Grant Agreement No. 611373

FP7-ICT-2013-10

D5.4. Final assessment of the validation tasks

Due date of deliverable: 31/12/2016
Actual submission date: 31/12/2016

Start date of project: 01 January 2014 Duration: 36 months

Organization name of lead contractor for this deliverable: DAN Europe

Revision: version 1

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PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
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1. Introduction

Final validations were performed from 19.10.2016 to 20.10.2016. in Biograd na moru, Croatia. From functionality point of view, validation assessment already provided evidence that developed system was capable to perform most of: dive buddy *"observer",* dive buddy *"slave",* and dive buddy *"guide"* roles. Final validation consists of final assessment of the overall system performance based on the key performance indicators defined in D5.1. These indicators are supplemented and benchmarked by the Advisory Board members as well.

The validation part is performed by DAN Europe and an objective judgement on the performance quality and safety validation is given at the end of this report as a conclusion. Within this task the Advisory Board members have a crucial part where they have to provide objective assessments of the validation tasks execution and planning. A key role also lies with the divers who will be included in the validation task execution. They were carefully selected among the diving industry segments that are more likely to adopt CADDY system, namely: Scientific divers, Public Safety Divers, Commercial divers and recreational divers.

The divers representing end users from different segments of diving industry who participated in the trials were: Pavel Ankon (Scientific Diving-Biology), Masa Frleta (Scientific Diving-Biology), Kruno Zupcic (scientific diver - archaeology), Claudio Lamolinara (Public Safety-Search and Rescue team), Jan Grootaerts (Commercial diver-Onshore) and Marco Pot (Recreational Diver and Fire Department diver).

A survey about CADDY performance was prepared by mid-August. Prior to the survey, end users received an 11 page presentation on CADDY on the 19th of August. They were requested to read it carefully and ask any question to the project coordinator by the 1st of September. The details are presented in the deliverable D5.3.

The dives were supervised by Guy Thomas from DANEU. A stand by diver, Marta Morocco, was available at the dive site to intervene in case of emergency. The formal risk assessment of the dive site and the vehicles were performed prior to dives. Divers were given a briefing on the validation tasks as well as the general emergency information. They also provided direct input for the final validation.

Final validation mission was composed of tasks common for both search & rescue and underwater archaeology. Therefore, relevant indicators are chosen from indicators proposed in D5.1 for both tasks.

The execution of the validation tasks was assessed by the members of the CADDY Advisory Board and DANEU by referring to the following groups of key performance indicators:

1) dive guide;
2) dive observer;
3) dive slave;
4) Diver safety and ergonomics;

2. Dive guide indicators

Description: The BUDDY guides the diver directly to the defined underwater location, following the search path and making sure that the diver is following the buddy, demonstrating the buddy "guide" functionality. The quality and precision of guidance should ensure that the target/object is found. Upon finding the object, diver decides to: recover the object, abort the search, and start diver recovery.

2.1. Guiding the diver (even in case of "unfavourable diver's behaviour and willingness to cooperate")

Dive guide functionality was achieved using slightly simplified guide algorithm. Although 3 trials were successfully completed, two trials (trial 4: Claudio Lamolinara and trial 5: Jan Grootaerts) were not completed due to technical problems. Problem during the mission 4 was imperfection in the navigation filter causing the sparse inaccurate estimation of the diver position relative to the BUDDY. During the preparation trial, it was 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, frequent and precise as it should be for the proper guide functionality based on pointer manoeuvring. Accurate BUDDY relative positioning in respect to diver, although important for observation behaviour, is much more important for guidance pointer behaviour. Therefore, for validation trial we exercised simplified guide functionality in which BUDDY led the diver straight to the target maintaining the observer position during the guidance. Technical problem during the mission 5 was failure of the port forward BUDDY thrusters which required longer intervention.

The set of results from the validation trials were not sufficient to make a firm conclusion on this performance indicator. 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 the CADDY did not fully comply with the goal of guiding the diver even in case of "unfavourable diver's behaviour and willingness to cooperate".

Navigation filter was modified immediately after the trials to correct detected error. The work on the guide pointer experiment was continued. Extra in-water experiments were held in the pool in Zagreb and CADDY was assessed to be compliant with this performance indicator as well, but the validation is not yet performed in real environment.

2.2. Locating the target for recovery

Using applied simplified algorithm, BUDDY brought diver to the exact a priori known location of the target where target was found, as planned. We can conclude that dive guide functionality was achieved using simplified guide algorithm.

3. Dive observer indicators

3.1. Diver behaviour interpretation

CADDY successfully detected the increased breathing rate and the heart rate that was induced by hyperventilation. CADDY also successfully detected high motion rate. The speed of monitoring is performed in near real time. Alert, manually triggered by diver was also successfully generated and displayed. At present, CADDY's performance is not at the level of complex behaviour interpretation such as the degraded behaviour due to Nitrogen narcosis but CADDY can monitor the most important physiological parameters that can detect the leading indicators of degraded health conditions:

breathing and heart rate. Those two parameters alone can prevent two major sources of diving fatalities: DAN Europe and DAN America have reported 70 percent of the 926 scuba diving fatalities of their members were caused by drowning over the period of 1992-2003. An additional 14 percent of the DAN America member fatalities and 13 percent of DAN Europe member fatalities were reported to be caused by cardiac events [1].

3.2. Gesture interpretation

The missions were observed to be vulnerable from the environmental conditions, such as the amount of light. During the third mission (diver: Kruno) command "take a picture" was not understood by BUDDY which affected the system performance and diver satisfaction with the diver-BUDDY communication, resulting in lower related rates in the questioner 3. 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. Gesture recognition could also be challenging task in other unfavourable environmental conditions, especially in high turbidity and darker conditions. Communication through hand signals overall remains somewhat challenging. With thick gloves or 3-fingered gloves used in cold environments the robot had problems in full understanding of the sign language. Problems with normal gloves were also experienced on occasion (visibility). This slows down communication and dive operations. The system seems to be sensible to interferences. 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.
Most of the end users expressed their desire to have more even more robust sign language interpretation. Reading the screen on the underwater vehicle was on occasions not possible due to the light from the surface on the screen.
This key performance is found to be adequate only in relevant controlled environment.

3.3. Quality of BUDDY observation position maintained during the dive

Quality of BUDDY observation position maintained during the dive was evaluated by divers, dive supervisors and from the log files. Divers rated “quality of observation” with 3 to 4 (on the scale 1 to 5 where 5 is the best grade) while dive supervisors and evaluation based on data from the log files rated it with grade 4. This key performance indicator is graded with 4 (very good), although improvement of estimation of diver orientation relative to BUDDY vehicle would further improve performance.

3.4. Real-time monitoring/supervision of the mission

Diver was monitored/supervised at all time from the surface control centre. The centre was equipped with different supervision screens. All involved agents were tracked using provided interface and tracking of mission progress was logical and comprehensive. Diver states and emotion clues were efficiently monitored using GUI. In the questionnaire supervisors stated that they felt like being in control of all aspects of the mission: progress and safety. Diver-surface and surface-diver communication were rated as easy and efficient by divers and mission supervisors. It means that the CADDY complied with this criterion.

4. Dive slave indicators

Description: While on the site, the diver communicates with the BUDDY using symbolic hand gestures, changes the mission parameters or commands the BUDDY to perform some compliant slave tasks. Each of the performed slave tasks should comply with the validation criteria: speed and success of BUDDY reaction and the mission performance and precision and compliance of BUDDY operations during the task.

4.1. Take a picture (photo)

The validation tasks showed that BUDDY reaction on “take a photo” command was fast and successful. The image taken was fused with the positioning data making image geo-referenced, as planned. The problem with the “take a photo” gesture recognition at mid-day ambient light emerged during the mission 3 affected the system performance and diver satisfaction.

The main validation criteria, speed and success of BUDDY reaction, the mission performance and precision and compliance of BUDDY operations during the task, was met. The task could be occasionally affected by environmental conditions, such as the amount and angle of the ambient light.

4.2. Take object to the surface

Diver was able to successfully load the object to the vehicle. The task was initiated by symbolic hand gesture which changed the mission parameters and BUDDY performed compliant slave task “take object to the surface”. The object/target was taken to the designated surface point on divers request using CADDIAN meaning that CADDY complied with this performance indicator.

5. Diver safety and ergonomics

This performance indicator evaluated safety and ergonomics aspects of the system such as: was the distance of BUDDY appropriate during the mission; was the diver safety area preserved during the mission; was work with CADDY vehicles comfortable; did CADDY disturb diver; did CADDY put extra workload on divers; was work with CADDY mentally and physically demanding.
During the real-life tasks, BUDDY vehicle preserved the safe distance confirmed by all the diving supervisor, stand by diver, the test diver as well as the log files. BUDDY did not disturbed divers and the work with the system was found comfortable. Divers rated mental and physical workload demand as very low. CADDY was assessed to be compliant with this performance indicator.

6. Conclusion

The technology is validated in relevant environment and the overall system reached TRL5 by the end of the project based on all key performance indicators. The prototype is not very far from TRL7, but robustness and the immunity to external conditions needs to be validated for a combination of challenging underwater conditions (waves, currents, turbidity, depth, obstacles) to assess the system with respect to the key performance indicators during the prototype demonstration in operational environment, especially for the precision and compliance of BUDDY operations during assistance to the diver.

7. Reference

[1] A. Marroni P. J. Denoble and R. D. Vann. Annual fatality rates and associated risk factors for recreational scuba diving. In Recreational diving fatalities workshop proceedings. Divers Alert Network, 2010.