CADDY - Cognitive Autonomous Diving budDY

- executive summary -

Divers (SCUBA, scientific, and technical) operate in harsh and weakly monitored environments in which the slightest unexpected disturbances, technical malfunctions, or lack of attention of a diver can result in catastrophic consequences. These issues are usually dealt with by pairing up divers and adopting well defined rules for diving operations to reduce the chance of accidents. However, during more challenging dives these procedures may not be sufficient to ensure almost accident-free operations, for the divers must manoeuvre in complex 3D environments, carry cumbersome equipment, and focus attention on operational details.

The core of the research and development effort will focus on setting up symbiotic links between a human diver and a set of companion autonomous robots. This motivates us to develop a multicomponent, highly cognitive underwater robotic system capable of learning, interpreting, and adapting to the diver's behaviour and physical state.

The core of the proposed envisioned concept consists of a **diver**, **autonomous underwater robot** and **autonomous surface robot** as it is shown in the figure. A diver will interact with the companion autonomous underwater robot who will manoeuvre underwater in the vicinity of the diver and exhibit cognitive behaviour with regard to the diver actions. The autonomous surface vehicle that communicates with the diver and the autonomous underwater robot is a communication relay link to the command centre but at the same time it also plays the key role of a navigation aid to the underwater vehicles. It must adapt its motion so as to optimize the conditions for increased communications efficiency and navigational accuracy of the three components of the formation.

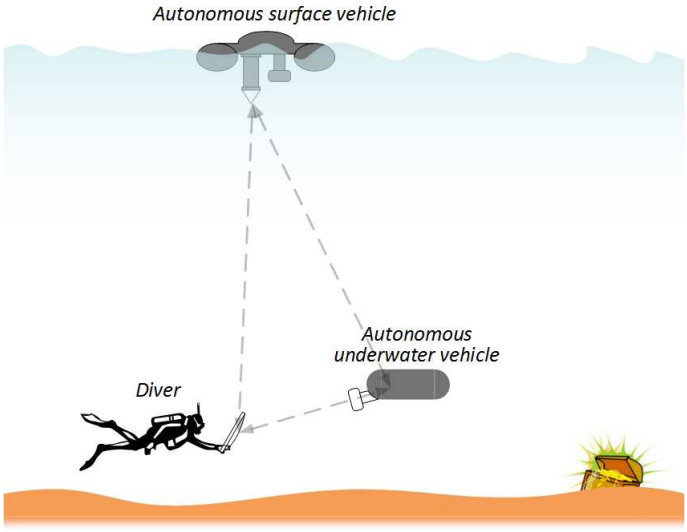

Fig. 1. The CADDY concept

CADDY Advanced Functionalities - *"observer"*, *"slave"*, and *"guide"*

Assistance and monitoring in the CADDY sense refers to a threefold functionality similar to the one that a human buddy diver should have. Stated in simple terms, the system to be developed should play, among others, the simultaneous roles of: *i)* dive buddy "observer", *ii)* dive buddy "slave", and *iii)* dive buddy "guide".

As a ***dive buddy "observer"***, the system observes the diver at all times during the dive and interprets his(her) behaviour by assessing for example the body state, detecting the onset of nitrogen narcosis and signs of panic, and interpreting symbolic gestures communicated by the diver. The robotic buddy must manoeuvre safely around the diver in order to assume the best viewpoint for observation without interfering with the normal unfolding of the mission.

As a ***dive buddy "slave"*** the system affords the diver a "helping hand" to examine the environment; e.g. hovering over a spot indicated by a laser beam operated by the diver and taking photos of the location, following the diver and acquiring a series of overlapping photos for mosaic making, illuminating a site from different angles upon request from the diver, and carrying a payload with tools and equipment.

As a ***dive buddy "guide"***, the system is in charge of actually guiding (upon request) the human diver from one spot to another, along a predefined search path, or steering the diver safely

(in case of an emergency) to an appropriate point at the surface without violating basic diving rules and acting as an intelligent communication router in situations where the diver loses line-of-sight to the surface vessel.

CADDY Specific Objectives

1. Develop a cooperative robotic system consisting of a surface and underwater vehicle that are capable of interacting with the diver.
2. Develop a reliable underwater sensing network that will enable recognition of diver pose and hand gestures.
3. Develop algorithms that will enable understanding of the diver behaviour, i.e. interpretation of both conscious (symbolic hand gestures) and unconscious (pose, physiological indicators) nonverbal communication cues.
4. Define and implement execution of cognitive guidance and control algorithms through cooperative formations and manoeuvres with a diver being a part of the formation.
5. Interpret complex sequences of diver gestures in order to achieve cognitive mission (re)planning.

CADDY Real-Life Validation Scenarios

These envisioned scenarios present measureable objectives that are to be achieved during the lifetime of the project.

A. Validation task: Search & recovery mission (S&R)

The CADDY system will guide the diver through the predefined mission. Specifically, the scenario is to search an area in a lawnmowing pattern and recover a specific object. With the CADDY system, there is no need to perform conventional rope laying on the sea bottom; instead, the RECUV will guide the diver underwater. During the S&R mission, the autonomous underwater buddy has to *i)* follow the predetermined path, *ii)* ensure that the diver is following the buddy, and *iii)* keep an appropriate distance to the diver at all times in order to ensure diver safety and enable interpretation of the symbolic hand gestures and the diver behaviour.
At any time the diver can stop the mission, change the mission parameters, or command the underwater buddy to perform compliant tasks.

B. Validation task: Underwater archaeology mission

The diver is led by the CADDY system directly to the place where the previous diver has stopped with the documentation of the underwater site. There will be no need for the conventional positioning of frames on the seabed. While on the site, the diver will use hand gestures to command the RECUV to perform some required tasks such as take a photo of a part of the sea bottom, make a mosaic of an area, direct light to a specific part at the sea bottom, etc. to alleviate the burden on the diver during the execution of a strenuous operation.
At all times during the excavation mission, the autonomous buddy has to *i)* attain optimal positioning with respect to the diver in order to ensure diver safety, enable interpretation of the symbolic hand gestures and interpretation of the diver behaviour, *ii)* accurately interpret commands issued by the diver and comply with the tasks requested, and *iii)* adapt the mission plan according to the diver's instructions.

The execution of the validation tasks will be assessed according to a number of **key performance indicators** such as: speed and success of diver behaviour interpretation; speed and success of autonomous underwater vehicle's reaction to a change in the mission plan; preservation of diver safety area during the mission; precision of path following during S&R mission and precision of path following during the descent to the underwater archaeology site; precision and compliance of the underwater vehicle operations during assistance to the diver.