

Autonomous Marine Robots Assisting Divers

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Abstract. Research related to diver safety, navigation and monitoring has been identified as crucial for advancing diving activities. 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 (such as technical 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. In this work it is stated that research and technological development in the area of cognitive robotics can significantly contribute to the effectiveness and safety of diving operations. The current research performed in LABUST is based on an autonomous surface platform for following divers and transmitting GPS signal to the underwater. Future envisioned applications include the development of a cognitive autonomous diving buddy consisting of both the surface platform and an underwater vehicle that will serve as diving "guide", "slave" and "observer".

Keywords: autonomous marine vehicles, human–diver interaction, cognitive robotics

1 Introduction

During the course of last 5 years, Laboratory for Underwater Systems and Technologies (LABUST), University of Zagreb have successfully organized "Breaking the Surface" workshop, [3], (initially funded by the FP7-REGPOT CURE project, [4], currently supported by ONR Global) that encourages multidisciplinary research of application of marine robotics and related technologies in underwater biology, archaeology and safety. These event have been an enabling element in gathering significant experience related to SCUBA diving which is classified as high-risk due to i) unpredictable, dangerous and unfamiliar environment constantly under influence of external disturbances; ii) dependency on technical equipment that ensures life support; and iii) health consequences that

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diving can have on a diver. In strong collaboration with professional and recreational divers, three major issues that emerge during classical diver operations have been identified: diver safety, diver underwater navigation and diver monitoring from the surface.

Diver safety, as the most important aspect, is seriously jeopardized during diving activity not only because of unpredictable underwater scenarios, but also because of diver invisibility to surface vessels. Currently, diving areas are marked by using passive buoys that serve as indicators for man operated surface vessels to avoid this area. Area of operation can be increased if the diving buoy is linked to the diver via a cable - this solution is unacceptable for deeper and long dives due to possible entanglement, drag and cumbersomeness.

Underwater navigation poses a challenge even for experienced divers. Classical techniques of underwater navigation, such as referencing according to the sun, compass, underwater features, are imprecise and tedious, and require significant amount of concentration and experience. Current technological solutions enable determining position of the diver relative to the surface station by using acoustic based technology. These systems, that rely on static transmitters/receivers, exhibit serious performance deterioration when the diver is distanced from the ship.

Another identified issue is related to diver **monitoring from the surface**. This issue is important to diving supervisors who monitor the progress of diving operations, as well as divers themselves who appreciate monitoring as a way of increasing their safety during the dives. Current systems, similarly as in the case of underwater navigation, are not appropriate at larger distances (due to multipath) or in the cases when obstacles are present between the diver and the base station.

Preliminary research at LABUST has demonstrated that cooperation between autonomous marine vehicles and divers is the most appropriate solution to the above identified issues. Initial results propose a concept that includes an autonomous surface platform with the ability to follow the diver thus significantly increasing their safety during underwater activities. The platform has the primary task to dynamically position itself above the diver, with the following results:

- There is no need for conventional marking of the diver area by using static buoys which will increase allowed diver operation area since the autonomous surface platform is always above the diver.
- A vertical acoustic communication channel is formed that ensures communication reliability. A reliable transmission of GPS coordinates to the diver is accomplished thus providing the diver with absolute GPS coordinates on the diver tablet.
- The diving supervisor has reliable data of the diver position and reliable communication between the diver and the diving supervisor is established through the vertical communication channel thus significantly increasing reactivity in the case of danger.

The following part of the paper is devoted to describing the current achievements in the development of the autonomous surface platform for navigation and monitoring of divers and the link to the diver interface in the form of a diver tablet. Key technical and application challenges are addressed. Research related to the development of a cognitive autonomous diving buddy is given as a look into the future of robot-diver multidisciplinary research.

2 Technical description

The proposed concept as a solution to the above mentioned issues consists of an autonomous surface platform and an underwater interface (tablet) carried by the diver, as shown in Fig. 1(a). The autonomous surface platform, that carries the international flag marking underwater activity, is overactuated with 4 thrusters forming the "X" configuration. This configuration enables motion in the horizontal plane under any orientation. The platform has been developed at LABUST and the current version is 0.35m high, 0.707m wide and long, as it is shown in Fig. 1(b). It weighs approximately 25kg - the goal is to reduce the weight so that it becomes one-man-portable (cca 10kg). More details can be found in [2]. The control computer (isolated from environmental disturbances inside the platform hull) is in charge of performing control and guidance tasks (dynamic positioning, path following, diver following) and all the data processing. Currently implemented guidance and control algorithms based on virtual target method have proved satisfactory during laboratory and field tests, [1]. Apart from the compass, batteries and CPUs, the platform is equipped with:

- a GPS for determining the platform position, and indirectly the diver position in the horizontal plane;
- Ultra Short Baseline (USBL) used to determine the position of the diver relative to the platform. The USBL is used simultaneously for localization and two-way data transmission via an acoustic link (the second modem is mounted on the diver);
- a wireless modem used to transmit data from the platform to the surface station, thus making the platform a router from the diver to the surface station where the diving supervisor is stationed.

The diver has an underwater interface which is in fact a commercially available tablet sealed in a waterproof casing. In addition to that, the diver carries an acoustic modem connected to the RS232-Bluetooth converter. Our preliminary research has shown that Bluetooth communication has a range of about 15cm underwater which allows the Bluetooth module to be simply leaned on the waterproof tablet casing in order to establish connection. This way, physical interfaces are avoided, and there is no need to introduce connectors in the waterproof casing. In order to achieve diver sending feedback to the surface platform via an acoustic modem, a tablet with inductive touchscreen is integrated in the overall system.

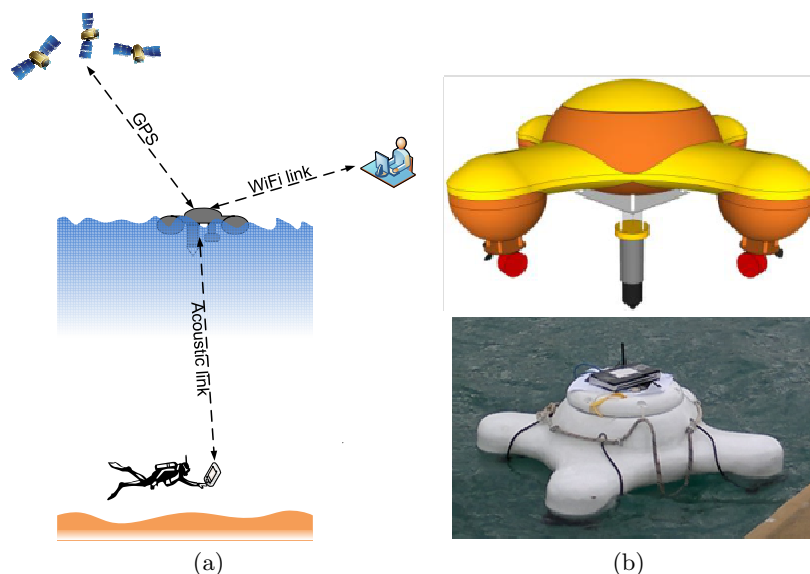


Fig. 1. (a) Concept for diver navigation and monitoring consisting of an autonomous surface platform and a diver tablet and (b) CAD design and a prototype of the autonomous surface platform developed in LABUST.

3 Key challenges

Through the course of research, numerous technical and scientific challenges have been tackled. Some application and S&T challenges that will be met in the near future are identified in the following part.

3.1 Application challenges

System affordability to the diver community. Scientific and recreational divers have expressed their concern regarding the price of the proposed system. Even though they are prepared to invest funds in high-tech diving watches with advanced capabilities, assistant robotic systems are still out of their affordability limits. It is our intention to raise awareness of this community that the advances that autonomous robotic systems bring are worth the extra cost. A series of validation scenarios specifically designed for scientific archaeology and biology divers will be conducted. The most expensive components of the autonomous platform, USBL and acoustic modems, will be replaced with custom made low-cost, acoustic based positioning systems and acoustic modems.

Successful accomplishment of validation scenarios. The validation scenarios have been motivated by our end user partners, i.e. underwater archaeologists and biologists. Scenarios such as, performing a pattern search without prior

installation of markers on the sea bottom, or guiding a diver to a specific point on the underwater site, will prove the effectiveness of having a robotic surface assistant that is providing GPS data to the diver.

Dealing with legal issues. The common problem that communities involved with autonomous robotics are facing is legal issues related to autonomy operation. Having an autonomous platform that follows the diver is not regulated by international maritime law. This challenge has to be dealt with on an international level.

3.2 S&T challenges

Achieve controllability in rough seas. An issue that has been raised by the end users is the applicability of the developed platform in rough seas. Our current mechanical design of the platform is a first iteration that has only been tested in calm sea and lake conditions. After the design is tested in higher sea state conditions, modification in the mechanical design will be performed if found necessary. The developed control and guidance algorithms are robust and it is expected that this functionality will be maintained even in high sea state. A problem that is foreseen is the accuracy in diver localization when the platform is exhibiting high roll and pitch movements due to waves. This issue will be tackled by implementing precise inertial measurement units that will enable inclusion of sea dynamics in the localization algorithms.

Use of single beacon acoustic units to localize divers. This challenge is tightly connected to the affordability challenge. USBLs that are currently used are costly. In collaboration with IST, Portugal, an idea has arisen to investigate the possibility of using cheap, single beacon sonars to estimate diver location. Some recent work on this methodology can be found e.g. in [6], [5] and references within. In the proposed case, the platform would perform "persistently exciting" manoeuvres to gather single beacon measurements that would enable precise localization. This methodology will significantly reduce the cost of the overall system, at the price of increasing the required power to perform necessary manoeuvres.

Integrating the underwater tablet with the acoustic modem. As it was described before, a commercial tablet will be embodied within an underwater casing. Our intention is to keep the casing as simple as possible, i.e. to avoid connectors or any other type of cables entering the casing in order to reduce the risk of flooding. This is why available wireless technologies such as Bluetooth will be used to link the acoustic modems mounted on divers and the tablets that are used as diver interfaces. Preliminary research has shown that underwater Bluetooth connection can be established at distances less than 15cm. We will investigate the applicability of radio communications (that are documented to

have larger range). This would increase the ergonomics of the equipment (the communication module would be on the diver's back, without any wires on the diver's arms).

4 Future

The current research and technological achievements are only a stepping stone towards the ultimate goal - establishing high level, symbiotic collaboration between cognitive marine robots and divers. Even though cognitive robotics have advanced quite a lot in the recent years, advances in the underwater environments are limited, and are yet to be established. Interaction between divers and cognitive underwater vehicles is the future that will significantly advance our notion of the underwater as well as current state of the art in the diving operations. In order to achieve this, engineering research and skills must be complemented with cognitive sciences as well as end users from different areas of application. The following paragraph mentions only few questions that have to be addressed in the future to bring underwater robotics to a new human-oriented level.

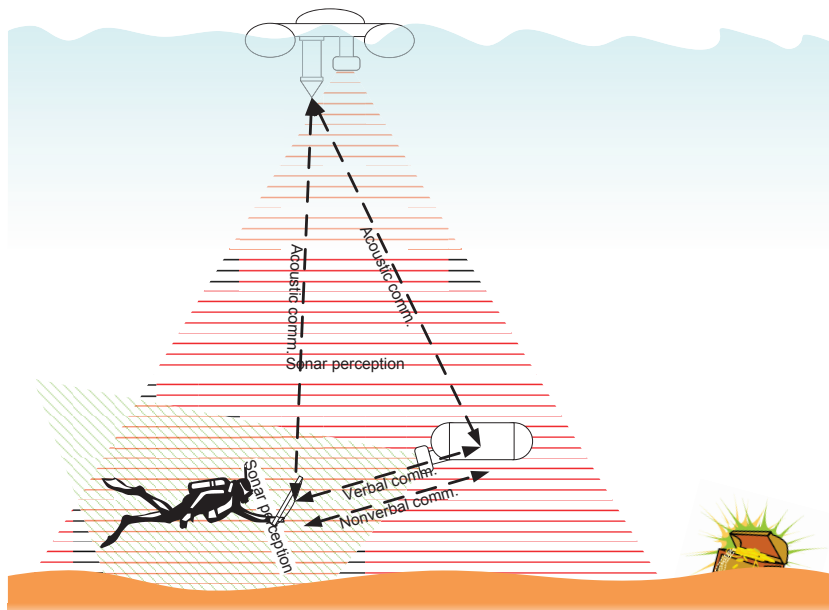


Fig. 2. Concept of a cognitive autonomous diving buddy.

Can underwater robots replace diving buddies? Service robotics have almost become state of the art - robotic receptionists are welcome guests, guiding

them to their rooms, carrying their luggage; robotic nurses are bringing medication to patients; etc. It is our future goal to show that human-robot cooperation and interaction is also possible in the underwater. Currently, remotely operated vehicles are used to follow divers during their hazardous undersea operations. We want to extend this to a new level where autonomous, cognitive, underwater vehicle(s) can replace or supplement diving buddies who are required during dives. These robotic diving buddies have to collaborate and assist the divers with the purpose of reducing risks during diving operations and increasing diver efficiency. The concept of having underwater robots as diving buddies is depicted in Fig. 2.

How can underwater robots cooperate and interact with divers? Divers' actions are very limited in the underwater. The amount of time they can spend underwater is limited, and the ability to perform physical tasks rapidly decreases with time. It has been reported that at large depths (below 60m) simple tasks such as placing markers in predefined locations, or turning a valve in a predefined direction, pose great difficulty due to underwater nausea or pure exhaustion. Achieving full cooperation and interaction between robots and humans is well beyond state-of-the-art; however focusing research to solving specific related tasks is a stepping stone in this direction. Our future research will focus on developing cooperation algorithms in order to achieve robotic diver buddy functionalities such as diver "guide" and diver "slave". The diver "guide" will lead the diver through the underwater environment thus helping him in surveying a specific area. During this task, the "guide" has to adapt to the diver motion, e.g. ensure it stays always in the line of sight, modify its motion according to the diver's wishes (e.g. command "come closer", "distance yourself"). From the technical point of view, this task comes down to developing cooperative guidance algorithms where master-slave roles switch stochastically. The diver "slave" will assist the diver in performing advanced operations, such as doing a mosaic of an area, illuminating a desired area, or bringing the diver a specific tool to operate with. From the technical point of view, these compliant tasks require development of online mission replanners and low level control algorithms.

How can natural diver-robot communication be accomplished? During most dives, divers are not able to perform verbal communication but they use standardized signs to communicate their status, intentions or commands to other divers. It is only natural to expect that this type of communication should be used while interacting with cognitive robotic divers. The issue of recognizing sign language is currently tackled by numerous research groups, primarily to interpret the hearing impaired sign language. The challenges that appear in the underwater are i) what sensors to use for perceiving hand gestures, ii) how to construct a complex language for issuing mission commands to robots with a limited number of symbols used by divers, iii) how to provide feedback to the diver from the cognitive underwater robot.

How can we interpret diver behaviour? Anthropology is continuously giving us answers on how human posture, motion or expression can be related to the person's state. Sweaty hands are an indicator of nervousness; legs crossed towards a partner indicate affection, etc. The set of motions, postures and expressions in divers is much more limited so it is reasonable to expect that some characteristics such as speed of limb movement, frequency of bubble emissions, speed of head movement, can be linked to certain diver states (panic, relaxation, underwater nausea, etc.). Integration of anthropological and physiological research with cognitive robotics is of high importance and a required step towards achieving diver understanding. The relation between body indicators and physiological characteristics (heart rate, breathing frequency) to diver emotional states is an important addition to the future cognitive robotic systems. The underwater diving buddy will then not only be a "guide" or a "slave", but it will also be an "observer" capable of identifying critical diver behaviours and initiating prompt reaction to prevent catastrophic outcomes. The challenges that will be addressed with respect to this issue include i) 3D diver pose reconstruction using invasive (inertial sensor networks) and non-invasive (acoustic and/or visual) sensors underwater, ii) defining diver anthropological and physiological cues and determining sensors to measure them, and iii) performing emotional analysis, i.e. correlating measurements to a set of diver behaviours.

Answers to these questions and solutions to the mentioned technological challenges will significantly increase cognitive abilities of robots in the underwater environment and thus contribute the full cognitive robotic diving buddy functionality. Needless to say that results arising from this broad research will significantly enhance the state-of-the-art methodologies that are currently applied in marine biology, marine archaeology, marine security, offshore industry as well as recreational diving activities.

References

1. Stilinovic, N. and Miskovic, N. and Nad, D. and Vukic, Z.: Testing and technical characteristics of a small overactuated marine platform. In: Proceedings of the 35th International Convention MIPRO, pp. 812–816 (2012)
2. Miskovic, N. and Triska, Z. and Nad, D. and Vukic, Z.: Guidance of a small-scale overactuated marine platform – Experimental results. In: Proceedings of the 34th International Convention MIPRO, pp. 684–689 (2011)
3. "Breaking the Surface" field training and workshop, <http://bts.fer.hr>
4. FP7-REGPOT project "Developing Croatian Underwater Robotics Research Potential – CURE", <http://cure.fer.hr>
5. Moreno-Salinas, D. and Pascoal, A.M. and Aranda, J.: Surface sensor networks for Underwater Vehicle positioning with bearings-only measurements. In: IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 208–214 (2012)
6. Moreno-Salinas, D. and Pascoal, A.M. and Aranda, J.: Optimal sensor placement for underwater positioning with uncertainty in the target location. In: IEEE International Conference on Robotics and Automation (ICRA), pp. 2308–2314 (2011)