Executive summary

The CADDY project replaces a human buddy diver with an autonomous underwater vehicle and adds an 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 assists the diver; and *iii)* the buddy "guide" that leads the diver through the underwater environment.

In order to achieve this goal we have **developed a multicomponent system** consisting of a **BUDDY AUV** custom made for interaction with divers, equipped with an underwater tablet as a means of interaction with the diver, a stereo camera, mono camera, multibeam sonar; and **MEDUSA ASV** modified to serve as the surface vehicle in the CADDY scenario. In order to ensure reliable communication, a new generation of **small scale USBL and acoustic modems** has been developed together with a new **calibration procedure** resulting in significantly improved accuracies in azimuth (< 5deg) and elevation errors (< 4deg).

Three core research themes have been set within the CADDY project:

1. **"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;

High resolution multibeam sonar has been used to detect diver hands (short distances) and the diver at larger distances (>3 meters) and his global pose (direction). **Stereo camera in combination with monocular camera** has been used to determine both diver pose and hand gestures. Instead of calibrating underwater directly, a technique was developed to **estimate the underwater calibration parameters** based on the much easier and well understood in-air calibration and basic measurements of the underwater housing used.

An innovative body network of inertial sensors called **DiverNet** has been designed and manufactured in order to reconstruct the pose of the diver. **Wireless version** enables acoustic transmission of data processed on the diver tablet. **Heart rate and breathing sensor** have been integrated with the DiverNet, allowing recording of heart rate, breathing data and motion data during the experiments

Developed **Diver State Monitor** shows the supervisor in real time diver status using several critical values like: diver depth, average flipper rate, heart rate, breathing rate, motion rate, PAD space, diver state alarms, and predefined chat messages.

A **database of stereo images and point clouds** was made available online at http://robotics.jacobs-university.de/datasets/2017-underwater-stereo-dataset-v01/.

2. **"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;

Artificial neural networks were trained using the DiverNet data do **detect different diver activities** such as standing, sitting, T-pose, etc. Accuracy of around 90% was achieved allowing to transmit only this high-level diver activity data to the surface. A multilayer perceptron was trained to predict **pleasure, arousal and control** using breath rate, heart rate and motion rate measurements. This approach proved fairly successful with classification rates reaching from 60 % (dominance/control high) to only 18% (pleasure, neutral). Overall classification score was 40 %.

Language of communication between the diver and the robot based on gestures, called **CADDIAN**, has been developed – a total of 52 symbols have been defined, together with the „slang" group of symbols for better acceptance by the diving community. A **fault tolerant symbolic language interpreter** was developed, allowing robust interpretation of the commands issued by the diver to BUDDY.

The following set of algorithms have been developed: **hand gesture recognition using stereo camera** imagery based on feature aggregation algorithm developed to cope with the highly variant underwater imagery; **hand detection using multibeam sonar** imagery to detect the number of extended diver fingers within sonar imagery; algorithms for **diver pose recognition and localization from mono and stereo** imagery, and algorithms for **diver pose and localization recognition using the sonar** to determine diver position and orientation relative to the BUDDY AUV.

3. "**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.

Diver-BUDDY cooperative controller was developed in order to ensure that BUDDY is positioned in front of the diver regardless of the diver's orientation. **Diver-BUDDY-USV formation control** was developed in order to ensure the surface vehicle is in an area close-by in order to improve, among other things, the acoustic communications with the underwater agents, while avoiding being on top of them, for safety purposes.

Single beacon navigation algorithms based on extremum seeking and Fisher Matrix Inversion approach was implemented for the purpose of navigation using only ranging devices, without angle measurements.

Automatic selection system for the execution of the proper autonomous robotic tasks was developed with the aim of providing a compliant behaviour of the overall robotic system, with respect to the command issued by the diver. **Modular framework of the mission controller** based on Petri nets was designed and developed with the aim of managing the state tracking, task activations and reference generation that fulfils the requirements in order to support the diver operations.

Obtained results were tested during **two validation trials** that took place in 2015 and 2016 in Biograd na Moru Croatia.

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