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 01/01/2016 to 30/06/2016**

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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: Asst. Prof. Dr. Nikola Mišković

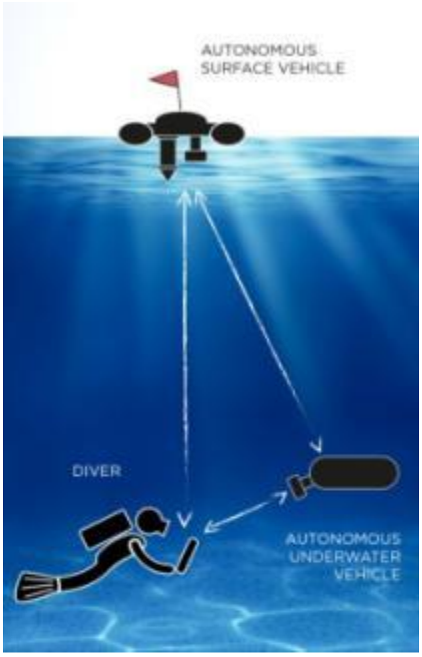
Date: 10/02/2016

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 and carry cumbersome equipment performing their missions. 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.

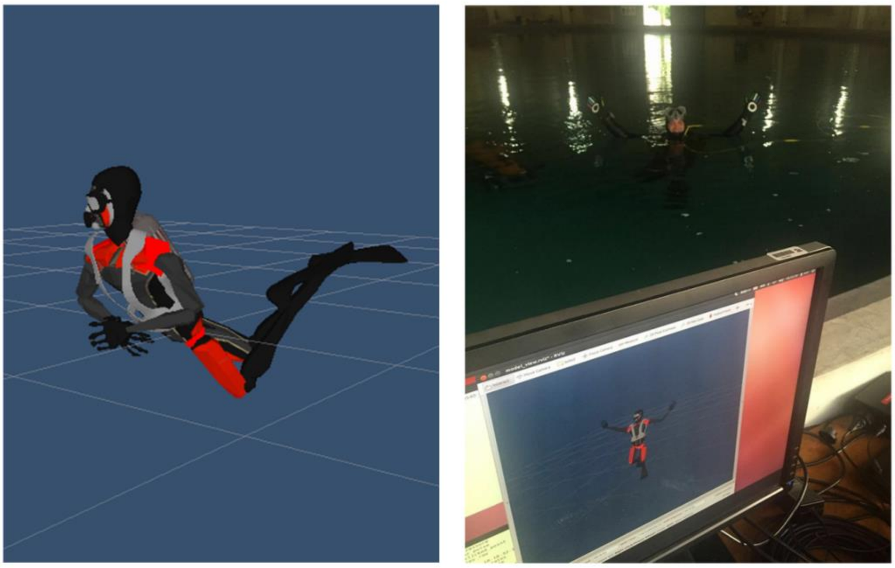
In the third year of the project, focus is placed on preparing all the required algorithms for the final validation trials. A **software integration week** was organized in May in Zagreb during which simulations were carried out along with real diver data acquisition that proved out to be really useful to integrate software developed by different partners and to take notes on what needs further development.
Summary of main results in year 3 is given in the following part.

- **Development of the multicomponent system**

All the technological development regarding the multicomponent system has been completed. The developed systems are being extensively used to validate developed algorithms and envisioned scenarios.

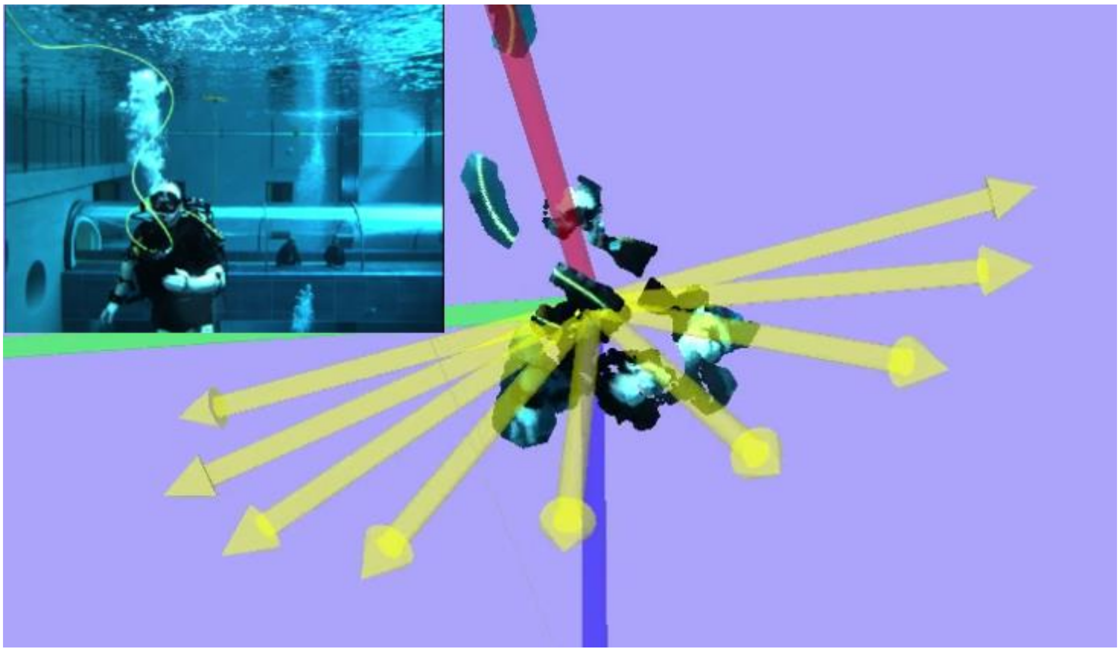
- **"Seeing the diver" – DiverNet and stereo imagery for determining diver orientation**

Diver posture estimation and visualization using the **DiverNet** has been completed and validated, making the DiverNet a ground truth measurement for the diver pose that is used to evaluate other posture estimation techniques.

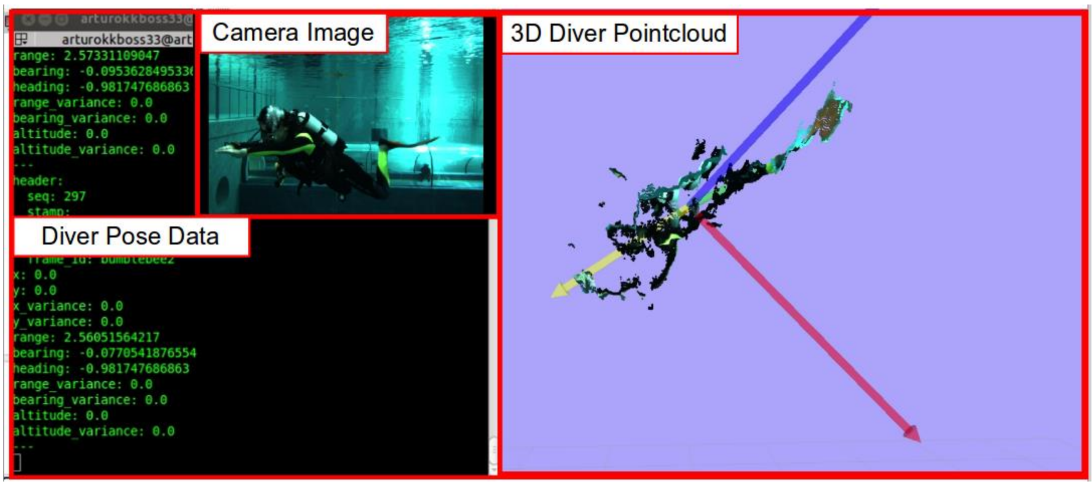


(left) Diver model displayed in Rviz; (right) Diver in the background

Algorithms for **stereo imagery processing for the purpose of determining diver orientation** were also developed. On the test set the Extremely Randomized Forest classifier achieves *71.6% accuracy*. However, results show that there is a 90% probability (less than 2 bins error) that the classifier will output a heading close enough to the true value for it to be used by the control filter that positions the BUDDY vehicle in front of the diver.



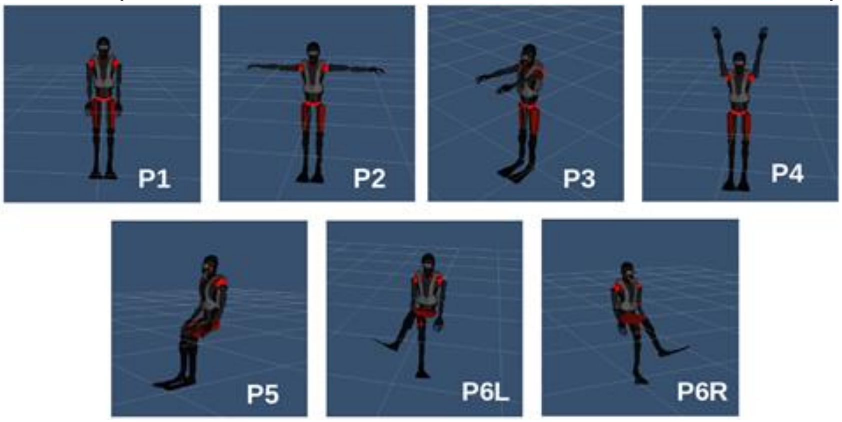
Point cloud of the diver shown in the top left corner. The visual markers are the yellow arrows that divide the Y-Z plane into 8 angular bins from -90° to 90° (zeros degrees corresponds to the diver facing the stereo camera).



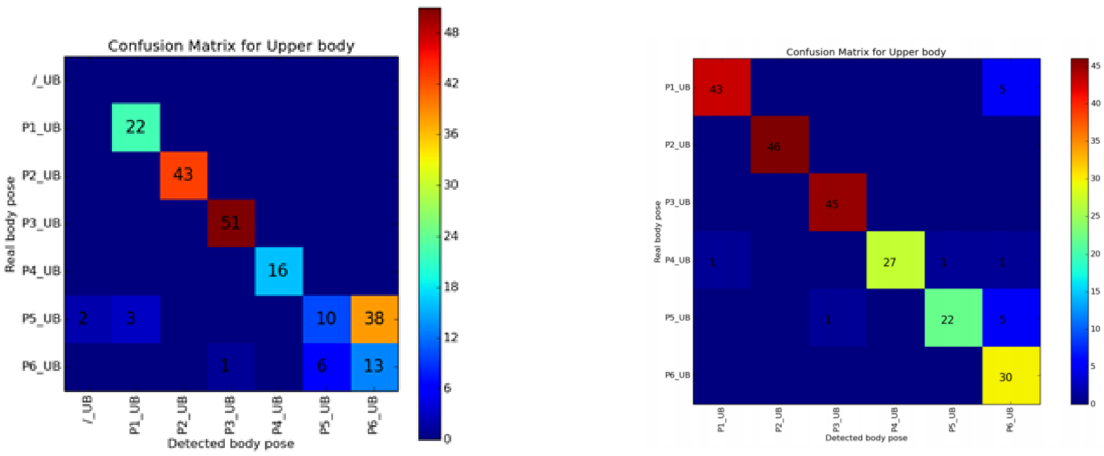
Screenshot of ROS and Rviz showing the camera images, the diver's pointcloud (top view) and the terminal displaying all important measurements about the diver's pose.

- **"Understanding the diver" – CADDIAN language and linking diver parameters (respiration, heart rate, posture) to emotions**

The reconstructed diver posture obtained from DiverNet is used for **automatic activity classification**, where the system classifies diver's actions even without a human operator observing.

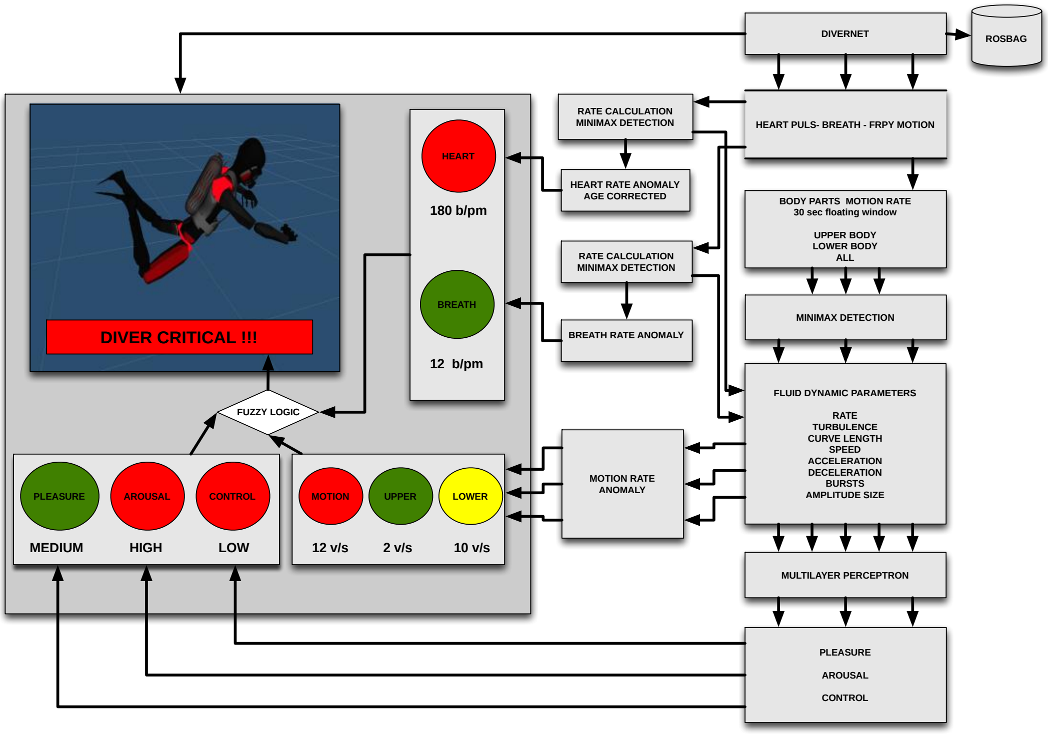


Poses used in initial classification tests.



Two approaches are currently being tested: a Dynamic time warping (DTW) algorithm and artificial neural networks (ANN) that have proven to be more successful according to the results shown in the confusion matrix above: DTW is shown in left and ANN in right figure.

The preliminary results have shown that primary emotions (happy, disgust, anger, fear, surprise, sadness, neutral) can be mapped onto secondary emotions (pleasure, arousal and control) thus reducing the dimensionality of the **diver behaviour interpretation** to three as compared to six.



Flowchart of suggested control parameters and variables for diver control. The flowchart outlines the procedures which are necessary to monitor the diver. We have implemented heart rate and heart rate anomaly based on age data, the same is done for breath rates. Red light depict abnormal rates. We also used motion rates in this system and pleasure, arousal, dominance/control values from the neural network. We plan to implement a Fuzzy logic modul for decision making if the diver mission is critical or not.

During this period of the project, the integration of the different **modules for the mission generation based on diver gestures** has been done. This encompasses the next tasks: gesture recognition, identification of valid phrases (parsing), generation of missions and feedback delivery to the diver via a tablet. The main purpose of the integration is to build a fault tolerant system against human errors (gestures badly performed or with no correct syntactical structure) and software errors (misclassification of gestures).

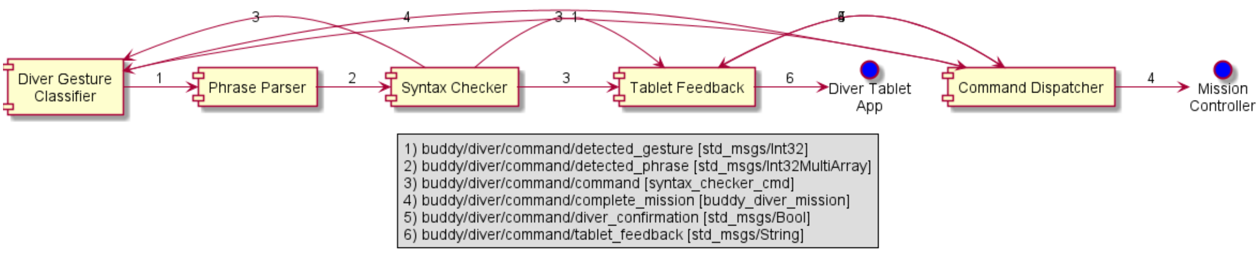
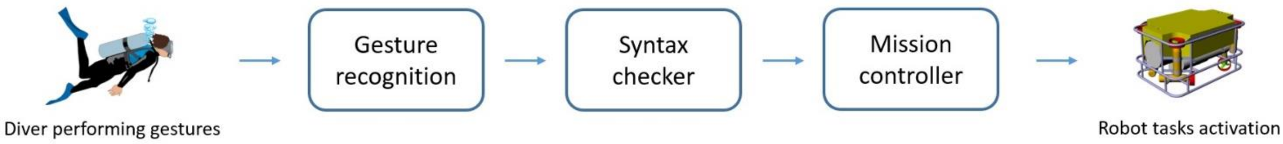


Diagram of the ROS software nodes and how they communicate each other during a mission generated through diver gestures. On the bottom the name of each ROS topic is displayed.

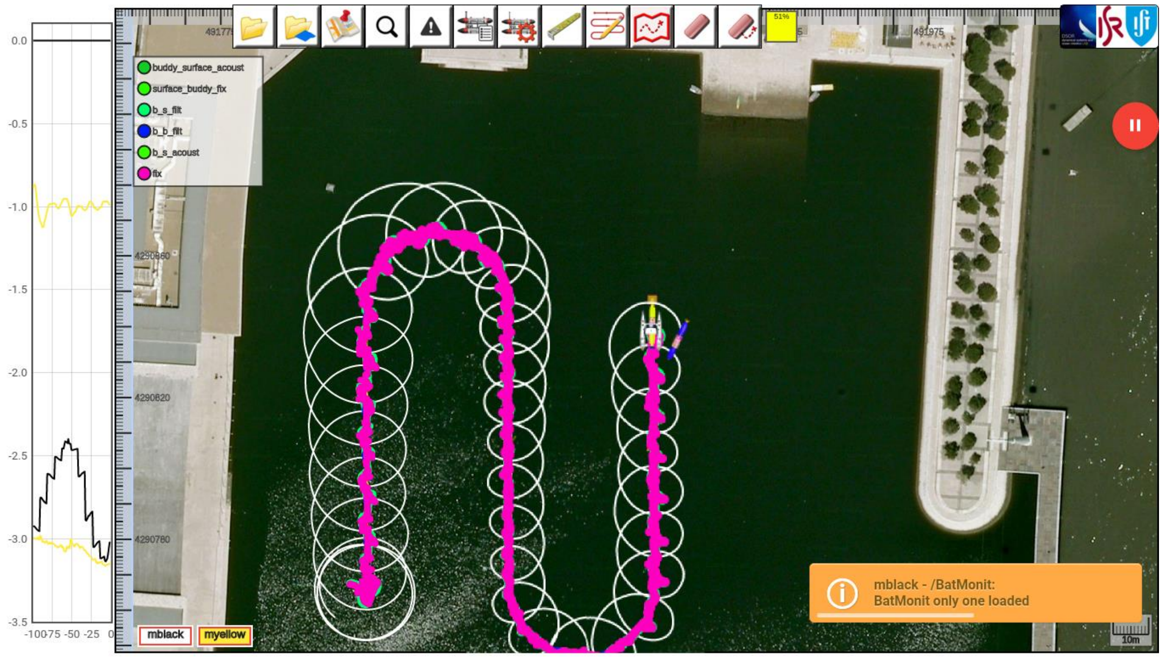
- **"Diver-Robot Cooperation and Control"**

The CADDY **mission control system** is a modular framework designed and developed with the aim of managing the state tracking, task activations and reference generation that fulfills the requirements in order to support the diver operations.



Main modules of high-level CADDY functionalities. The mission controller acts as a cognitive planning and supervision system taking as input the decoded gesture sequence executed by the diver, in turn generating proper task activation actions in such a way to trigger the required capabilities needed to provide the requested support.

In order to tackle the scenario of using ranging devices only, without angle measurements as the ones provided by USBLs, a **single beacon navigation** (SBN) system was implemented. The overall system of SBN has 3 components, namely: estimator, planner and tracking that operate in a cascade architecture.



Some preliminary results on single beacon navigation: the underwater vehicle was performing a mission at 0.2 m/s (purple/pink dots). In the beginning of the mission, the radius that the surface vehicle does around the underwater is bigger, due to the higher covariance of the estimator, reducing to a asymptotic value in the middle of the mission.

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 Project objectives for the period

3.2.1 Overview

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.

This objective has been successfully completed during the first two years of the project.

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.

This subobjective has been successfully completed during the first two years of the project.

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.

A graphical user interface has been developed for the surface monitoring station, that automatically detects anomalies such as:

- high/low motion activity, determined by processing DiverNet measured dana
- high/low breathing rate, determined by using Nerites measurements
- high/low heart rate, determined by using a commercially available sensor integrated with DiverNet
- flippering rate and difference in flippering rate, determined by processing DiverNet sensors, useful for determining lost flipper or possible cramp in a leg.

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

Further experiments will follow until the end of the project, contributing to the full accomplishment of the set objective.

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

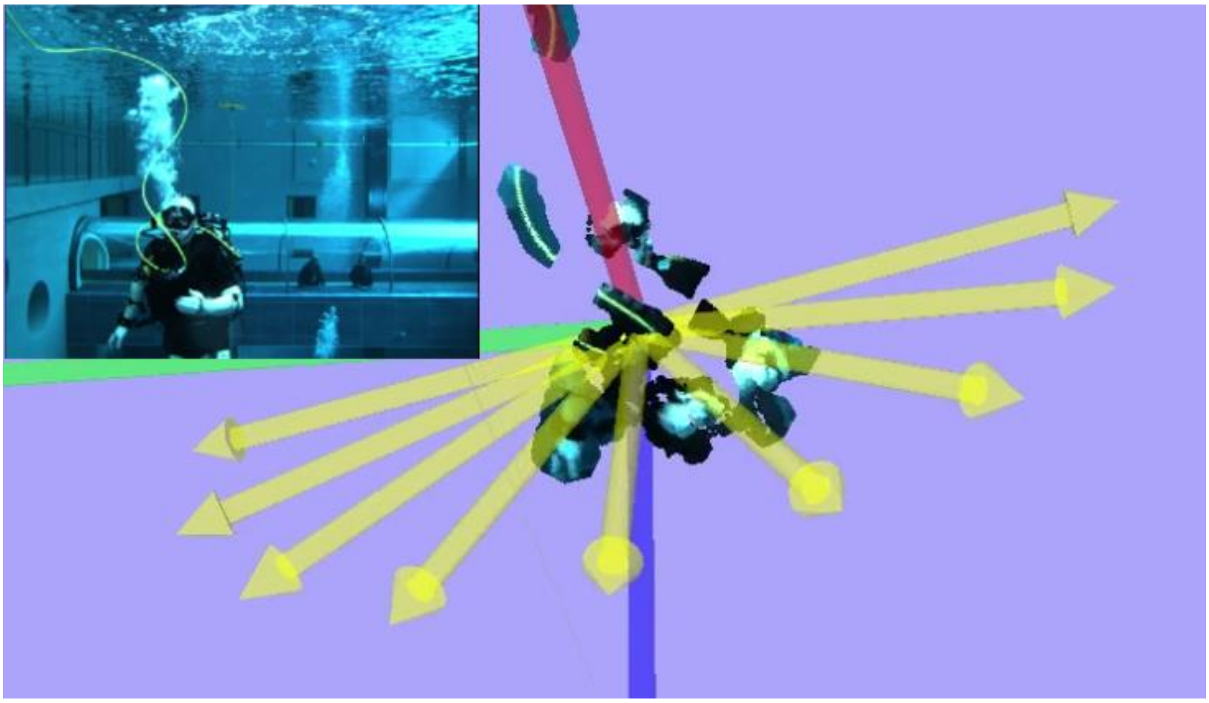
SO1.a. Develop efficient and near real-time algorithms for diver pose estimation and gesture recognition based on acoustic and visual conceptualization data obtained in a dynamic and unstructured underwater environment.

During the first two years of the project the following advances have been made with respect to this subobjective:

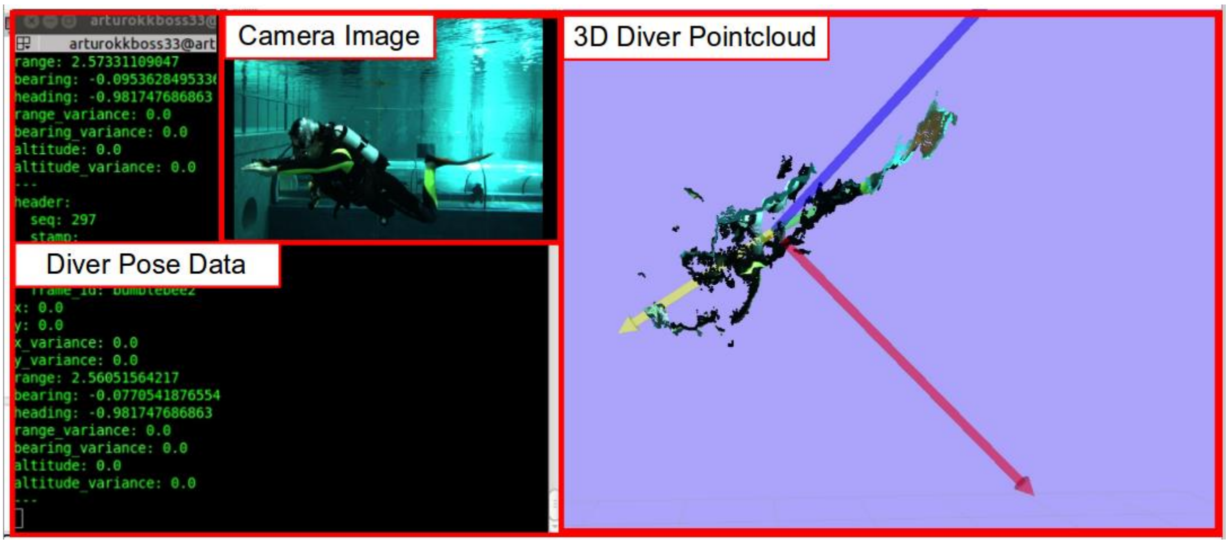
- algorithms for hand gesture recognition using stereo camera imagery
- algorithms for hand detection using multibeam sonar imagery
- algorithms for diver pose recognition using the sonar imagery

The first bulletpoint has proven to be the most efficient in real experiments hence this approach was chosen as the most robust one. Pose recognition using sonar imagery is chosen for determining the position of the diver, used afterwards in cooperative control between the surface vehicle, the underwater vehicle and the diver.

In year 3 we focussed on determining diver orientation using stereo camera imagery for the purpose of obtaining diver orientation onboard the BUDDY vehicle in order to achieve BUDDY positioning relative to the diver. The main results of determining the orientation are shown in the figures below.

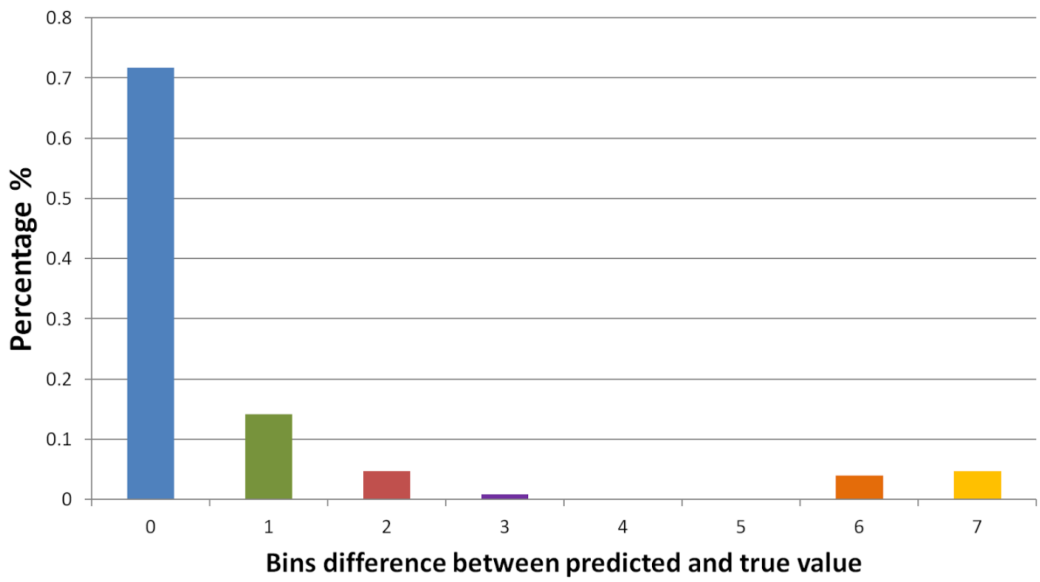


Point cloud of the diver shown in the top left corner. The visual markers are the yellow arrows that divide the Y-Z plane into 8 angular bins from -90° to 90° (zeros degrees corresponds to the diver facing the stereo camera).



Screenshot of ROS and Rviz showing the camera images, the diver's pointcloud (top view) and the terminal displaying all important measurements about the diver's pose.

On the test set the Extremely Randomized Forest classifier achieves *71.6% accuracy*. However, as it can be seen in the figure below, the majority of the predicted headings lie within 1 or 2 bins of the true heading. So, we can state that even when the classifier outputs an incorrect value, there is a 90% probability (less than 2 bins error) that it will output a heading close enough to the true value for it to be used by the control filter.



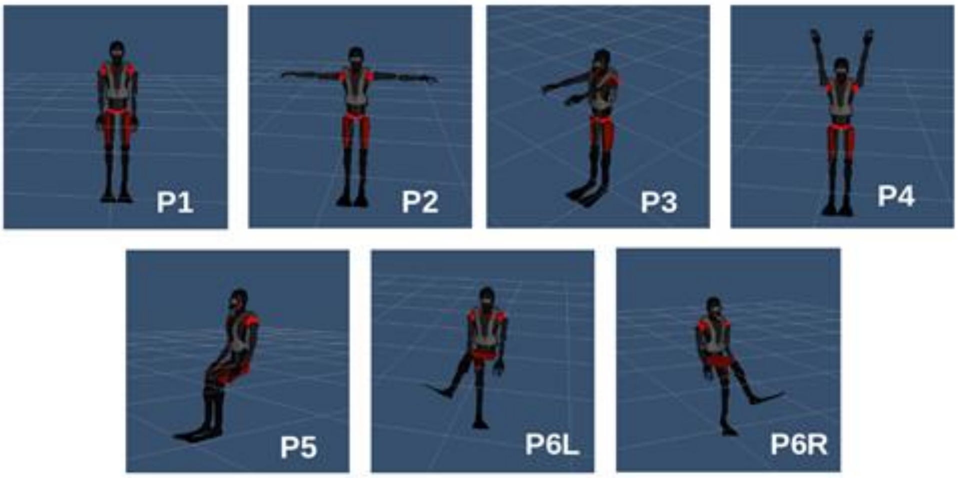
Graph showing the percentage of times the classifier predicted a heading with a difference of N angular bins. N=0, represents the number of times the classifier output the true heading of the diver.

This subobjective is considered to be completed. The algorithm will be further tested during extensive validation trials.

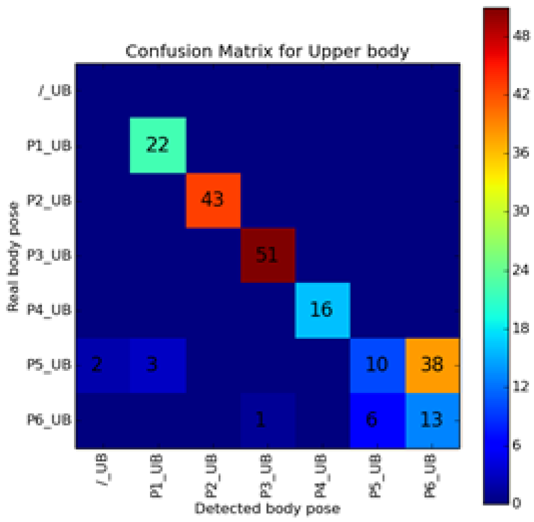
SO1.b. Develop adaptive algorithms for interpretation of diver behaviour based on nonverbal communication cues (diver posture and motion) and physiological measurements.

Two major achievement were made with respect to this subobjective: automatic diver activity classification and detection of diver states.

The reconstructed diver posture obtained from DiverNet is used for **automatic activity classification**, where the system would know what the diver is doing even without a human operator observing. We tested the dynamic time warping algorithm and artificial neural network. Tests were conducted with 7 poses. The results of activity classification are summarized using the confusion matrix below.

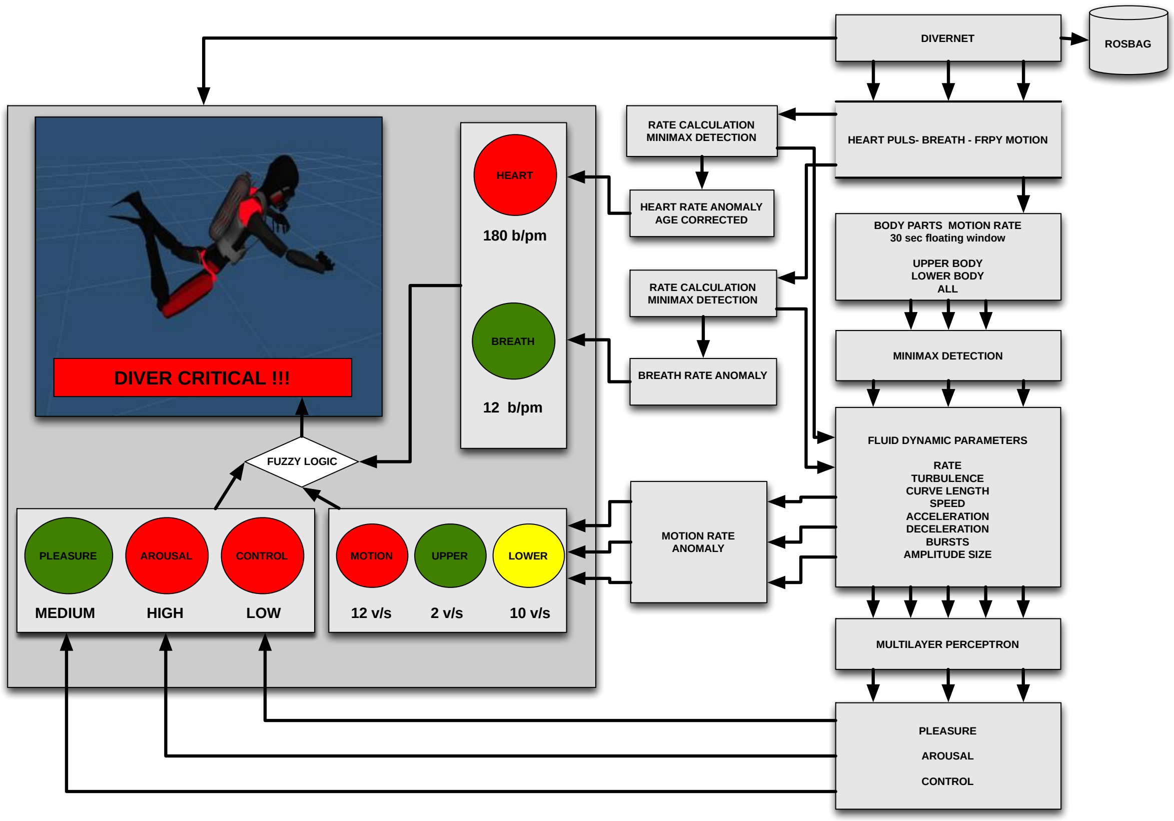


Poses used in initial classification tests with Dynamic time warping



Confusion matrix for Dynamic time warping tests

Diver states have been assessed based on the breathing and the walking experiment. The flowchart shown below demonstrates the functionality of the developed system The respective values are calculated continuously for each data point in a 30 second window and the results are displayed in the developed diver control center that is also used for validation purposes.



Flowchart of suggested control parameters and variables for diver control. The flowchart outlines the procedures which are necessary to monitor the diver. We have implemented heart rate and heart rate anomaly based on age data, the same is done for breath rates. Red light depict abnormal rates. We also used motion rates in this system and pleasure, arousal, dominance/control values from the neural network. We plan to implement a Fuzzy logic modul for decision making if the diver mission is critical or not.

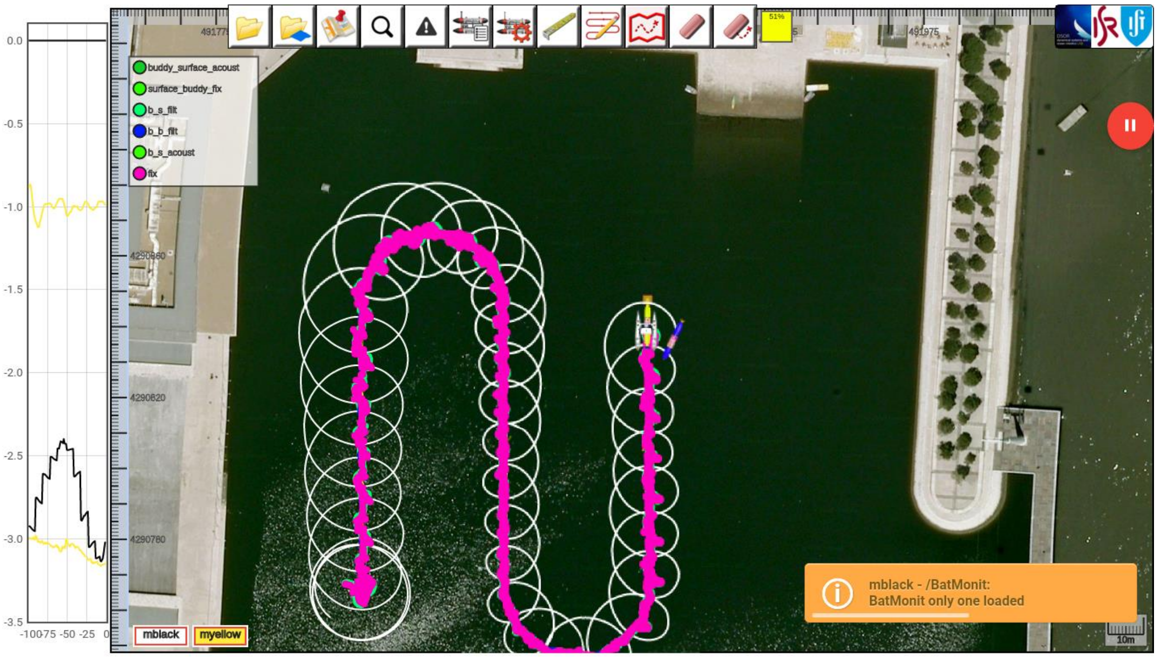
SO2. Define and implement execution of cognitive guidance and control algorithms through cooperative formations and manoeuvres in order to ensure diver monitoring, uninterrupted mission progress, execution of compliant cognitive actions, and human-machine interaction.

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

This subobjective is considered to be completed. What remains is to perform extensive tests during the final validation trials.

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

While this objective has been fully completed, we continue to perform experiments with the newly developed single beacon navigation algorithms that require only range measurements from a single source to localize the underwater vehicle. Some results obtained using the Fisher Information Matrix approach are shown in figure below.



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

The development of algorithms related to this subobjective is considered fully completed. What remains is to perform extensive tests during the final validation trials.

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.

During this period of the project, the integration of the different modules for the mission generation based on diver gestures has been done. This encompasses the next tasks: gesture recognition, identification of valid phrases (parsing), generation of missions and feedback delivery to the diver via a tablet. The main purpose of the integration is to build a fault tolerant system against human errors (gestures badly performed or with no correct syntactical structure) and software errors (misclassification of gestures).

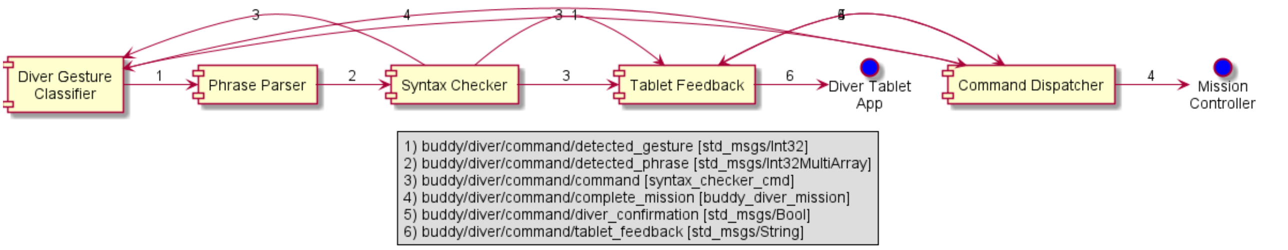


Diagram of the ROS software nodes and how they communicate each other during a mission generated through diver gestures. On the bottom the name of each ROS topic is displayed.

As part of the gesture-based underwater communication protocol between the diver and the BUDDY vehicle, a feedback system has been developed that provides the diver with immediate visual information pertaining to the robot's reception and interpretation of the gesture command in progress, for both simple and complex gestures.

Fig.1. Example of feedback messages displayed on BUDDY tablet during gesture recognition

This subobjective is considered to be completed. The developed system has been tested and is ready to be used during the final validation trials.

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

The cognitive mission replanner based on Petri nets has been developed and tested. The CADDY mission control system is a modular framework designed and developed with the aim of managing the state tracking, task activations and reference generation that fulfills the requirements in order to support the diver operations. As depicted in figure below, the mission controller acts as a cognitive planning and supervision system taking as input the decoded gesture sequence executed by the diver, in turn generating proper task activation actions in such a way to trigger the required capabilities needed to provide the requested support.

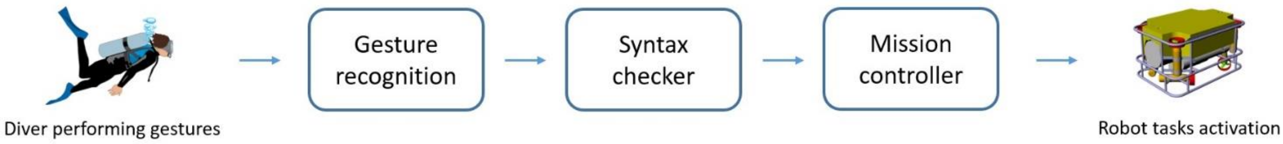


Fig.1. Main modules of high-level CADDY functionalities

This subobjective is considered completed. The developed algorithms have been tested and validated during the workshop in Zagreb, and are ready to be extensively tested during the final validation trials.

3.2.2 Follow-up of previous review

The main recommendations from the reviewers concerning the period under review are:

- ***… there is still room for improving the quality of documentation, with the objective to better highlighting what are the technical and scientific achievements of the consortium with respect to the state of the art.***

The consortium is determined to make the reports shorter. The problem that we face is the required structure of the report that forces us to partially repeat parts of the text. In order to make the basic results clearly visible, we will produce a 1 page summary report.

- ***… an effort for publishing more papers in scientific journals is expected for the last year of the project.***

Even though it was identifies that a large number of publications was made during the first two years of the project, we have devised a list of publications for the last year. Significant number of publications, both journal and conference, are expected for the final year.

The main recommendations from the reviewers for the next period are.

- ***Regarding the reports and presentations: improve them according to the comments above and try to be more concise in presenting the contributions, avoiding useless repetitions between them. Reorganize the structure of the reports accordingly.***

- ***For the last year trials, focus on a single scenario where everything is integrated rather than multiplying separate case studies.***

It was agreed that we will have a single scenario.

- ***Regarding the impact, exploitable results shall be clearly identified and highlighted. All the subsystems have been designed to be integrated in CADDY but an exploitation plan should also allow evaluating the impact of some promising subsystems in different fields outside of CADDY context, i.e. outside the underwater domain.***

It was agreed that DAN Europe will revise exploitation plan: identify potential products, and send the document to other partners for review.

- ***Try to incorporate suggestions and comments by actual end users, i.e. divers, all along the next period. Implication of end users is not obvious yet in the deliverables.***

We will organize an End user event where we will invite important persons from public safety, military, commercial, and have them dive in real situations. The agreement is not to go with the high number of end users but to focus on the most important limited number of people. They will first be approached with a questionnaire based on which the final scenario will be defined. After the validation trials, they wil have the chance to test the developed system.

Other:

- ***Apart from the acoustic positioning/communication segment, which not only shows a very high potential but already went to market, the project does not show yet a clear evidence***

of the exploitable results. The absence of a proper exploitation plan did not allow the reviewers to assess the potential for result valorisation.

This will be dealt with the revised exploitation plan.

- ***Although the project demonstrates a strong scientific and technical content, it does not show a real involvement from end users in terms of systems specifications, performances appraisal and general project guidance. It is expected that such situation will improve in the following periods.***

The action plan is described above.

3.3 Work progress and achievements during the period

3.3.1 Progress overview and contribution to the research field

3.3.2 Work packages progress

WP1 Robotic diver assistance system

The activities for the WP1 are completed according to the DoW.

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

T1.2. The underwater segment

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

T1.4. Data distribution network

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

WP2 Seeing the diver

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

T2.2. Motion compensation and fusion of passive sensors

T2.3. DiverNet sensor and communication development

The breathing belt sensor proved to be unreliable during the 1st validation trials and it was found that it is very difficult to make this sensor robust and waterproof. It was also found that it is impossible to accurately distinguish breathing from other upper body muscle activity on a diver. For this reason UNEW worked with DAN Europe to investigate the feasibility of using a pressure sensor on the intermediate pressure leg of the diver's breathing apparatus. This proved to be a more robust sensing mechanism, providing very clear signals (such as in figure 2.3.1) from which the breathing rate can be extracted by simple processing algorithms. The compromise is that this signal may not enable the more detailed analysis of breathing patterns possible with sensors that reveal the depth of breathing as well as rate. A digital pressure sensor with pneumatic hose interface has been designed, constructed and interfaced with the Divernet hub (pictured in figure 2.3.2(a)). The receiver for a wireless heart rate sensor has also been integrated with the divernet hub to provide additional physiological parameters to estimate the diver's health and emotional state.

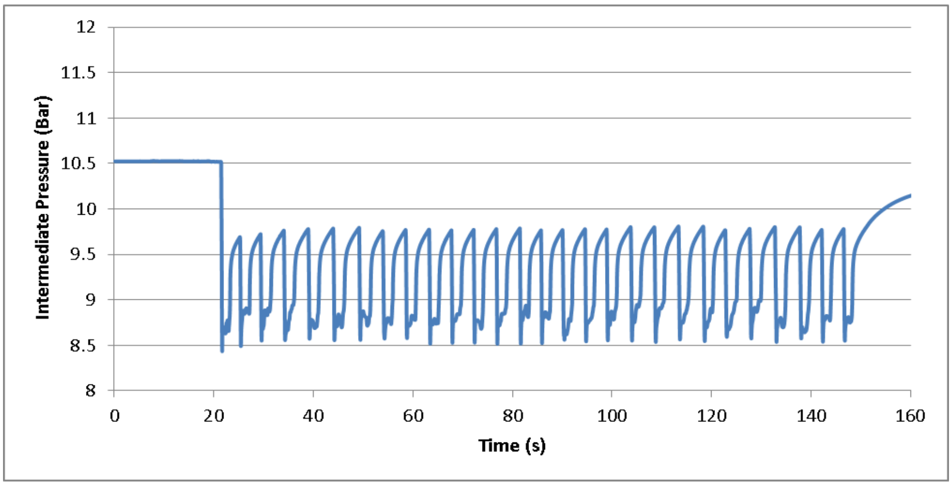


Fig. 2.3.1 – Typical output from intermediate pressure sensor to measure diver breathing pattern

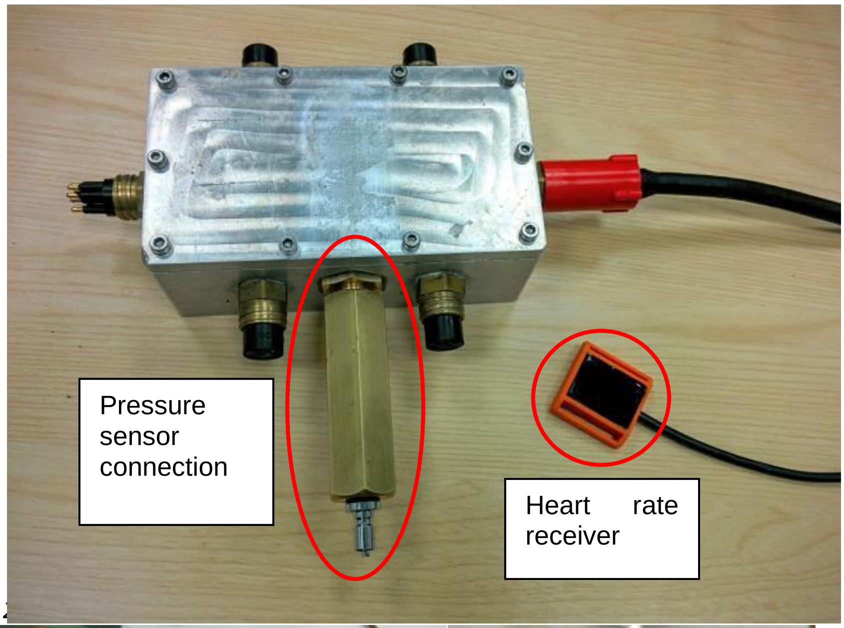


Fig. 2

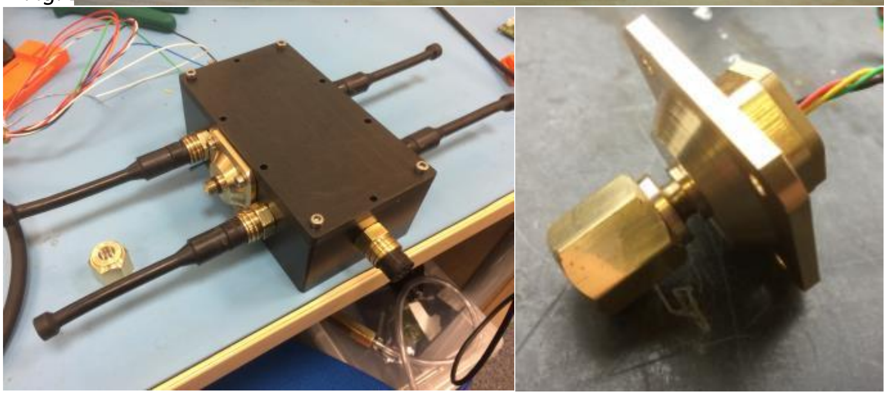


Fig. 2.3.2(b) – anodised Divernet hub and improved pressure sensor assembly

The divernet hub was later anodised to avoid corrosion problems and an improved pressure sensor assembly was designed to avoid the possibility of leakage into the housing and to ensure that the divernet operates correctly without the hose attached. This is illustrated in figure 2.3.2(b). Two divernet systems have been constructed and tested to provide redundancy for the final validation trials and to enable parallel experiments.

The divernet has now been fully integrated with the diver tablet and a Seatrac acoustic modem. This enables motion and physiological data to be processed on board the tablet and keym metrics to be transmitted via the acoustic modem to the BUDDY vehicle and/or the surface. Figure 2.3.3 shows an example where the motion sensors on the diver's feet have been analysed to extract padding rate on the left and right flippers. This parameter is then transmitted periodically to the surface and displayed. The result shows the diver paddling steadily for periods at various different rates, interspersed with periods of treading water. Around 95% data delivery was achieved over this period with drop usually occurring due to masking of the acoustic transducer by the diver's body.

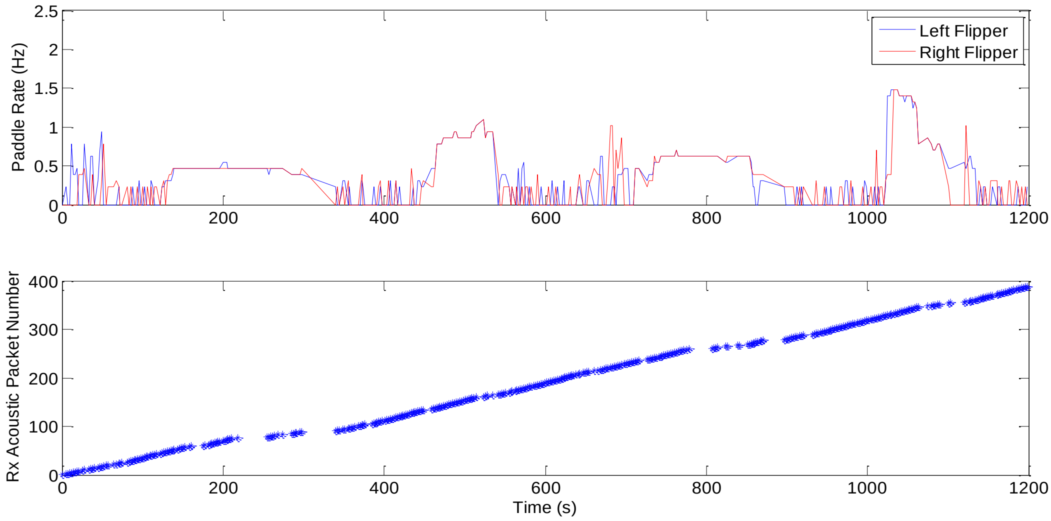


Fig. 2.3.3 – example of Divernet data analysis and transmission through acoustic link

To maximise communication reliability work is ongoing to investigate how transmissions may be time synchronised with the diver's breathing pattern. For example, transmission through the Diver's exhaled bubble plume can prove problematic due to the severe acoustic attenuation. The intermediate pressure sensor provides a good mechanism for this synchronisation but this sensor input may not always be available. Hence we have also investigated using a hydrophone for the monitoring of the acoustic emissions that correspond with the diver's breathing cycle. An example of this is shown in figure 2.3.4 which shows the amplitude of acoustic emission (bottom) and spectrogram (top) as the divers changes between periods at different breathing rates. This also seems to be an effective mechanism for breathing detection with relatively simple signal processing which could be integrated into the acoustic modem or divernet hub for comms synchronisation or the estimation of health/emotional state. One challenge which must be overcome is distinguishing the diver's acoustic emissions from the modem transmissions and thruster noise and appropriate filtering techniques for this will be investigated during year 3.

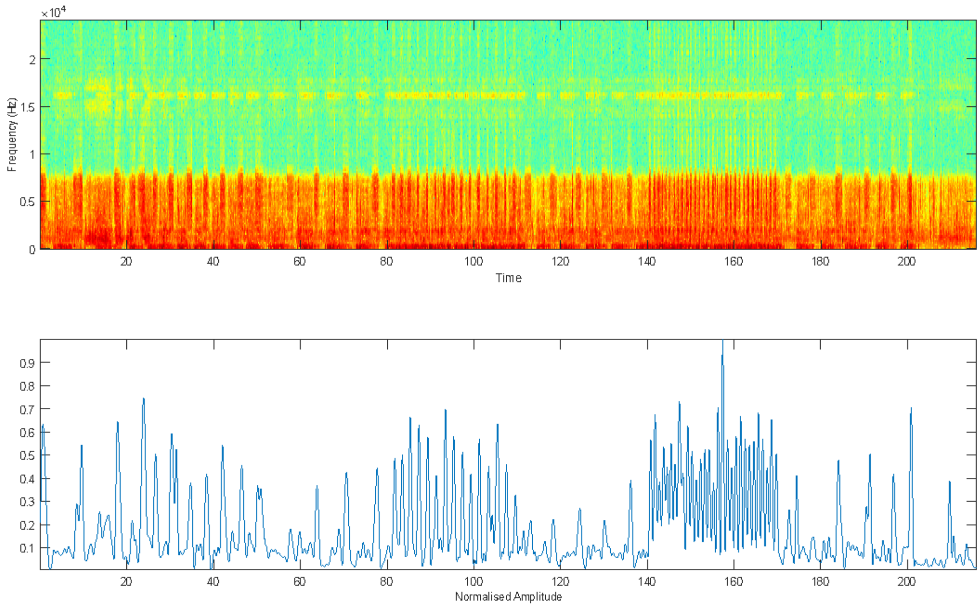


Fig. 2.3.4 – Acoustic emission monitoring for diver breathing pattern

T2.4. Experimental data collection

Data collection in Padova

Based on the experimental paradigm used in the prior diver data collections, nine divers were asked to complete a number of tasks while wearing the DiverNet (including a heart rate and breath rate sensor). Task list:

- Breathing without a regulator while swimming (1 minute)
- Breathing under water through the regulator (1 minute)
- Taking off the mask and putting it back on
- Taking off the regulator and putting it back on
- Making a decompression stop (floating for 20 seconds)
- Retrieving objects from underwater in a particular order
- Moving between markers positioned in a vertical line
- Swimming at a leasurely pace
- Swimming at a fast pace
- Free behaviour segment («Do what you want to for 1 minute»)

After each task, the divers completed a Pleasure-Arousal-Dominance questionnaire. After the first day of data collection, the DiverNet Hub did not transmit reliable data because the pressure sensor's valve was leaky. As the problem could not be fixed in Padova, the data collection was discontinued.

T2.5. Diver pose estimation

DiverNet Model

DiverNet is a network of 17 9-axis inertial measurement units (IMU) mounted on the diver´s body parts to compute their orientations and form a complete human diver kinematic model. Figure 2.5.1 shows the position of each IMU and the T-posture performed by the diver to calibrate them; the coordinate frame of each sensor is rotated so that it matches the expected orientation of that body part in the T-posture. This is done because it is very hard to have each sensor perfectly aligned and firmly in place; they are mounted in a special diver suit with sewn-in velcro patches as in Fig. 2.5.2.

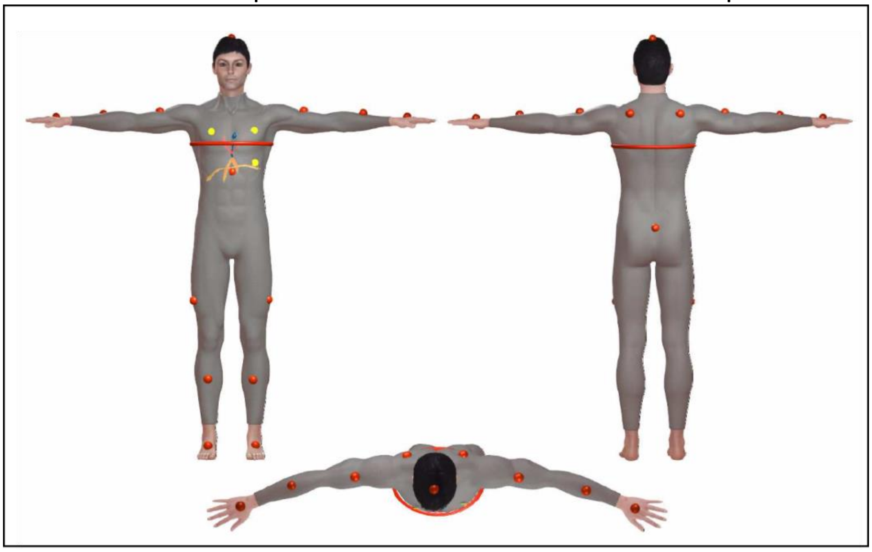


Figure 2.5.1. *IMU positions on diver's body and T-posture used for sensor's calibration*

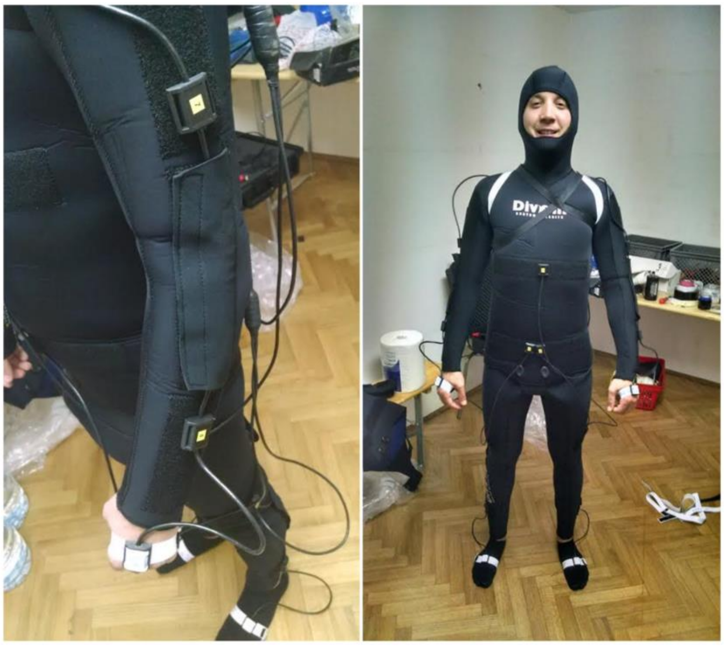


Figure 2.5.2. *DiverNet mounted on the diver*

<u>Diver posture estimation and visualization</u>

In order to estimate the orientation of each body part, a complementary filter that uses a gradient descent algorithm is used, as in the paper *Estimation of IMU and MARG orientation using a gradient descent algorithm* from the Rehabilitation Robotics (ICORR), 2011 IEEE International Conference by Sebastian Madgwick. This filter was chosen over often used Kalman filter-based solutions as it has shown to perform with similar accuracy, but has a much lower computational cost.

After the absolute orientation of each individual body part is calculated, this data is fused in a complete model, where the orientations are translated from absolute to relative, and this data is used to visualize the model. The entire processing is done in ROS in C++, and Rviz is used for visualization. Fig. 2.5.3 displays the visualized diver model.

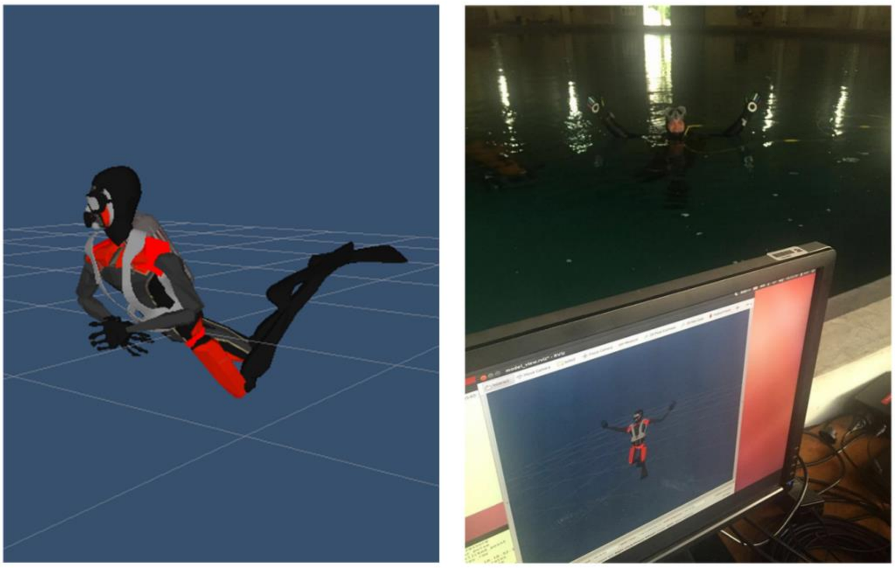


Figure 2.5.3. *(left) Diver model displayed in Rviz; (right) Diver in the background*

Automatic diver activity classification

The reconstructed diver posture obtained from DiverNet is used for automatic activity classification, where the system would know what the diver is doing even without a human operator observing.

Two approaches are currently being tested. The first one uses a Dynamic time warping algorithm to align the live data with recorded training data. It classifies current activity based on the distance to aligned training set, choosing the activity with the smallest distance. This method showed good results with static postures, but is not as appropriate for dynamic activity which is important for most diving activities as it cannot cope with huge variances in speed in performing the same tasks. Tests were conducted with 7 poses shown in Figure 2.5.4. Confusion matrix for initial tests is shown in Figure 2.5.5a).

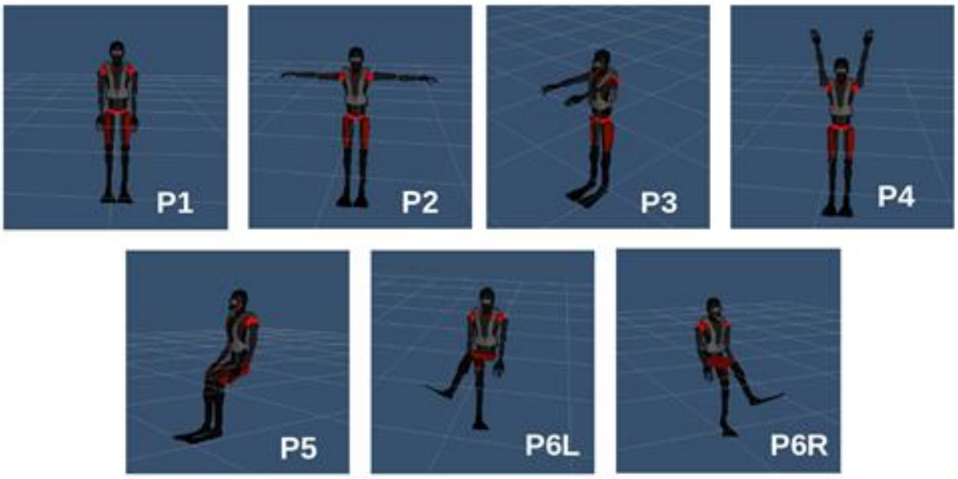


Figure 2.5.4. *Poses used in initial classification tests with Dynamic time warping*

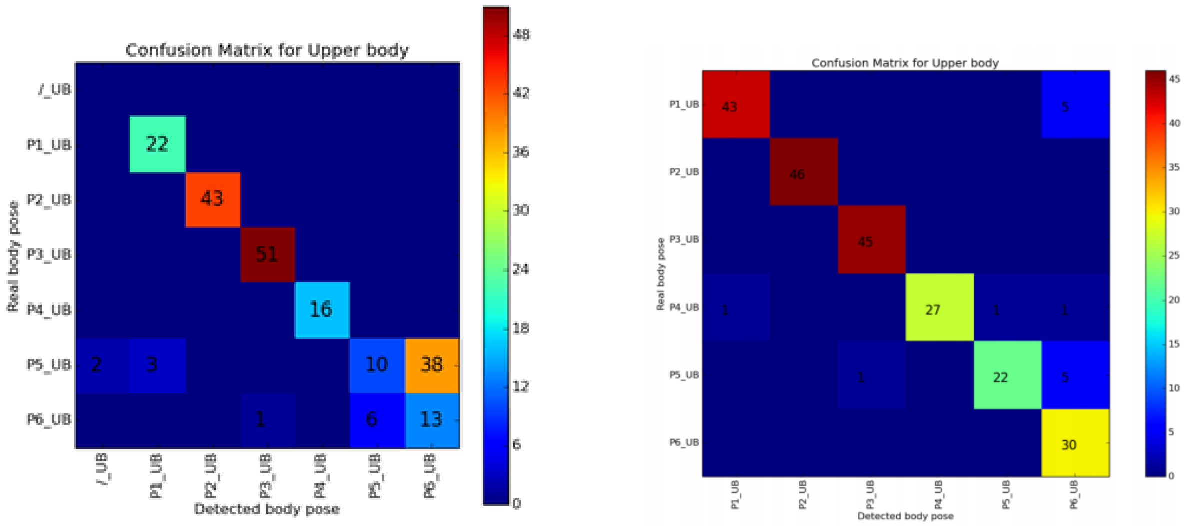


Figure 2.5.5. *Confusion matrix for a) Dynamic time warping tests and b) Artificial Neural Networks based dynamic activity recognition*

The second approach that is currently being tested are artificial neural networks. Inputs to the network are calculated joint orientations of the diver, for both current and past frames. This allows time awareness and recognition of dynamic activity. Neural network models are currently being assessed to find a good structure for our task. A simple and shallow (1 hidden layer) feed-forward neural network has been tested so far, and has shown good results on a small dataset with static poses. Provided with reasonably good reconstruction and joint orientation estimate from DiverNet, the algorithm works very well. However, more data needs to be collected to try to also cope with the reconstruction errors. As for now, some improvement was made with artificial data generation. The artificial training data was created by adding a Brownian motion-inspired error to existing training data.

The tests conducted with dynamic poses have shown even stronger need for more data. Even with relatively simple networks, it was hard to prevent the network from overfitting. Initial results, with a single hidden layer network, and using current frame, and three past frames with 0.5s sampling time, have resulted in achieving 100% in the test set, but only 80% in the validation set, showing severe overfitting. After recording some more data and adding artificial training data, the results have improved slightly, to 99% recognition rate on test set and 88% on training set. This still suggest quite a bit of overfitting, but is an improvement. The confusion matrix is shown in the figure 2.5.5b).

Diver pose estimation based on stereo imagery

The information from the DiverNet is only available every 5 seconds approximately since it is passed hrough acoustics from the diver suit's modem to the underwater vehicle (BUDDY). For the application, it is not indispensable to have a full pose estimation of the diver's limbs at all times, but it is important to at least have the diver's heading i.e. the direction to where the diver is swimming to. In this way, the BUDDY can position itself always in front of the diver in case it has to guide him to a certain location or if it needs to record the diver's gestures to perform a certain task.

To obtain the diver's heading between each DiverNet's measurement, we compute principal component analysis (PCA)[2] in the point clouds generated from the stereo images. In dense point clouds, we can visually find a correlation between the PCA eigenvectors and the pose of the diver. However, point clouds from stereo images rely on feature matching and the rather textureless underwater environment (diver suit and uniform background) causes the point clouds to be sparse or with holes. Hence, the correlation between PCA eigevectors and diver's pose will not be one-to-one and there will be some noise in the data. For this reason, a Random Forest classifier was trained with collected data from 20 divers; with enough data, the classifier can map PCA eigenvectors to a set diver's pose and assign degrees of confidence (probabilities) to these mappings.

- Dataset creation

Divers were asked to rotate in front of a stereo camera 360° in vertical and horizontal position (Padova, Italy; February, 2016). Since the classifier cannot output continuous values, all possible orientations were quantized in 8 bins of 22.5° as shown in the Figure 2.5.6. The data was manually labelled by watching the diver's rotate while passing through visual markers.

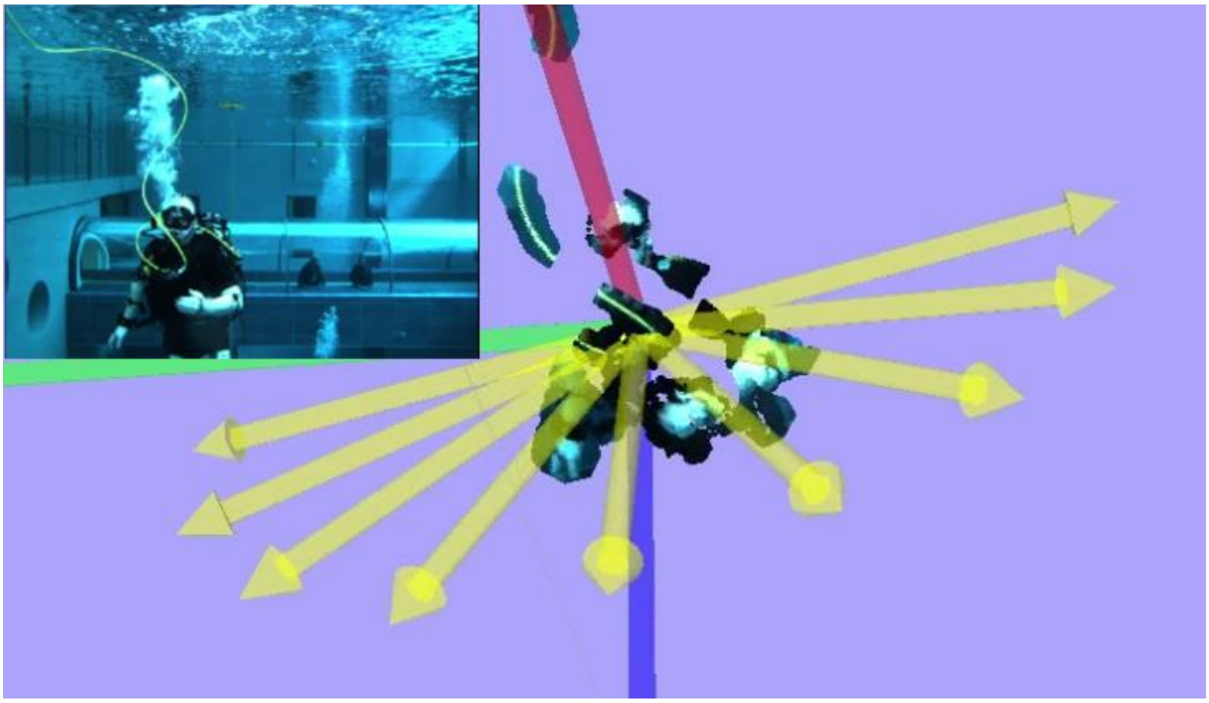


Figure 2.5.6. *Point cloud of the diver shown in the top left corner. The visual markers are the yellow arrows that divide the Y-Z plane into 8 angular bins from -90° to 90° (zeros degrees corresponds to the diver facing the stereo camera).*

Then we build a 15 element feature vector from the labelled data as such:

Eigen - value[0]	Eigen - vector[0]	Eigen - value[1]	Eigen - vector[1]	Eigen - value[2]	Eigen - vector[2]	Maximum variations (distance) along the eigenvectors

The first 12 elements of the feature are the ordered eigenvectors (3 dimensions) and their respective eigenvalues (1 dimension); and the last 3 elements are the maximum variations or absolute distances between pointcloud points along each eigenvector. As a result we have a dataset with 1270 samples, which were divided in sets of 889, 254 and 127 (70%,20%,10%) to create the training, validation and test set respectively and train through cross validation.

- **Experiment results**

On the test set the Extremely Randomized Forest classifier achieves *71.6% accuracy*. However, as it can be seen Fig. 2.5.7, the majority of the predicted headings lie within 1 or 2 bins of the true heading. So, we can state that even when the classifier outputs an incorrect value, there is a 90% probability (less than 2 bins error) that it will output a heading close enough to the true value for it to be used by the control filter mentioned in the DiverNet section.

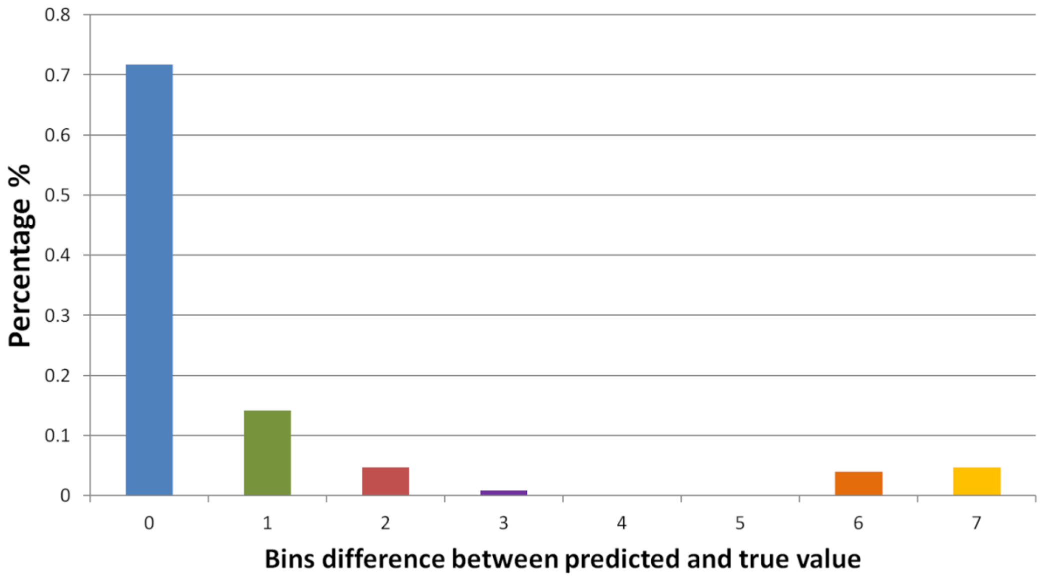


Figure 2.5.7. *Graph showing the percentage of times the classifier predicted a heading with a difference of N angular bins. N=0, represents the number of times the classifier output the true heading of the diver.*

During the CADDY Software integration Week in Zagreb, Croatia on May 18th, 2016; the algorithm was tested on never before seen data of one diver wearing the DiverNet, so that we could compare the output given by the inertial sensors and the classifier. The ground-truth we used was the measurement of the inertial sensor in the diver's chest. *The accuracy achieved was 83.4%*.

As it is shown in Figure 2.5.8, besides the diver's heading, the bearing angle (angle between the camera's direct line of view and the diver's center of mass) and the range (distance between the camera and the diver's center of mass - magnitude of the blue arrow in Figure 2.5.8) are given as extra information for the control filter. A screenshot of the ROS message containing this information is given in Figure 2.5.9; the next step is to compute the variance of all these values from the labels probabilities the Random Forests inherently give.

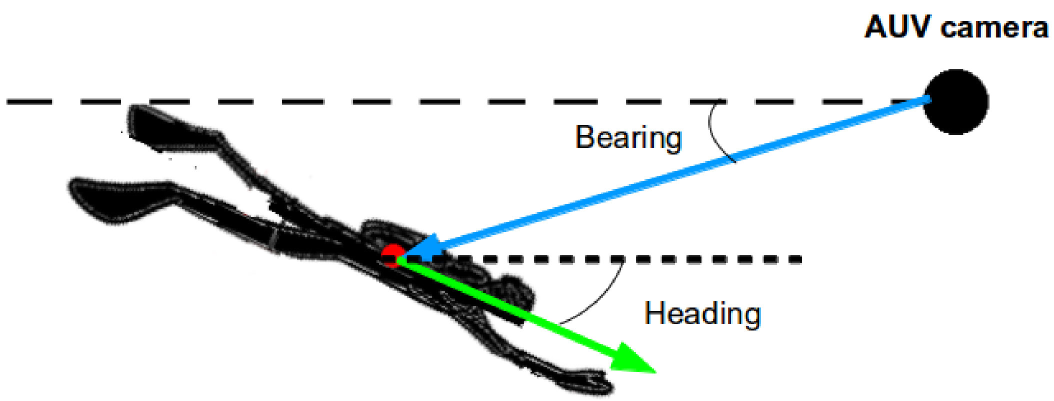


Figure 2.5.8. *Diagram of the diver's pose measurements done from the generated pointcloud, includes: bearing, heading and range (magnitude of blue arrow).*

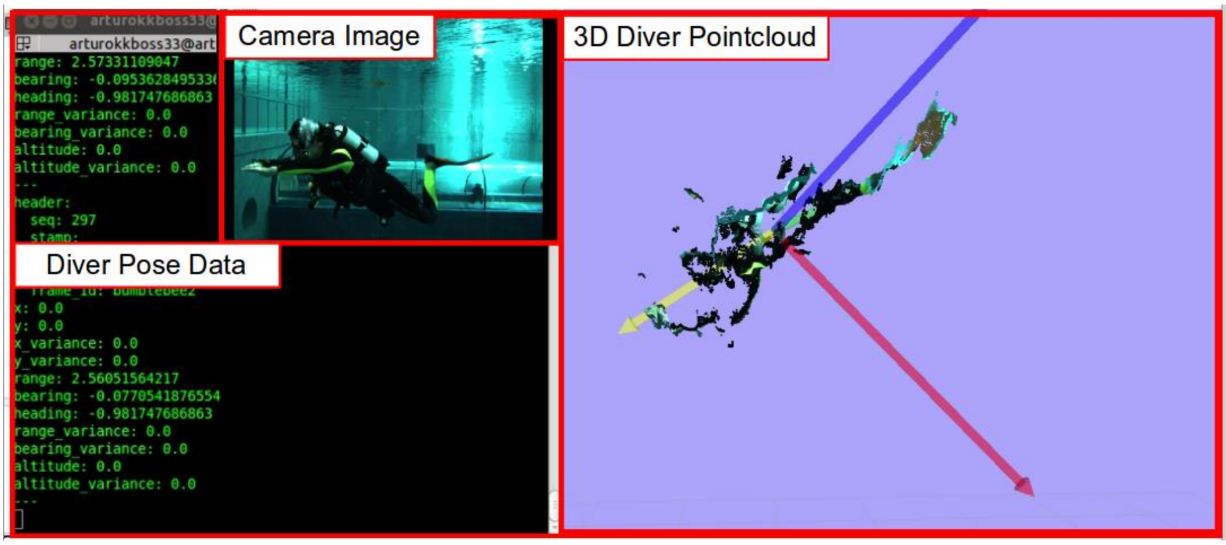


Figure 2.5.9. *Screenshot of ROS and Rviz showing the camera images, the diver's pointcloud (top view) and the terminal displaying all important measurements about the diver's pose.*

T2.6. Recognition of hand gestures

WP3 Understanding the diver

T3.1. Adaptive interpretation of diver behaviour

In the ongoing project we showed as a proof of concept that it is possible to determine experienced primary emotions (happy, disgust, anger, fear, surprise, sadness, neutral) from chest motions when captured with a breathing belt. In the second experiment we extended this to secondary emotions (pleasure, arousal and control).

The results are that primary emotions can be mapped onto secondary emotions – this is why we will proceed with this approach, because it has only three dimensions as compared to six.

Another problem we tried to solve is data reduction of the time series. Time series have specific dynamic features that usually get lost in machine learning. Thus we developed a procedure that extracts time series dynamics. In order to do so we suggest to apply peak detection – and then calculate dynamic features (turbulence, speed amplitude, acceleration, deceleration, curve length, time for acceleration/deceleration and number of minima and maxima) of the time series in a 30 sec window. These dynamic features than can be fed to any machine learning algorithm. This approach was quite successful for the prediction of pleasure arousal and dominance when fed to a multilayer perceptron. A second test with TDNNs showed generally lower prediction rates than the procedure above.

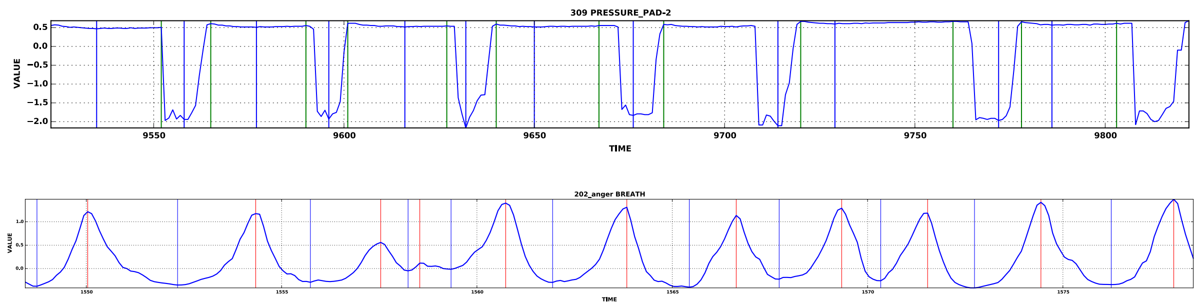


Fig 3.1.1 – Raw breathing curves from different sensors: pressure sensor (upper), breathing belt (lower). The sensor switch is the reason we can not use the breathing curves from the experiments in the further analysis of divers – we only can use rates. Rates are calculated from the peak distances.

Another problem which occurred was the change from breathing belt sensor to the pressure valve sensor for collecting breathing data – the data collected with this sensor are quite different from the old ones. Thus we tried to figure out if the prediction of secondary emotions is possible from breathing rates and not the original breath curves. The results indicate that this is possible but the prediction rate is much lower. On the same data we then analyzed the time series using breath and/or heart rate to predict pleasure, arousal and control with a multilayer perceptron.

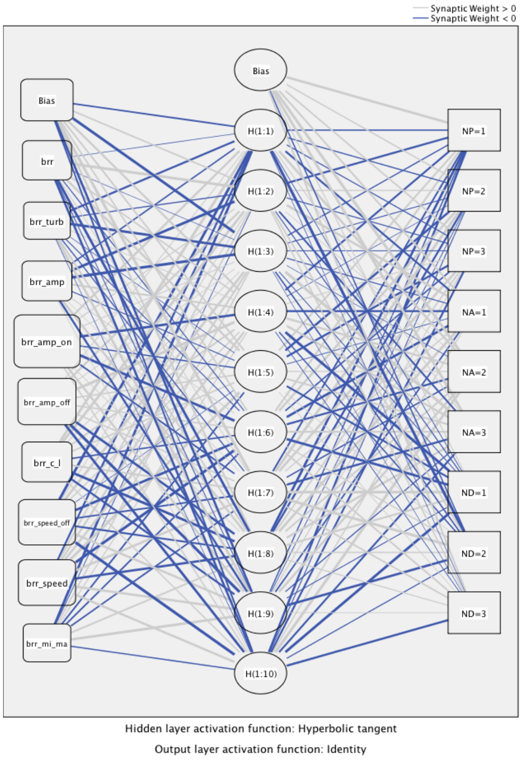


Fig 3.1.2 – This figure shows a multilayer perceptron with dynamic features as input (right) and the predicted states od pleasure, arousal and dominance/control. This special network reached an overall classification correctness of 37%.

In a final step we applied the above developed procedures to the data from the third experiment – which was walking under different emotional conditions. This allows us to integrate the different data sources – heart rate, breath rate and motion rate. Motion rate was calculated as the sum of the first derivate of the quaternions from all motion sensors.

If motion rate, breath rate and heart rate together are fed into a multilayer perceptron we reach the highest values for the prediction.

Our multilayer perceptron reached an overall correct classification percentage of 43,2% (for the test, for the training dataset we reached 63,2%). The values for correct classification range between 34,4% (prediction of pleasure) and 47,5% for the prediction of arousal and control.

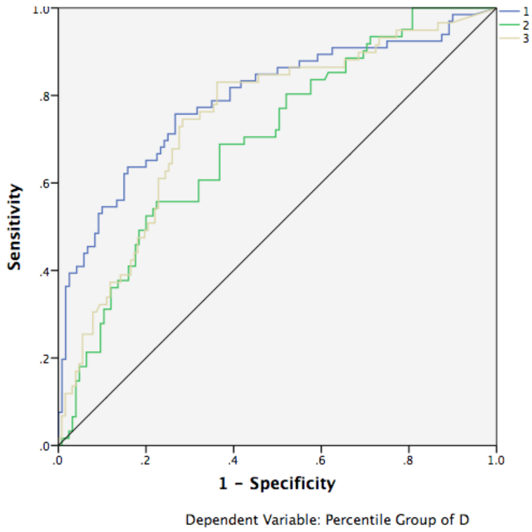


Fig 3.1.3 - ROC Curve for Dominance/Control Classification in the walking experiment. The prediction of low Control (green), middle control (yellow) and high control (blue) is fairly high.

The case of anomaly prediction has been applied to the pressure sensor data – which are highly cyclic and thus can be analyzed with Symbolic Aggregation Approximation – this data source can be used to detect breathing irregularities or function of the regulator.

We also carried out new experiments in Padua – unfortunately we only got four useful experiments with divernet, because of malfunctioning of time synchronization and leaks in the pressure sensor. Nevertheless the experiments showed that our approach is feasible and yields usable results.

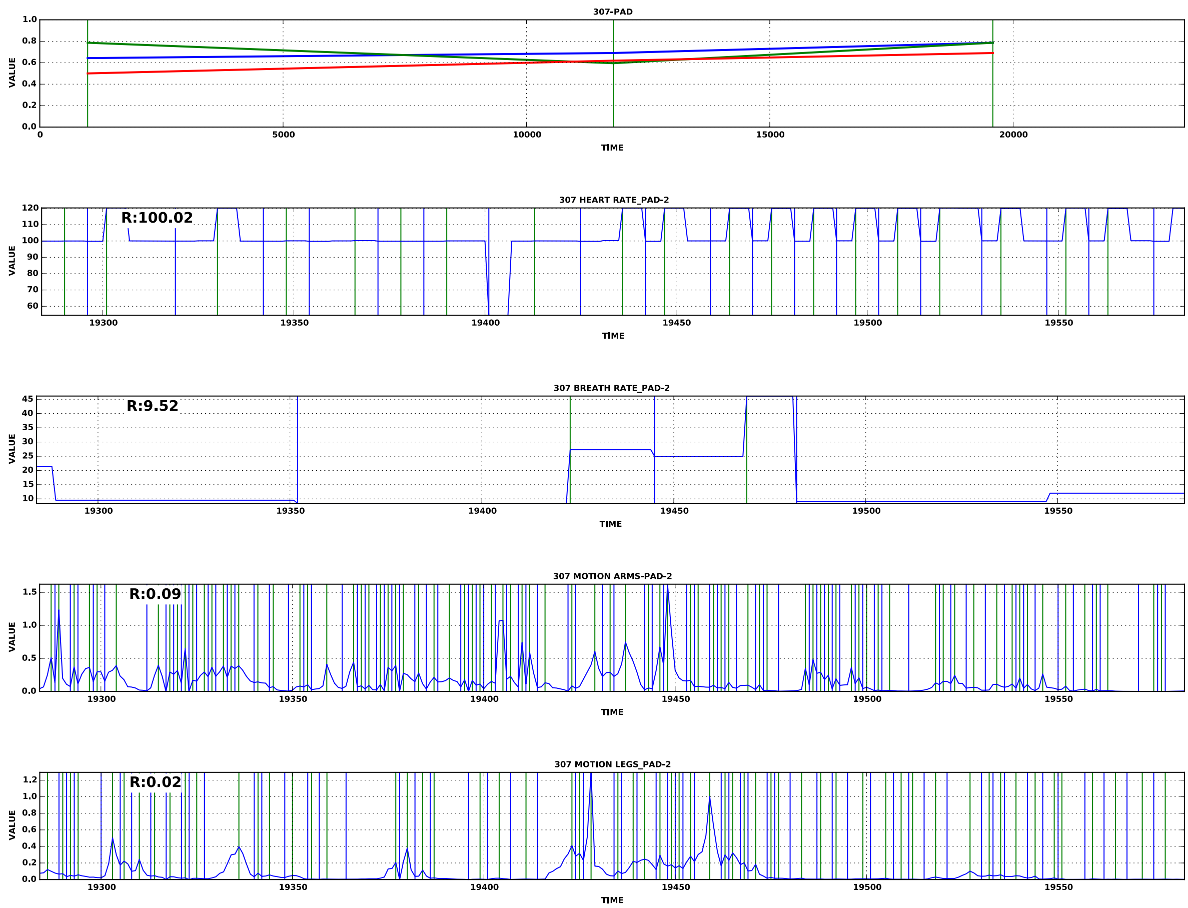


Fig 3.1.4 – Raw data from an experiment in Padua. The top graph shows the pleasure (green), arousal (blue) and dominance/control (red) values during the experiment. These values stem from the 18 items questionnaire used also in experiment 2 and the walking experiment. The divers filled out three questionnaires underwater on the tablet. The other four graphs depict a 30 second window (heart rate, breathing rate, motion rate, motion rate arms, motion rate legs) collected before filling out questionnaire two.

This is why we planned a final data collection for the verification of our approach in October in Biograd na Moru with n=20 divers.

So far we developed a procedure for assessing diver states based on the breathing and the walking experiment. (see flowchart). The respective values are calculated continuously for each data point in a 30 second window. These procedures are implemented in our playback tool (diver control center), so we can immediately check data that come from underwater experiments. This program will also be used for validation purposes. We plan to used neural networks coming from the walking experiment and then try to classify diver secondary emotions.

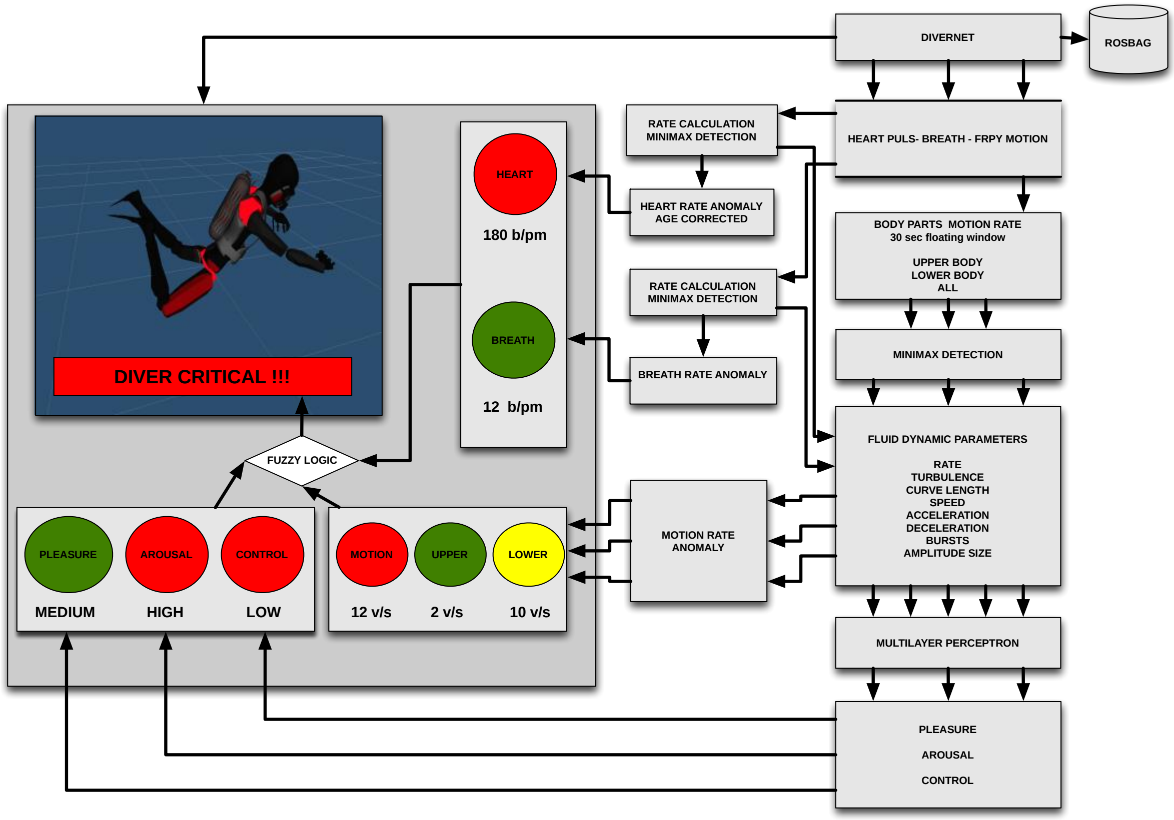


Fig 3.1.5 - Flowchart of suggested control parameters and variables for diver control. The flowchart outlines the procedures which are necessary to monitor the diver. We have implemented heart rate and heart rate anomaly based on age data, the same is done for breath rates. Red light depict abnormal rates. We also used motion rates in this system and pleasure, arousal, dominance/control values from the neural network. We plan to implement a Fuzzy logic modul for decision making if the diver mission is critical or not.

T3.2. Symbolic language interpreter

During this period of the project, the integration of the different modules for the mission generation based on diver gestures has been done. This encompasses the next tasks: gesture recognition, identification of valid phrases (parsing), generation of missions and feedback delivery to the diver via a tablet. The main purpose of the integration is to build a fault tolerant system against human errors (gestures badly performed or with no correct syntactical structure) and software errors (misclassification of gestures).

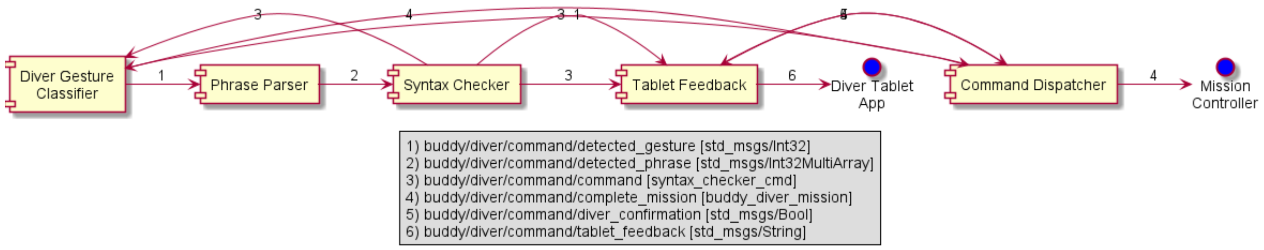


Figure 3.2.1. *Diagram of the ROS software nodes and how they communicate each other during a mission generated through diver gestures. On the bottom the name of each ROS topic is displayed.*

Figure 3.2.1 shows how the different modules communicate each other in the ROS environment (via topics). The purpose of each software module or ROS node is the following:

- Diver gesture classifier: Recognize diver gestures from stereo images. The first gesture to be recognized must be START COMMUNICATION; if any other gesture is performed before it will not be recognized.

- Phrase Parser: The code of each recognized gesture is sent to this module; the performed gestures between two START COMMUNICATION signals or a START COMM and an END COMM are saved as a string of codes and send to the Syntax checker module. Thus, the purpose of this node is to identify a sequence of gestures that for a phrase within the CADDIAN language.

- Syntax checker: CADDIAN phrases are received by this module and are evaluated to see if they are syntactically correct based on the CADDIAN rules. If they are valid these phrases are sent to the Command Dispatcher module; otherwise, an alert is sent to the tablet to indicate the diver there was a mistake and the stored string of gestures are erased.

- Command dispatcher: The purpose of this module is to save valid CADDIAN phrases in a queue until an END COMM signal is received. It then sends these phrases or missions to the Mission controller which functionality is described in the following sections.

- Tablet Feedback: This module receives flags/signal from the others in order to give feedback to the diver during all the communication process. Every time a gesture is performed, the tablet displays what was recognized; in this way, the diver can know if it was misclassified or not and restart the process. Likewise, when a phrase is not syntactically correct, a message to the diver is sent. Finally, when an END COMM gesture is recognized, the tablet shows all the recognized phrases/mission until that moment and asks the diver to confirm or abort their execution. This ROS node prepares the topic to communicate with the tablet, the ROS topic is send via Bluetooth from the vehicle computer to the tablet, and an application on the tablet interprets the topic to display it in an appropriate format.

Figure 3.2.2. shows a state machine diagram of the overall process, indicating which action is performed by each ROS node.

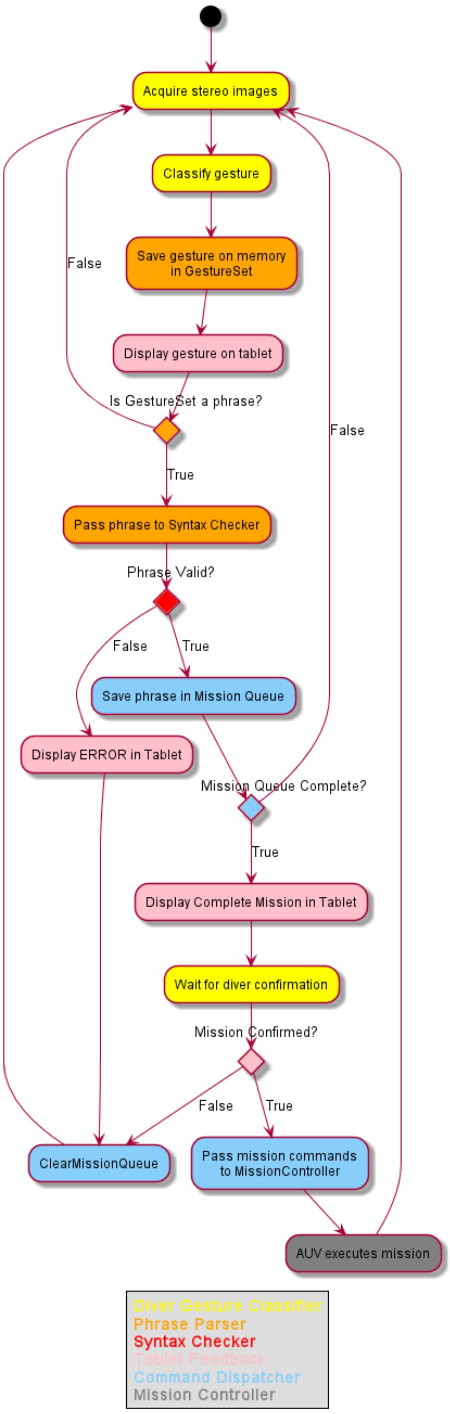


Figure 3.2.2. *State machine diagram of the gesture recognition and mission generation process. Each action is color coded according to which ROS node/module performs it.*

BUDDY tablet feedback

As part of the gesture-based underwater communication protocol between the diver and the BUDDY vehicle, a feedback system has been developed that provides the diver with immediate visual information pertaining to the robot's reception and interpretation of the gesture command in progress, for both simple and complex gestures.
As depicted in Fig. 1, the tablet mounted in an underwater casing at the front of the BUDDY vehicle displays full screen colour-coded messages to the diver. Automatic font scaling has been implemented, ensuring an optimal visibility-to-information-density ratio in often challenging underwater conditions.

Fig.1. Example of feedback messages displayed on BUDDY tablet during gesture recognition

Each time the robot deems it has successfully parsed a given gesture command, it displays the result of its processing before actually starting mission execution, and requests confirmation from the diver in the form of simple YES or NO gestures, thus granting an additional layer of error protection (the diver can easily stop the robot from launching an unwanted mission based on misunderstood commands).

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

Mission controller general description

The CADDY mission control system is a modular framework designed and developed with the aim of managing the state tracking, task activations and reference generation that fulfills the requirements in order to support the diver operations.
As depicted in Fig. 1, the mission controller acts as a cognitive planning and supervision system taking as input the decoded gesture sequence executed by the diver, in turn generating proper task activation actions in such a way to trigger the required capabilities needed to provide the requested support.

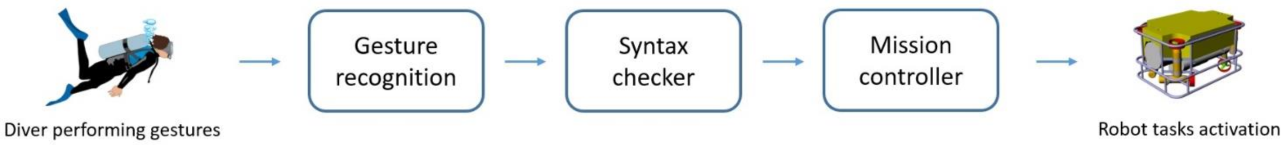


Fig.1. Main modules of high-level CADDY functionalities

The main goal of the mission control module is to abstract the robotic capabilities at logical level and manage the activation of the real robotic primitives, while at the same time resolving possible conflicts that may arise when selecting the robotic capabilities to be triggered.
In the CADDY logical framework, three classes of executable units have been identified and shown in Fig. 2:

- functional primitives represent the macro-actions that the robotic platform has to carry out in order to support the diver operation and that are strictly related to the current functional mode (slave, guide, observer);
- high-level logical tasks are the interface between the primitives and the operative task provided by robot. This logical task set is common in the overall architecture and will provide the required functionalities activating the proper low-level tasks that are currently made available by the employed robotic platform;
- low-level robotic tasks are the actual implemented autonomous functionalities on the target robot, e.g. speed regulators, heading and depth controller, etc. Depending on the low-level task availability, the CADDY compliant mission control system will properly select which high-level functionalities can be activated allowing, in turn, the enabling of the required primitives to fulfil the mission operations.

The primitives are linked to the support action that the diver can require by means of the gesture-based language: once a gesture or a complex sequence of gestures is recognized and validated, it is sent to the mission controller that will activate the proper primitive to start the support operation.
Each primitives activates as set of high-level tasks that represent the logical functionalities required to fulfill the required operation.
The high-level logical tasks activate in turn a set of robotic tasks which enable and execute the physical operations on the real robot devoted to the support of the diver operations.

As an example, Fig. 3 reports the case of activation of the "Follow me" primitive; such a primitive requires the system to turn on the following functionalities: "go_to_depth" to reach and maintain a desired depth (i.e. the same of the diver); "go_to_2D_point_fa" is the procedure to track a 2D point (the diver position) for fully-actuated (fa) platforms, that generates proper horizontal velocities for point tracking; "turn_towards" enabling the auto-heading capability to always look towards the diver.

In turn, each of the high-level task has to be linked with one or more low-level tasks in order to physically execute the required actions:

- "go_to_depth" requires the activation of a depth_controller;
- "go_to_2D_point_fa" requires the activation of surge and sway velocity regulators;
- "turn_towards" enables the auto-heading controller.

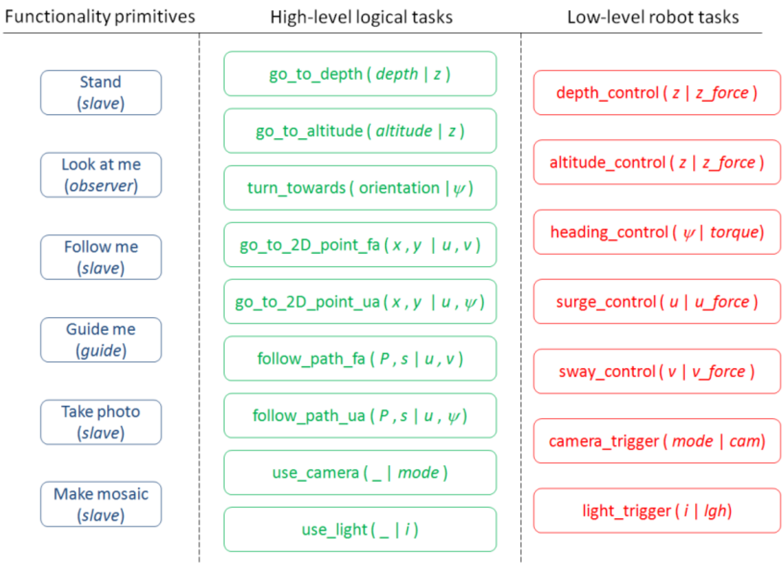


Fig. 2. Task classification in the CADDY logical framework

The logical links between the high- and low-level layers are set on the basis of the input/output variables: the output generated by a high-level task is the input for one or more low-level tasks, e.g. "go_to_2D_point_fa" generates the u and v speed reference signals that feed the low-level speed controllers.

If, as a second exemplificative case, an under-actuated platform is employed, it implies in turn that the "sway_speed" controller is not available (due to the under-actuation, e.g. of a rudder based vehicle). The unavailability of this latter low-level task reflects on the inhibition of the "go_to_2D_point_fa". Anyway to fulfil the "follow me" primitive requirements, the system can automatically swith to the "go_to_2D_point_ua" that can drive the robotic platform towards the desired point generating proper surge velocity and heading signals. The activation of the "go_to_2D_point_ua" task goes in conflict with the "turn_towards" one, given the generation of the ψ reference signals by both the tasks. Detecting this logical conflict, as depicted in Fig. 4, the system deactivates the execution of the "turn_towards" (that, by user definition, has a lower priority with respect to the "go_to_2D_point_ua" in relation to the "follow me" primitive).

For the automatic selection, activation and inter-task conflict management, a Petri net based execution control system has been developed. The system is configured by means of a set of configuration files that specify, on one side, the capabilities of the robot in terms of autonomous tasks and, on the other side, the set of high level functionalities that the CADDY system has to provide for the diver support. A real-time Petri net engine models the logical interconnections among the tasks and primitives and, depending on the specific actions commanded by the diver, automatically handle the activation/deactivation of the proper task sets.

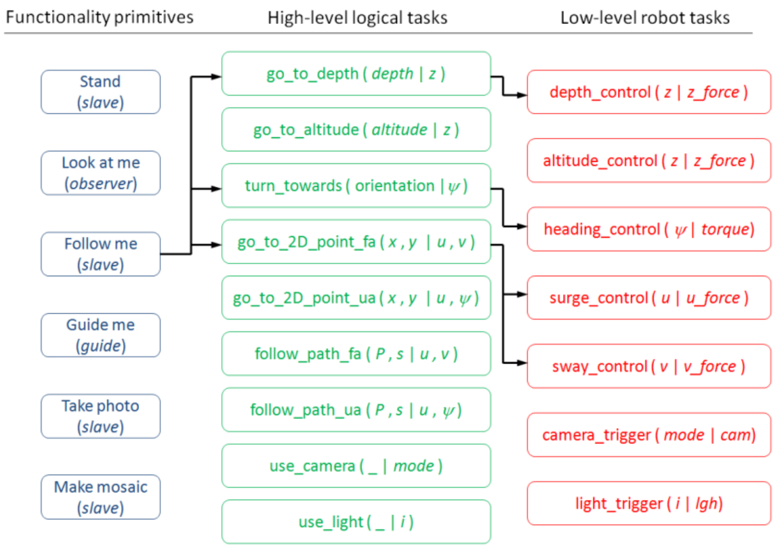


Fig. 3. Example of "follow me" primitive activation for fully-actuated robot

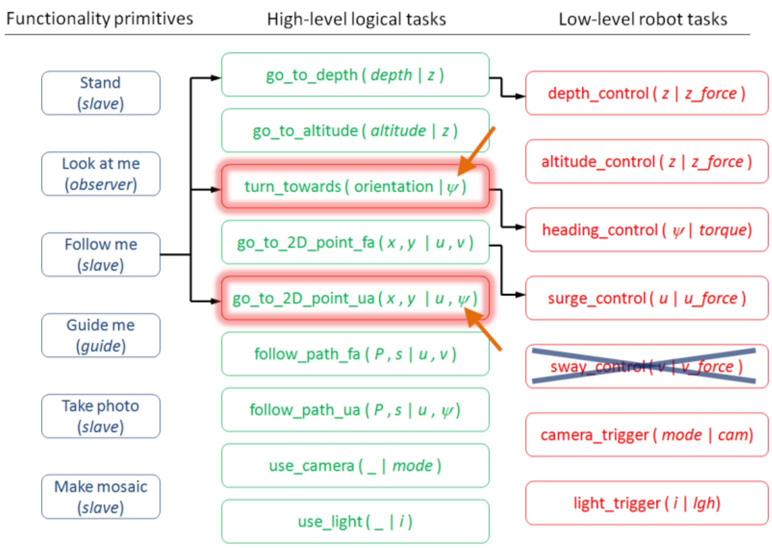


Fig. 4. Example of "follow me" primitive activation for under-actuated robot and inter-task conflict management

Each mission controller related task is logically represented by a simple Petri Net which define the state of activation of the task. As shown in Fig. 5, two *places* represent the two state of the task: *idle* and *running*. Two other places represent the start and stop events, while two *transitions* define the task net evolution rules. The idle place is initially marked, representing an initial condition of deactivated task.

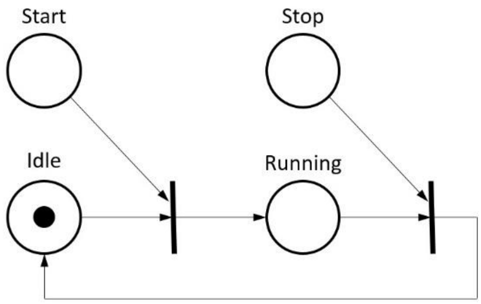


Fig. 5. Basic task representation in the Petri Net based mission controller

The Petri Nets representing the tasks are then connected through suitable arcs joining the *running* state of a logical layer to the *start* place of the following layer, as depicted in Fig.6. In such a way a cascade activation of the task chain is carried out.

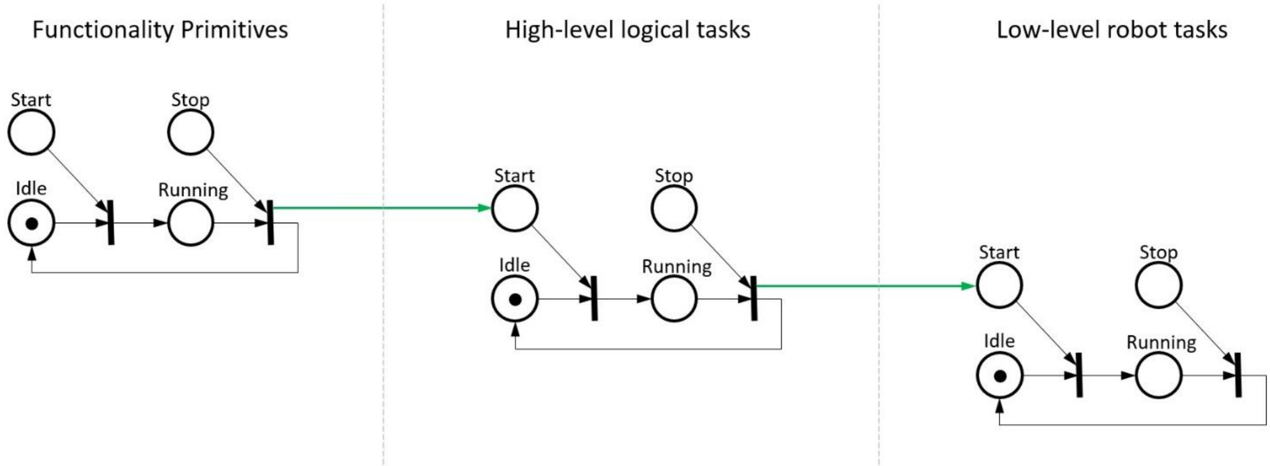


Fig. 6. Cascade-layer tasks connection

With such a proposed scheme, two main issues remain to be handled: the mutual exclusive activation of the functionality primitives and the conflict management in high- and low-level tasks execution.

For the issue of primitives mutual exclusion it is sufficient to insert an additional control place at primitives level, in such a way that only one single primitive can switch to running state, as shown in Fig. 6.

The inter-task conflict issue is raised from the fact that different tasks can generate output for the same output variable; the abovementioned example shows that the activation of the two high-level tasks “turn_towards” and “go_to_2D_point_ua” bring to a conflict due to the generation of the same output variable “ψ”. To resolve the conflicts, a constraint place is added between two or more conflict tasks whenever a same output variable is shared among those tasks (see Fig. 6). The presence of this new constraint place allows the mutual exclusion of the conflicting task execution and providing a consistent state of the mission net.

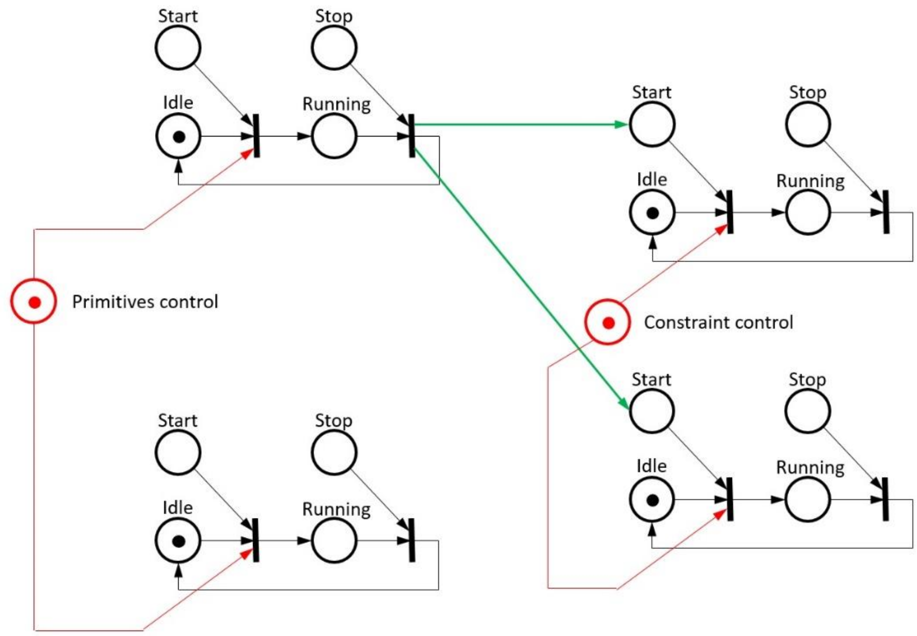


Fig. 6. Mutual exclusive and conflict-free mission control Petri Net

Validation experiment

The envisioned final validation experiment sets the goal of demonstrating the main advanced capabilities in supporting the diver operations through the exploitation of a highly autonomous robotic system.

With respect to the CADDY framework and provided functionalities, the experiment is composed by the following three main phases:

1. the robotic system, in guide mode, navigates at constant distance from the diver performing observation activity. From the ground station, a new point of interest is fed to the robotic team in order to guide the diver to the requested position. Performing the "pointer experiment", the underwater buddy starts guiding the diver towards the selected point;
2. the diver stops its motion towards the point and initiates a gesture-based communication with the buddy requiring the robot to stop the current guide activity and start a "go to boat and carry equipment" action. In this phase the underwater robot will surface and move to a specific base location in order to collect some specific equipment unit and then returning at the operational point close to the diver;
3. the guide function towards the point of interest is recovered and carried out until the desired location is reached by the diver.

Definition of technical details for the implementation and execution of the validation experiment

Given the envisioned experiment plan, the functionalities required are "guide_me" and "go_ and_carry"; if needed, two additional primitives can be added to complement the functionality set: "idle" (no action is executed) and "emergency" (to trigger the robot to signal a problem or to immediately surface).

The defined primitives are linked to a set of logical tasks that indicates the activation of the related high-level modules which allow the execution of the required actions. In particular the following tasks are selected:

- "go_to_fa" – 2D position tracking in full-actuated configuration;
- "go_to_ua" - 2D position tracking in under-actuated configuration;
- "pointer" – the control scheme to perform the pointer experiment
- "go_to_depth" – automatic control for desired depth maintenance
- "turn_towards" – auto-heading controller

A set of low-level robot tasks are also defined and triggered by the activation of the high-level ones. If needed, they can activate specific modules or procedure on-board the actual robot.
For the specific case, the following robot tasks are defined: "depth_control", "heading_control", "surge_control", "sway_control"," x_control", "y_control".
The activation of the tasks is automatically triggered by the mission control Petri net that, on the basis of the requested action, computes the correct sequence of task execution.
The activation of the primitives can be commanded through the topics:

/buddy/mission_controller/command/<primitive_name>

Setting the value: 0 -> stop , 1 -> start

The mission control Petri net computes the task activation sequence and the result is published into the following topics (the values are again: 0 -> stop , 1 -> start):

/buddy/mission_controller/primitives/<primitive_name>
/buddy/mission_controller/high_level_tasks/<high_level_task_name>
/buddy/mission_controller/robot_tasks/<robot_task_name>

Proper reference signals have to be generated and consumed by different modules.

"guide_me" mode - A continuous generation of the references for position, orientation and depth for the buddy has to be carried out.
The depth reference will be always the same as the diver depth.
The position reference of buddy is function of the current diver position & orientation and it is computed with respect to the desired point of interest to be reached.
Orientation reference is computed with respect to the current position of diver, in order to orient buddy always to face the diver.

"go_and_carry" mode - A set of action has to be sequentially executed.

1. Buddy sets position keeping to maintain current 2D position;
2. Buddy sets autoheading to set a desired orientation;
3. Buddy sets depth reference to zero and surfaces;
4. Buddy switches to wifi comm mode in order to maintain connection with MedusaS and ground station;
5. Position reference is changed to "virtual boat" location;

6. As the “virtual boat” location is reached within a specified threshold, buddy waits for a “go back” signal (we can command the action through a specific topic, that can be triggered by a timer or by human notification);
7. Go back to starting 2D position;
8. As the initial position is reached, “guide_me” mode is triggered and buddy goes to correct depth, orientation and position in order to continue the guide operation of the diver towards the desired location.

“idle” mode – no action, no references
“emergency” - to be defined

In the following, a table resumes the functional modes, running modules, topics published and consumed.

T3.4. Performance evaluation

WP4 Diver-robot cooperation and control

T4.1. Compliant diver buddy tasks

T4.2. Cooperative control and optimal formation keeping

Global Trajectory Tracking Controller

In order to enable the Single Beacon Navigation, described in task 4.3, a trajectory tracking controller was developed. The tracking guidance law can be seen in equations below, where the velocity vector in the inertial frame is $\boldsymbol{V_d}$, the desired surge and yaw references, u_d and ψ_d, respectively.

$$\boldsymbol{V_d} = \boldsymbol{V_t} - K \cdot \tanh\frac{e}{n}$$

$$u_d = \|\boldsymbol{V_d}\|$$
$$\psi_d = \angle \boldsymbol{V_d}$$

In this equation, $\boldsymbol{V_t}$ represents the velocity of the target, K and n are tuning gains, $\boldsymbol{e}$ the error vector defined by (own position – target position), u_d is the norm of V_d and ψ_d its angle.

T4.3. Cooperative distributed navigation and localization

Single Beacon Navigation (SBN)

In order to tackle the scenario of using ranging devices only, without angle measurements as the ones provided by USBLs, a SBN system was implemented. All of the work done was only in the surface vehicle that did not had any USBL angle measurement, while the underwater vehicle navigated combining USBL + DVL, as described in previous reports.

The overall system of SBN has 3 components, namely: estimator, planner and tracking that operate in a cascade architecture, as seen in Fig 4.3.1, where $\hat{x}$ is the state estimate, P its associate covariance and $\boldsymbol{u}^*$ the optimal control input.

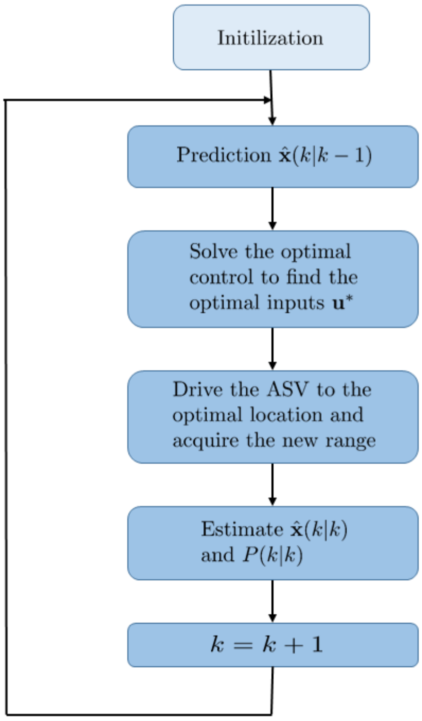


Fig 4.3.1 – SBN architecture diagram

Regarding the estimator, the Extended Kalman Filter described in year 2 report was used, without any USBL measurements. To estimate the underwater vehicle position, it had access to both range and velocity vector measurements once every 6 seconds.

While assuming that the BUDDY vehicle was performing an arbitrary underwater mission, the surface vehicle has to position itself in order to maximize the range information that gets from him. For that an online planner was developed that every time there is a new range measurement, recalculated the trajectory to be tracked.

As our emphasis is on the accuracy of the range-based target localization, we resort to optimal control where the cost functional is the logarithm of the determinant of the Fisher information matrix (FIM). As the inverse of the FIM is a lower bound for the achievable covariance by any unbiased estimator, maximizing the FIM lowers the covariance, thereby improves the accuracy. To achieve this goal for the single-target scenario, we provide first provide optimal trajectories analytically.

The planner block in Fig 4.3.1. solves the optimal control problem. As a first it solves the optimal control problem to find the optimal sequence of inputs for the next six samples, that is, it provides optimal values for the piecewise constant body-speed and the heading angle for the next six samples. In the next step, we apply the first optimal speed and heading angle to the surface vehicle to drive to the optimal location to acquire the ranges. The process is repeated at this new optimal location.

T4.4. Experiments and performance evaluation

Single Beacon Navigation (SBN)

Some preliminary results on SBN are shown in the figure 4.4.1, where the underwater vehicle was performing a mission at 0.2 m/s (purple/pink dots). As one can see, in the beginning of the mission, the radius that the surface vehicle does around the underwater is bigger, due to the higher covariance of the estimator, reducing to a asymptotic value in the middle of the mission.

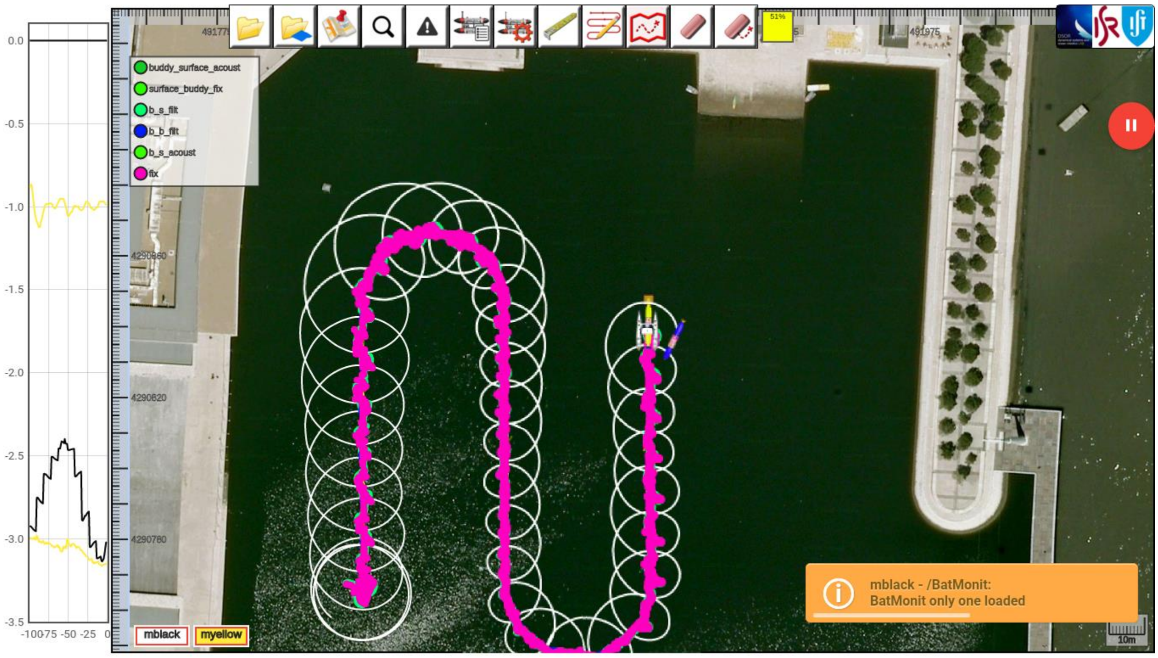


Fig. 4.4.1.

WP5 Integration and validation

T5.1. System integration

Acoustic modem and positioning integration

The CADDY vehicle and Diver units have been upgraded to the latest hardware and software for the Seatrac underwater acoustic communication/positioning network. This incorporates broader band signal transmission for improved multipath rejection on the USBL fix and improved calibration routines. The latest testing results on the Seatrac units provided for the CADDY project are shown in figure 5.1.1 where the white trace is the USBL fix and the blue trace is from DGPS. These were generated with a USBL at the yellow marker position and a modem suspended 2-3m below a boat with co-located GPS receiver.

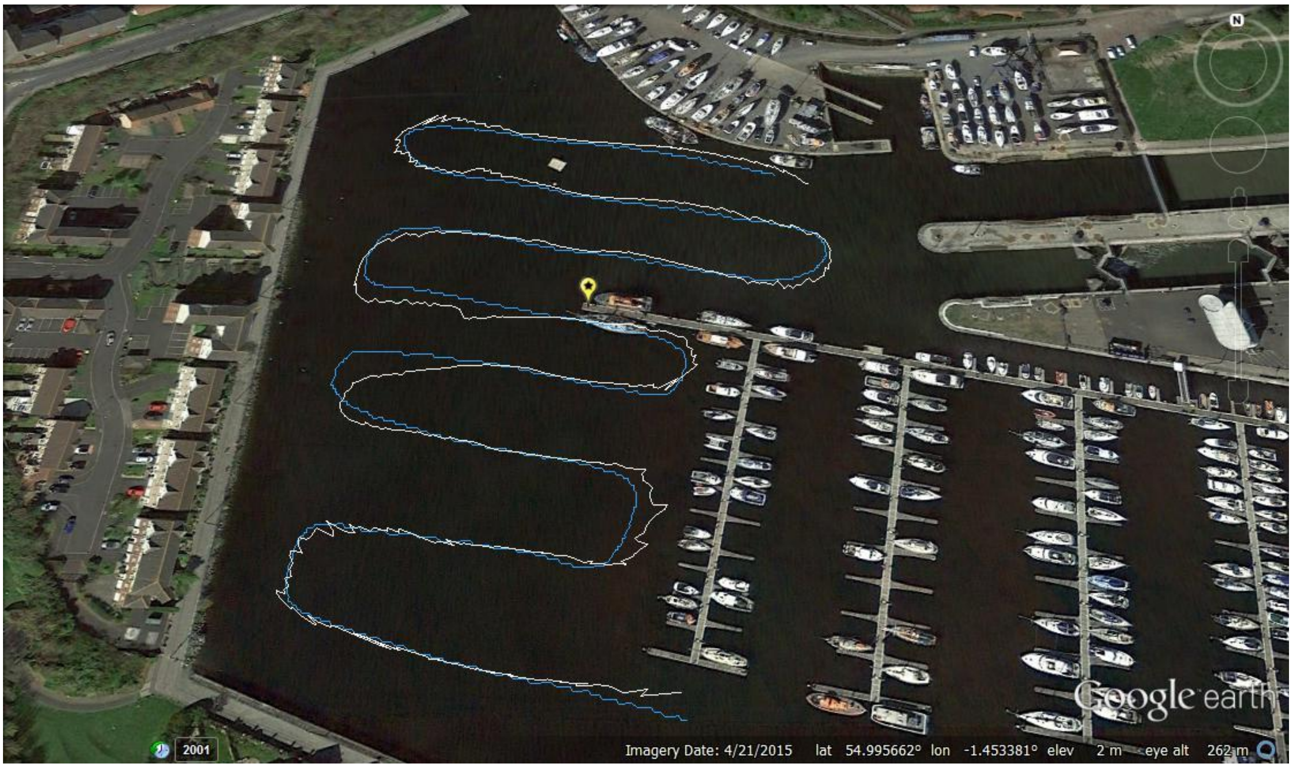


Figure 5.1.1 – USBL positioning performance from latest broader band Seatrac units

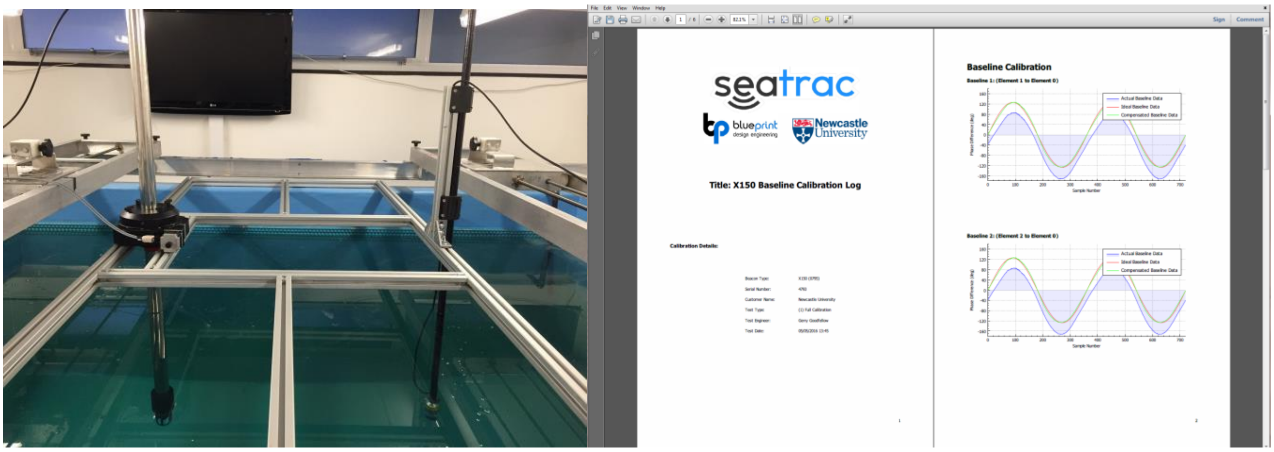


Figure 5.1.2 – USBL automated calibration rig

The calibration procedure for the Seatrac USBL units is now fully automated, using UNEW's acoustic calibration tank, to allow it to be applied efficiently to all of the hardware used in CADDY and this facility and process is being replicated by our industrial partner for production units. The calibration process generates automatic reports and the calibration files which are programmed into EEPROM on the Seatrac units.

The higher data rate DSSS modulation mode is now operating on Seatrac units and integration with the serial command interface is complete to enable it to be tested with the existing ROS communication drivers. Final testing of communication performance has started at UNEW.

Software integration week in Zagreb

On the week of 16th May, the CADDY team was together in Zagreb in order to prepare the final October trials without all the team and equipment that the latter require. Simulations were carried out along with real diver data acquisition that proved out to be really useful to integrate software developed by different partners and to take notes on what needs further development.

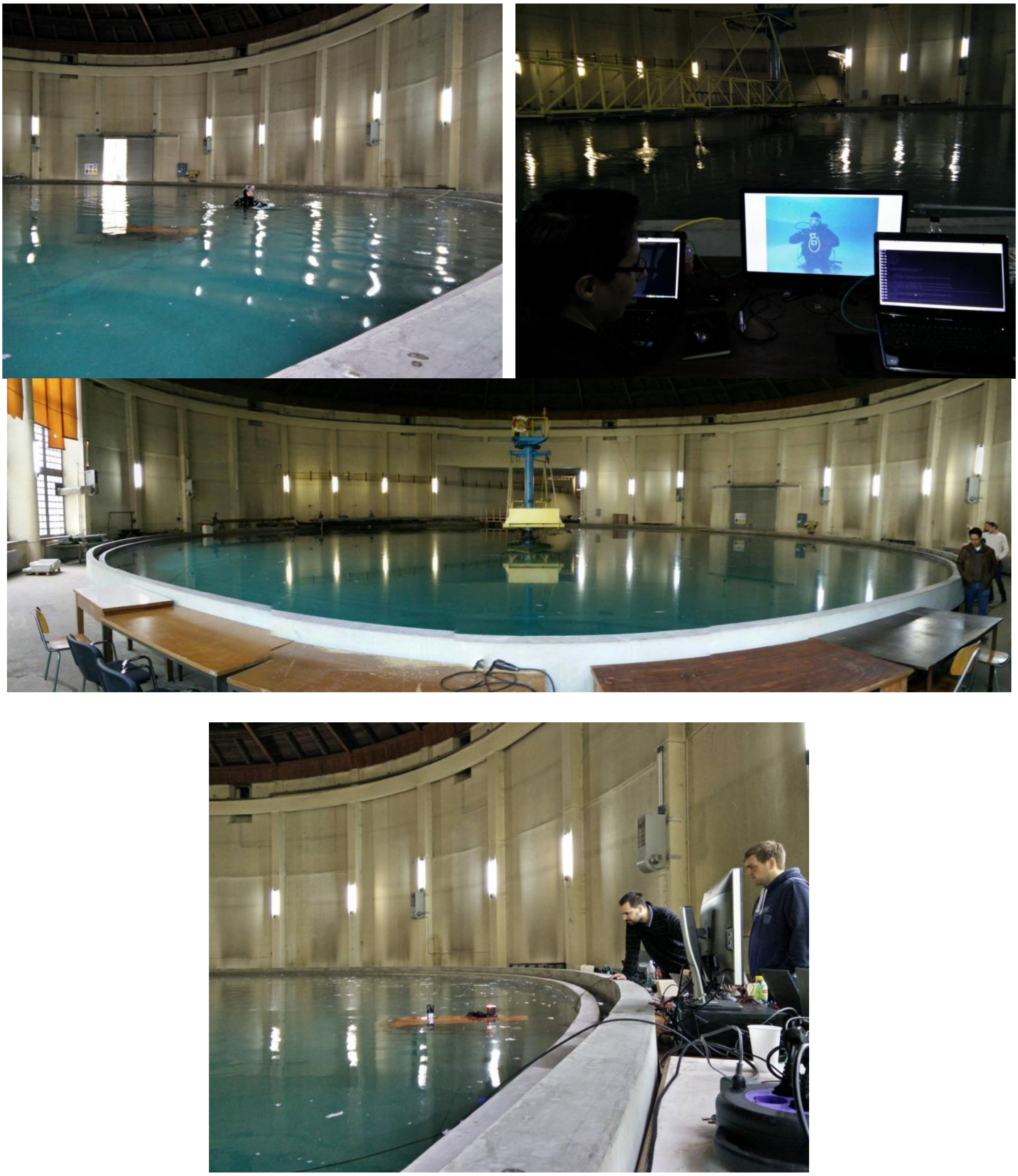


Figure 5.1.2 – Zagreb software integration week

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

T6.2. Regulatory and professional acceptance road-map

T6.3. Automatic diver status report generation system

Diver state monitor

Diver state monitor is a small factor GUI that shows the supervisor real time diver status using several critical values like: heart rate, breathing rate, paddling rate, motion rate, calculated PAD space. These values are calculated by the diver underwater tablet and transmitted periodically through acoustic messaging. There are three alarms sent through acoustic messaging: Breathing rate, Heart rate, Flipping difference; which are generated when the corresponding value surpasses a certain threshold. Each alarm received on the top side is shown as a pop-up dialog to divert the supervisor's attention and reduce response time.

Developed using WxWigdets and as an RQT plugin, it can be run on any machine with ROS installed. When run as standalone GUI it enables two graphic modes:

Compact view – small factor window, indented to be kept on top (or on the side) of a mission control GUI. Shows heart rate, breathing rate, paddling rate, motion rate, calculated PAD space current values. Compact view enables the operator to work in the mission control GUI while still being able to keep watch of the diver status.

Extended view – extends the compact view with graphs showing heart rate, breathing rate, paddling rate, motion rate trends and alarms history list containing alarm type and corresponding timestamps.

Pop-up dialog windows are generated for each alarm to divert supervisor's attention to diver status and potential health problem.

Testing and validation summary:

Shown values:

Heart rate (bpm) - validated
Breathing rate (bpm) - validated
Paddling rate (ppm) - validated
Motion rate - validated
PAD space (not tested) - not tested

Alarms:

Breathing rate - validated
Heart rate - validated
Flipping difference - validated

WP7 Dissemination and exploitation

Task 7.1 Reporting and outreach

<u>Main activities</u>

One of the main activities is continuous update of the official CADDY web-site (www.caddy-fp7.eu) with recent news, developments and results of CADDY project, project deliverables, published papers, press releases, events, etc.

Social media accounts are updated on regular basis:

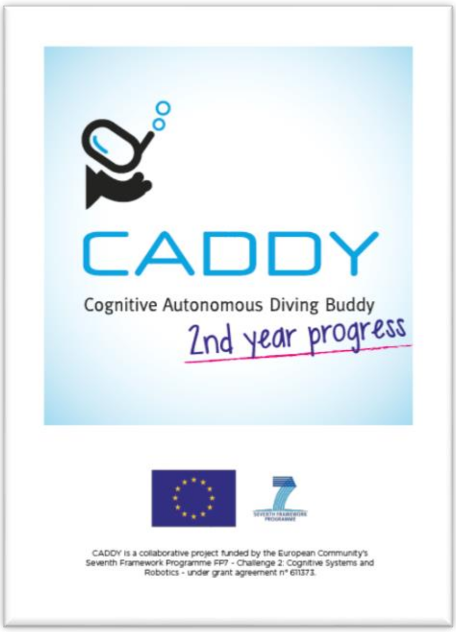
- Facebook page - https://www.facebook.com/caddyproject
- YouTube channel - http://www.youtube.com/user/caddyproject

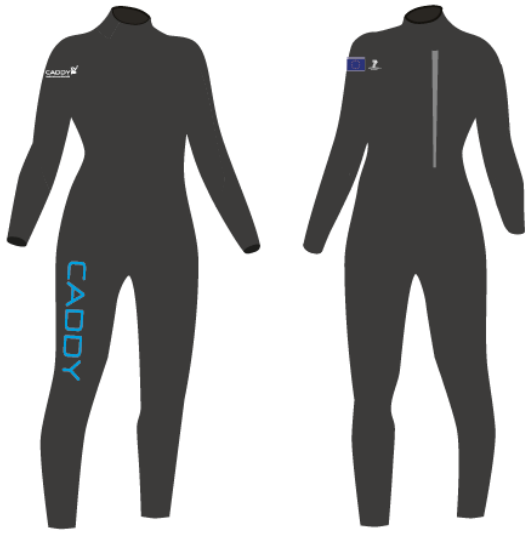
Along with the project web-site and social media accounts, partners' Universities and organizations web-site deliver recent information regarding the project and thus provide a broader reach to possible project's end-users.

In order to achieve best communication between project partners and collaborators Google Drive, Google Calendar and Google Plus are filled with recent information regarding CADDY project.

After the first year of the project and in the last six months materials that describe the meaning and significance of the project and the first year progress and results were made:

- Printed materials for distribution at conferences, workshops, seminars etc.: **"CADDY 2nd year progress" brochure**, which is also available online
- Promotional materials at conferences, workshops, seminars etc.: **CADDY stress relief balls**, **key-rings and magnets**
- **CADDY softshell jackets for staff** – for field trials and experiments but also for promotion at conferences, workshops, seminars etc.
- **CADDY diving suit** – for field trials and experiments but also for promotion at conferences, workshops, seminars etc.





<u>TV/newspaper appearance of CADDY</u>

Publisher	**Partner**	**Country**	**Date**	**Link**
Lider	UNIZG—FER	Croatia	05/03/2016	http://lider.media/tehnopolis/fer-robotikom-duboko-uronio-i-u-podmorje/
Dnevnik.hr	UNIZG—FER	Croatia	26/01/2016	http://dnevnik.hr/vijesti/hrvatska/studenti-zagrebackog-fer-a-osvjetljavaju-hrvatski-obraz-na-svjetskoj-znanstvenoj-sceni---424308.html

<u>Outreach</u>

1. **OCEANOLOGY INTERNATIONAL, 15-17 MARCH, LONDON (UK)**

CADDY was presented in front of **more than 8,400 industry professionals** and alongside **more than 520 exhibiting companies** at the world's premier event for marine science and ocean technology.

Presented equipment:

- MEDUSAs primary surface vehicle by IST
- BUDDY primary underwater vehicle by UNIZG-FER
- PlaDyPos 2.0 backup surface vehicle by UNIZG-FER
- CADDY diving suit and mask by UNIZG-FER and DAN Europe
- USBLs by UNEW

2. EUROPEAN ROBOTICS FORUM – ERF, 20-23 MARCH 2016, LJUBLJANA (SLOVENIA)

CADDY was presented as part of robotics research at UNIZG-FER under affiliation robotics@fer.hr at European Robotics Forum - ERF 2016 **in front of more than 650 visitors**.


3. OPEN DOOR EVENT AT UNIZG-FER: JOBFAIR, 9-10 MAY, ZAGREB (CROATIA)

CADDY was presented alongside other UNIZG—FER LABUST projects as part of the robotics@fer.hr brand. More than 2,000 students got a chance to get to know the laboratories' members, their research and academia activities, and the equipment and technologies used.

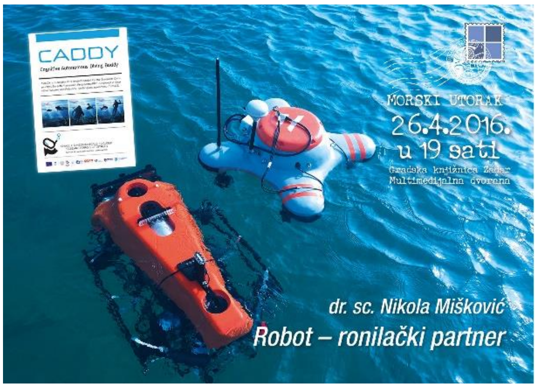
Job Fair is a career fair that was held on 9th and 10th of May in the halls of the Faculty of Electrical Engineering and Computing (FER), University of Zagreb (UNIZG), Croatia. It gathered the best students and companies in the field of electronics, information technology and computing.



4. LECTURE FOR GENERAL AUDIENCE IN THE SCOPE OF EVENT MORSKI UTORAK, 26 APRIL, ZADAR (CROATIA)

On **Tuesday 26.04. Asst. Prof. Nikola Mišković (UNIZG FER, LABUST)** presented CADDY project in front of the general audience in **Zadar, Croatia**. The lecture is organized by **Zadar City Library** (Gradska Knjižnica Zadar) in the scope of regular evening events under the name ***Morski utorak*** - series of lectures held once or twice a month with the themes related to life in the sea.

Evenings are designed in the form of forums, lectures, exhibitions, literary events and book presentations, film, drama and music performances, etc. including some of the most important topics: underwater archeology, maritime navigation, fishing, marine ecology, maritime heritage and shipbuilding, yachting, marine adventure, poetry and prose.



5. **Oceans Business Week, June 2016**

Figure 7.1.1 – Oceans Business Week LARSYS booth with DSOR vehicles

AIP Foundation and the Portuguese Ministry of the Sea promoted “Oceans Business Week”, a large business meeting of the Sea Economy.

This was a space and a single moment where companies and organizations revealed the importance of the sea and oceans in the balance of global ecosystems, the conservation and utilization of marine resources, management of continental shelves and international connectivity.

CADDY project was presented at LARSYS booth in the exhibition space which offered a high visibility for project promoting, catching the attention of international diving community.

Task 7.2 Scientific dissemination

Conferences attended

1. Oceanology International, 15-17 March, London (UK)
2. European Robotics Forum, 20-23 March, Ljubljana (Slovenia)
3. SPARC TG Marine Robotics, 12-13 January, Twente (Netherlands)
4. EMRA'16 – Workshop on EU-funded marine robotics and applications, 14-15 June 2016, Newcastle (UK)
5. IEEE/MTS OCEANS, 10-13 April 2016, Shanghai, China
6. COMPIT- Conference on Computer Applications and Information Technology in the Maritime Industries, 9-11 May 2016, Lecce, Italy

Special sessions

1. **Robotics in the Western Balkans session at European Robotics Forum – ERF 2016, 20 March, Ljubljana (Slovenia)**

Project Coordinator Prof. Nikola Mišković presented CADDY project through UNIZG—FER LABUST projects' presentation and participated in discussion and round table on work on a memorandum for future development and cooperation between interested parties from Western Balkan.

List of scientific publications

1. Nađ, Đ.; Ribeiro, M.; Silva H.; Ribeiro, J.; Abreu, P.; Miskovic, N. and Pascoal, A.; **Cooperative Surface/Underwater Navigation for AUV Path following missions**, 10th IFAC Conference on Control Applications in Marine Systems (CAMS). Trondheim, Norway, 2016.
2. Moreno-Salinas, D.; Crasta, N.; Ribeiro, M.; Bayat, B.; Pascoal, A.; Aranda, J., **Integrated Motion Planning, Control, and Estimation for Range-Based Marine Vehicle Positioning and Target Localization**, 10th IFAC Conference on Control Applications in Marine Systems (CAMS). Trondheim, Norway, 2016.

3. Abreu, P; Botelho, J.; Gois, P.; Pascoal, A.; Ribeiro, J.; Ribeiro, M.; Sebastiao, L.; Silva, H.; **The MEDUSA class of Autonomous Marine Vehicles and their Role in EU Projects**, Proceedings of IEEE/MTS OCEANS, Shanghai, China, 2016
4. M. Bibuli, G. Bruzzone, D. Chiarella, M. Caccia, A. Odetti, A. Ranieri, E. Saggini, E. Zereik. "**Underwater robotics for diver operations support: the CADDY project**". Proc. of the 15th Conference on Computer Applications and Information Technology in the Maritime Industries, Lecce, Italy, 9-11 May 2016.
5. A. G. Chavez, M. Pfingsthorn, R. Rathnam and A. Birk, "**Visual speed adaptation for improved sensor coverage in a multi-vehicle survey mission**," *OCEANS 2016 - Shanghai*, Shanghai, 2016, pp. 1-6.
6. A. G. Chavez, J. Fontes, P. Afonso, M. Pfingsthorn and A. Birk, "**Automated species counting using a hierarchical classification approach with Haar cascades and multi-descriptor random forests**," *OCEANS 2016 - Shanghai*, Shanghai, 2016, pp. 1-6
7. M. Pfingsthorn, R. Rathnam, T. Luczynski and A. Birk, "**Full 3D navigation correction using low frequency visual tracking with a stereo camera**," *OCEANS 2016 - Shanghai*, Shanghai, 2016, pp. 1-6.
8. Max Pfingsthorn and Andreas Birk. **Generalized graph SLAM: Solving local and global ambiguities through multimodal and hyperedge constraints**. The International Journal of Robotics Research May 2016 35: 601-630, first published on June 29, 2015.

<u>**Invited lectures and courses**</u> (containing materials prepared in the scope of the CADDY project)

1. Lecture: "Underwater vision in Robotics in the scope of the EU projects: CADDY, MORPH, DEXROV" at ShanghaiTech University, Shanghai. April 14th, 2016.
2. Invited talk on CADDY project by Project Coordinator Assoc. Prof. Nikola Mišković at European Robotics Forum – ERF2016, 20 March 2016, Ljubljana (Slovenia)
3. Invited talk on CADDY progress in Year 2 by Project Coordinator Assoc. Prof. Nikola Mišković at EMRA'16, 14 July 2016, Newcastle (UK)
4. Invited talk in teh scope of event ***Morski utorak*** by Project Coordinator Assoc. Prof. Nikola Mišković, 26 April 2016, Zadar (Croatia)

Task 7.3 Exploitation

<u>**New board members**</u>

<u>**Commercialisation**</u>

The commercialisation of the Seatrac acoustic modems and USBL via Blueprint Subsea has stepped up and the product is now being actively marketed leading to substantial orders. Sales figures for year 2 have been confirmed as 60 units with a total value of approximately 350k Euro. Orders recently placed account for another 150 units in the first half of year 3.

Task 7.4 Education and training

1. **3rd CADDY WORKSHOP EMRA 2016, 14-15 JUNE, NEWCASTLE (UK)**

EMRA'16

Date: 14 – 15 June 2016

Location: UNEW, Newcastle (UK)

Website:

http://conferences.ncl.ac.uk/emra2016/index.html

The **3rd CADDY Workshop** was organized as a part of the **EMRA'16 - Workshop on EU-funded Marine Robotics and Applications**, which took place at Newcastle University, UK, from 14-15 June, 2015. This event followed on from the previous successful events held in Rome 2014 (CNR) and Lisbon 2016 (IST) and followed a similar format to these events.

The EMRA 2016 workshop presented the latest developments from 10 current EU FP7 and H2020 projects on marine robotics and provided a platform for marine stakeholders to share and discuss current technological challenges and achievements. Together with speakers/ delegates from European industry and end users, future directions and challenges were highlighted. Through group and individual discussions, potential collaborations were identified and the need for closer industry-academic was highlighted.

The workshop brought together a total of 19 speakers from academia, industry and research institutes covering a wide range of topics in subsea robotic technology together with applications in marine science and industry, including deep sea mining, oceanography, geological surveying and oil & gas.

Website: http://conferences.ncl.ac.uk/emra2016/index.html

FP7/HORIZON2020 PROJECTS PRESETED: CADDY, EXCELLABUST, ROBOACADEMY, WiMUST, DexROV, subCULTron, OceanRINGS, VAMOS, STRONGMAR, LAkHsMI

EMRA 2016 INVITED TALKS:

- **Nikola Miskovic**, Laboratory for Underwater Systems and Technologies, UNIZG FER: CADDY Year 2: What we learned from first validation trials
- **Pere Ridao**, Vision and Robotics Research Institute, University of Girona: 3D Survey of Areas with Strong Relief Using Hovering Capable AUVs
- **Jeremi Gancet**, Space Applications Services NV/SA: DexROV: dexterous ROV interventions operated from an onshore control center
- **Alessio Turetta**, Graal Tech s.r.l: Seismic exploration with a swarm of 16 AUVs: from the system design to the first survey at sea
- **Ronald Thenius**, Artificial Life Lab - University of Graz: Subcultron: a learning, self-regulating, self-sustaining underwater society/culture of robots
- **Maarja Kruusmaa**, Centre for Biorobotics, Tallinn University of Technology: Flow sensors for robotics and environmental monitoring

- **Maryam Haroutunian**, School of Marine Science and Technology, Newcastle University: Towards bio-inpiration for underwater vehicles
- **Eduardo Silva**, ISEP / INESC TEC: Underwater mining
- **Edin Omerdic**, Mobile & Marine Robotics Research Centre, University of Limerick: OceanRINGS: Current State of Development and Future Work
- **Guiseppe Casalino**, University of Genova (ISME): DexROV: enabling effective dexterous ROV operations in presence of communication latencies
- **Maaten Furlong**, National Oceanography Centre: Marine Autonomous Systems development at NOC: an overview
- **Fraser Macdonald**, Scottish Association for Marine Science: The Scottish Marine Robotics Facility: Marine observation spanning atmosphere, ocean and ice
- **Miguel Morales Maqueda**, School of Marine Science and Technology, Newcastle University: Water surface height determination with a GPS Wave Glider: A demonstration in Loch Ness, Scotland
- **Guiseppe Casalino**, University of Genova (ISME): ROBUST: Robotic subsea exploration technologies
- **Giovanni Indiveri**, University of Salento (ISME): The WiMUST H2020 project: Widely scalable Mobile Underwater Sonar Technology
- **Jeff Neasham**, School of Electrical & Electronic Engineering, Newcastle University: Low power and low cost underwater acoustic communication & positioning
- **David Lane**, Ocean Systems Laboratory, Heriot-Watt University: ROBOCADEMY ITN: What's Hot and So What - Building Links to Relevant EU Projects
- **Fausto Ferreira**, NATO STO CMRE: Pushing the state of the art through competitions and high level educational programmes

References:

3.4 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	
1.1	Technical and performance characteristics of the robotic diver assistance system consisting of three	1	1	UNIZG-FER	Report	PU	11	30/11/2014	submitted	

	agents									
1.2.1	Initial communication transceiver units, protocols and software	1	1	UNEW	Report	PU	11	30/11/2014	submitted	
3.1	Initial list of gestures and syntax	2	3	CNR	Report	PU	11	30/11/2014	submitted	ver 2 based on reviewers' comments
8.1.1	Minutes of the meetings	1	8	UNIZG-FER	Report	CO	12	10/02/2015	submitted	delayed to include review meeting
6.2.1	Regulatory and professional acceptance road-map – draft	1	6	DAN Europe	Report	PU	13	30/01/2015	submitted	
6.1.2	Evaluation of safe technology	1	6	DAN Europe	Report	PU	13	30/01/2015	submitted	
4.1	Cooperative control and navigation with diver in the loop – HIL simulation results	1	4	CNR	Report	PU	13	20/03/2015	submitted	
1.2.2	Enhanced communication transceiver units, protocols and software.	1	6	UNEW	Other	PU	14	17/03/2015	submitted	
2.3	DiverNet local sensor network integration on diver	1	2	UNEW	Report	PU	17	30/05/2015	submitted	
1.3	Report on integration of the robotic assist. system – experim. and performance	1	1	CNR	Report	PU	17	28/07/2015	submitted	delayed due to larger number of experiments
2.2	Motion compensation algorithms	1	2	JACOBS	Report	PU	18	30/06/2015	submitted	
2.4	An online repos. of diver datasets obtained from remote and local (DiverNet) sensing	1	2	UNIVIE	Other	PU	18	30/06/2015	submitted	
7.4.2	Proceedings of the 2nd CADDY Workshop	1	7	IST	Report	PU	18	27/07/2015 (30/6/2015)	submitted	

8.3.2	Six-month project report	1	8	UNIZG-FER	Report	PU	18	30/6/2015	submitted	
2.2	Motion compensation algorithms	1	2	JACOBS	Report	PU	18	10/07/2015 (30/6/2015)	submitted	
2.4	An online repository of diver datasets obtained from remote (video, sonar) and local (DiverNet) sensing	1	2	UNIVIE	Other	PU	18	30/6/2015	submitted	
5.2	Report on first validation trials: execution procedures, results and initial assessment	1	1	UNIZG-FER	Report	PU	22	30/11/2015 (30/10/2015)	submitted	
6.1.3	Evaluation of safe technology	1	6	DAN Europe	Report	PU	23	31/11/2015	submitted	
8.1.2	Minutes of the meetings	1	8	UNIZG-FER	Report	CO	24	31/03/2016 (31/12/2015)	submitted	delayed to include review meeting
3.2	Symbolic language interpreter	1	3	CNR	Report	PU	25	04/02/2016 (31/01/2016)	submitted	
2.5	Algorithms for diver pose estimation through remote and local sensing	1	2	JACOBS	Report	PU	28	09/06/2016 (31/04/2016)	submitted	delayed due to larger number of experiments
2.6	Algorithms for recognition of diver symbols and special gestures for execution of compliant tasks	1	2	CNR	Report	PU	28	03/05/2016 (30/04/2016)	submitted	
4.2	Implementation of cooperative control and formation keeping with diver in the loop	1	4	CNR	Report	PU	29	31/05/2016	submitted	
4.3	Implementation of cooperative navigation algorithm	1	4	IST	Report	PU	29	31/05/2016	submitted	

3.3	A Petri net-based online mission replanner with diver symbol inputs	1	3	CNR	Report	PU	30	30/06/2016	submitted	
7.4.3	Proceedings of CADDY workshop 3	1	7	UNEW	Report	PU	30	04/07/2016 (30/06/2016)	submitted	
8.3.3	Six-month project report	1	8	UNIZG-FER	Report	PU	30	30/6/2016	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
1	Integrated diver assistance systems	1	UNIZG-FER	30/11/2014	Yes	30/11/2014	
2	First validation trials completed	1, 2, 3, 4, 5	UNIZG-FER	31/10/2015	Yes	31/10/2015	

3.5 Project management

3.5.1 Management activities

In the following part, we give a short overview of the meetings that took place during M25 – M30 of the project. All the meeting minutes and agendas are available in the Google Drive.

1. **07/01/2016 :: technical meeting Skype**

The topic of the meeting was acoustic interrogation scheme (CNR, IST, UNIZG-FER).

2. **26/01/2016 :: technical meeting Skype**

The topic of the meeting was determining diver orientation from stereo camera (JACOBS, UNIZG-FER).

3. **02/02/2016 :: technical meeting Skype**

The topic of the meeting was related to issues on thermal camera (DAN Europe, UNIZG-FER).

4. **05/02/2015 :: 2nd Review meeting**

The second review meeting took place in Pavilhão do Conhecimento – Ciência Viva (http://www.pavconhecimento.pt/contactos/?lang=2) in Lisbon, Portugal and was hosted by IST. The goals of the meeting were to:

- familiarize the reviewers with CADDY activities in Year 2
- acknowledge reviewers' comments

The meeting was successful and was followed by reviewers' comments on how to proceed with the project.

5. **04/03/2016 :: SB & EB meeting after 2nd review meeting, Lisbon, Portugal**

This meeting was held the day after the review meeting. The goals of the meeting were to:

- Discuss reviewers' comments
- Establish a detailed workplan and deliverable list for the following period
- Make arrangements for Oceanology'16 exhibition, EMRA'16, and BtS'16
- Make arrangements for second validation trials

6. **13/06/2016 :: SB & EB meeting, Newcastle, UK**

This meeting was held prior to 3rd CADDY workshop (EMRA workshop) at UNEW, Newcastle, UK. The goals of the meeting were to:

- Discuss reviewers' comments
- Establish a detailed workplan and deliverable list for the following period
- Make arrangements for BtS'16
- Make arrangements for second validation trials

3.5.2 Dissemination and use of knowledge

These activities are described in Chapter 3.3. under WP7.

3.6 Explanation of the use of the resources and financial statements

3.6.1 Justification of major cost items and resources

UNIZG-FER:
Personnel:
- Antonio Vasilijević is working approx. 80% of his time on the project, Zoran Vukić 50% and Nikola Mišković (project Coordinator) 30%
- Filip Mandić is hired 100% on the project. Salary of Filip Mandić is covered by the Croatian Science Foundation
- Đula Nađ have been working approx. 90% of his time on the project

Major equipment:
No major purchase went in period M25 – M30

Travel:
For travel we spent around 17.000 EUR. This includes all meetings, workshops, conferences and field trials for UNIZG-FER staff and Advisory Board members

UNIVIE:
UNIVIE bought two flight cases for the safe transport of equipment to the meeting in Lisbon and London (Costs: see the financial report)

3.6.2 Budgeted versus Actual Costs

TABLE 4: COST/BUDGET FOLLOW-UP TABLE												
Contract N°:	**611373**	**Acronym: CADDY**					**Date:**	**01.01.2014. - 31.12.2015.**				
Beneficiaries	**TYPE of EXPENDITURE (as defined by participants)**	**BUDGET Whole project**	**ACTUAL COSTS (EUR)**					**% spent**				**Remaining Budget (EUR)**
			Period 1	**Adj**	**Period 2**	**Period 3**	**Total**	**Year 1**	**Year 2**	**Year 3**	**Total**	
		e	*a1*	*adj1*	*b1*	*c1*	*e1*	*a1/e*	*a1+b1/e*	*a1+b1+c1/e*	*a1+b1+c1+d1/e*	*e-e1*
UNIZG-FER	**Person-months**	**120**	39,3		45,42	27,74	**112,46**	33%	71%	94%	94%	**7,54**
	Personnel costs	**318.900**	82.558		106.906	67.555	**257.019**	26%	59%	81%	81%	**61.881**
	Subcontracting	**19.500**	2.469		1.773	6.156	**10.398**	13%	22%	53%	53%	**9.102**
	Equipment/ consumables	**120.000**	117.022	-9	9.293		**126.306**	98%	105%	0%	105%	**-6.306**
	Travel	**96.900**	24.728		43.384		**68.112**	26%	70%	0%	70%	**28.788**
	Other direct costs	**36.000**	11.891	458	12.668	40.763	**65.780**	33%	68%	181%	181%	**-29.780**
	Indirect costs	**343.080**	141.718	269	103.351	64.991	**310.329**	41%	71%	90%	90%	**32.751**
	Total Costs	**934.380**	**380.386**	**718**	**277.375**	**179.465**	**837943,62**	**41%**	**70%**	**90%**	**90%**	**96.436**
CNR	**Person-months**	**94**	33,1		33,84	20	**86,94**	35%	71%	92%	92%	**7,06**
	Personnel costs	**376.000**	136.677		129.479	73.720	**339.876**	36%	71%	90%	90%	**36.124**
	Subcontracting	**2.400**	0		0	0	**0**	0%	0%	0%	0%	**2.400**
	Equipment/ consumables	**20.700**	0		20.351		**20.351**	0%	98%	0%	98%	**349**
	Travel	**49.200**	18.924		11.163		**30.087**	38%	61%	0%	61%	**19.113**
	Other direct costs	**30.000**	7.241			14.005	**21.246**	24%	0%	71%	71%	**8.754**
	Indirect costs	**262.824**	89.114	-1.231	83.254	42.389	**213.526**	34%	66%	82%	82%	**49.298**
	Total Costs	**741.124**	**251.956**	**-1.231**	**244.247**	**130.114**	**625086**	**34%**	**67%**	**85%**	**85%**	**116.038**
IST	**Person-months**	**76**	25,6		21,10	14,65	**61,35**	34%	61%	81%	81%	**14,65**
	Personnel costs	**394.000**	155.607		124.566	87.554	**367.727**	39%	71%	93%	93%	**26.273**
	Subcontracting	**2.500**	0		0		**0**	0%	0%	0%	0%	**2.500**
	Equipment/ consumables	**40.000**	41		6.159		**6.200**	0%	16%	0%	16%	**33.800**
	Travel	**47.000**	7.165		23.344		**30.509**	15%	65%	0%	65%	**16.491**
	Other direct costs	**27.500**	0		13.285	15.320	**28.605**	0%	48%	104%	104%	**-1.105**
	Indirect costs	**346.200**	104.341		85.814	59.560	**249.715**	30%	55%	72%	72%	**96.485**
	Total Costs	**857.200**	**267.154**	**0**	**253.168**	**162.434**	**682756**	**31%**	**61%**	**80%**	**80%**	**174.444**
JACOBS	**Person-months**	**63**	13,08		30,59	16,5	**60,1725**	21%	69%	96%	96%	**2,8275**

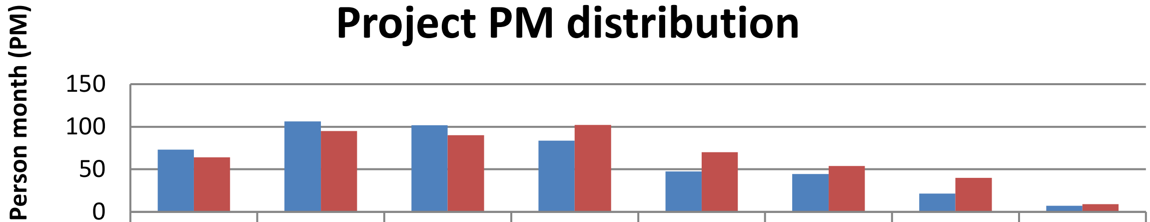
	Personnel costs	**308.800**	50.078		129.796	71.350	**251.224**	16%	58%	81%	81%	**57.576**
	Subcontracting	**2.500**	0		0	0	**0**	0%	0%	0%	0%	**2.500**
	Equipment/ consumables	**31.000**	0		3.045		**3.045**	0%	10%	0%	10%	**27.955**
	Travel	**34.000**	5.198		18.045		**23.243**	15%	68%	0%	68%	**10.757**
	Other direct costs	**14.000**	0		0	13.279	**13.279**	0%	0%	95%	95%	**721**
	Indirect costs	**232.680**	33.165		90.531	50.777	**174.473**	14%	53%	75%	75%	**58.207**
	Total Costs	**622.980**	**88.441**	**0**	**241.417**	**135.405**	**465263,46**	**14%**	**53%**	**75%**	**75%**	**157.717**
UNIVIE	**Person-months**	**70**	33,82		30,04	12,2	**76,06**	48%	91%	109%	109%	**-6,06**
	Personnel costs	**384.762**	132.043		127.016	60.056	**319.115**	34%	67%	83%	83%	**65.647**
	Subcontracting	**2.500**	0		0	0	**0**	0%	0%	0%	0%	**2.500**
	Equipment/ consumables	**10.000**	4.313		3.637		**7.950**	43%	80%	0%	80%	**2.050**
	Travel	**32.000**	4.473	1.324	5.195		**10.992**	14%	30%	0%	30%	**21.008**
	Other direct costs	**10.000**	0		0	5.696	**5.696**	0%	0%	57%	57%	**4.304**
	Indirect costs	**262.057**	84.497	794	81.508	39.451	**206.250**	32%	63%	78%	78%	**55.807**
	Total Costs	**701.319**	**225.326**	**2.118**	**217.356**	**105.203**	**550003,4**	**32%**	**63%**	**78%**	**78%**	**151.316**
UNEW	**Person-months**	**49**	17		20,77	9	**46,77**	35%	77%	95%	95%	**2,23**
	Personnel costs	**222.700**	70.610		98.254	36.467	**205.331**	32%	76%	92%	92%	**17.369**
	Subcontracting	**0**	0		0	0	**0**	0%	0%	0%	0%	**0**
	Equipment/ consumables	**27.000**	15.816		2.516		**18.332**	59%	68%	0%	68%	**8.668**
	Travel	**26.300**	4.985		8.143		**13.128**	19%	50%	0%	50%	**13.172**
	Other direct costs	**30.000**	0		0	16.310	**16.310**	0%	0%	54%	54%	**13.690**
	Indirect costs	**183.600**	54.845		65.347	31.666	**151.858**	30%	65%	83%	83%	**31.742**
	Total Costs	**489.600**	**146.256**	**0**	**174.260**	**84.443**	**404959,36**	**30%**	**65%**	**83%**	**83%**	**84.641**
DAN	**Person-months**	**52**	12,5		20,3	8,66	**41,46**	24%	63%	80%	80%	**10,54**
	Personnel costs	**259.000**	72.813		119.726	50.357	**242.896**	28%	74%	94%	94%	**16.104**
	Subcontracting	**2.500**	0		0	0	**0**	0%	0%	0%	0%	**2.500**
	Equipment/ consumables	**40.000**	11.525		5.263		**16.788**	29%	42%	0%	42%	**23.212**
	Travel	**23.500**	8.797		9.459		**18.256**	37%	78%	0%	78%	**5.244**
	Other direct costs	**10.000**	112		0	9.500	**9.612**	1%	0%	96%	96%	**388**
	Indirect costs	**199.500**	55.951		80.669	35.377	**171.997**	28%	68%	86%	86%	**27.503**
	Total Costs	**534.500**	**149.198**	**0**	**215.117**	**95.234**	**459548,6**	**28%**	**68%**	**86%**	**86%**	**74.951**
TOTAL	**Sum Person-months**	524	174,4	0	202,0625	108,75	**485,2125**	33%	72%	93%	93%	**38,7875**
	Sum Personnel costs	**2.264.162**	**700.386**	**0**	**835.743**	**447.058**	**1.983.187**	31%	68%	88%	88%	**280.975**

	Sum Subcontracting	**31.900**	**2.469**	**0**	**1.773**	**6.156**	**10.398**	8%	13%	33%	33%	**21.502**
	Sum Equip / consum	**288.700**	**148.717**	**-9**	**50.264**	**0**	**198.972**	52%	69%	0%	69%	**89.728**
	Sum Travel	**308.900**	**74.270**	**1.324**	**118.733**	**0**	**194.327**	24%	62%	0%	62%	**114.573**
	Other direct costs	**157.500**	**19.244**	**458**	**25.953**	**114.873**	**160.528**	12%	29%	102%	102%	**-3.028**
	Sum Indirect costs	**1.829.941**	**563.631**	**-167**	**590.474**	**324.211**	**1.478.148**	31%	63%	81%	81%	**351.793**
	Total Costs	**4.881.103**	**1.508.717**	**1.606**	**1.622.940**	**892.298**	**4025560,44**	**31%**	**64%**	**82%**	**82%**	**855.543**

3.6.3 Planned versus Actual effort

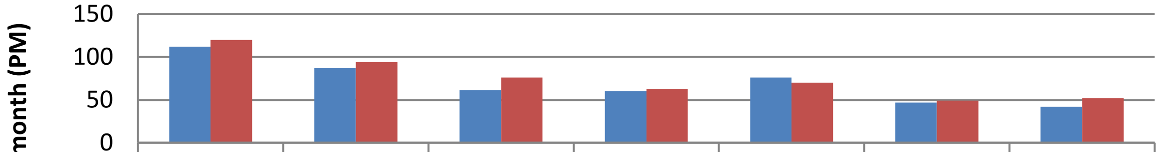
PERIOD: 3 => 01/01/2016 - 30/06/2016			UNIZG-FER	CNR	IST	JACOBS	UNIVIE	UNEW	DAN	TOTALS
Workpackage 1:	Robotic diver assistance system	Actual WP total:	0	0	0	0	0,2	0	0	*0,2*
		Planned WP total:	15	16	12	9	0	12	0	*64*
Workpackage 2:	Seeing the diver	Actual WP total:	0	0	0,48	9	1	6	0	*16,5*
		Planned WP total:	20	6	4	24	13	24	4	*95*
Workpackage 3:	Understanding the diver	Actual WP total:	0	12	1,39	4	11	0	3,6	*32*
		Planned WP total:	0	27	6	10	35	0	12	*90*
Workpackage 4:	Diver-robot cooperation and control	Actual WP total:	8,23	7	6,99	0	0	0	0,3	*22,5*
		Planned WP total:	29	26	34	5	5	2	1	*102*
Workpackage 5:	Integration and validation	Actual WP total:	2,73	0	3,29	3,5	0	2	0	*11,5*
		Planned WP total:	19	12	13	10	8	4	4	*70*
Workpackage 6:	Diver safty and regulations issues	Actual WP total:	15,56	0	0	0	0	0	4	*19,6*
		Planned WP total:	24	0	0	0	4	0	26	*54*
Workpackage 7:	Dissemination and exploitation	Actual WP total:	0,65	1	2,39	0	0	1	0,6	*5,64*
		Planned WP total:	10	6	6	4	4	6	4	*40*
Workpackage 8:	Managemet	Actual WP total:	0,57	0	0,11	0	0	0	0,16	*0,84*
		Planned WP total:	3	1	1	1	1	1	1	*9*
Total Project Person-months		Actual total:	27,74	20	14,65	16,5	12,2	9	8,66	*109*
		Planned total:	120	94	76	63	70	49	52	*524*

Project PM distribution



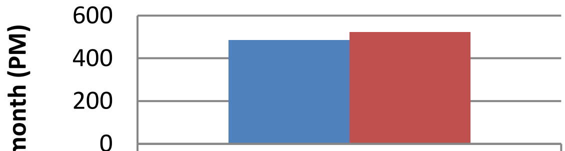
	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8
Actual	73,14	106,208	101,72	83,7	47,68	44,37	21,35	7,05
Planned	64	95	90	102	70	54	40	9

Total PM distribution per partner



	UNIZG-FER	CNR	IST	JACOBS	UNIVIE	UNEW	DAN
Actual	112	86,94	61,35	60,168	76,07	46,89	41,8
Planned	120	94	76	63	70	49	52

Total PM distribution



	TOTAL
Actual	485,218
Planned	524

3.7 Financial Statements – Form C and Summary Financial Report

3.8 Certificates on the Financial Statements