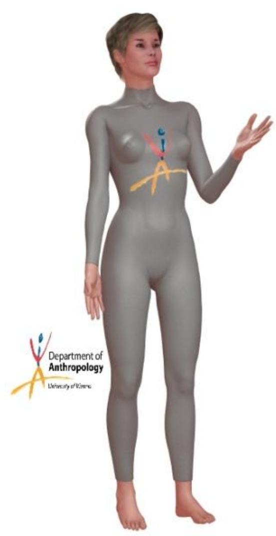


Fig. 2.4.7. Female avatar in a dominant, aroused and pleased mood.

The data from the questionnaire were analysed with principal component analysis (with Varimax Kaiser Rotation), yielding a dimension reduction of the 18 adjectives into three factors (Pleasure, Arousal and Dominance, henceforth PAD).

The participant’s posture in the moment he/she was approached by the interviewer was then transferred to an avatar in Poser Pro 2014 (eliminating all personal features). From this avatar, the body angles were derived and regressed onto the factors of the PAD analysis. Based on this regression, avatar postures corresponding to these factors were created by calculating means and regressions for each factor onto the body angles.

These calculated postures are used in a rating study: 50 women and 50 men will rate the postures in random order on PAD scales (18 bipolar adjectives). The rating study started on the 24th of June and will likely be finished by the 8th of July 2014.

Results: We expect to finish data analysis by the mid of July. For preliminary results regarding the regressions consult Table 2.4.2.

Table 2.4.2.Significant regressions: PAD and Joints

	Joint	Movement	Mean (°)	S.D. (°)	Regression coefficient	p-Value
Women						
Pleasure	Right upper arm	Abduction/ adduction	67,142	5,045	-1,381	0,039
	Right lower leg	Flexion/ extension	8,620	4,645	-1,245	0,047
Arousal	Left upper arm	Flexion/ extension	0,956	13,169	-3,755	0,029
	Left lower arm	Pronation/ Supination	-5,203	33,046	9,023	0,043
	Left hand	Rotation	0,368	2,128	0,597	0,033
	Left upper leg	Flexion/ extension	-5,166	4,317	1,279	0,026
	Left foot	Flexion/ extension	-1,465	2,866	0,844	0,024
Dominance	Right leg	Rotation	-0,954	10,963	3,271	0,027
	Lower leg	Rotation	-0,727	4,776	-1,338	0,038
	Left leg	Rotation	1,620	10,450	-2,885	0,040
Men						
Pleasure:	Abdomen	Bend	-8,515	5,445	-1,856	0,017
	Right upper leg	Flexion/ extension	-4,742	5,028	-1,660	0,028
	Right upper leg	Abduction/ adduction	-0,021	0,939	-0,350	0,012
Arousal:	Left upper arm	Rotation	1,098	5,091	1,529	0,047
	Left lower arm	Pronation/ Supination	-2,699	25,772	-9,237	0,015
	Right foot	Pronation/ Supination	-0,521	2,126	0,637	0,041
	Right foot	Rotation	-0,869	3,556	1,742	<0,001
Dominance	Abdomen	Bend	-8,515	5,445	1,631	0,034
	Right hand	Rotation	-0,096	1,919	0,355	0,221

Significance to CADDY: This experiment will establish a baseline of how internal states of pleasure, arousal and dominance affect body posture to which results from divers can be compared.

2.3 Pag, 12-16 May 2014: Testing the DiverNet – Diver's behavior

This experiment's aim was to test the DiverNet and to record typical diver behavior under water.

Material: DiverNet v1, Sony Action Pro Camera, Volunteers used their own diving equipment

Procedure: Six divers (3 men, 3 women) volunteered to participate in the experiment. The volunteers were equipped with the DiverNet and informed of their tasks:

- Remaining in a standard position (standing upright with the arms stretched out laterally) for several seconds
- Swimming approx. 10m in a straight line at a relaxed pace (see Fig. 2.4.8)
- Swimming approx. 10m in a straight line at a fast pace
- Swimming in a circle at a relaxed pace
- Swimming in a circle at a fast pace
- Moving away from an obstacle
- Simulating a safety stop

Fig. 2.4.8. Diver swimming in a straight line wearing the DiverNet

During the entire procedure a safety diver was standing by and extra care was taken to help the divers avoid entangling themselves in the DiverNet cable. Several of the divers were filmed during the experiment with underwater cameras. Data was collected on the 13th and 14th of May 2014.

Results: We are presently waiting on the processed data from this experiment.

❖ ***Safety evaluation and report by DAN Europe***

The initial dive experiments were carried out at the Island of Pag between the 12th - 16th of May . The formal Hazard Identification and Risk Assessment on the dive site revealed that the conditions are adequate for shallow confined water dives only. In order to improve safety, 12 divers were trained for the Neurological Assessment and 6 divers were trained for Basic Life Support and Automated External Defibrillation.

9 dives have been carried out with a total bottom time of 786 min, maximum depth 5 meters. Minimum preparation time for dressing up the DiverNet is 21 min.

Pre dive Briefing and Experiments Sign up:

The scope of the experiments is explained to the divers. One diver refused to join the experiments stating that he was put on the list without his consent (Zlatan Trokic). One diver's without recent medical examination and a story of ear barotrauma is also eliminated from the volunteers (Katarina Batur). Eight divers signed the written informed consent. A copy of the insurance document is given to the volunteers. The emergency plan and related documents are distributed to the volunteers as well. A rehearsal on detailed equipment check, buddy check and in water check that will be performed by the dive supervisor is performed.

Selection and control of the SCUBA equipment:

The control list given in WP 6.1 was carried out together with volunteers. Normally that will constitute a medium term check in a preventive maintenance schedule. Compressor gas is sampled and was analyzed (Bauer, Aerotest Simultan, Germany) and results are tabulated below.

Content	Actual measured	Maximum allowed	Compliant (Yes/No)
Oxygen	N/A	22% (for air)	N/A
CO	< 5ppm	10 ppm_v	YES
CO2	< 100 ppm	500 ppm_v	YES
Total Hydrocarbons	N/A	25 ppm_v	N/A
Oil/Particle	< 0,04 mg/m^3	0.5 mg/m^3	YES
Water vapour	< 20 mg/m^3	50 mg/m^3 for pressure < 200 bar 35 mg/m^3 for pressure > 200 bar	YES
Odours	None	None	YES

Dives:

The first dive started on the 13th of May at 17:45 with Victor Kovacic and lasted 39 min. followed by Sebastian Govorcin with 40 min. The entry point was a rocky with potential trip hazards. Divers needed help for entry and exit. The second day, the entry point changed to a sandy beach with less potential trip hazards. The second days, experiments divided into two stations, divers were either requested to perform the experiments with hand signals in front of the SONAR and the 3-D camera or they were requested to swim and exercise with DiverNet. Splitting two experiments increased the efficiency, while dressing up the DiverNet still remained as the bottle neck. Even at the last experiment, while the attendants gained experience in fixing the DiverNet, the minimum time required to dress the diver is above 21 min. The second bottle neck was the one by one briefing time required for each volunteer to explain the series of actions needed to be performed in front of the cameras. Obviously, the written briefs, enhanced by story board type of drawings will speed up the experiments and prevent inconsistencies in personal briefing.

Divers usually do not prefer to carry knife, depth gauge or safety equipment like pocket masks, SMBs and were advised about the advantages of having them. There was one incident related to rolling down at swallow water (40-50 cm) while exit, primarily caused by insisting on walking with fins and without assistance. The incident ended up without an injury. The summary of the dive data is presented below.

Name of the diver	Viktor Kovačić	Sebastian Govorčin	Ines Šelendić	Sebastian Govorčin	Viktor Kovačić	Matko Čvrljak	Sebastian Govorčin	Ivana Hanzlić	Tena Festini
Date	13.05	13.05	14:05	14:05	14:05	14:05	14:05	14:05	14:05
SPG read (Bar)	200	210	200	150	200	210	200	200	150
Time In	17:45	17:35	11:57	11:59	12:00	16:10	16:35	16:57	17:10
Time Out	18:24	18:25	13:17	13:27	13:17	17:00	18:00	18:09	18:10
SPG End of dive (Bar)	135	150	130	110	110	150	130	100	90

It is important to note that out of 10 divers who were in the list of volunteers, only 6 made dives. The volunteers were part of an archaeological excavation and had other dives and duties and no one regretted the fact that they could not dive. However, this may not be the case for Y40.

Recommendations for Y 40 dives:

1. Maximum diver per day is limited to 8 based on the 1 hour per diver observation.
2. DiverNet needs to be more practical to wear. (Minimum time recorded to dress up is 21 min). At least a set of 3-4 neoprene fixtures needs to be built to speed up the experiments.
3. A written copy of the scope of the experiments needs to be given to the volunteers before the dives.
4. A group briefing is necessary explain the volunteers what they have to do instead of explaining them one by one. That will eliminate the time losses and the inconsistencies.
5. The list of the actions required from the volunteers needs also to be handed out in a written form; together with clear “story board” type of pictures to explain better the position of the divers, equipment, what to do and what to avoid. This list must be available before the 30th of June.
6. Separation of the recording stations for SONAR, stereo camera from the DiverNet may allow some redundancy that will avoid any catastrophic event in case of failure of one computer/one system.

2.4. Padova. Y-40 pool, 3-4-June 2014: Diver behavior

The aim of the experiment in the Y-40 pool was to record typical diver behavior under water via the DiverNet and video.

Material: DiverNet v1, Sony Digital HD Video Camera Recorder HRX-MC2000E + Tripod, 7kg weight, printed instructions (English/Italian), Volunteers brought their own diving equipment

Procedure: All participants were equipped with the DiverNet (Fig. 2.4.9, 2.4.10). In addition participants were filmed from a window into the pool facing the experimental area. The divers' air consumption was recorded before and after the physically exertive task. Participants were asked to stay in the area marked by buoys and to keep above 5m depth. The participants performed the following tasks in order:

- the diver takes off the diving mask and puts it back on
- the diver takes out the regulator and puts it back in
- the diver swims to the end of the experimental area and back
- the diver simulates a decompression stop for 20s
- 1,5min of free behavior
- the diver carries a weight (7kg) to the end of the experimental area and back -five times (physical exertion task)
- 10min of free behavior

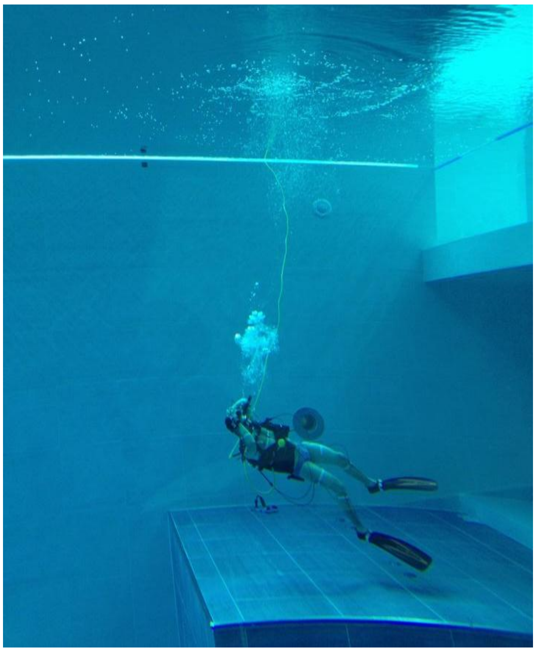


Fig. 2.4.9. Diver under water while doing tasks.

2.4.10. Participant wearing the DiverNet.

All in all 16 participant (12 men, mean age 48,1yrs; 4 women, mean age 39,3yrs) were recorded on the 3rd and 4th of June 2014.

Results: Analysis of the DiverNet data will begin in July. The video data will also contribute to the development of a behavior repertoire for divers (July, August).

❖ *Safety evaluation and report by DAN Europe*

The second series of experiments were carried out at the world deepest pool, Y-40, at Padua on the 3rd and 4th of June. A formal Hazard Identification and Risk Assessment on the dive site (Y-40 pool) revealed that the conditions are perfect for the confined water CADDY dives. Due to the fact the Y-40 pool was not open to the public yet and workers were busy during the second day, certain rooms, such as the compressor room were very tidy and neat in the morning, but full of materials by the evening. This did not cause any safety issues as cylinders where not filled during the day and divers are not allowed in those areas and this also will not be possible once the pool officially opens.

16 CADDY dives have been carried out with a total bottom time of 408 min, maximum depth 8 meters. Minimum preparation time for dressing up the diver with DiverNet is +/-15 min.

Hazard Identification and Risk Assessment :

Following checklist is performed on the 2nd and 3rd of June. Some important non-compliance issues such as emergency phone numbers needed to be resolved during the assessment.

Pre dive Briefing and Experiments Sign up:

A safety briefing including the scope of the experiments was explained to the divers. One diver (Alfonso Sacco did not dive due to a medical problem. All other divers signed the written informed consent and showed proof of certification and fitness to dive certificates. A copy of the insurance document was given to the volunteers (2) who did not have an active insurance cover. A detailed equipment and buddy check review was given and an in water check by the Safety Director or Dive Supervisor was performed for every diver.

All divers made a fun dive to 41.6m (dive time: 30-39 min) before their CADDY dive, with exception of Guy Thomas, who made the fun dive after his CADDY dive.

On diver showed up at about 16.00 on 04/06 and was not allowed in the water as he did not have an insurance and was not on the participants list.

The safety briefing was done at the side of the pool, while the experiments and their scope were explained in a classroom on day one and in the pool area on day 2.

During day one all divers arrived in the morning and one briefing was organized. On the second day there was a morning and afternoon group and the briefing was repeated

Selection and control of the SCUBA equipment:

The control list given in WP 6 was carried out together (where appropriate) with volunteers. Normally that will constitute a medium term check in a preventive maintenance schedule. Compressor gas is sampled and was analyzed (Bauer, Aerotest Simultan, Germany) and results are tabulated below.

Content	Actual measured	Maximum allowed	Compliant (Yes/No)
Oxygen	N/A	22% (for air)	N/A
CO	< 5ppm	10 ppm_v	YES
CO2	< 100 ppm	500 ppm_v	YES
Total Hydrocarbons	N/A	25 ppm_v	N/A
Oil/Particle	< 0,04 mg/m^3	0.5 mg/m^3	YES
Water vapour	< 20 mg/m^3	50 mg/m^3 for pressure < 200 bar 35 mg/m^3 for pressure > 200 bar	YES
Odours	None	None	YES

Dives:

The first dive started on the 3rd of June at 11:17 with Claudio Corsale and lasted 28 min. followed by Roberto Zatti at 12.10 with 25 min. Divers entered the water using the entry steps of the swimming pool. The last dive was done on the 4th of June and ended at 16:54. Due to a potential slippery hazard all divers were helped during entry and exit. A safety diver was present during all dives. This safety diver also took the cylinder pressure during the exhaustion test. All divers were requested to do some exercises wearing DiverNet and were filmed through a window opposite the area (5m) where the diver operated. During the dressing up of the DiverNet, each exercise was reviewed again with the diver, pointing out that written, waterproof, instructions were also available under water.

One diver (Federico Cecchini) dropped to 8m and the safety diver brought him back to the correct level. Another diver (Emanuel Carraro) was brought up from 8m during the dive to explain again what he needed to do as he was performing the exercises wrongly. He then went back to 5m and performed the exercises again.

Due to the dive site being a 40 m pool with several depth levels (so divers could easily be monitored and kept under control) and filled with Thermal water, the temperature in the water was 33°C (water enters the facility at 87° and is cooled down before it enters the pool). Also the pool area was very warm (and humid). A total of 72 0.5lt (36lt in total) water bottles were provided to the divers and researchers making sure they kept hydrated.

Divers did not carry a knife, dive light, weights, compass, suit, SMBs or other safety equipment due to the dives done in a pool with high visibility. A computer or watch/gauge, in addition to a BCD, mask and fins was carried by all divers. There were no incidents. The summary of the dive data is presented below.

03/06/2014

NAME	Claudio Corsale	Roberto Zatti	Natasha Bertozzi	Astrid Passera	Claudia Imperiali	Francesco Malgaroli	Guy Thomas		
Bar In	130	200	200	200	205	150	205		
Bar Out	90	160	160	160	160	130	175		
Volume cylinder	15	15	10	10	10	15	10		
Time In	11,17	12,10	13,08	13,56	14,35	15,15	15,55		
Time Out	11,45	12,35	13,32	14,16	14,57	15,40	16,13		
Dive time	28	25	24	40	22	25	18		
Depth	5	5	5	5	5	5	5		

4/6/2014

NAME	Alessandro Scappatura	Raffaella Signorini	Federico Cecchini	Andrea Rasia Dani	Renato Girardello	Emanuel Carraro	Gianluca Bertacche	Rene Lipmann	Giuliano Zin
Bar In	140	140	180	200	130	120	200	140	115
Bar Out	110	110	110	150	100	75	140	90	90
Volume cylinder	15	15	10	10	15	10	10	10	15
Time In	11,02	11,38	12,34	13,21	14,06	14,42	15,16	15,56	16,32
Time Out	11,19	12,01	13,03	13,52	14,29	15,07	15,40	16,16	16,54
Dive time	17	23	31	31	23	35	24	20	22
Depth	5	5	8	5	5	8	5	5	5

There were no incidents and no diver complained of medical problems at the end of the day.

Recommendations for future Y 40 dives:

1. The maximum amount of divers per day is limited to 8-9 based on the +/- 1 hour per diver preparation and observation time for DiverNet only.
2. DiverNet was relatively fast to apply and the time between dives was rather short. This is also because of the set up and advantages of using a specific pool with easy access to the water. Most time was lost before the first dive (set-up and briefing and fun dive). This should be calculated for next times. Also the exercises that need to be performed need to be communicated well in advance and not the evening before or the morning of the tests.
3. A written copy of the scope of the experiments needs to be given to the volunteers before the dives.
4. A group briefing, including the explanation of the tasks is necessary. Exercises and tasks can be reviewed just before entering the water when the DiverNet is set up.
5. The list of the actions required from the volunteers needs also to be handed out in a written form; together with clear “story board” type of pictures to explain better the position of the divers, equipment, what to do and what to avoid. This list must be available at least a week before the event.
6. Separation of the recording stations for SONAR, stereo camera from the DiverNet may allow some redundancy that will avoid any catastrophic event in case of failure of one computer/one system.

T2.5. Diver pose estimation

JACOBS has started first preliminary work in order to investigate both full diver pose and joint angle estimation (6 DoF for torso pose, and limited joint set (15 DoF): Hip, knees, ankles, shoulder, elbow, wrist. Total joints: 21 DoF) from stereo vision data alone. An approach using genetic algorithms and a model reprojection based fitness function is currently under development, which previously showed promising results on monocular thermal images in a safety, security, and rescue robotics (SSRR) scenario.

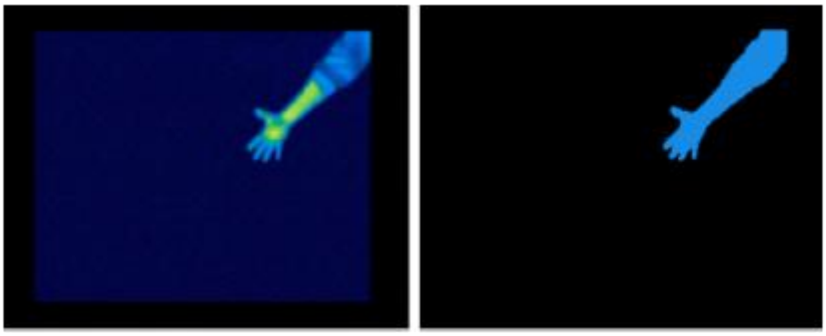


Fig. 2.5.1. Example segmentation result from thermal imagery in a safety, security, and rescue robotics (SSRR) scenario.

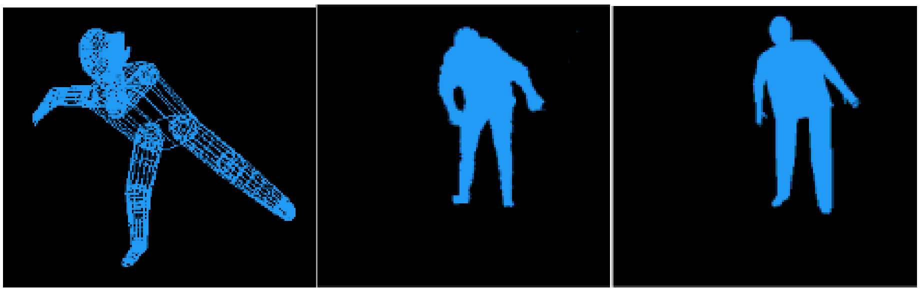


Fig. 2.5.2. Left: Human model. Center: Example segmentation result. Right: Model rendering of best fit to center segmentation result.

So far, the focus was on gathering ground truth data in simulation, specifically UWSim, for facilitating further development of diver pose estimation. A 3D model of a diver was generated and constructed in URDF format for use in UWSim. Each DoF is either accessible as joints (mutable by the ROS sensor_msgs/JointState message) or as the 3D pose of the model itself (mutable by the ROS nav_msgs/Odometry, by the way of UWSim's implementation).

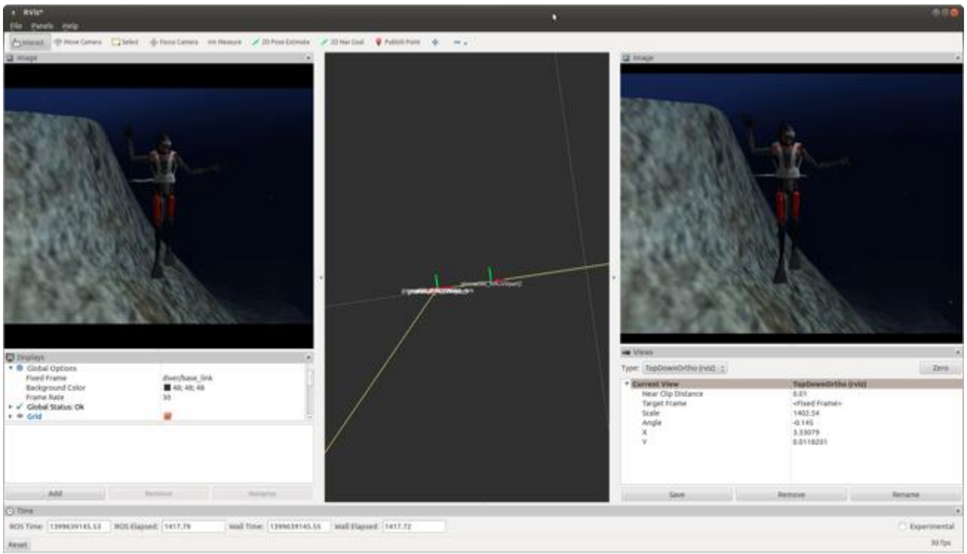


Fig. 2.5.3. Screenshot: Example of a stereo image pair observing the simulated diver model

T2.6. Recognition of hand gestures

CNR-ISSIA is working on the hand gesture recognition based on the feedback from one mono-camera.

At the moment, preliminary tests are made by acquiring the video stream and searching for one (or more) hand(s) in real time within each camera frame. To the present moment, the acquisition is made "in air", thus trying to recognize a bare hand, in such a way to identify the most suitable vision algorithm; this will have to be adapted to gesture recognition in an underwater environment (with issues such as possibly less visibility in the water, diver wearing gloves, …).

CNR-ISSIA distinguishes between **static** and **dynamic** gestures: the first type is characterized by a specific combination of hand position and orientation observed in a specific time instance (*not time-varying*), while the second type is a *sequence* of postures connected by motions over a short time span (dynamic gesture recognition needs a combination of posture analysis and temporal context information). In Fig. 2.6.1. and Fig. 2.6.2, the differences among static and dynamic gestures can be derived.

In the CNR-ISSIA preliminary tests only static gestures are considered.

Fig. 2.6.1. Static hand gestures.

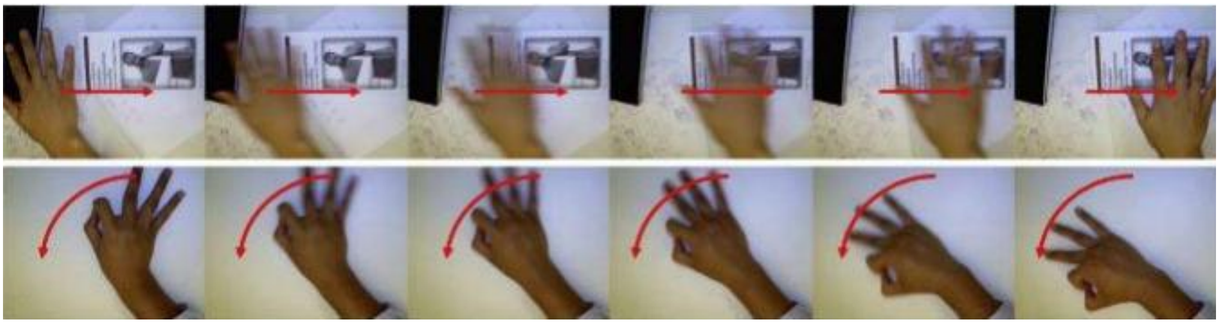


Fig. 2.6.2. Dynamic hand gestures.

In general, a gesture is an intentional meaningful movement or posture that a human agent performs in order to communicate and interact with environment. A gesture can involve physical movements of fingers, hands, arms, face or body and constitute a small subspace of possible human motion.

Typically, a recognition system is made up of the following essential components:

- **Feature extraction**, necessary to extract posture and motion cues that are discriminative with respect to the human gestures.
- **Gesture learning and classification**, learning statistical models from the extracted features and using those models to classify new gesture observations.
- **Gesture segmentation**, aiming to cut motion streams into single gesture instances to be matched with the learnt models.

The current gesture classifier software, implemented in C/C++ and exploiting the OpenCV vision library, is simply based on image processing. First of all each frame is converted into the HSV space color and a suitable thresholding (skin detection) is applied in order to find the hands (surely this has to be slightly changed to find the diver's hand position). After this the image is smoothed through a cycle of erosion/dilation operators and then a suitable blob finder eliminates the useless frame portions, giving as intermediate result a masked image only containing the blob labelled as "skin". Finally, the SURF feature detector is applied to the obtained image and the (static) gesture in the image is matched with all the models that have been previously stored in the system. Fig. 2.6.3. shows some of the employed hand models, while Fig. 2.6.4. is an example of a correctly matched (static) gesture.

Fig. 2.6.3. Some of the hand models stored in the system.

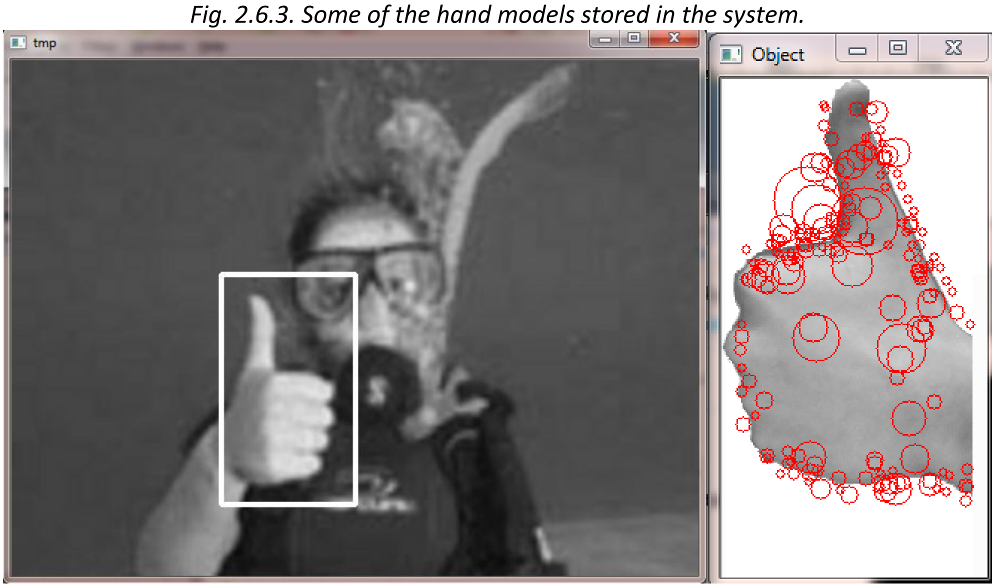


Fig. 2.6.4. Static hand gesture correctly matched by the system.

At the present moment, a **Haar cascade-classifier** is being studied (and should be better trained) and a preliminary integration within the image processing software for (static) hand gesture recognition is being carried out.

As for dynamic gestures, we envision to build up a sort of "graph", in which each leaf represents a static hand position, together with the suitable connections in order to find a proper path along the graph representing each possible diver dynamic gesture. Anyway, this approach is to be better explored and discussed.

Another possible improvement consists in the integration of the visual information with input from other sensors/from other system components; this issue, too, is to be better detailed and discussed.

For what concerns both static and dynamic hand gestures, there is a huge set of open problems such as, for static hand signals:

- *hand* segmentation in a cluttered background;
- selection of the *frame of interest*;
- development of methodologies for *hand pose* analysis.

Concerning dynamic signals, some of the envisioned problems are the following:

- *diver* segmentation in a cluttered background;
- extraction of the *start/end frames* of the gesture;
- extraction of the *relative position* of body and hands in all the sequence frames ;
- extraction of features that are *relevant* to the gesture and *invariant* to different gesture lengths;
- development of (statistical) models to represent the feature evolution for each gesture.

The UNIZG-FER team focused on both static and dynamic gesture recognition, by using hidden Markov models. In the initial work related to recognition of diver gestures, 8 prime diver hand signals were observed:

- "*Look at me*" – static gesture with two fingers straight up pointing to eyes,
- "*I have a cramp*" – dynamic gesture with the fingers bending to and from the palm,
- "*Going up*" – static gesture with a thumb pointing up,
- "*Running out of air*" – dynamic gesture with an open palm facing down and moving left and right,
- "*Turn around*" – dynamic gesture with one finger pointing up and making a circle in the horizontal plane,
- "*Danger*" – extended arm with open palm moving left and right,
- "*Slow down*" – dynamic gesture with an open palm facing down and moving up and down, and
- "*Stop*" – static gesture with an open palm and fingers together pointing up.

UNIZG-FER used hidden Markov models (HMM) to interpret both static and dynamic divers' hand signals using real time video feed. Two methods of collecting features that describe diver gestures are described and two types of HMMs are investigated: one based on discrete outputs variable distribution and the other based on mixture of Gaussians outputs variable distribution. For 8 basic diver gestures, 800 data samples were collected and the results were analyzed for the purpose of determining the most appropriate

i) feature vector describing diver gestures - whether to use three features (number of fingers and palm position in the video frame) or two features (number of fingers and the direction of palm movement in the video frame),

ii) HMM parameters - number of states and mixture components, and

iii) type of the hidden Markov model - discrete or mixture of Gaussians outputs variable distribution.

A simplified scheme of the envisioned approach is given in Fig. 2.6.5. The first step is to detect the hand from the sequence of image frames. Using the image processing system the hand is recognized and the hand feature vector is obtained for the training and recognition process. The image processing system only extracts hand features when the hand is detected, therefore reduces the computation load when the hand is not detectable.

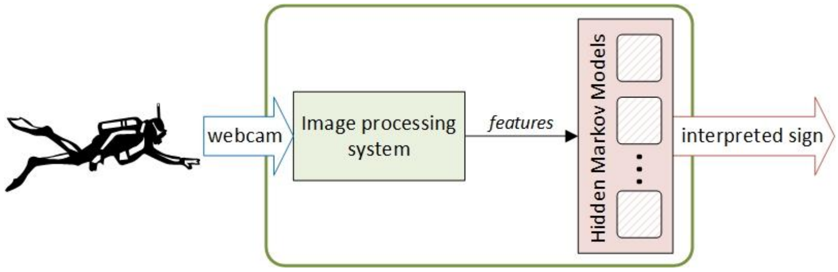


Fig. 2.6.5. UNIZG-FER approach using hidden Markov models.

It has been shown that the HMM with the mixture of Gaussians outputs variable distribution and a two component feature vector gives the best performance among the tested models. The results show an average of 72% accuracy.

In the conducted experiments, the camera was fixed in from of the test subject. Since this methodology has to be applied on a diver, by observing her/him from a moving underwater vehicle, the approach to recognizing gestures had to be changed. The future research will focus on measuring hand motion relative to the divers head, i.e. in the divers coordinate system. It is expected that this would solve the problem of a moving observation underwater vehicle.

WP3 Understanding the diver

T3.1. Adaptive interpretation of diver behavior

T3.2. Symbolic language interpreter

T3.3. Cognition-based mission (re)planner

T3.4. Performance evaluation

WP4 Diver-robot cooperation and control

T4.1. Compliant diver buddy tasks

T4.2. Cooperative control and optimal formation keeping

At the core of the CADDY concept is the ability of two or more “agents” (vehicles and human divers) to maneuver in close cooperation by exchanging motion-related information over the acoustic channel and reacting accordingly. As an example of a cooperative maneuver the IST cite the case where *the underwater vehicle (the robot companion) is guided by the surface vehicle along a desired trajectory.* In this situation, the surface vehicle trajectory acts as a reference or leader (in 2D) and the underwater vehicle must track this reference in the horizontal plane (albeit with a desired x-y offset, if required), while undergoing independent motion in the vertical plane (e.g. staying at a constant depth or constant altitude above the seabed).

This technical problem is sufficiently rich in that its solution sheds light into the solution of other cooperative motion problems that are key to the implementation of the CADDY concept. Furthermore, the problem can be simply motivated by an interesting missions scenario that can be referred to as the “guided tour”: one or more divers are interested in visiting an archaeological site, and to this effect they wish to be guided by an underwater “tour guide” that acts as a reference for them to follow visually, at close range. It is therefore up to the underwater vehicle to maneuver along a desired, pre-determined “tour path”. *Because of stringent navigational constraints underwater, this is done by having the underwater vehicle track the reference trajectory set out by the surface vehicle;* see Fig.4.2.1. It is against this background of ideas that this maneuver, henceforth called Leader Tracking, was chosen as a case study to illustrate the sequence of steps that go into the design, implementation, and field testing of the systems that contribute to the execution of a cooperative maneuver. In this respect, the work in this workpackage is ahead of schedule in that it has witnessed the transition from the laboratory to the real world. The methodology developed and the lessons learned should be viewed as a first contribution to the development of the systems needed to execute the cooperative maneuvers envisioned in the scope of CADDY.

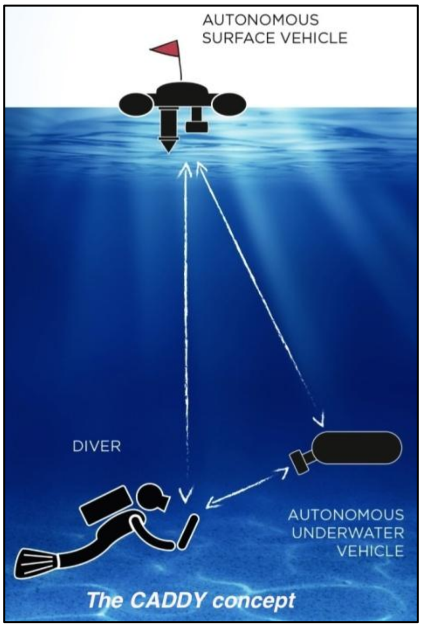


Fig. 4.2.1. The CADDY concept.

The Leader Tracking System (LTS)

The general scheme adopted to run a Leader Tracking maneuver can be best explained by referring to the block diagrams below, that illustrate the navigation and control architectures for the Autonomous Surface Vehicle (ASV) and Autonomous Underwater Vehicle (AUV) units.

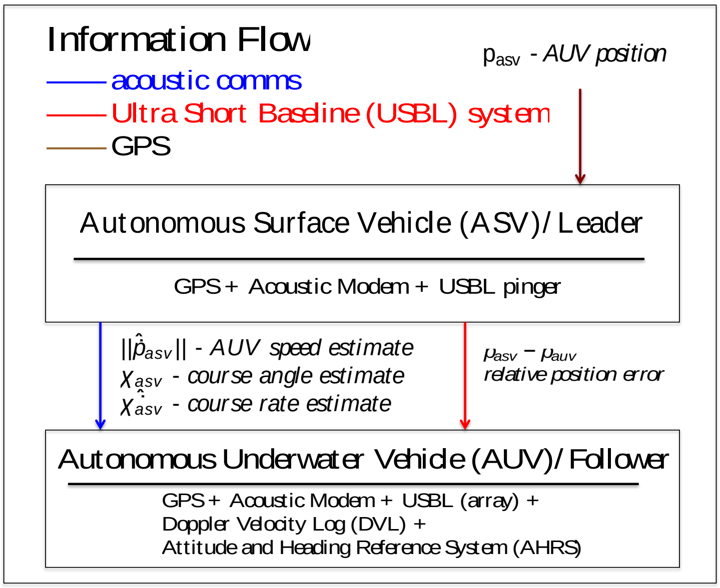


Fig. 4.2.1 Leader tracking system: general architecture showing the motion sensor units used and the flow of data over the acoustic channel.

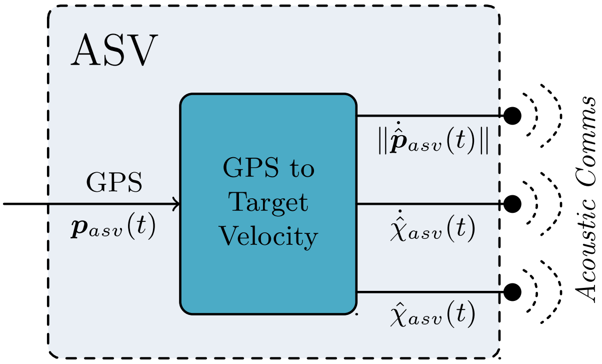


Fig. 4.2.3. Leader tracking system: the ASV architecture

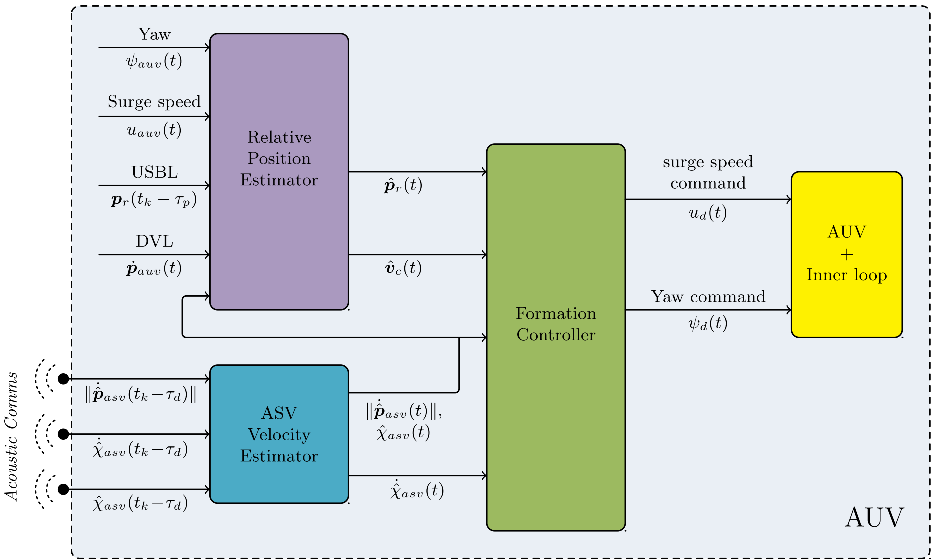


Fig. 4.2.4. Leader tracking system: the AUV architecture

The ASV is the leader and maneuvers “at will” (e.g., following a pre-planned path with a desired speed profile). The AUV is the follower: based on proprioceptive motion data as well as ASV motion-related data, acquired and transmitted using acoustic units (*USBL and acoustic modems*), it maneuvers so as to track the motion of the leader. The architectures for the ASV and AUV segments are detailed next.

ASV Architecture. In the set-up adopted, the leader (ASV) is equipped with a GPS and runs a filter to estimate its inertial speed, course angle, and course angle rate. This information is transmitted to the AUV via an acoustic modem. In its present form, this system is mechanized as a Kalman Filter (KF). It uses the position measurements obtained from a GPS receiver, in a ENU (East, North, Up) reference frame, to estimate the inertial velocity of the surface vehicle in polar coordinates (norm and course angle) and the rate of the course angle. Both the norm of the velocity vector and the rate of the course angle are assumed to be constant in the model used for this KF, therefore the latter embodies in its design model piecewise constant-velocity and constant-curvature trajectories.

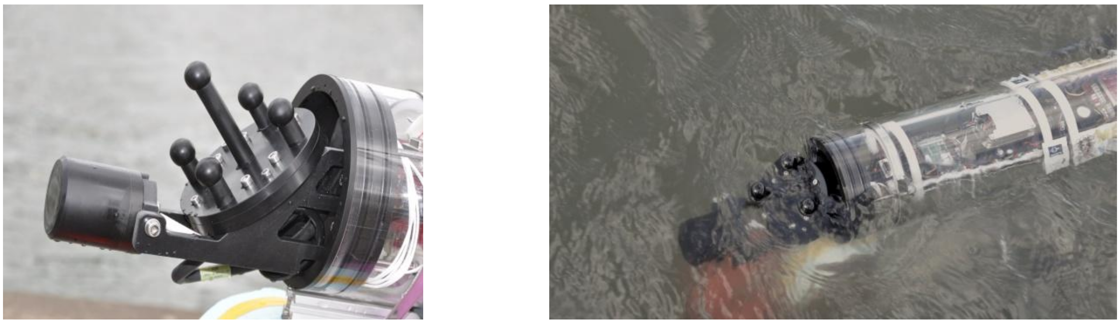
AUV Architecture. The AUV counterpart involves four main subsystems:

1. *ASV velocity estimator* – the follower (AUV) receives the information broadcast by the leader at discrete, possibly asynchronous instants of time (with a time delay) and runs an internal filter to generate estimates of the ASV´s inertial speed, course angle, and course angle rate at a faster rate.
2. *Relative position estimator* – this block is in charge of fusing data available from different sources: i) the ASV´s speed, course angle, and course angle rate generated by the *ASV velocity estimator; ii)* the (delayed) relative position of the ASV with respect to the AUV using an Ultra-Short Baseline (USBL) system installed on-board, iii) the velocity of the AUV with respect to the seabed using a Doppler log (this is the case in shallow water; in deep water, the unit can yield both the velocity with respect to the seabed and to the water), iv) Heading, provided by an Attitude and Heading Reference System (AHRS), and v) surge speed with respect to the water, where the latter is estimated using a quasi-static propulsion model that relates the speed of rotation of the vehicle propellers with the vehicle´s forward speed. Its output consists of the estimate of the relative position of the AUV with respect to the ASV, together with the estimate of the underwater current, both at a sufficiently fast update rate.
3. *Formation controller* – this block is in charge of generating commands for the AUV surge speed and yaw angle (tracked by the AUV inner loops) so as to make the AUV track the position of the ASV with a properly chosen, possibly time-varying offset, as per the requirements of the maneuver being performed. In fact, the formation controller can be viewed as the cascade composition of two operations: i) generating a virtual target (determined by the trajectory described by the ASV and the requisites of the leader tracking maneuver) and ii) and tracking the virtual target. The generation of the virtual target and its velocity relies on the fact that the AUV has access not only to the relative position and velocity of the ASV, but also to the curvature of its trajectory. Two options have been considered so far: i) the position of the virtual target is a constant vector in the ASV´s body-axis, or ii) the virtual target is positioned at a point defined by desired along- and across-path distances with respect to the path defined by the AUV (which, we assume,

is either a straight line or a segment of a circumference, or a combination thereof). Any of these options allow for the characterization of the trajectory of the virtual target, both in terms of its position relative to the underwater vehicle (follower) and its inertial velocity. These parameters are then fed to a trajectory-tracking controller that forces the actual vehicle to track the virtual one.

LTS Experimental results

The Leader Tracking system was fully implemented and tested using an ASV and an AUV, both members of the Medusa class of autonomous marine vehicles owned by IST. Figures 4.2.5a) and b) show the USBL and acoustic communication systems installed on-board the diving $MEDUSA_{D.}$



a) b)

Fig. 4.2.5 a) USBL system installed on-board the diving $MEDUSA_D$, and b) $MEDUSA_D$ with USBL system deployed in the water

During the tests, the ASV was requested to perform a U-shaped path following maneuver at the surface (see Fig. 4.2.6). In the set-up adopted, the virtual target (to be tracked by the AUV) is positioned at a point defined by desired along- and across-path distances with respect to the path defined by the AUV (which, as explained before, is either a straight line or a segment of a circumference, or a combination thereof). The along and cross- path distances were set to -17 and +5 meters, respectively (intuitively speaking, this means that the AUV was requested to stay 17 meters behind along the path and 5 meters to the right). Throughout the maneuver, the AUV was commanded to remain at a fixed depth. The nominal speed of both vehicles was set to 0.3 m/s. In the mission performed, the following computation / computation cycles were used:

Acoustic communications cycle:	3s
Time slot for comms (each vehicle):	1s
DVL:	0.2s (5Hz)
AHRS:	0.1s (10Hz)
GPS (on the ASV):	0.2s (5Hz)
Control and Navigation:	0.2s (5Hz)
Data sent from ASV to AUV:	18 bits per cycle

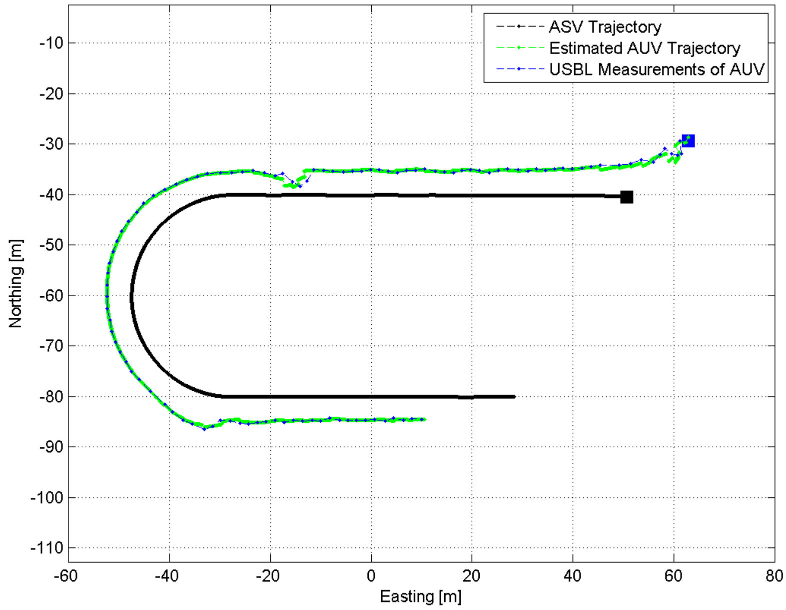


Fig. 4.2.6. Leader tracking system: experimental tests with the MEDUSA class of vehicles (ASV trajectory in black; AUV trajectory in green)

Figure 4.2.6. shows the paths taken by both the ASV and the AUV in the 2D plane. Figure 4.2.7. shows the along-path and cross track errors. Finally, Figure 4.2.8. contains the plots of the estimates of the current.

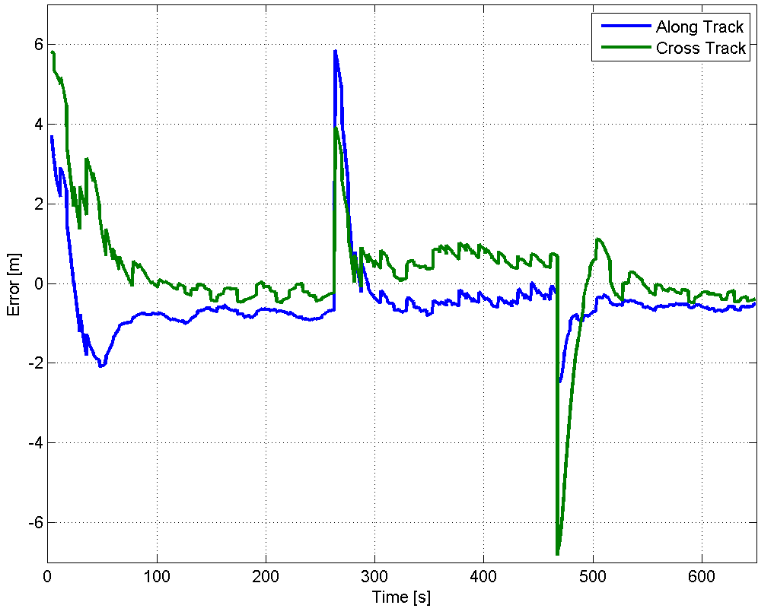


Fig. 4.2.7. Leader tracking system: along-path and cross track errors.

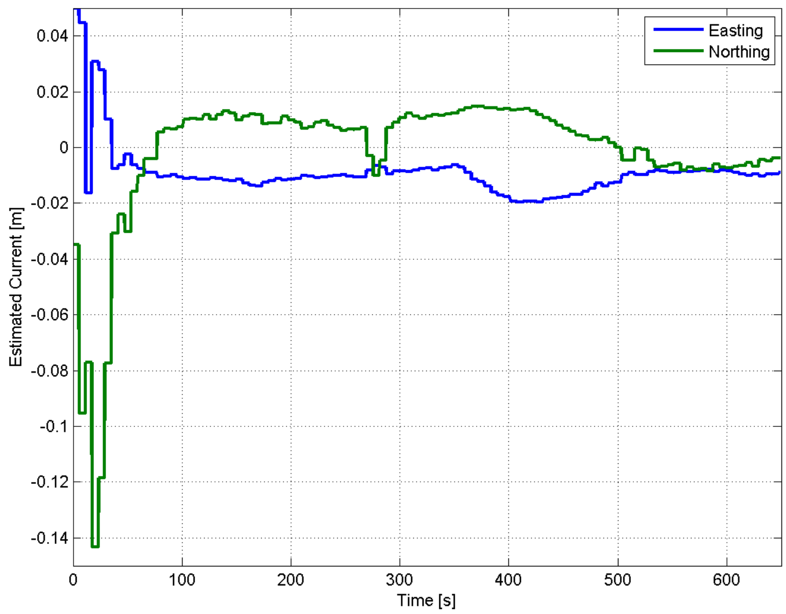


Fig. 4.2.8. Leader tracking system: current estimates.

The figures show that the performance of the Leader Tracking system is quite good. The deterioration in performance that occurs when the ASV enters or leaves the circular part of the maneuver is simply due to the fact that the along- and cross track position specification for the virtual vehicle (to be tracked by the ASV) are done considering that the circular part of the path is extended backward as a circumference (upon detection that the ASV actually entered the circular path). This was done to simplify the implementation of the Leader Tracking system. The problem will be overcome by actually extending back the path taken by the AUV taking into consideration the actual path traversed, stored in memory. This will allow capturing correctly the transitions from straight lines to curvilinear paths. Nevertheless, *the experiments have shown that collectively the partner group masters the techniques needed to fully implement and run multiple agent cooperative motion control and navigation systems.*

Diver tracking

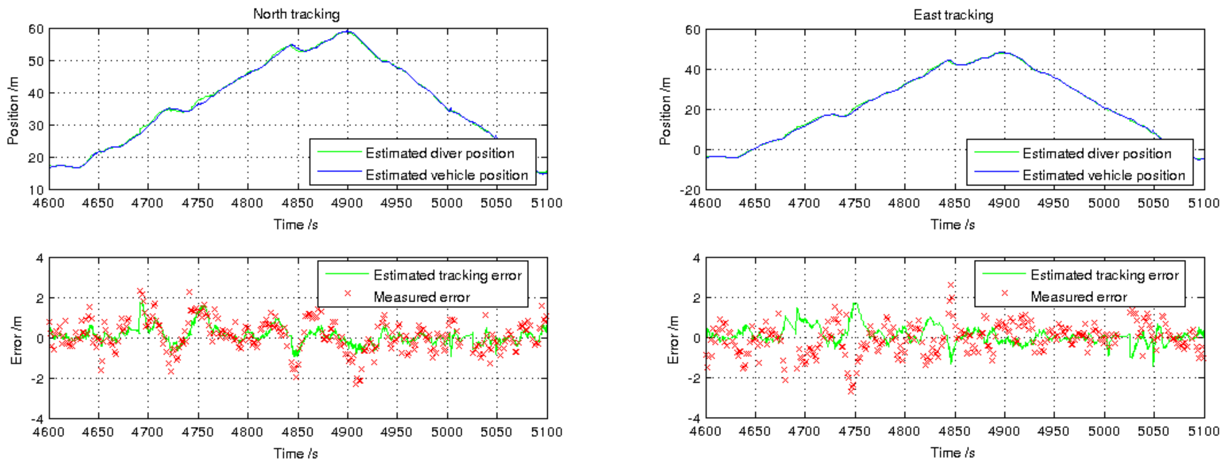
Diver tracking approach is taken by UNIZG-FER. On a bit different note in comparison to the IST group, the problem that is being solved here is tracking the diver using an autonomous surface vehicle. The UNIZG-FER group is using an overactuated surface platform PlaDyPos for this purpose. While the diver can take any direction at any speed underwater (with physical diver limitations), the platform should follow the diver as precisely as possible by staying right above the diver.

Diver tracking was achieved with a extended Tritech MicroNav USBL system. The tracking was performed from the PlaDyPos autonomous surface craft. The hardware side of the diver tracking application consists of the USBL transponder mounted on the surface platform and the acoustic modem located on the diver. Additionally, for tracking and data exchange scenarios the diver is also equipped with the underwater tablet.

The software side is implemented in ROS and consists of several nodes. The third party application is the SeaNet proprietary application which provides necessary USBL signal processing. The ROS side contains the driver node that commands the USBL interrogation and encodes/decodes payload data. The navigation data published by the driver node is used by the kinematic filtering node to estimate diver motion during unavailable measurements. Data exchange requires also the USBL communication manager node that handles incoming topics on chat, KML, alert and diver position that need to be processed and packed in small USBL messages.

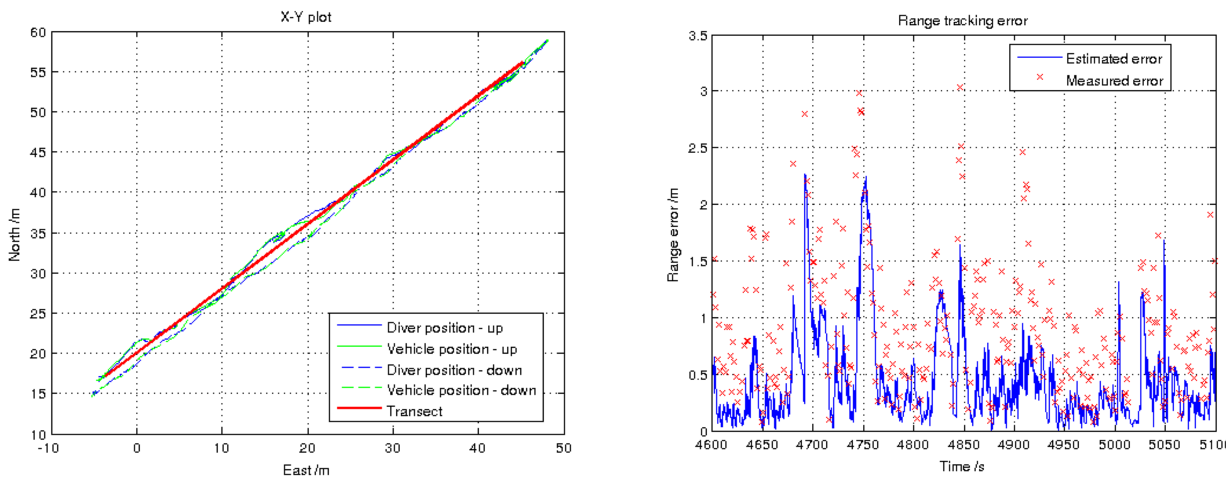
Diver tracking experimental results

Experiments were performed with pure diver tracking and diver tracking with navigation and data exchange. Performance testing took place during the June 2014. fieldwork at the Croatian Navy base in Split. Tracking evaluation was done based on prepositioned underwater transect. The diver was moving along the transect to assure repeatable movement between experiments. For visual validation a camera was mounted on the autonomous surface platform that was only used for observation. All diver tracking was done only using USBL measurements.



a) b)

Fig. 4.2.9. a) North and b) east diver tracking and tracking error.



a) b)

Fig. 4.2.10. N-E plot of diver movement and the tracking range error.

Expected USBL performance was 0.7 Hz refresh rate during pure tracking and 0.23 Hz during tracking with navigation aiding and data exchange. The average depth of the transect was 6m which assures enough vertical room for the USBL communication while maintaining visibility in the camera. The appropriate depth allowed the USBL to be caught in the air-bubble wake in order to analyze the communication robustness in presence of diver breathing. The position, error and time plot of the platform and diver movement are shown in Fig. 4.2.9. and 4.2.10.

These results show excellent diver tracking performance with measured error never greater than 3 m (using USBL). In order to further validate results, we obtained videos of the view below the diver. One such frame from the video during the tracking experiment is shown in Fig. 4.2.11. Full video data processing still has to be finished in order to fully validate the tracking results.

Fig. 4.2.12. Diver in the vehicle camera during diver tracking.

The biggest problem that we occurred during the experiments is the emission of bubbles that disturbs the acoustic channel. Our further research will focus on surface platform cognitive path planning in order to avoid bubble clouds and thus eliminate errors in the acoustic channel.

T4.3. Cooperative distributed navigation and localization

Range-Based Target Localization

In the context of the CADDY project, the need arises for the surface unit (ASV) unit to locate the position of one or more underwater targets (e.g. diver and/or the companion AUV). This is done for safety purposes, and also for the ASV to aid the underwater targets navigate in the underwater medium (that is, to compute their positions and velocities). In fact, because in the types of operations envisioned the underwater targets will be accompanied by the ASV and the latter has access to GPS, it is appropriate to use it as a navigation aid. To this effect, the ASV may be equipped with an Ultra-Short Baseline (USBL) system capable of measuring the relative position of the underwater targets with respect to itself. By fusing this information with other relevant information (e.g. GPS and target depth transmitted over an acoustic modem), it becomes possible for the ASV to estimate the position of a target and transmit this information to the latter (again, using an acoustic modem). However, this solution may meet with practical and economic difficulties: USBL systems are relatively expensive, and the accuracy of the relative position estimates that they provide is strongly dependent on a painstaking calibration procedure and the availability of a high grade AHRS system on board the ASV.

For the above reasons, over the past few years there has been interest in the development of complementary, cheap, and easy to install and operate systems that can yield good estimates of the position of an underwater target. One such example includes the use of a range measuring device, whereby the ASV undergoes “persistently exciting motions” and measures its distance to the underwater target periodically, or even asynchronously. By exploiting the motion “richness”, it becomes possible for the ASV to estimate the location of the target underwater. This strategy, henceforth referred to as *Range-Based Target Localization*, is illustrated in Fig. 4.3.1. and has been the subject of intensive research recently.

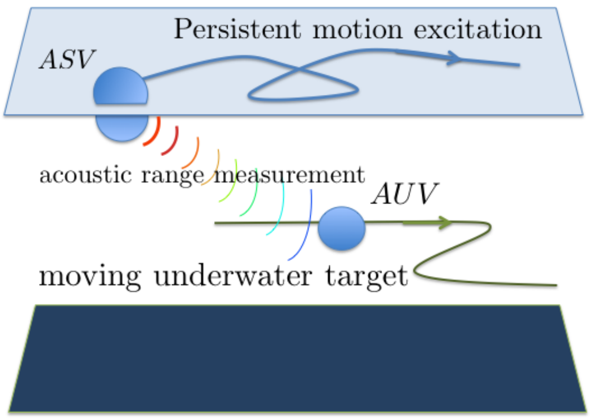


Fig. 4.3.1. Range Based Localization.

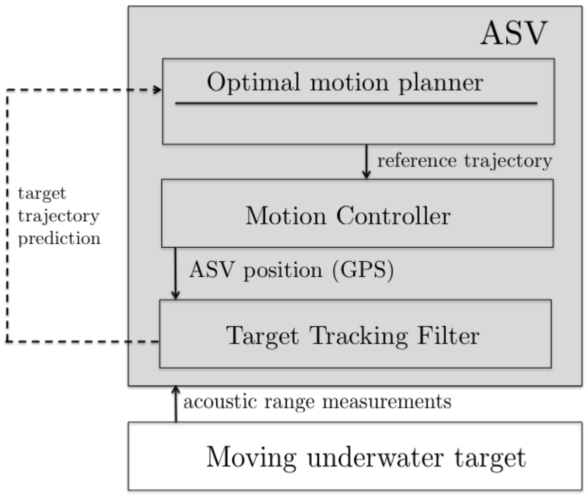


Fig. 4.3.2. Range Based Localization System: Functional Organization

Clearly, at the core of this strategy is the computation of the optimal maneuvers that the ASV should undergo in order to “maximize” the range-related information available for underwater target localization. However, this is but the first in the sequence of steps needed to make such a system “work” effectively. This is best explained by referring to Fig. 4.3.2., which can be viewed as the “master plan” for the development of the range target localization system envisioned in the scope of CADDY.

In the set-up adopted, from a conceptual point of view, the following chain of events is triggered as the mission unfolds:

1. The *Optimal Motion Planner* computes, based on the prediction of the target trajectory, the optimal motion sequence that maximizes the range-related information available for

underwater target localization.

2. The output of the Optimal Motion Planner yields a reference trajectory for the ASV to track. This is done by the *Motion Controller* block, which implements a by now classical Trajectory Tracking strategy.
3. As the ASV moves under the action of the Motion Controller, it measures the ranges to the moving underwater target and estimates its position by resorting to a *Target Tracking Filter*. The latter, in turn, should yield not only estimates of the position of the target, but also of the level of uncertainty with which the estimate is computed. This issue has not been tackled yet, but promising results along these lines have been obtained by resorting to the theory of Minimum Energy Estimation (MMEs), see [3]. We plan to exploit these results in the scope of CADDY

From the above, it follows that the implementation of the Range-Based Target Localization system requires that the blocks defined above run in parallel, relying on a strategy that intertwines, over a sliding temporal window, the phases of target motion prediction and optimal motion planning, where the latter is based on the information provided by the prediction phase.

It was against this backdrop of ideas that in the scope of the CADDY project IST started by addressing the problem of Optimal Motion Planner for both stationary and moving targets. To make the problem tractable, we considered the case where the target undergoes motions that consist of straight lines, arcs of circumferences, or a combination thereof. Complementary research work was done by the partners IST and the UNIZG-FER.

The work of IST, reported in [4], addressed the problem of single underwater target positioning based on acoustic range measurements between the target and a moving sensor at the sea surface (ASV). In particular, the goal of the work was to compute optimal trajectories for the surface sensor that would, in a well-defined sense, maximize the range-related information available for underwater target positioning and tracking. By resorting to the mathematical machinery of estimation theory, a properly defined Fisher Information Matrix (FIM) and the maximization of its determinant were used to determine the sensor trajectory that would yield the most accurate positioning of the target, while the latter describes a given trajectory. It was shown that the optimal sensor (AUV) trajectory depends on the velocity of the sensor, the velocity and trajectory of the target, the sampling time between measurements, the measurement error model, and the number of measurements used to compute the FIM. The examples studied (stationary targets as well as targets undergoing straight line and circular motions) showed that the approach proposed holds good potential to be used in practice (in a moving-horizon type of approach) to compute the sensor trajectory that will yield optimal target localization. Future work will aim at bringing together the blocks referred in Fig. 4.3.2. and carrying out tests with the resulting *Range-Based Target Localization* system at sea. Fig. 4.3.3., taken from [4], shows the optimal sensor (ASV) trajectories obtained for the cases where sliding windows of *n=5* and *n=8* points (range measurements) are taken to compute the FIM, for both the cases where the covariance of the (acoustic range) measurement noise is constant or distance dependent.

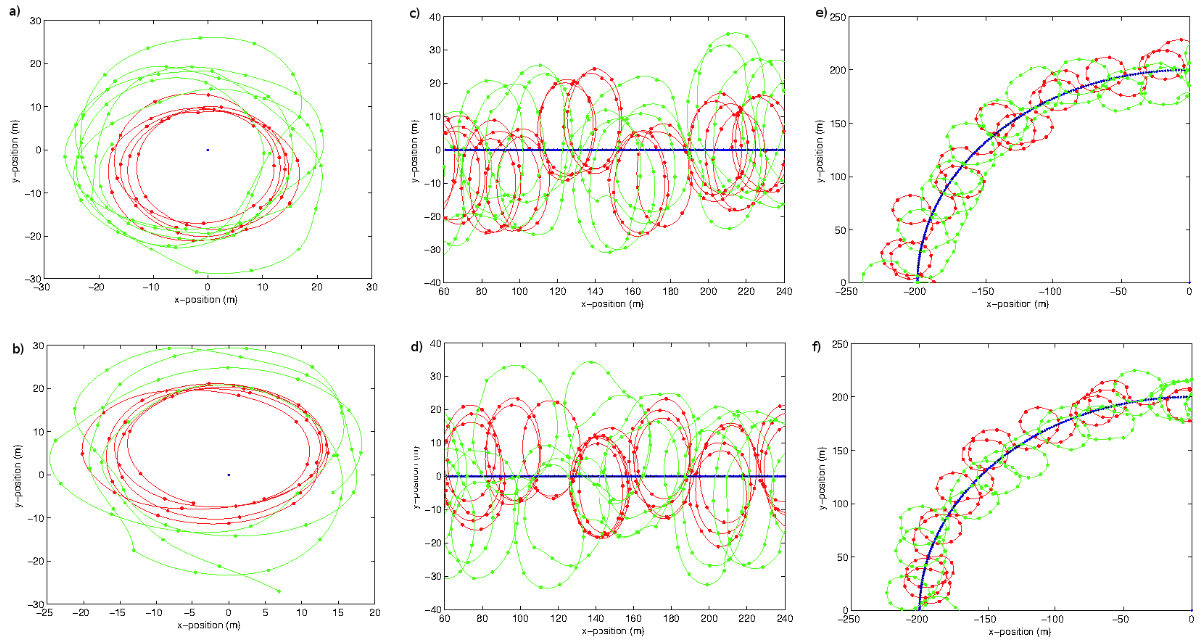


Fig.4.3.3. Optimal sensor trajectories to position a static target, a) and b), a target following a straight line path, c) and d), and a target following a circular path, e) and f), assuming constant covariance (upper figures) and distance dependent covariance (lower figures) of the measurement noise; for n = 5 (red) and n = 8 (green).

UNIZG-FER team took a similar approach in investigating rang-only underwater navigation. We investigated different motions of the surface platform to study observability of the underwater vehicle/diver that was moving in constant course trajectory, and square trajectory. Platform trajectories that were tested were:

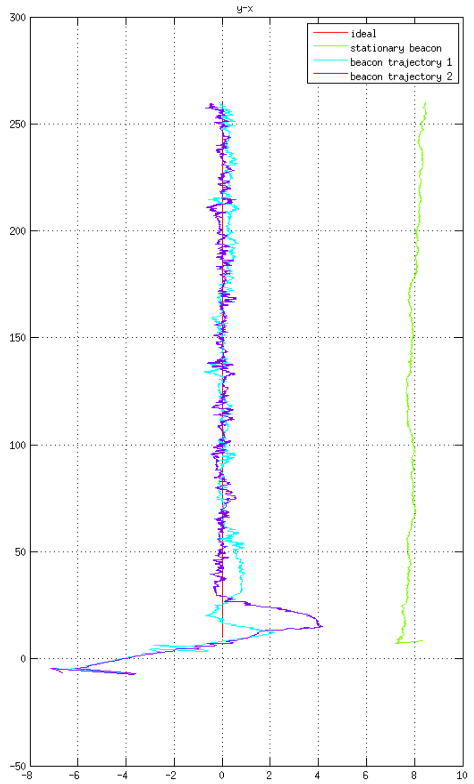
1. Stationary beacon, i.e. surface platform
2. Circular motion of the beacon
3. Determining optimal beacons trajectory by solving optimization problem using dynamic programming

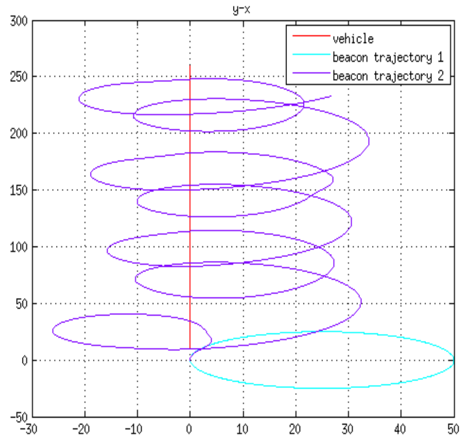
Simulation results are shown in Figs 4.3.4. and 4.3.5.

From these figures it can be seen that for constant course vehicle trajectory in the presence of unknown underwater currents navigation system is not observable when range measurements arrive form a stationary beacon. In the case of mobile beacons it can be seen that navigation filter successfully estimates vehicle position.

Optimal path of beacon trajectory, labelled as trajectory 2, was determined by solving optimization problem using dynamic programming. Goal of optimization problem was to minimize positioning error in tangential direction using beacon course as control input.

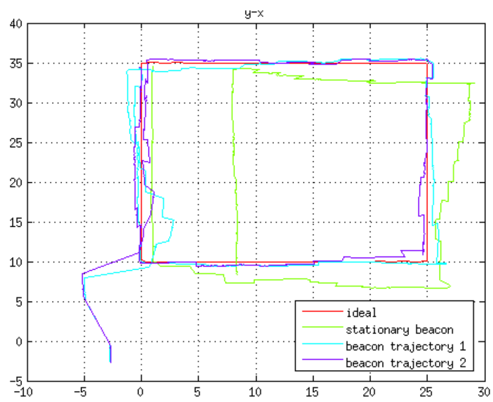
Further research will tackle problem of delayed measurements when navigating using single range measurements because sending beacon state measurements to vehicle via low-bandwidth acoustic link affects estimation performance. Also it will be very interesting to explore how path planning algorithms behave in online operation when underwater vehicle trajectory is susceptible to change or to see observability of the navigation system when beacon trajectory is optimized with beacon energy consumption or speed constraints imposed.

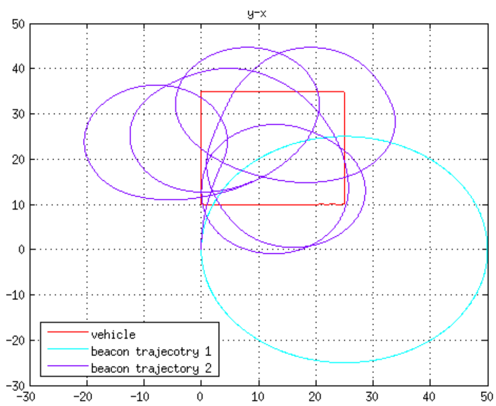




a) b)

Fig. 4.3.4. a) Estimated AUV/diver trajectory and b) beacon trajectory (with constant AUV/diver course).





a) b)

Fig. 4.3.4. a) Estimated AUV/diver trajectory and b) beacon trajectory (with square AUV/diver course).

T4.4. Experiments and performance evaluation

WP5 Integration and validation

Deliverable D5.1 “Scenario description and validation procedure for the validation trials” is submitted and is available online here and in the internal Google Drive Repository under *\CADDY-FP7\6 - Deliverables\D5.1. Scenario description and validation procedure for the validation trials*. The document describes validation objectives, procedures and validation criteria for the validation trials. Document also describes two validation scenarios (search & recovery mission and underwater archaeology mission) with guidelines on how the mission should be performed.

This deliverable is linked to the safety guidelines submitted with the deliverable 6.1.1. DAN Europe evaluated the two validation trials in term of safety issues and made the necessary recommendations in order to ensure the compliance with 6.1.1. DAN Europe also reviewed the validation process in order to ensure the key performance indicators to be compliance with the expectation of the diving industry.

A Validation Plan provides the evidence needed for final evaluation of the system performance. The Validation Plan consists of:

- **validation of the hardware safety.** The aim is to ensure diver safety when interacting with AUV. Successful validation means that developed AUV for diver assistance is safe to be used.
- **validation of the system functionalities (first validation trial).** Objective is to assess system capability to perform some of the dive buddy "guide", "slave" and "observer" functionalities, validating the state of the project progress, trends and accomplishments, rectifying the significant issues and providing the guideline for the future work.
- **validation of the overall system in real life scenarios (second validation trial)** - includes performance assessment and experimental validation of the integrated CADDY system. Two validation Real-life tasks are the Search & Recovery mission and the Underwater Archaeology mission.
- **validation of the human machine interface and ergonomics** - subjective assessment of diver confidence, comfort and safety in using CADDY system and assessment of ergonomics and performance in complex tasks

UNIZG-FER has an agreement with the Croatian Navy to hold the experiments in their Navy base in Split. Fig. 5.1. shows some photos of the venue. UNIZG-FER team has already conducted experiments there in June/July 2014 and the venue has proven to be appropriate.

The validation trials are scheduled for:

- 1st validation trials: 20/09/2015 - 04/10/2015
- 2nd validation trials: 18/09/2016 - 02/10/2016

Fig. 5.1. Venue for validations trials at Croatian Navy base in Split, Croatia.

T5.1. System integration

T5.2. Task A: Search and rescue (S&R) mission validation task

T5.3. Task B: Underwater archaeology mission

T5.4. Validation tasks assessment

WP6 Diver safety and regulation issues

T6.1. Rules for development and evaluation of safe technology

The existing vehicles that will be adapted for the purposes of the CADDY project were evaluated regarding safety issues. The hazards of ancillary equipment such as scaling LASERs and acoustic modems or relocators are addressed as well. UNIVIE has cooperated with DAN Europe in the research of existing safety standards and has given input on potential safety issues. A safety guideline is compiled as to report in the form of deliverable D6.1.1. The relevant standards and safe practices are included in this report. The process of formal Hazard Identification and Risk Assessment (HIRA) for CADDY is identified. A diving safety manual is decided to be compiled before the first open water dives.

Details of the safety measures taken during the initial experiments are described in detail in WP 2. For WP2 and WP3 a relatively large number of dives and divers are needed. These dives do not require any special skill set nor includes any interaction between AUV's and divers. A written consent form is prepared and the following part is added to emphasize the skill set required: "*Experimenters will not require you to make any change to your dive plan or ask you to perform some skills, none of them in any case exceeding the level of an entry level diving course*".

On the other side, future dives will involve the divers interacting with AUV's. DAN EUROPE will allocate a team of 6 very experienced divers for future CADDY dives. These divers will be trained on through water communication devices, will be using protected and redundant SCUBA in order to avoid any accident. Although each individual has enough experience; the rehearsal on actions against catastrophic scenarios as an integral team will be ensured by a 8 month internal training and exercise program. The program includes:

- The rehearsal on: Basic Life Support, First AID, Automated External Defibrillation
- Neurological assessment
- Advanced Oxygen administration
- In water rescue
- Search and Recovery
- Full face masks
- Through water communication
- Exercises on redundant and protected SCUBA

Redundant and Protected SCUBA system is especially designed to avoid collision damages and prodives double independent breathing system.

Fig. 6.1.1. Redundant and Protected SCUBA system

T6.2. Regulatory and professional acceptance road-map

Building on the professional and regulatory input by DAN Europe, the Advisory Board started to chart a regulatory and professional acceptance road-map document. This road-map will provide a clear, well-intentioned, intermeshed set of sequential measures to be taken in order to facilitate the penetration of the CADDY concept of robot-assisted human diver operations into the scientific, technical, and leisure- and sports-oriented diver community. The first step in the exploitation plan is to reach a consensus on market segmentation according to different diver categories through emails and Skype meetings with DAN and the advisory committee members:

1. Offshore Diving
2. Inshore Diving
3. Inland Diving
4. Fish Farms
5. Fishing, and collecting activities (abalony, sea cucumber, etc)
6. Scientific Diving
7. Media Diving
8. Recreational Diving
9. Public safety (police, fire brigade etc)
10. Armed forces

On the other side, each type of diving activities has its own particular needs. Within these different segments it is possible to identify three scales according to the size of the market. CADDY research results offer flexible solutions that enable targeting multiple markets with different costs and services. In order to emphasize the scalability of CADDY research results, the target market is divided into small, medium and large scale, depending on the end users' available funds and resources. Each market segment is then analyzed with respect to the identified possible commercial products that directly utilize CADDY research results.

For the follow up of this task it is necessary for the Advisory Board will organize bilateral, multilateral, in-person or e-facilitated discussions with targeted professional divers, regulators, representatives of diver education, training and administration bodies (associations, schools etc.), and possibly round tables or discussion panels.

T6.3. Automatic diver status report generation system

WP7 Dissemination and exploitation

Task 7.1 Reporting and outreach

Main activities

Web-site: www.caddy-fp7.eu.
Facebook page https://www.facebook.com/caddyproject
You tube channel http://www.youtube.com/user/caddyproject
Google drive
Google Calendar
CADDY video
CADDY teaser

Additional promotional materials such as t-shirts, pens, folders, etc. were also produced.

TV/newspaper appearance of Caddy

Press release has been generated and distributed by the partners

Publisher	Partner	Country	Date	link
Scubalife	UNIZG-FER	Croatia	10/11/2013	http://www.scubalife.hr/magazin/gadgets/robotski-ronilacki-buddy.html
24 sata tv	UNIZG-FER	Croatia	14/11/2013	https://www.youtube.com/watch?v=KU61LT4ozD8
Croportal	UNIZG-FER	Croatia	83	http://www.croportal.net/gospodarstvo/FER_koordinira_izradu_robotskog_sustava_koji_ce_nadzirati_fizicko_stanje_ronioca-2825143
Vijesti.hr	UNIZG-FER	Croatia	8/11/2013	http://www.vijesti.hr/vijest/liderpress.hr/biznis-i-politika/hrvatska/fer-koordinira-izradu-robotskog-sustava-koji-ce-nadzirati-fizicko-stanje-ronioca/
Limun.hr	UNIZG-FER	Croatia	8/11/2013	http://limun.hr/main.aspx?id=969558
Lider	UNIZG-FER	Croatia	8/11/2013.	http://liderpress.hr/biznis-i-politika/hrvatska/fer-koordinira-izradu-robotskog-sustava-koji-ce-nadzirati-fizicko-stanje-ronioca/
Portal TRIS	UNIZG-FER	Croatia	18/11/2013	http://tris.com.hr/2013/11/milijunski-istrazivacki-projekt-roboti-ce-moci-prepoznavati-gestikulaciju-ronilaca/
Der Standard	UNIVIE	Austria	4/2/2014	http://derstandard.at/1389859278537/Smarte-U-Drohnen-Abtauchen-in-die-inneren-Zustaende-unter-Wasser
Austrian press agency	UNIVIE	Austria	4/2/2014	http://science.apa.at/rubrik/natur_und_technik/Denkender_Roboter_schafft_Symbiose_zwischen_Taucher_und_Rechner/SCI_20140204_SCI39471352416784536
MoneyCab	UNIVIE	Austria	5/2/2014	http://www.moneycab.com/mcc/2014/02/05/denkender-roboter-schafft-symbiose-zwischen-taucher-und-rechner/
Univie frontpage News	UNIVIE	Austria	4/2/2014	http://medienportal.univie.ac.at/presse/aktuelle-pressemeldungen/detailansicht/artikel/robotic-system-enables-symbiotic-links-between-human-diver-and-computer/

wien.at	UNIVIE	Austria	25/3/2014	http://forschen-entdecken.at/CADDY-Roboter-Tauchen-Karl-Grammer-Universitaet-Wien.17607+M54a708de802.0.html
orf.at	UNIVIE	Austria	4/2/2014	http://science.orf.at/stories/1732838/
hitech.at	UNIVIE	Austria	6/2/2014	http://www.hitech.at/2014/02/06/intelligenter-assistent/
Federal Ministry of Education and Research Germany	UNIVIE	Germany		http://www.kooperation-international.de/detail/info/eu-foerderung-fuer-roboter-die-tauchern-assistieren.html
ingenuer.de	UNIVIE	Austria	5/2/2014	http://www.ingenieur.de/Fachbereiche/Robotik/Symbiose-Unterwasser-Roboter-denkt-fuer-Taucher
Alert Diver	DAN Europe	Europe	18/2/2014	http://www.alertdiver.eu/home;jsessionid=D8EE58AD8EE7788A9B458F1D59D7014D
ALMANACCO della SCIENZA	CNR	Italy	12/2/2014	http://www.almanacco.cnr.it/reader/cw_usr_view_articolo.html?id_articolo=5286&id_rub=13&giornale=5281
HRT Croatian National Television	UNIZG-FER	Croatia	25.5.2014.	http://www.hrt.hr/enz/more/245602/

An Austrian TV crew from TM Wissenscaft participated during the UNIZG-FER experiments in Split in June/July 2014 and made a documentary about the CADDY project. The TV report is in the process of editing.

Outreach

- DAN EUROPE had a broad, real-time media coverage of the Y40 experiments on DAN Europe's social media. This is the first time ever that a single event is broadcasted "as-it-happens", in 5 languages, on the official Facebook pages of DAN Europe (International in English, Italian, German, Dutch and French) and later on the Spanish page too.

- Nikola Miskovic attended and presented CADDY results at the NATO Research Task Group (RTG) meeting in Paris on 17-18 March 2014

Task 7.2 Scientific dissemination

Conferences attended

All partners attended the Workshop on EU-funded Marine Robotics and Applications (EMRA´2014), Rome, Italy, June 9-10, 2014.

1. Mediterranean Conference on Control and Automation (MED'14), Palermo, Italy
2. ISUR - 8th International Symposium on Underwater Research; 26-29 March, Procida, Italy

Special sessions

1. Invited session **Marine robotics and applications** at Mediterranean Conference on Control and Automation (MED'14), Palermo, Italy; organizers: David Scaradozzi and Nikola Mišković

List of scientific publications

1. S. Murat Egi, Guy Thomas, Massimo Pieri, Danilo Cialoni, Costantino Balestra, Alessandro Marroni, ***Safety rules for the development of a Cognitive Autonomous Underwater Buddy (CADDY)***, ISUR - 8th International Symposium on Underwater Research; 26-29 March, Procida, Italy.
2. M. Menix, N. Mišković, Z. Vukić, **Interpretation of divers' symbolic language by using hidden Markov models,** Proceedings of the 35th international convention on information and communication technology, electronics and microelectronics MIPRO/CTS 2014), Opatija, Croatia
3. D. Salinas, A. Pascoal, and J. Aranda, "**Optimal Sensor Trajectories for Mobile Underwater Target Positioning with Noisy Range Measurements**," to appear in Proc. 19th IFAC World Congress 2014, Cape Town, South Africa, 24-29 August, 2014.
4. N. Mišković, Đ. Nađ, A. Vasilijević, Z. Vukić, "**Dynamic Positioning of a Diver Tracking Surface Platform**" to appear in Proc. 19th IFAC World Congress 2014, Cape Town, South Africa, 24-29 August, 2014.

Task 7.3 Exploitation

DAN Europe prepared in report on the exploitation plan together with the advisory board. This report is prepared to establish a roadmap for the industry acceptance and future benefits from technological, scientific and economical opportunities. Since it is prepared in the beginning of the project, it will be a general draft for exploitation based on the above aims and the innovative products arising from CADDY results. Potential innovations and findings through the progress of CADDY imply the need to fine tune this deliverable in order to target conclusive business plan at the end of the project.

New board members

- *Octopus Diving Center*, City: Leszno/Poznań, Poland, www.octopus.net.pl, Area of activity: Diving, marketing, management and new technology

Task 7.4 Education and training

1st CADDY Workshop was organized as a part of the EMRA'14 - Workshop on EU-funded Marine Robotics and Applications. Founders of this new workshop are coordinators of four FP7 projects related to marine robotics: CADDY, MORPH,ARROWS and PANDORA.

The underlying **motivation** of this new workshop is to increase the efficiency in orchestration and dissemination across EU marine research. We have observed a close coupling between individual FP7 projects and their intended application audience, yet many of the technologies developed are applicable beyond their motivating problem. Currently, for a marine technology stakeholder to fully digest EU marine research requires attending too many overly technical, and overly specific individual workshops. We hope EMRA2014 will condense an exciting range of cutting edge research developments into a single manageable event.

EMRA'14
Workshop on EU-funded
Marine Robotics and Applications

Date: 9-10 June 2014

Location: CNR, Rome, Italy

Website: http://www.issia.cnr.it/wp/?page_id=3490

Download the **programme** here.

Download the **poster** here.

EMRA'14 in numbers:

- **4** FP7 projects
- **7** speakers from industry
- **9** speakers from academia
- more than **100** participants from all over Europe

EMRA'14 speakers and their presentations:

Speaker	Presentation
Nikola Mišković, University of Zagreb	CADDY project presentation
Nando Boero, National Research Council of Italy	Challenges for Mediterranean Biodiversity
Massimo Garbo, CNS International	Current trends in Commercial Diving and Robotics development
Alessio Turetta, GRAALTech, Italy	FOLOGA and UMA: two stories from research market
Antonio Pascoal, Instituto Superior Technico, Portugal	MORPH Project Presentation
Vegard Evjen Hovstein, Maritime robotics, Norway	Unmanned systems for maritime operations - trends and opportunities
Peter Weiss, COMEX	From sea to Space: Subsea robotics at COMEX

Benedetto Allotta, University of Florence, Italy	ARROWS Project Presentation
Irena Radić Rossi, University of Zadar, Croatia	The ˝Breaking the surface˝ Workshop - A Path of Collaboration and Mutual Understanding
Justin Manley, Teledyne	Advancing unmanned vehicle trough networking and modularity
Laura Gallimberti, ENI Norge, Norway	The Oil&GAS Industry Requirements for Marine Robots of the 21st century
John Hale, University of Luisville, USA	Mapping a Submerged Preclassic Maya Site in Lake Atitlan, Guatemala
Raffaele Grandi, *L3 Calzoni, Italy*	Research Activities in Maritime Robotics for Mobility and Manipulation: Industrial and Academic Perspectives
Claudio Melchiorri, *University of Bologna, Italy*	A Three-Fingered Cable-Driven Grippe for Underwater Applications
Marc Carreras, *University of Girona, Spain*	PANDORA Project Presentation
Jeronimo Dzaack, *ATLAS Elektronik*	Innovations for Maritime Security
Sebastian Eckstein, *Technische Universität Ilmenau*	Strategies for Robust Mission Planning of Distributed Maritime Systems

The next workshop will be held in June 2015 in Portugal. We will try to organize it again as an EMRA workshop where we will invite other EU-funded projects related to marine robotics. This workshop will be organized by IST.

References:

[1] ORTE: Real-Time Publish-Subscribe (RTPS) Implementation – http://orte.sourceforge.net/rtps1.2.pdf

[2] Treibitz, T.; Schechner, Y.Y.; Kunz, C.; Singh, H.: "*Flat Refractive Geometry*". Pattern Analysis and Machine Intelligence, IEEE Transactions on , vol.34, no.1, pp.51,65, Jan. 2012.)

[3] B. Bayat, N. Crasta, A. Aguiar, A. Pascoal, "*Range-Based Underwater Vehicle Localization in the Presence of Unknown Ocean Currents: Theory and Experiments*," submitted for publication to IEEE Transactions on Control Systems Technology, June 2014.

[4] D. Salinas, A. Pascoal, J. Aranda, "*Optimal Sensor Trajectories for Mobile Underwater Target Positioning with Noisy Range Measurements*," Proc. 19th IFAC World Congress, 24-29 August, Cape Town, South Africa.

3.2.3 Project management during the period

The following table gives distribution of PMs per WP per partner for the period M1 – M6

Partic. no.	Partic. short name	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	Total person months
1	**UNIZG-FER**	**7,77**	5,6	0	0,7	1,69	**0,01**	1,64	**0,89**	18,1
2	**CNR**	4	**0,75**	1,55	1	0	0	1,5	0,2	9
3	**IST**	6	1	1	2	**2**	0	0,5	0,1	12,6
4	**JACOBS**	0	5,375	**0**	0	0	0	0	0	5,375
5	**UNIVIE**	0	15,5	0	**0**	0	0,5	0,4	0,5	16,9
6	**UNEW**	2	3	0	0	0	0	0	0	5
7	**DAN Europe**	0	1,77	0	0	1,89	2,8	**0,47**	0,2	7,13
Total		19,77	33	2,55	3,7	5,58	3,31	4,51	1,89	74,305

In the following part, we give a short overview of the meetings that took place during the first 6 months of the project. All the meeting minutes and agendas are available in the Google Drive.

1. **05/10/2013 :: Pre-kickoff meeting, Murter, Croatia**

This meeting was an informal gathering of the project partners during the “Breaking the Surface” workshop organized by UNIZG-FER. Costs of this meeting were not charged to the CADDY project since in had not yet started.

2. **22-23/01/2014 :: Kick-off meeting, Zagreb**

The meeting was held at the University of Zagreb. All partners participated and three Advisory Board members. The goals of the meeting were:

- Get introduced to CADDY partners and AB members
- Get familiarized with the management structure and the communication methodology
- Establish a detailed meeting schedule for project 1st year and a draft meeting schedule for the 2nd and 3rd year of the project
- Establish internal reporting procedure
- Get familiarized with the dissemination and exploitation activities
- Get familiarized with each partners 3-year activity plan and responsibilities
- Establish a detailed work plan and deliverable list for the 1st year of the project

3. **20/02/2014 :: technical meeting, Skype**

The meeting was held via Skype and organized by UNIVIE. DAN Europe, UNEW and UNIVIE participated. The main objective of the meeting was to determine which physiological parameters will be included in the next versions of Diver Net as well as how these parameters will be measured and analysed.

4. **03/03/2014 :: technical meeting, Skype**

The meeting was held via Skype and organized by CNR. CNR, IST, JACOBS and UNIZG-FER participated. The main topic of the meeting was discussion about ROS framework and acoustic communication simulation.

5. **26/03/2014 :: technical meeting Skype**

The meeting was held via Skype and organized by UNIVIE. The main topic of the meeting was to determine the procedure, location and aim of the next experiments with diver recording.

6. **14/06/2014 :: SB & EB meeting, Rome, Italy**

The meeting was held at the CNR in Rome. All partners participated and three Advisory Board members. The goals of the meeting were:

- Get familiarized with each partner's activity since the last meeting
- Establish a detailed work plan and deliverable list for the following 12 months of the project
- Establish a detailed meeting schedule for the following year
- All meetings were held as planned in the DoW.

It was arranged that the next large meeting will be held together with the review meeting that will take place in Feb/March 2015 (depending on the arrangements with the Project Officer) in Padova, Italy at the Y-40 pool. Before that the consortium will try to meet at the “Breaking the Surface” workshop held in Biograd na Moru, Croatia from 5/10/2014 - 12/10/2014.

3.3 Deliverables and milestones tables

TABLE 1. DELIVERABLES										
Del. no.	**Deliverable name**	**Version**	**WP no.**	**Lead beneficiary**	***Nature***	**Dissemination level**	**Delivery date from Annex I (proj month)**	**Actual / Forecast delivery date Dd/mm/yyyy**	**Status No submitted/ Submitted**	**Comments**
7.1	WEB page	1	7	UNIZG-FER	Other	PU	1	1/1/2014	submitted	
6.1.1	Safety rules for the development of diver assistance system components	1	6	DAN Europe	Report	PU	1	28/2/2014	submitted	
7.2	Dissemination plan	1	7	UNIZG-FER	Other	PU	3	31/3/2014	submitted	
5.1	Scenario description and validation procedure for the validation trials	1	5	UNIZG-FER	Report	PU	3	31/3/2014	submitted	
7.3.1	Exploitation plan	1	7	DAN Europe	Report	PP	3	31/3/2014	submitted	
2.1	Diver remote sensing in the underwater	1	2	UNIZG-FER	Report	PU	5	31/5/2014	submitted	
7.4.1	Proceedings of the 1st CADDY Workshop	1	7	CNR	Report	PU	6	30/6/2014	submitted	
8.3.1.	Six-month project report	1	8	UNIZG-FER	Report	PU	6	30/6/2014	submitted	

TABLE 2. MILESTONES							
Milestone no.	Milestone name	Work package no	Lead beneficiary	Delivery date from Annex I dd/mm/yyyy	Achieved Yes/No	Actual / Forecast achievement date dd/mm/yyyy	Comments

3.4 Explanation of the use of the resources and financial statements

Financial forms are submitted in a separate Excel document, summarizing all partners expenses for the period M1 – M6.

UNIZG-FER personnel:

- Antonio Vasilijević and Đula Nađ are working 50% of their time on the project
- Filip Mandić (from M3) and Ivor Rendulić (from M5) are hired 100% on the project
- Nikola Mišković (Coordinator) and Zoran Vukić have been working approx 40% of their time on the project

UNIZG-FER major equipment:

The cost for UNIZG-FER in the period M1 – M6 is high due to the fact that the following major items were purchased:

- high resolution multibeam sonar: cca 70.000 EUR
- underwater cables for BUDDY AUV: cca 10.500 EUR
- batteries for BUDDY AUV: cca 4.000 EUR
- navigation units and modems: cca 5.000 EUR
- banking provisions as a coordinator: cca 4.000 EUR

UNIZG travel:

For travel we spent around 12.500 EUR. This includes all meetings, workshops, conferences and field trials for UNIZG-FER staff and Advisory Board members.

UNIZG-FER deviations:

- we were not aware of the banking provisions that the coordinator needs to pay while transferring the funds to the partners (cca 7.000 EUR). For this reason, the MGT costs are much higher than expected and almost 50% of the MGT funds are already spent. Specific arrangements will be made with the bank for the following transfer of funds.

- Tihana Sesar, who is not employed by the CADDY project, attended the Padova trials and her expenses were reimbursed by CADDY project due to lack of staff during the experiments.

IST:

Henrique Silva, Jorge Ribeiro, and Miguel Ribeiro from IST, are systems designers and developers participating directly in the CADDY project. They travelled to attend the Oceanology International event in London, UK, 2014, to become acquainted with state-of-the-art marine technologies and to meet with Marcus Cardew (who is involved in the CADDY project as Advisory Board member) to discuss issues related to modem/USBL systems integration, two basic systems at the core of the CADDY development work.

DAN Europe deviations:

- Dr Chiara Ferri, who is not part of the staff designated to the CADDY project, attended the Padova trials on behalf of Dr Marroni, who could not join the event, in order to ensure the presence and assistance of a medical doctor in case of an emergency. Her expenses were reimbursed by CADDY.
- Vanessa Rapini, who is not part of the staff designated to the CADDY project, attended the Padova trials to carry out communication and dissemination activities and her expenses were reimbursed by CADDY.
- There has been a change in the research staff designated to the project: Amir F. Gerges has been replaced by Murat Egi; Massimo Pieri has been replaced by Guy Thomas.

Conclusion:

For the period M1 – M6 total EC contribution for all partners is about 15.7% which is a bit less than 1/6 of the overall requested amount.