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FP7-ICT-2013-10

D5.3. Report on second validation trials: execution procedures and results

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Dissemination level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

1 Introduction

Second validation trials were performed from 10.10.2015 to 21.10.2015. in Biograd na moru, Croatia. Trials were, per the project timeline, scheduled close to the end of the project when all components and functionalities of the system were developed. The second validation trial assessed full system functionalities, validating the project accomplishments, eventually providing the guideline for the future work.

Figure 1 Debriefing session during the CADDY validation trials in Biograd na Moru

The basis for defining validation activities was Validation Plan presented in D5.1. and Report from the first validation trials D5.2.

Validation procedures and criteria were designed to incorporate planned real-life validation scenarios and divers (end-users) preferences. Sections 2 to 4 elaborate validation experiment in details, present results. Divers subjective evaluation of the validation task is recorded in ANNEX A of the section 5. Final conclusion based on evaluation of the results (objective measures) and subjective, diver's validation task evaluation is provided in the section 6.

2 Validation scenario

Scenario for the CADDY validation mission was motivated by real-life tasks: Search & Rescue and Underwater Archaeology. To design the mission which covers envisioned scenarios but also addresses end-user (divers) specific interest and expectation from the CADDY system, we created questionnaire to be filled out by divers before mission design. The CADDY system functionalities proposed in the questionnaire were compiled to incorporate most common functionalities of the Search & Rescue and Underwater Archaeology missions. Validation mission was finally design by fusing the real-life scenarios with divers' preferences.

2.1 Divers specific preferences

Divers, end-users of the CADDY system filled out the questionnaire expressing their specific application preferences. The results from the questionnaire were:

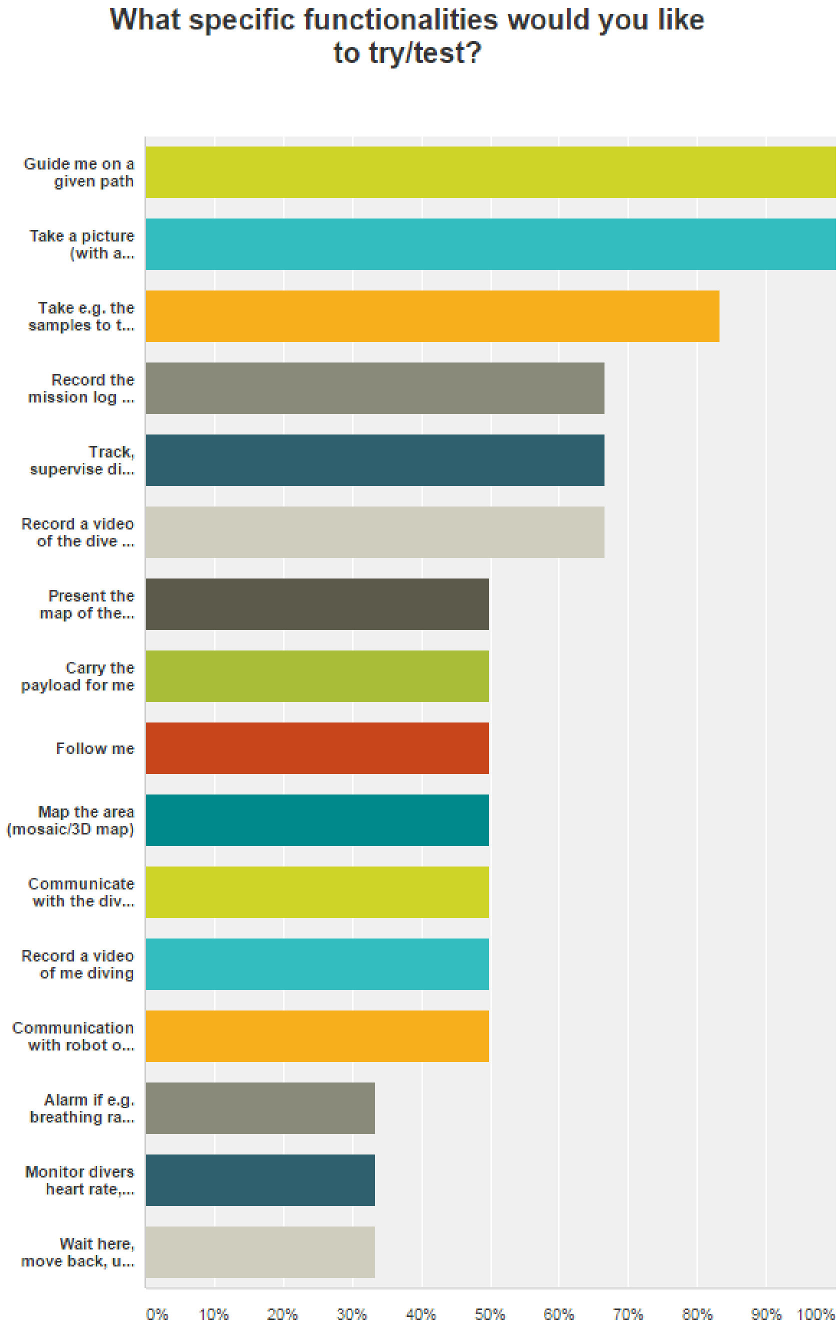


Figure 2 Bar graph – diver's preferences

Answer Choices	Responses
Guide me on a given path	100.00%
Take a picture (with a location tag) or save my position	100.00%
Take e.g. the samples to the surface or bring me e.g. tool from the surface	83.33%
Record the mission log and reconstruct the events - "black box mode"	66.67%
Track, supervise diver from the surface using graphic interface	66.67%
Record a video of the dive for analisys	66.67%
Present the map of the logged positions and tagged pictures (google earth like) after the end of the dive	50.00%
Carry the payload for me	50.00%
Follow me	50.00%
Map the area (mosaic/3D map)	50.00%
Communicate with the diver or robot during the dive/mission	50.00%
Record a video of me diving	50.00%
Communication with robot or surface using underwater table, diving signs or gestures	50.00%
Alarm if e.g. breathing rate is too high	33.33%
Monitor divers heart rate, breathing rate or emotion clues from the surface	33.33%
Wait here, move back, up or down	33.33%

Figure 3 Diver's preferences

Q: Do you have any comment or other functionality to suggest?

A: The alarm function, if something happens with the diver during the dive

Based on a result from the questionnaire, functionalities chosen for the final validation trial were: "guide me", "take a picture", "take something to the surface", "supervise diver during the mission" etc.

2.2 Validation mission design

During the first validation trials functionality of BUDDY vehicle, supported by surface vehicle, to perform high-tracking-quality lawn-mower mission was validated. Mission was initiated using CADDIAN. Collected data were processed offline to create the mosaic of the mission area giving us opportunity to localize object of interest. Designed validation scenario for the second trials was continuation of this real-life task to find and recover the previously localized object with support of the CADDY robotic fleet. The scenario incorporated functionalities pointed out by the diver in the questionnaire.

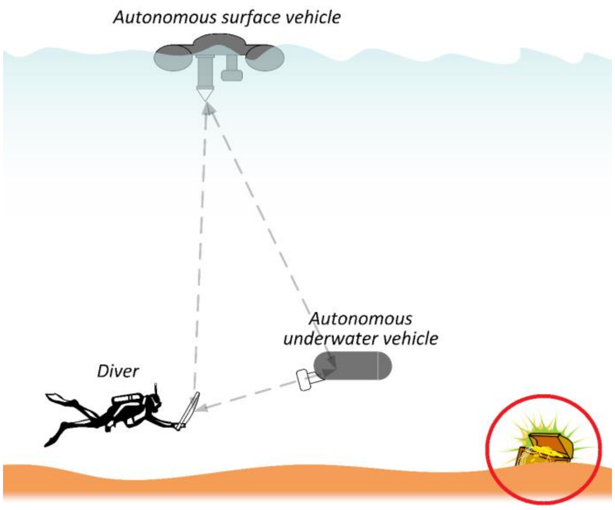
Specific objectives were to validate functionalities:

- Dive guide
    - to guide the diver efficiently to find/detect the object/objects located on **the known position** even in the case of unfavourable divers behaviour and willingness to cooperate

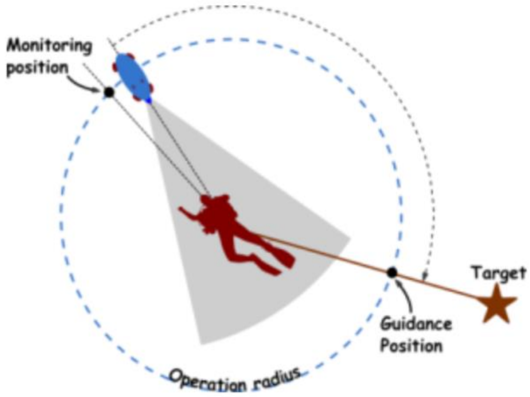
- Dive slave
    - to geo-reference objects of interest
    - to collect data for object identification, geo-referenced image or 3D image
    - to recover selected objects, i.e., to take it to the surface
- Dive observer
    - to monitor/supervise diver states in real-time during the mission
    - to trigger alarm on e.g. high breathing rate

2.3 Validation Procedure:

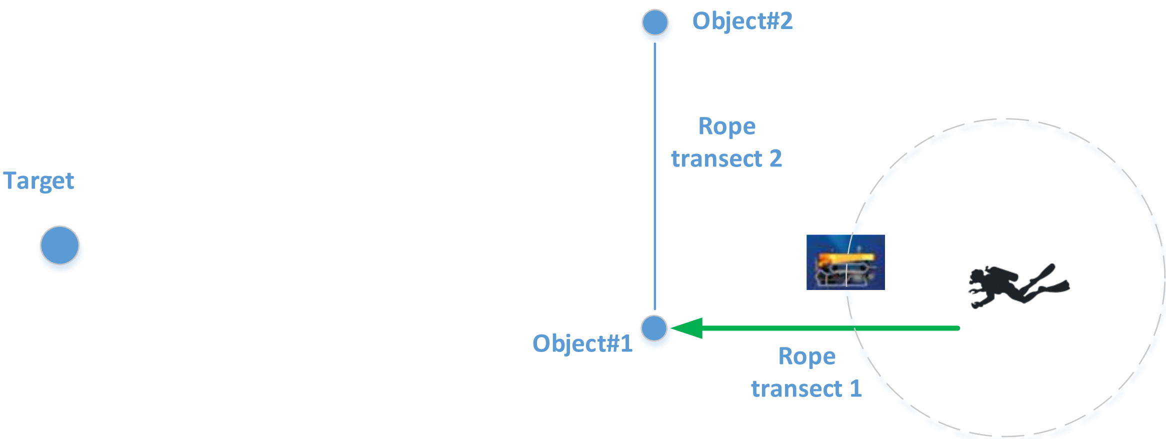
1. Briefing:
    a. All participants in the trial are briefed about the mission scenario and plan. Participants are divers and diving supervisor, CADDY system operators and CADDY supervisor.
    b. Diver learns CADDIAN signs needed for this task
    c. Perform the Pre Dive Check. The diving supervisor and CADDY supervisor must perform the required checks before each dive according to the safety recommendations given in deliverable D6.1. Post dive checks are post dive debrief meetings are also recommended.
    d. Pre-dive safety briefing for human-robot diving. Check of robot safety devices.
2. Diver wears DiverNet and tablet, BUDDY vehicle is underwater while surface vehicle is on the surface, half way in between underwater agents.



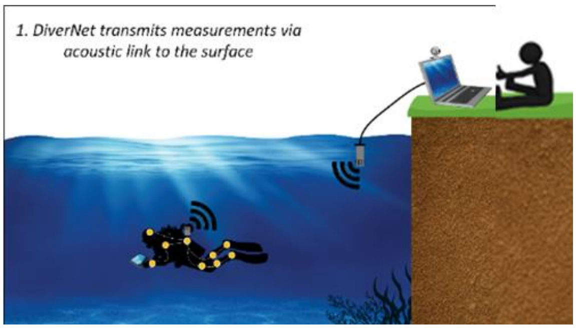
3. BUDDY performs pointer manoeuvre observing the diver at all time.



4. Diver searches for the target i.e. follows the transect1 (rope) laid down on the seabed.

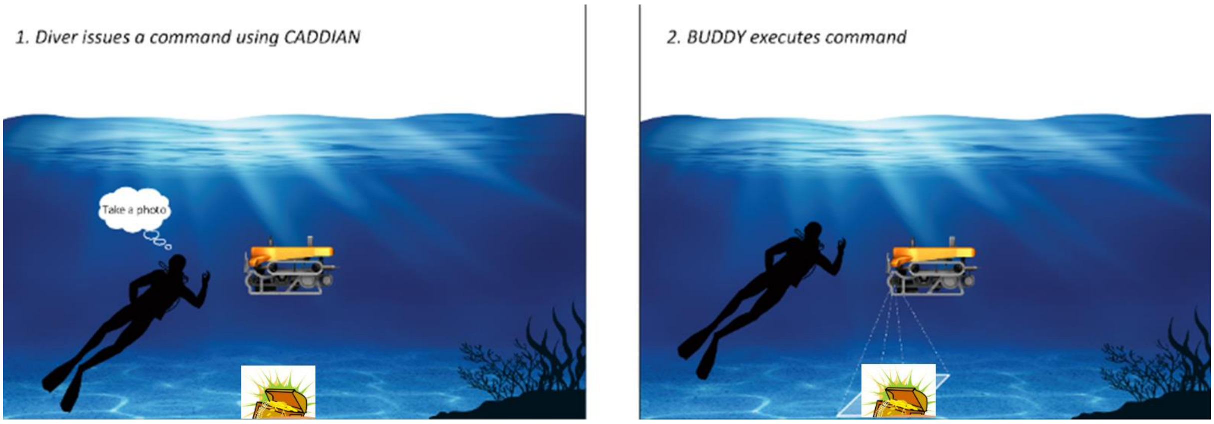


5. Mission is supervised from the surface centre.

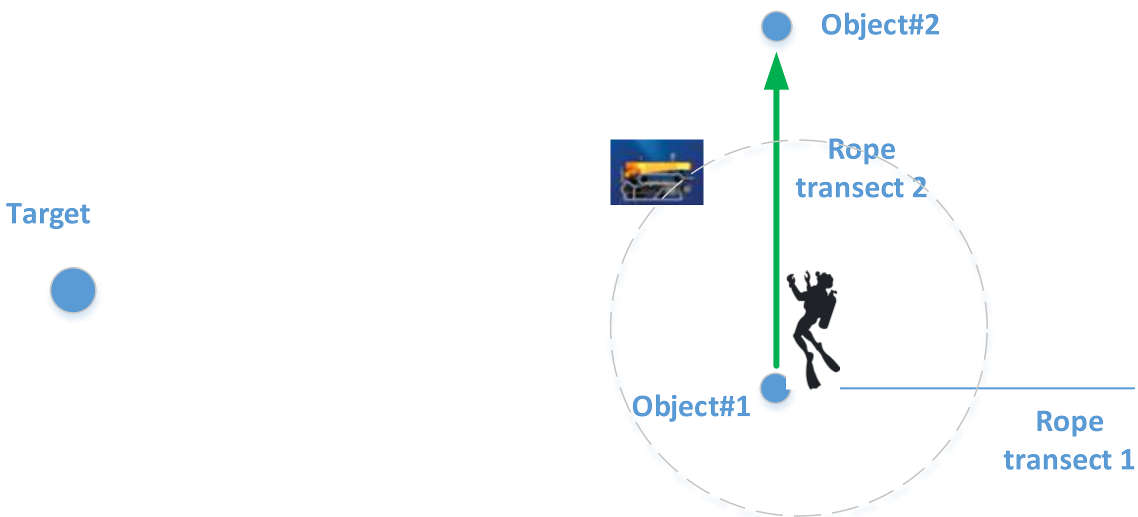


6. At the end of the first seabed transect object#1 is found. Diver informs surface centre that object#1 is spotted.

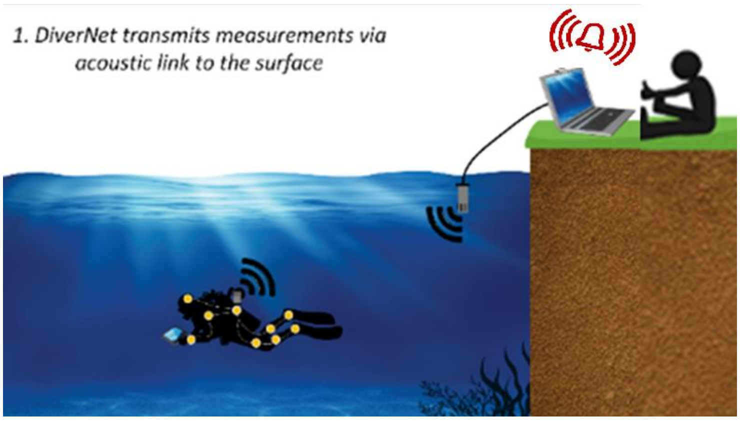
7. Diver orders BUDDY to take a picture of object#1 using CADDIAN.



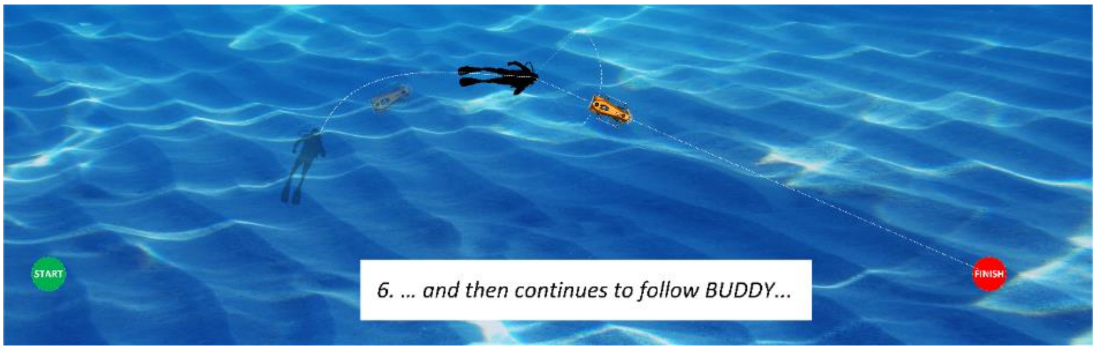
8. Diver continues along second transect laid down on the seabed. BUDDY monitors the diver.

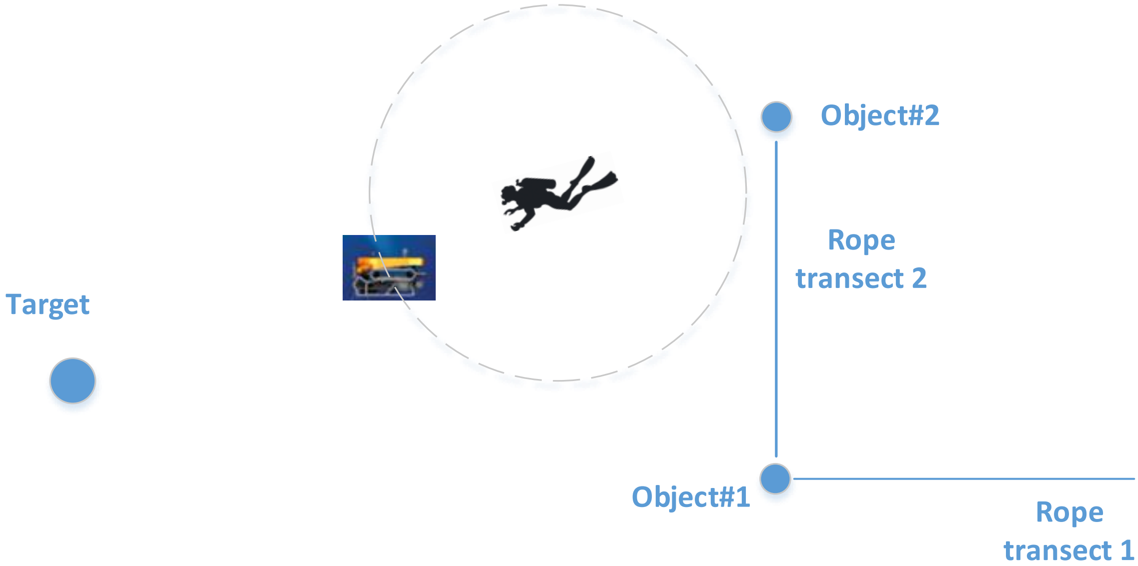


9. Diver informs surface centre that he/she reached the end of the second seabed transect.
10. Diver receives message from the surface to simulate high breathing rate.
11. Alarm of high breathing rate is received in the control centre.



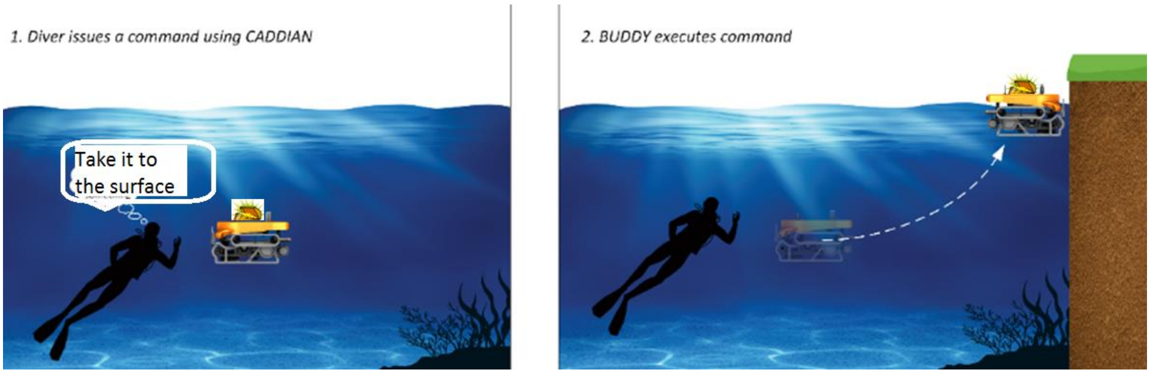
12. Diver now receives the message to follow the BUDDY.





13. Diver follows the BUDDY until Target is found.
14. Diver informs surface centre that Target will be recovered to the surface.
15. Diver loads the Target onto the BUDDY

16. Diver orders BUDDY to take the Target to the surface using CADDIAN.



17. Mission completed.
18. Diver surface in a safe way.
19. Perform task evaluation using provided questionnaire during debriefing session.

3 Integration experiments

Integration experiments were conducted prior to full validation trials. The scope of the integration experiments was:

Experiment 1: BUDDY “GUIDE”

1.1. BUDDY approaches the diver

1.2. Diver follows the square transect on the seabed

Experiment 2: BUDDY “OBSERVER”

2.1. Diver tests chat and DiverNet measurements

Experiment 3: BUDDY “SLAVE”

3.1. Diver issues “take a photo” (simple) gesture

3.2. Diver issues “carry something” (complex) gesture

3.3. Diver issues “stay” command via tablet

Experiment 4: Report generation

4.1. Replaying the mission

4 Full validation experiment - experiment 5

Validation mission:

Validation trials were performed 20.10.2016. Only one trial was performed day earlier i.e. 19.10. Divers participated in the trials were: Masa Frleta, Pavel Ankon, Kruno Zupcic, Claudio Lamolinara, Jan Grootaerts and Marco Pot.

Altogether five trials were performed. Three trials were completed (divers: Pavel Ankon, Masa Frleta, Kruno Zupcic), while two trials (divers: Claudio Lamolinara and Jan Grootaerts) were not completed due to technical problems. Problem during the mission 4 was error in the navigation filter causing the occasional inaccurate estimation of the diver position relative to the BUDDY. Accurate BUDDY relative positioning in respect to diver is very important for both observation and guidance pointer behaviour. Thus, mission 4 was aborted. Technical problem during the mission 5 was failure of the port forward BUDDY thrusters which required longer intervention and resulted in cancelation of that trial as well as the trial with the sixth diver.

Although we experienced certain problems performing integral real-life scenario trials, we can say that data collected and experience gained were valuable. Having in mind that work was done in real environment with the robotic prototypes and novel, CADDY developed applications, thus not with off-the-shelf thoroughly tested products and software, some problems were expected. Nevertheless, the complete set of results from the missions were sufficient to evaluate and validate work done in the scope of the CADDY project.

1. Briefing and familiarization with the DiverNet, underwater tablet and application, CADDIAN and CADDY system in general.

Figure 4 CADDY equipment prepared for a diver. CADDY gloves and DiverNet with the battery and acoustic USBL unit.

Figure 5 Preparation of three different divers for the validation mission. Jan is familiarizing himself with the tablet application (left image), final check-up of the Pavel's equipment before the trial (middle image) and Kruno exercises the CADDIAN signs relevant for the validation mission (right image).

2. Mission agents.

   Agents participating in all missions were: diver wearing DiverNet and tablet, BUDDY underwater vehicle and MedusaS surface vehicle.

Figure 6 Agents are getting ready for the mission

3. BUDDY performs pointer manoeuvre observing the diver at all time.

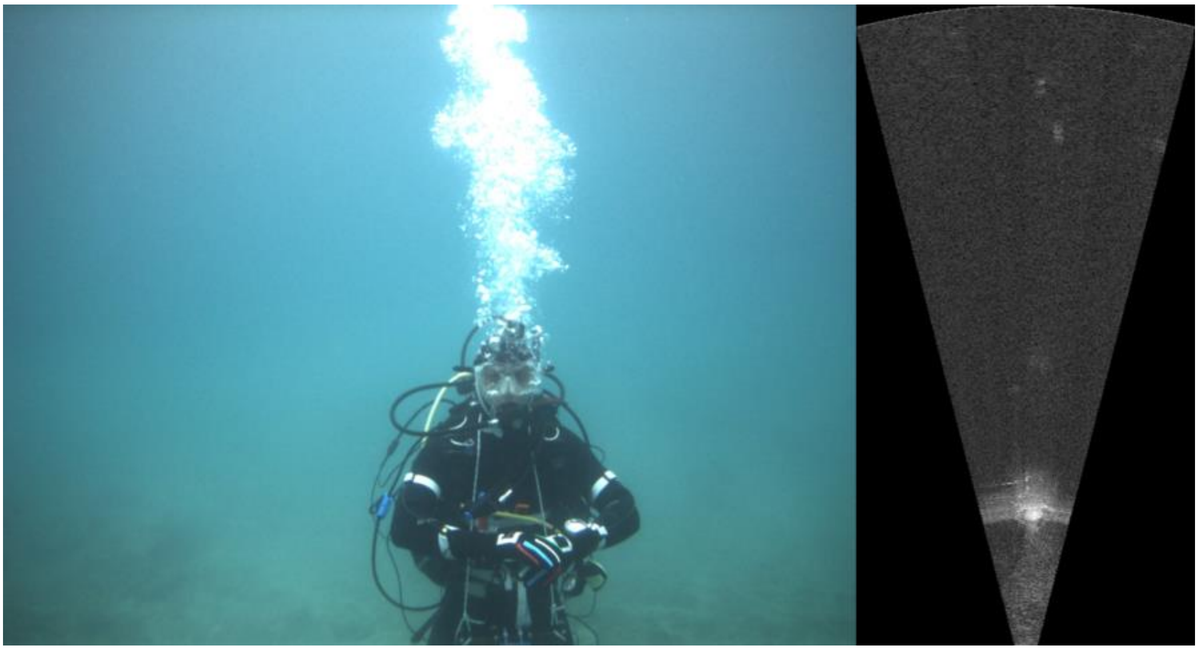
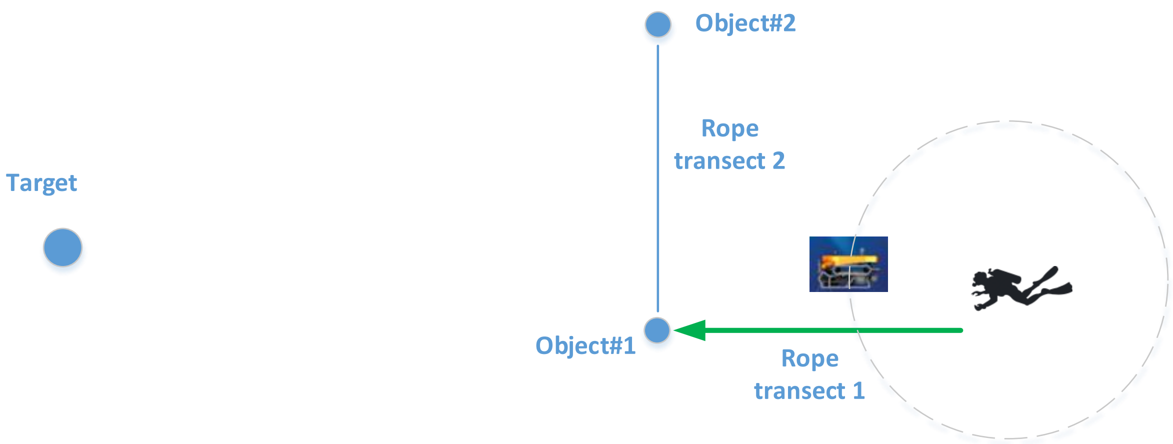


Figure 7 BUDDY maintain observer position in front of the diver

4. Diver searches for the target i.e. follows the transect1 (rope) laid down on the seabed. BUDDY continues with pointer observation manoeuvre.



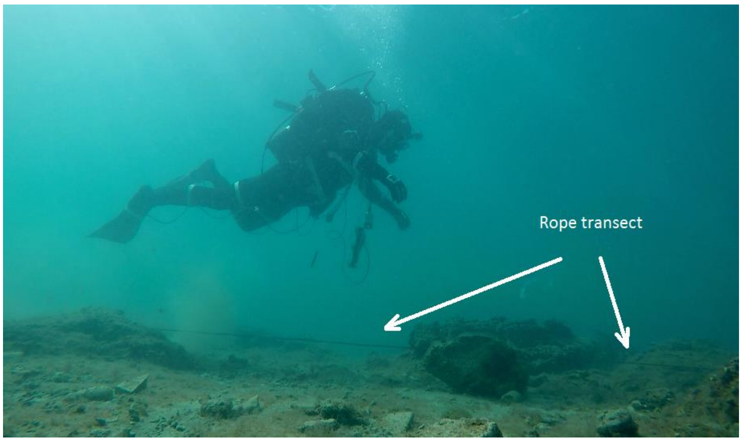


Figure 8 Diver follows the transect i.e. rope laid on the seabed

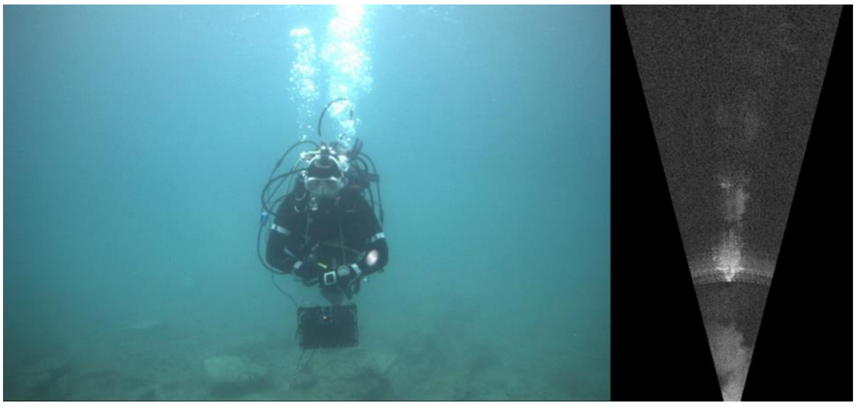


Figure 9 BUDDY maintains observer position while diver swims along the transect

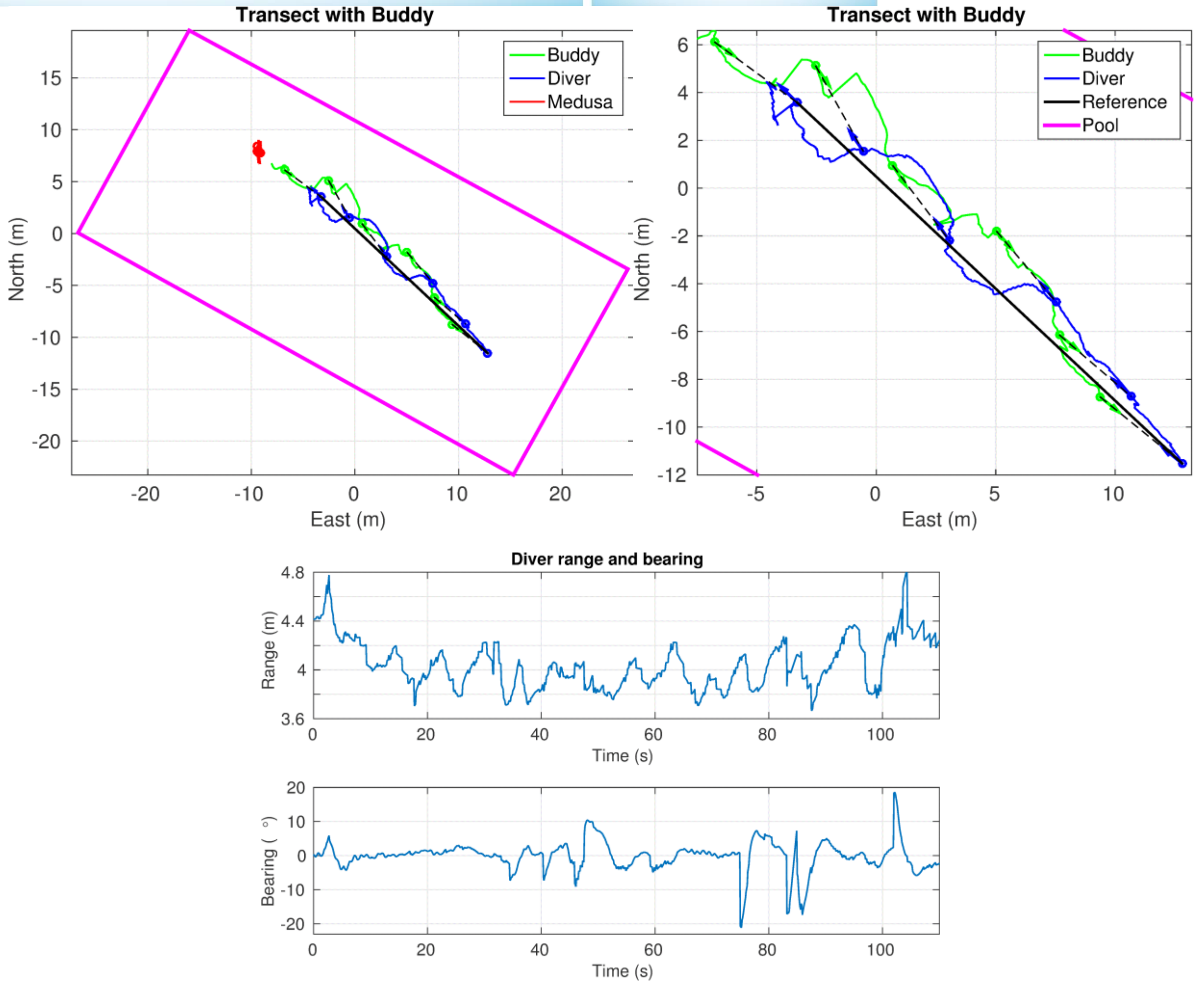


Figure 10 Transect 1. Presented purple frame is layout of the pool. Upper images present diver and BUDDY trajectories (blue and green) and corresponding orientations (arrows). Images show that BUDDY maintained distance from and orientation towards diver. The same but in the form of time plot is presented in Lower Image: range and bearing of diver relative to BUDDY

5. Mission was supervised from the surface centre.

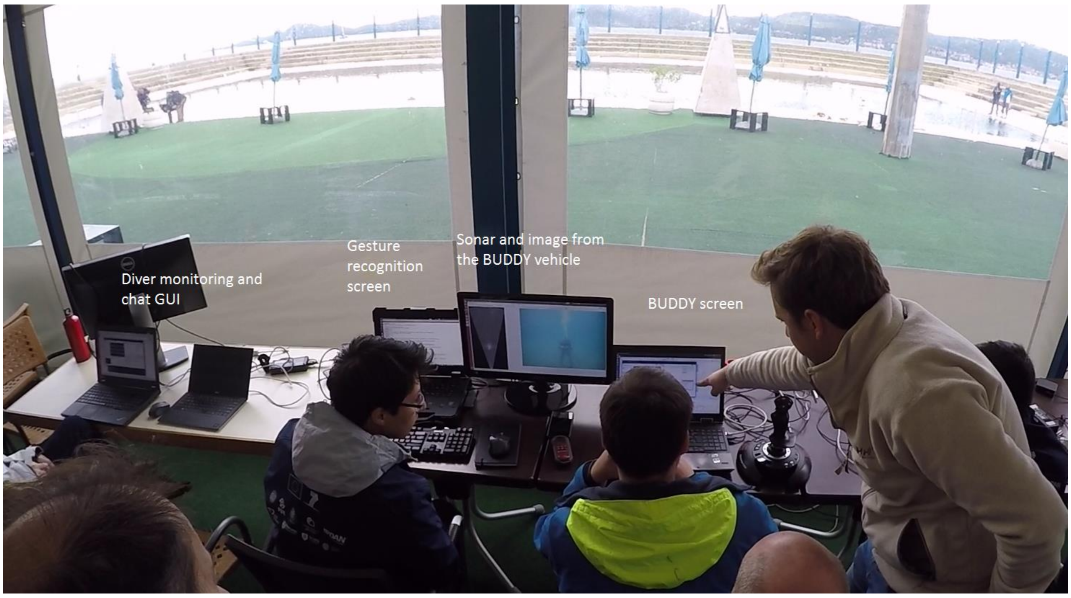


Figure 11 Surface control centre with different supervision screens

Figure 12 Mission in progress: Supervisory team

6. At the end of the first seabed transect object#1 is found. Diver informs surface centre that object#1 is spotted.

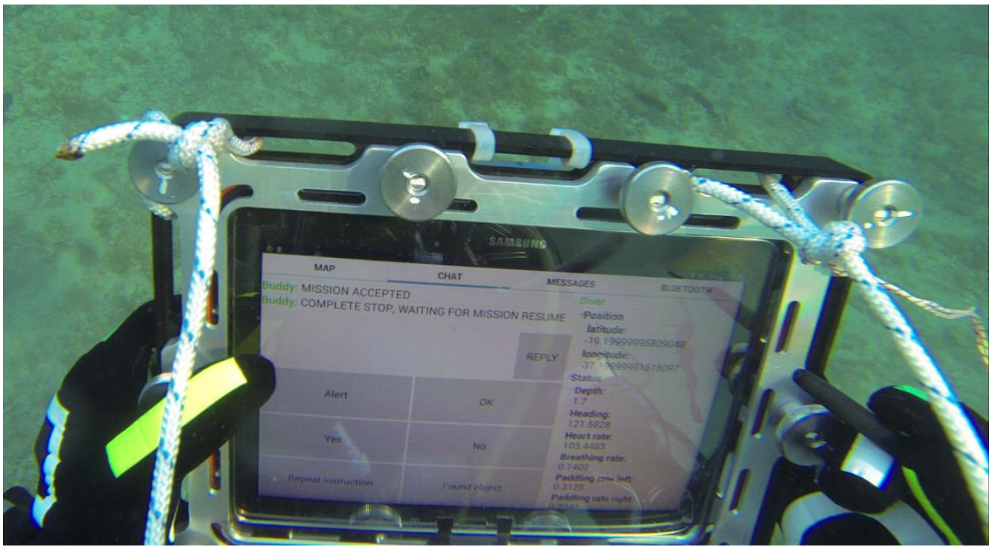


Figure 13 Diver uses underwater tablet for communication with the surface supervisory base.

7. Diver orders BUDDY to take a picture of object#1 using CADDIAN.

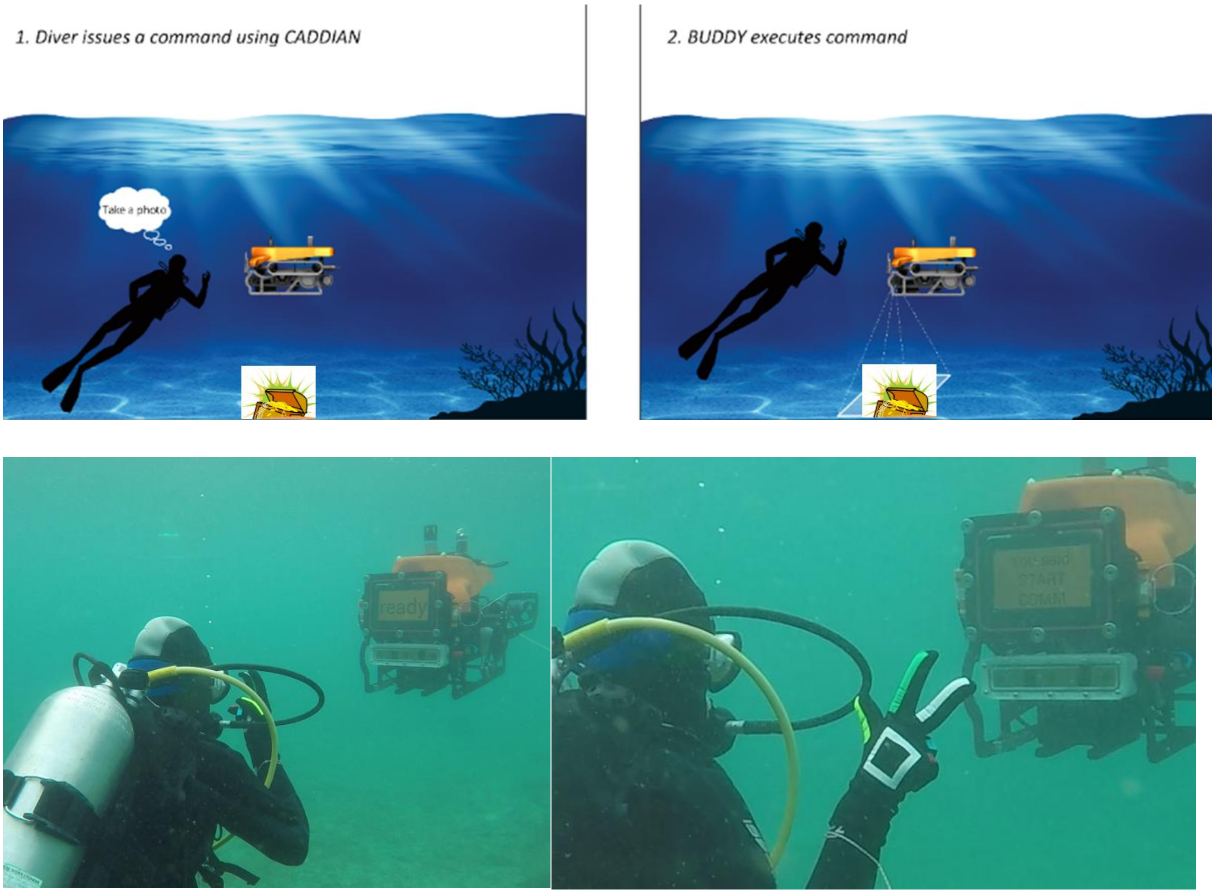
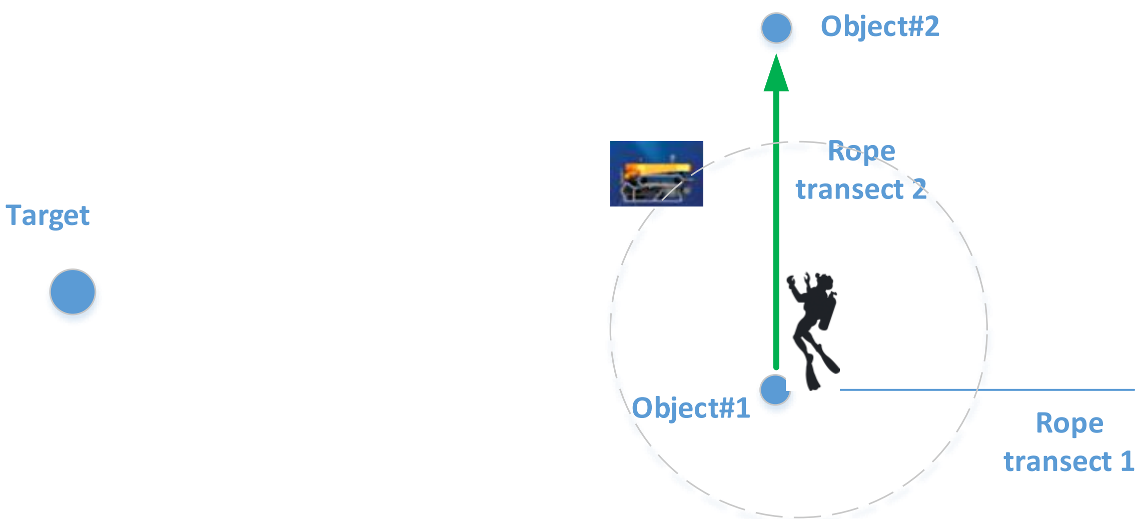


Figure 14 Diver first initiated communication using static gesture "start a communication" (left image) and then commanded "take a picture" (right image). Correct reception of the "start comm." message was acknowledged on the BUDDY tablet screen (right image)

Figure 15 Picture of the object#1

From three completed validation missions in two of them this task was accomplished successfully. During the third mission (diver: Kruno) command "take a picture" was not understood by BUDDY. After analysis, the conclusion was that this particular mission was performed like other missions in shallow waters but unlike other missions around mid-day when sun was high which made gesture recognition much more challenging.

8. Diver ignores BUDDY guiding manoeuvre and continue along second transect.



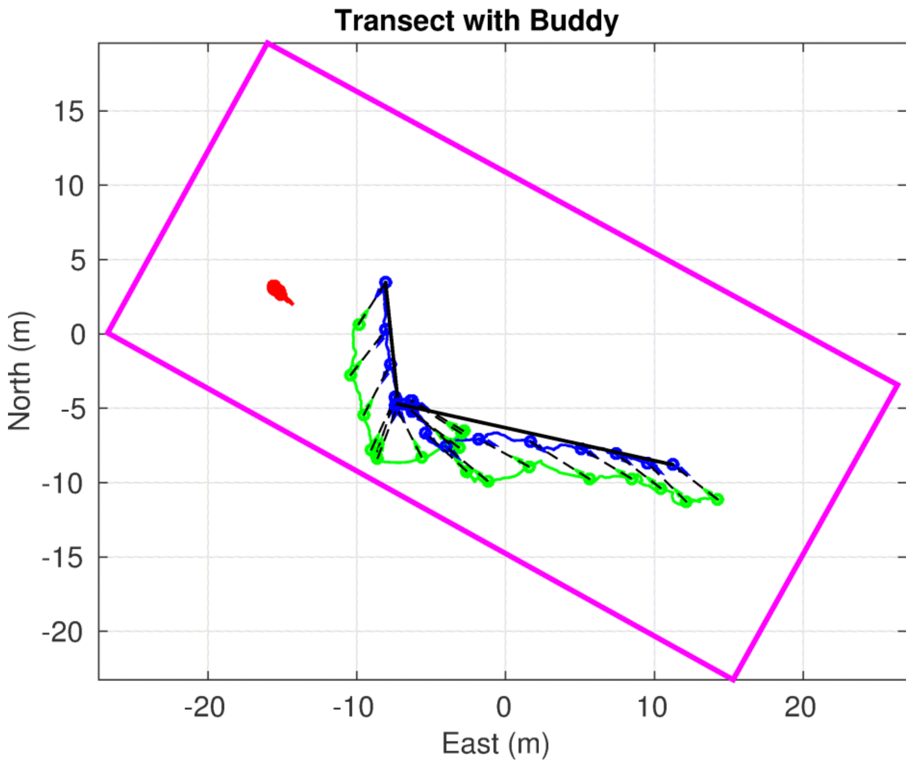


Figure 16 Transition from the first transect to the second one. Diver waited (as instructed) at the end of the transect (position -8, -5), for a BUDDY to take correct observation position, and then proceeded with the movement along transect two.

9. Diver informs surface centre that the end of the second seabed transect is reached.
10. Diver receives message from the surface to simulate different alarms. Messages were issued using the top side GUI chat window and transferred to the diver via CADDY acoustic link. Diver received the message on the underwater tablet.
    a. Diver simulated High Heart and Breathing rates. Alarms were triggered and indicated on the top side GUI.

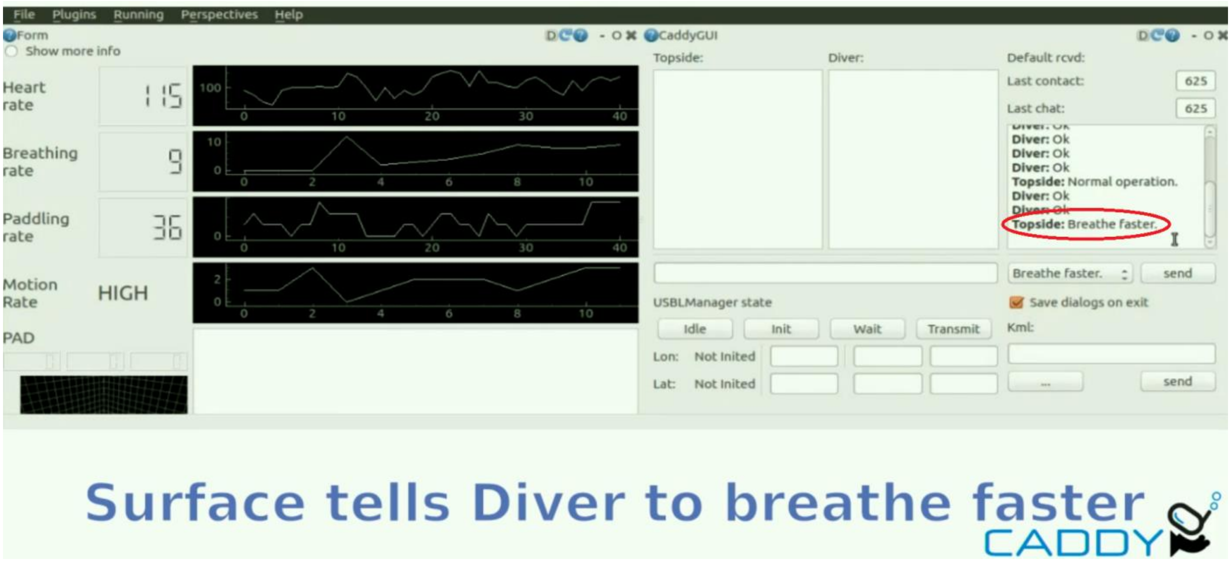


Figure 17 Top side GUI used for communication with the diver, monitoring of the diver physical state and alarm window. Command "Breathe faster" was issued top side.

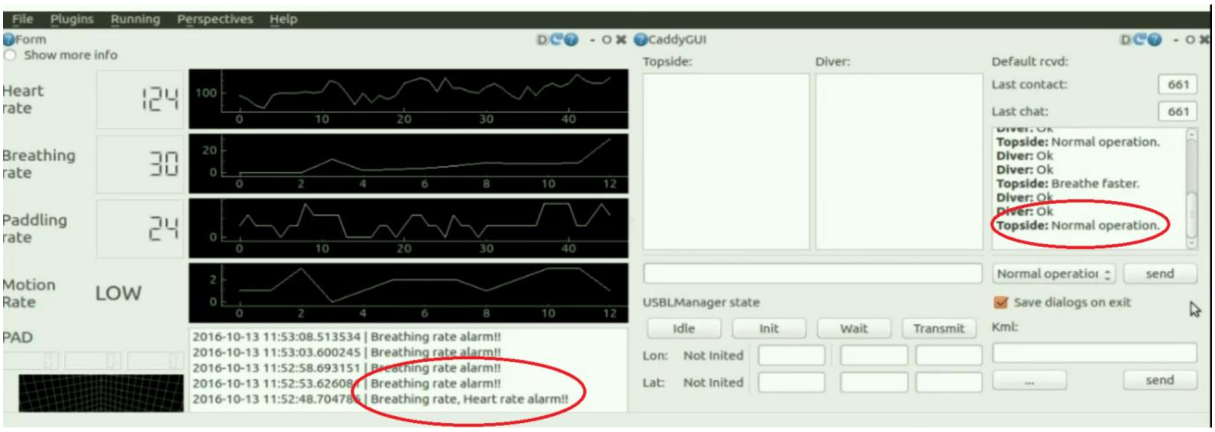


Figure 18 Alarm of both Heart rate and Breathing rate were received in the control centre. Diver was advised to continue with the normal operation

b. Diver was advised to move faster i.e. to increase paddling rate in order to trigger "High motion" alarm. Diver increased paddling rate and alarm was triggered and indicated on the top side GUI.

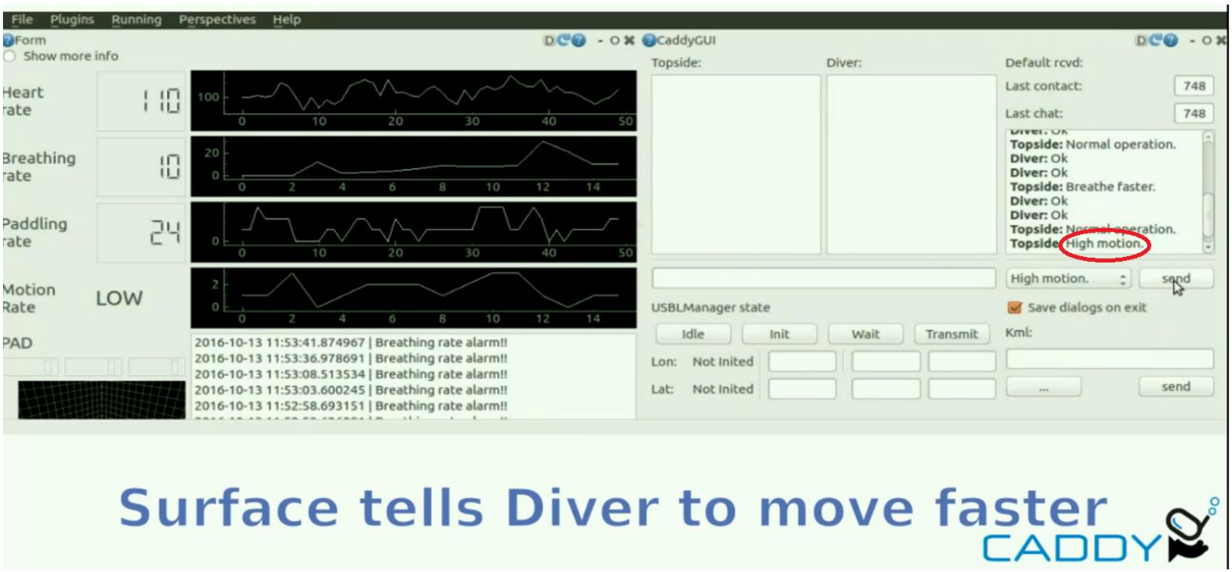


Figure 19 Command "High motion" was issued top side.

Figure 20 Diver acknowledged the reception of the command by sending "OK" message. High motion rate alarm simulated by the diver has been received on the top side GUI (control centre).

c. Diver was advised to manually issue alert message. Diver issued the message and Alert was displayed on the top side GUI.

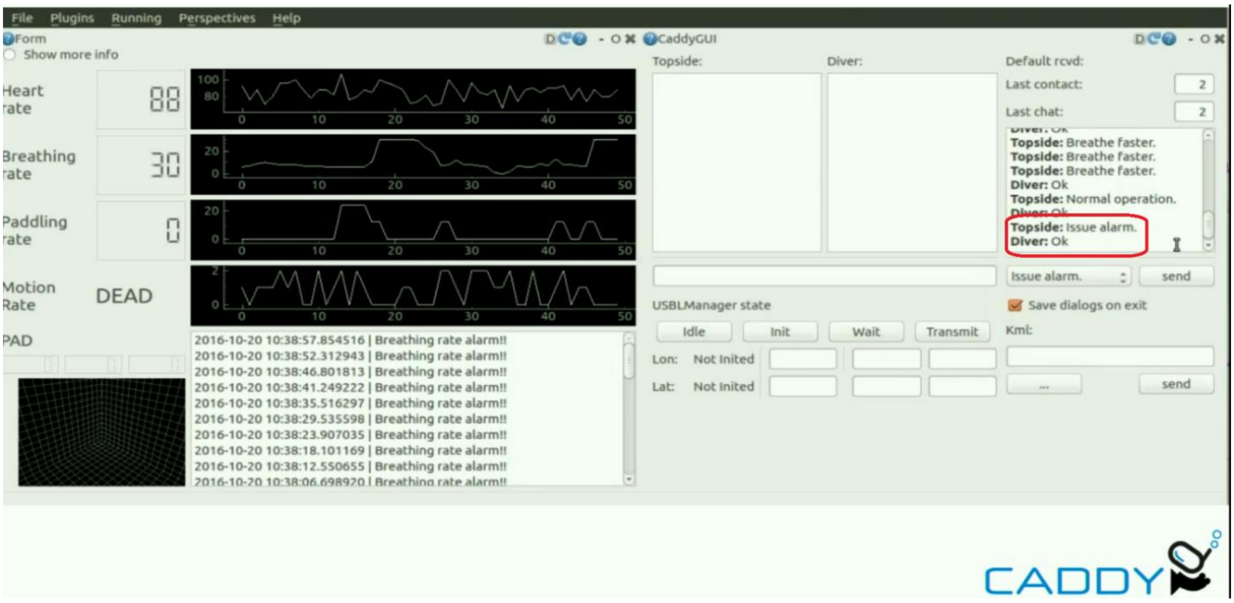
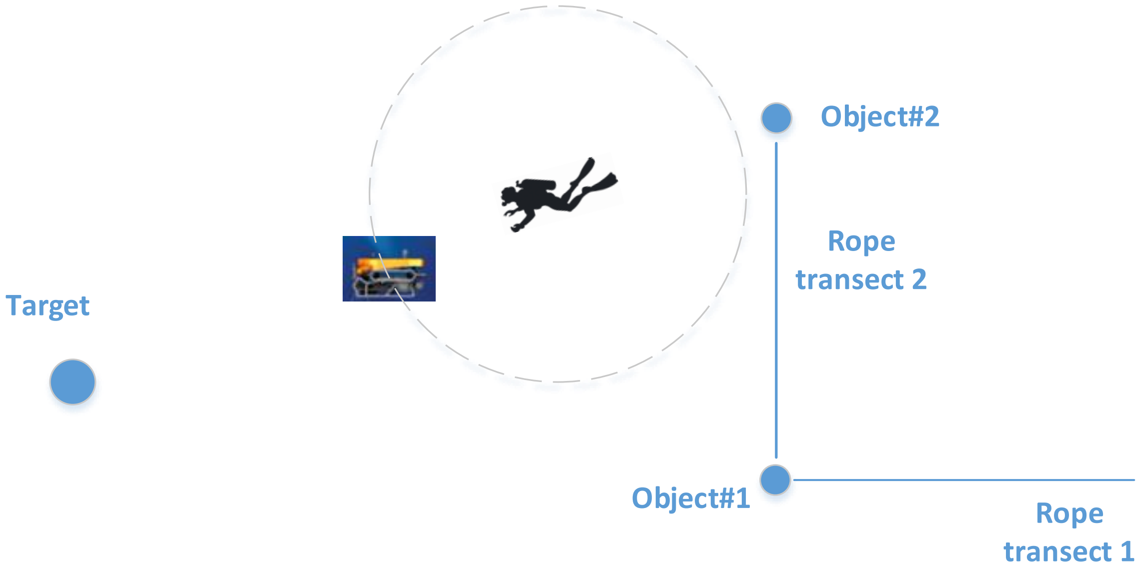


Figure 21 Command "Issue alarm" was sent to diver from top side. Diver acknowledged the reception by the "OK" message

Figure 22 Diver sent "Alert" message. Message received in the chat window.

11. Diver now receives the message to follow the BUDDY.

Simplifed guiding algorithm was used here instead of planned pointer algorithm. The reason for that was fact that diver orientation relative to BUDDY, obtained from the DiverNet inertial/magnetic sensors and real-time point cloud from the visual data, was not as accurate, precise and frequent as needed for the proper guide functionality based on pointer manoeuvring. Orientation measurement from DiverNet was affected by the change of diver’s posture from rather horizontal, while standing still, to vertical, while swimming. Also, the rate of the DiverNet measurements was only 0.2Hz. Orientation estimate from real-time point cloud, which was much faster i.e. near real-time, on other hand was rather noisy. Therefore, for validation trial we exercised simplified guide functionality were BUDDY led diver straight to the target maintaining the observer position during the guidance.



12. Diver follows the BUDDY until Target is found.

Target object (amphora, vase) was set to the designated point for the trials 20.10. Experiment with diver Masa, performed 19.10., was performed without target object.

Figure 23 Diver found the target.

13. Diver informs surface centre that Target will be recovered to the surface.

14. Diver load the Target onto the BUDDY

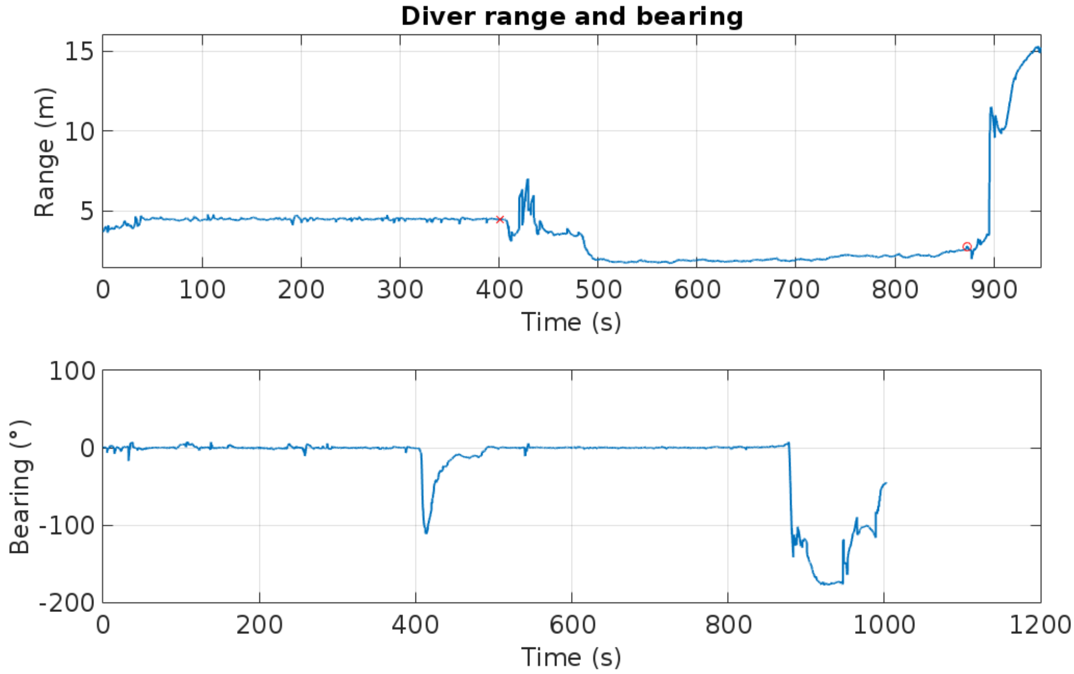


Figure 24 Figure presents end of the BUDDY guide sequence. Target was found at the time 400s. Diver picked up the target and showed it to the supervisory team (400s – 500s) via BUDDY front camera Figure 23. Approach of the diver to the BUDDY to load the object happened after 500s. Approximately at the time 880s, BUDDY left the diver and carried the object to the surface.

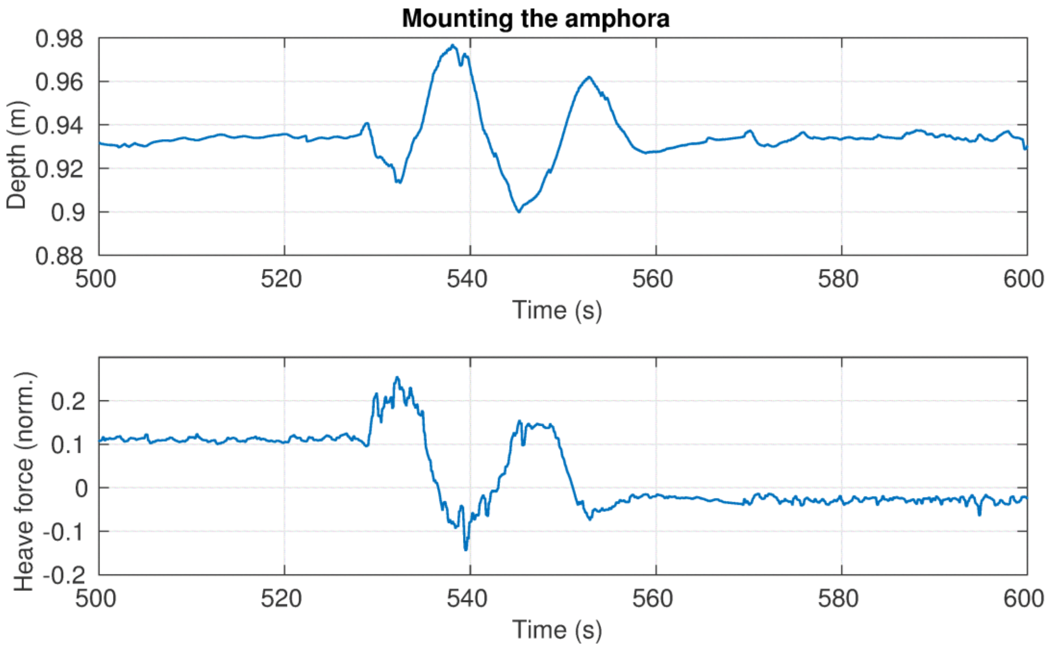
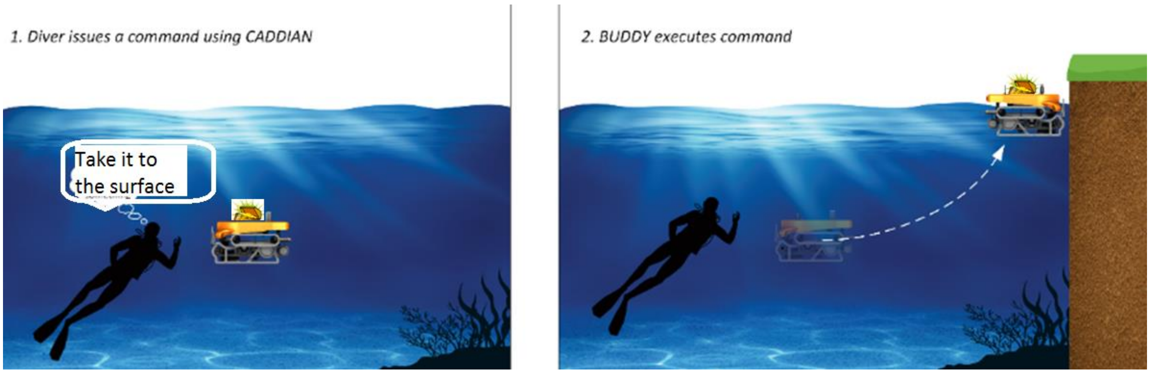


Figure 25 Figure presents BUDDY depth and heave control response at the moment of loading the object.

15. Diver orders BUDDY to take the Target to the surface using CADDIAN.



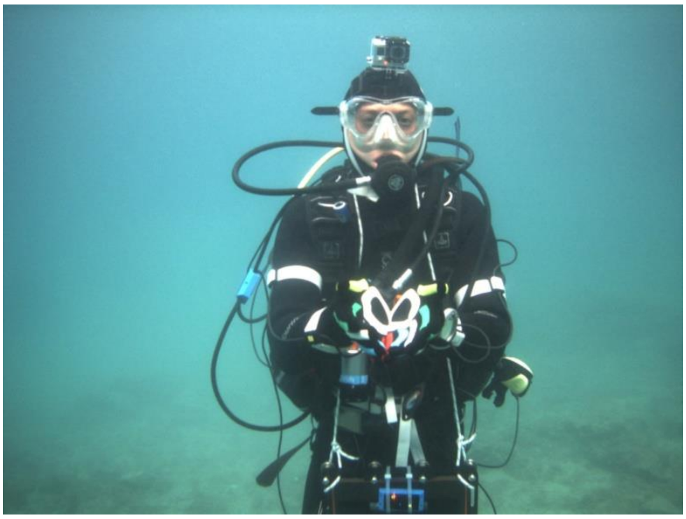


Figure 26 Diver issues command "carry to the surface"

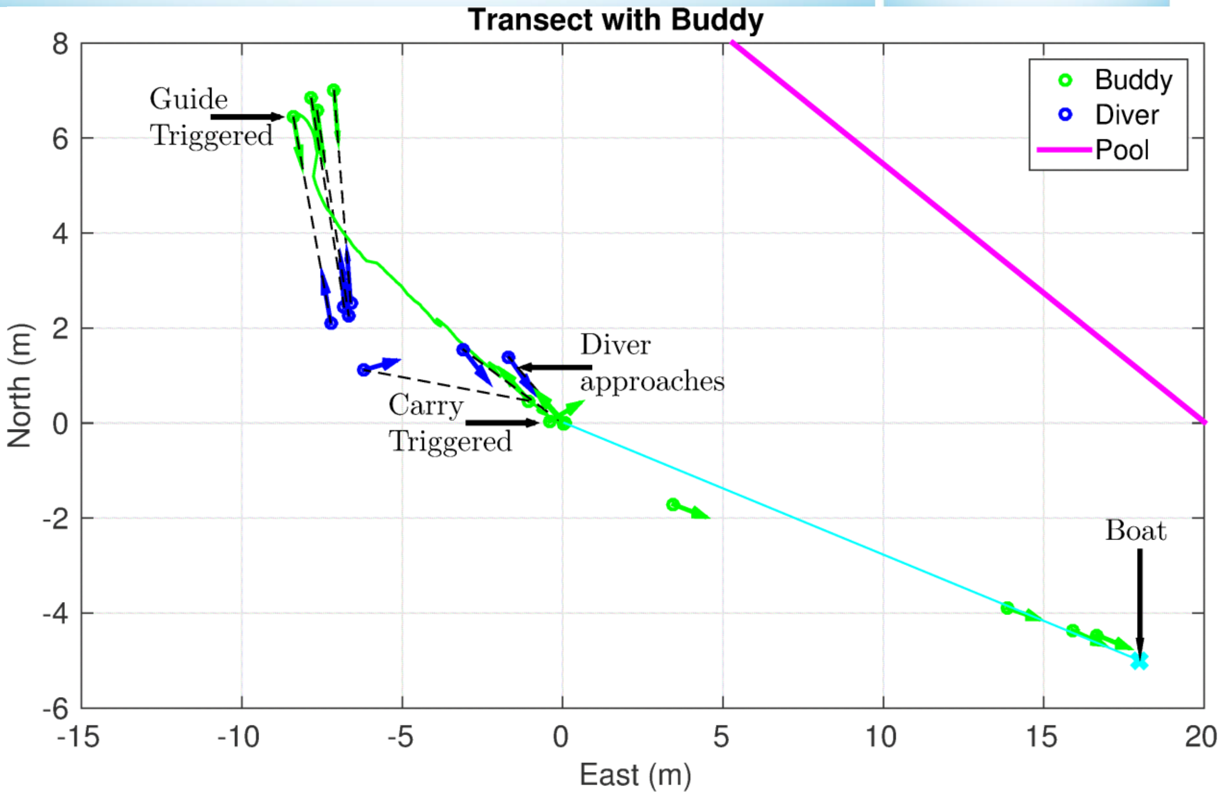


Figure 27 At the beginning of the sequence presented in this Figure, BUDDY was in observation position at the (-8, 7). It received "guide me" order issued by diver using tablet. Following command BUDDY moved to the a priori known target position (0,0). Diver followed the BUDDY and spotted the target. Diver collected the object, approached to the BUDDY and loaded it to the vehicle. Then "carry" command was issued and BUDDY went away to the designated position of the boat (18, -5).

16. Mission completed.
17. Diver surfaces in a safe way.
18. Perform task evaluation using provided questionnaire during debriefing session.

    Completed Questionnaires are attached in Annex A.

5 Annexes

ANNEX A. CADDY task evaluation questionnaire

The purpose of this questionnaire is to assess the usability of CADDY system and interface. Please indicate the extent to which you agree or disagree with each of the statements, by placing an **x** in appropriate box.

CADDY final validation trials							
Mission #__1__ Place: Biograd na moru - seawater pool Time and date: 15:00, October 19th 2016		Diver: Maša Frleta Supervisor: CADDY team					
Evaluator		disagree				agree	
	Performance	1	2	3	4	5	Comment
diver	Relevant CADDIAN signs were logical and easy to learn.					x	
diver	BUDDY maintained observer/guide position at all time during the mission				x		
supervisor	BUDDY maintained observer/guide position at all time during the mission				x		
log file	BUDDY maintained observer/guide position at all time during the mission				x		
diver	Communication with surface was easy and efficient					x	
supervisor	Communication with diver was easy and efficient					x	
diver	BUDDY understood and executed CADDIAN command to take a picture					x	
supervisor	All involved agents were tracked using provided GUI, operator interface					x	
supervisor	Diver state e.g. the heart and breathing rate, emotion clues were efficiently monitored using GUI					x	

supervisor	Tracking of mission progress using GUI was logical and comprehensive					x	
supervisor	Did you feel like being in control of all aspects of the mission e.g. progress or safety					x	
log file	High breathing rate alarm was triggered in the surface control centre					x	
diver	Guided by BUDDY I easily found the Target						not applicable
diver	It was easy to load the Target onto the BUDDY						not applicable
diver	BUDDY understood and executed CADDIAN command to take a Target to the surface.						not applicable
	Ergonomics						
diver	I found the work with CADDY vehicles comfortable.					x	
diver	CADDY helped me performing the task.					x	
diver	I would like to use this system					x	
diver	It was easy to handle the tablet and the program.					x	
diver	The menu of the program was well arranged.					x	
diver	The reaction time of the program was satisfying.					x	
diver	I understood immediately what is meant by the messages displayed by the program					x	
diver	CADDY did not disturb me					x	
diver	BUDDY kept a comfortable distance to me.					x	
diver	BUDDYs attention belonged to me.					x	
diver	BUDDY reacted to my instructions and gestures correctly.				x		
diver	BUDDYs reaction to my instructions was rapid.				x		
diver	I understood the instructions/ suggestions BUDDY gave me.					x	

diver	The communication between BUDDY and me was satisfying					x	
	Assessment of subjective mental workload	High/ Poor				Low/ Good	
diver	Rate the Mental Demand from 1 (low) to 5 (high). How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching)?					x	low
diver	Rate the Physical Demand from 1 (low) to 5 (high). How much physical activity was required? Was the task easy or demanding?					x	low
diver	Rate the Performance from 1 (good) to 5 (poor). How successful do you think you, aided by the CADDY system, were in accomplishing the tasks?				x		good
diver	Rate the Frustration Level from 1 (low) to 5 (high). How insecure, discouraged, irritated, stressed, and annoyed or secure, content, relaxed did you feel during the task?					x	low frustration level -> secure, content, relaxed

CADDY final validation trials

Mission #__2__ Place: Biograd na moru - seawater pool Time and date: 9:30 and 10:15, 20.10.2016		Diver: Pavel Supervisor: CADDY team					
Evaluator		disagree				agree	
	Performance	1	2	3	4	5	Comment
diver	Relevant CADDIAN signs were logical and easy to learn.					X	
diver	BUDDY maintained observer/guide position at all time during the mission				X		

supervisor	BUDDY maintained observer/guide position at all time during the mission				X		
log file	BUDDY maintained observer/guide position at all time during the mission				X		
diver	Communication with surface was easy and efficient					X	
supervisor	Communication with diver was easy and efficient					X	
diver	BUDDY understood and executed CADDIAN command to take a picture					X	
supervisor	All involved agents were tracked using provided GUI, operator interface					X	
supervisor	Diver state e.g. the heart and breathing rate, emotion clues were efficiently monitored using GUI					X	
supervisor	Tracking of mission progress using GUI was logical and comprehensive					X	
supervisor	Did you feel like being in control of all aspects of the mission e.g. progress or safety					X	
log file	High breathing rate alarm was triggered in the surface control centre					X	
diver	Guided by BUDDY I easily found the Target					X	
diver	It was easy to load the Target onto the BUDDY					X	
diver	BUDDY understood and executed CADDIAN command to take a Target to the surface.					X	
	Ergonomics						
diver	I found the work with CADDY vehicles comfortable.					X	
diver	CADDY helped me performing the task.					X	
diver	I would like to use this system					X	
diver	It was easy to handle the tablet and the program.					X	
diver	The menu of the program was well arranged.					X	

diver	The reaction time of the program was satisfying.					X	
diver	I understood immediately what is meant by the messages displayed by the program					X	
diver	CADDY did not disturb me					X	
diver	BUDDY kept a comfortable distance to me.					X	
diver	BUDDYs attention belonged to me.					X	
diver	BUDDY reacted to my instructions and gestures correctly.				X		
diver	BUDDYs reaction to my instructions was rapid.				X		
diver	I understood the instructions/ suggestions BUDDY gave me.					X	
diver	The communication between BUDDY and me was satisfying					X	
	Assessment of subjective mental workload	High/ Poor				Low/ Good	
diver	Rate the Mental Demand from 1 (low) to 5 (high). How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching)?					X	
diver	Rate the Physical Demand from 1 (low) to 5 (high). How much physical activity was required? Was the task easy or demanding?					X	
diver	Rate the Performance from 1 (good) to 5 (poor). How successful do you think you, aided by the CADDY system, were in accomplishing the tasks?					X	
diver	Rate the Frustration Level from 1 (low) to 5 (high). How insecure, discouraged, irritated, stressed, and annoyed or secure, content, relaxed did you feel during the task?					X	

CADDY final validation trials							
Mission #__3__ Place: Biograd na moru - seawater pool Time and date: 10:50, 20.10.2016		Diver: Kruno Zupčić Supervisor: CADDY team					
Evaluator		disagree				agree	
	Performance	1	2	3	4	5	Comment
diver	Relevant CADDIAN signs were logical and easy to learn.				X		
diver	BUDDY maintained observer/guide position at all time during the mission			X			
supervisor	BUDDY maintained observer/guide position at all time during the mission				X		
log file	BUDDY maintained observer/guide position at all time during the mission				X		
diver	Communication with surface was easy and efficient					X	
supervisor	Communication with diver was easy and efficient					X	
diver	BUDDY understood and executed CADDIAN command to take a picture	X					Gesture was not recognized by BUDDY
supervisor	All involved agents were tracked using provided GUI, operator interface					X	
supervisor	Diver state e.g. the heart and breathing rate, emotion clues were efficiently monitored using GUI					X	
supervisor	Tracking of mission progress using GUI was logical and comprehensive					X	
supervisor	Did you feel like being in control of all aspects of the mission e.g. progress or safety					X	
log file	High breathing rate alarm was triggered in the surface control centre					X	
diver	Guided by BUDDY I easily found the Target						N/A

diver	It was easy to load the Target onto the BUDDY						N/A
diver	BUDDY understood and executed CADDIAN command to take a Target to the surface.						N/A
	Ergonomics						
diver	I found the work with CADDY vehicles comfortable.					X	
diver	CADDY helped me performing the task.						Not sure
diver	I would like to use this system				X		
diver	It was easy to handle the tablet and the program.					X	
diver	The menu of the program was well arranged.					X	
diver	The reaction time of the program was satisfying.				X		
diver	I understood immediately what is meant by the messages displayed by the program					X	
diver	CADDY did not disturb me					X	
diver	BUDDY kept a comfortable distance to me.					X	
diver	BUDDYs attention belonged to me.				X		
diver	BUDDY reacted to my instructions and gestures correctly.		X	X			
diver	BUDDYs reaction to my instructions was rapid.		X	X			
diver	I understood the instructions/ suggestions BUDDY gave me.					X	
diver	The communication between BUDDY and me was satisfying			X			
	Assessment of subjective mental workload	High/ Poor				Low/ Good	
diver	Rate the Mental Demand from 1 (low) to 5 (high). How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching)?				X		

diver	Rate the Physical Demand from 1 (low) to 5 (high). How much physical activity was required? Was the task easy or demanding?					X	
diver	Rate the Performance from 1 (good) to 5 (poor). How successful do you think you, aided by the CADDY system, were in accomplishing the tasks?			X			
diver	Rate the Frustration Level from 1 (low) to 5 (high). How insecure, discouraged, irritated, stressed, and annoyed or secure, content, relaxed did you feel during the task?			X			Relaxed but partially annoyed by the success rate and speed of the gesture recognition

6 Conclusion

All CADDY partners participated in the sea trials in Biograd na Moru from 10-21.10.2016. The goal of the trails was to validate developed CADDY system in a mission simulating real-life scenarios. CADDY validation experiment was designed considering typical tasks in Search & Rescue and Underwater Archaeology missions and end-user (divers) specific interest and expectation from the CADDY system. The system performance was validated based on questionnaire filled out by divers and mission supervisors after the completion of the validation experiment.

First period of the sea trial period was devoted to the integration experiments preparing the CADDY system for the final integrated experiment. The result was fusion of the research achievements from different partners in one integrated CADDY system with all envision capabilities. Final validation trials were performed at the end, 19-20.10.2016. Three trials were completed, while two trials were not fully completed due to technical problems. Problem during the mission 4 was error in the navigation filter causing occasional inaccurate estimation of the diver position relative to the BUDDY. Accurate BUDDY relative positioning in respect to diver is very important for both observation and guidance pointer behaviour. Thus, mission 4 was aborted. It was possible to detect the problem only with full CADDY system in operation in real environment. Technical problem during the mission 5 was failure of the port forward BUDDY thrusters which required repair of the BUDDY vehicle.

During the trial, we also realized that diver orientation relative to BUDDY vehicle, obtained from the DiverNet inertial sensor and real-time point cloud from the visual data, was not as accurate, precise and frequent as needed for the proper guide functionality based on pointer manoeuvring. Therefore, for validation trial we exercised simplified guide functionality were BUDDY led the diver straight to the target maintaining the observer position during the guidance. Having in mind that work was done in real environment with the robotic prototypes and novel, CADDY developed applications, not final and thoroughly tested products and software, some problems were expected and did not come as a surprise.

To complete activities in the project, navigation filter was modified immediately after the trials to correct detected error. Also, the work on the guide pointer experiment was continued. Extra in-water experiments will be held in the pool in Zagreb.

Although we experienced certain problems performing integral real-life scenario trials we can say that data collected and experience gained were valuable. The complete set of results from the missions were sufficient to evaluate and validate work done in the scope of the CADDY project. Performance was validated using objective and subjective measures. The validation based on the specific validation objectives mentioned in the Section 2 is summarized in the table below.

Validation procedure:	Result:	Validation output and Comments:
Dive Guide		
to guide diver efficiently in order to find the object located on the known position	COMPLETED	The target was found on the a priori known location as planned. Dive guide functionality was achieved using simplified guide algorithm.
to guide diver efficiently to the known position even in the case of unfavourable divers behaviour and willingness to cooperate	PARTIALY COMPLETED	Applied simplified algorithm assumed certain level of diver's cooperation during the guide, diver can stop or move faster but cannot e.g. go to the opposite direction. It means that we did not fully complied with the goal of guiding the diver even in case of "unfavourable diver's behaviour and willingness to cooperate".
Dive Slave		
to geo-reference objects of interest and collect data for object identification, image or 3D image	COMPLETED	Image of the object of interest (object#1) was taken on divers request using CADDIAN and object was geo-referenced.
to recover selected objects, i.e., to take it to the surface	COMPLETED	The object/target was taken to the designated surface point on divers request using CADDIAN.
Dive Observer		
to monitor/supervise diver states in real-time during the mission	COMPLETED	Diver was monitored/supervised at all time
to trigger alarm on e.g. high breathing rate	COMPLETED	Alarms high heart, high breathing and high motion rate were successfully triggered and displayed at the surface centre. Alert, manually triggered by diver was also successfully generated and displayed.

Table 1 The results of the validation of the specific validation objectives

The results of the subjective, end-user validation is summarized in the Annex A. The conclusions drawn from the questionnaires related to CADDY system performance and divers comfort when using the system are:

- **Communication with the surface was easy and efficient**. It was easy to handle the tablet and the menu of the program was well arranged. Messages displayed were understood immediately and reaction time was satisfying. The same is valid for surface-diver communication which were rated as easy and efficient by the mission supervisors.
- **The communication between BUDDY and me was rather satisfying.** Based on experience with diving with human buddy, divers expected communication success rate of 100% and rapid reaction to their instruction. Although divers were generally satisfied with the communication with the BUDDY using CADDIAN they expected communication performance similar to the one with the human diving buddy. The problem with the gesture recognition at mid-day ambient light emerged during the mission 3 affected the system performance and diver satisfaction with the diver-BUDDY communication, resulting in lower related rates in the questionnaire 3.

- **Divers rated mental and physical workload demand as very low.** This was very important fact that system did not introduced extra mental or physical demand on divers.
- **Divers rated performance and frustration level from medium to low.** Frustration can mainly be attributed to communication.
- **BUDDY did not disturb divers and kept and maintained comfortable distance from them.**
- **Divers would like to use CADDY system in the future and found the work with the system comfortable.**

The summary of the most important conclusions is: divers felt safe and comfortable working with the robotic BUDDY, they recognized potential and possible benefit of using CADDY system but divers also expected system performance related to communication and guidance, to be comparable to the performance of the human buddy.