Autonomous Surface Vehicles as Positioning and Communications Satellites for the Marine Operational Environment – Step toward Internet of Underwater Things

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***Abstract*—Positioning, Navigation and Communication on land would be very difficult and nowadays unimaginable without satellite communication networks. The situation underwater is much more complex due to high attenuation of radio waves. Moreover, due to the different nature of communication above and underwater, facilitation of relevant data flow between these environments requires existence of some kind of communication hub. Idea of replicating concept of positioning/communication satellites able to play both roles simultaneously to set up Internet of Underwater Things (IoUT), is therefore, worth considering. In light of this idea, the University of Zagreb developed a one-man portable autonomous surface vehicle (ASV) with suitable lightweight localization and communication payload. This paper describes an ASV and its role as a satellite for the underwater environment and implementation of IoUT. The paper elaborates three real applications: support to diving operations where a diver tracking and communication link to diving tablet ensures multifunctional support to the diver, i.e. diver following, monitoring, assistance, and improved safety of the diver; support to Autonomous Underwater Vehicle (AUV) operations by allowing real-time remote access to underwater measurements and vehicle status and by extending AUV subsea deployment substantially by correcting the dead reckoning navigation error; underwater wireless sensor networks aided by swarm of ASVs for data forwarding, localisation, recharging and deployment under different environmental conditions.**

***Index Terms*—Autonomous Surface Vehicle (ASV), Acoustic Communication, Internet of Underwater Things (IoUT), Marine Satellites, Simultaneous Communication and Localization**

I. Introduction

Positioning, Navigation and Communication on land would be very difficult and nowadays unimaginable without satellite communication networks. The situation underwater is much more complex due to high attenuation of radio waves. As a result of the radio signal attenuation, existing positioning and communication systems are inapplicable for marine environment. Moreover, due to the different nature of communication above (radio) and under (acoustics) water, facilitation of relevant data flow between these environments requires existence of some kind of communication hub. Idea of replicating concept of positioning/communication satellites able to play both roles simultaneously to aid underwater operation, is therefore, worth considering.

II. Autonomous Surface Vehicle

Fig. 1: ASV at sea.

In light of this concept, the University of Zagreb developed a one-man portable autonomous surface vehicle (ASV), shown in figure 1. ASV is equipped with suitable lightweight localization and communication payload in order to act as a satellite for the underwater environment. The ASV H2Omni-X (also known as PlaDyPos and aPad) possesses acoustic link for underwater that provides improved underwater positioning and communication, and WiFi and GSM/LTE link for communication with terrestrial networks such as remote control station, smart city or internet. Thus, ASV acts as a communication hub between two environments as shown in figure 2.

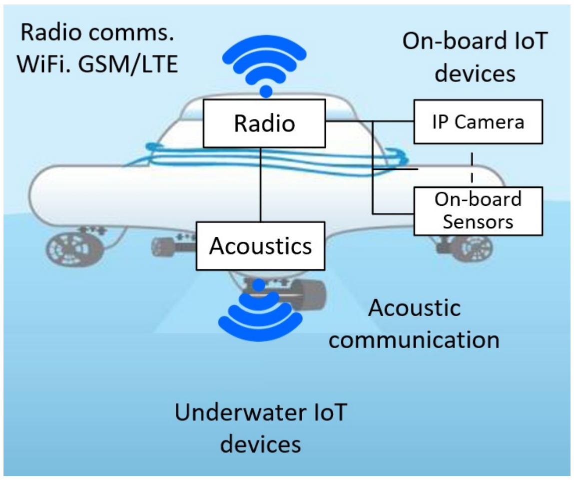

Fig. 2: ASV as a IoT hub for underwater "things".

Installed acoustic system is based on SeaTrac low-cost and light-weight Ultra-short baseline system (USBL) [1] and just recently, on low complexity, miniature acoustic nano-modem system developed by Newcastle University. While USBL system is capable of simultaneous localisation and communication, nano-modem is capable of simultaneous ranging and communication. Therefore, integration of the nano-modem requires using a new single-range localisation techniques elaborated in [2].

The navigation sensor suit consists of an Inertial Navigation System (9-axis) and high precision GPS. ASV is equipped with four thrusters, 200 watts each, placed in over-actuated X configuration. This configuration makes vehicle capable of identical and symmetrical horizontal motion in all 3 degrees of freedom. The length of the H2Omni-X vehicle is $0.75\,m$ with height of $0.35\,m$ and weight of approximately $20 - 30\,kg$, depending on the vehicle payload. Maximum speed (surge or sway) of the vehicle is approximately $1\,m/s$. Software which is used for ASV's navigation, control and mission planning is built in ROS (Robot Operating System). Control capabilities important for this work are underwater target tracking and Dynamic Positioning, both for maintaining the optimal position for acoustic communication with underwater "things".

III. Internet of Underwater Things

The Internet of Things (IoT) signifies a network of physical devices, vehicles or other items embedded with electronics, software, sensors, actuators, and network connectivity which enable these objects to connect and exchange data [3]. It is estimated that the IoT will consist of about 20 to 30 billion objects by 2020 [4]. The Internet of Underwater Things (IoUT) is a novel class of IoT, defined as the network of smart interconnected underwater objects [5]. Extension of the IoT concept to marine environments provides the missing tools for an unprecedented monitoring and exploration of marine environments [6].

The main components of IoUT are underwater nodes (agents or sensors). These nodes are distributed underwater and they are equipped with sensors to sense the environment and acoustic modems to forward data. The data is transferred to the unit on the surface of the water, called sink [7]. Sink is in our study represented by an ASV.

It is expected that IoUT will be applied to a diverse range of marine applications. However, there are some specific challenges related to IoUT due to fact that underwater communication and network properties are very different from those of the traditional Terrestrial Wireless Networks. These IoUT challenges include: most of the IoT communications protocols cannot be directly applied underwater, the propagation speed is much slower, a bandwidth is very narrow (data rates of tens of kbps) and link reliability underwater is low and unstable [7]. Some of these challenges are addressed by introduction of optical and radio underwater modems [8]. Still, their use is limited to very low range i.e they are applicable for systems with close proximity of network nodes.

In this paper we do not address challenges related to acoustic protocols, channels or bandwidth, here we focus on role of a sink or more specifically on potential role of an ASV in IoUT. We investigated use of ASV to improve functionality and reliability of the underwater wireless network. ASV that autonomously position itself in such a way to improve communication link and to optimize link reliability represents a step toward setting up the IoUT. Moreover, this marine satellite (communication hub) positioned on the edge of the marine and terrestrial environments, ensures wireless communication within both environments. That gives us an opportunity to link terrestrial and underwater wireless networks into one unified IoT network. Another important requirement to achieve the IoUT on a large scale is to minimize the costs and size of underwater sensors, increase reliability and durability of the underwater technology and to create a system for monitoring the communication between nodes. The presented system that is based on lightweight and low-cost acoustic devices and portable autonomous vehicle that manages acoustic wireless communication, is absolutely in line with this requirement.

IV. Applications and Project Results

Comprehensive introduction and classification of the practical underwater IoUT applications is given in [7]. Contribution of this paper is in presentation of three specific applications, results of our recent research projects. All applications are based on ASVs that act as positioning and communication satellites for the underwater environment. These studies cover different scenarios of IoUT and include use of standard mobile devices underwater, operational

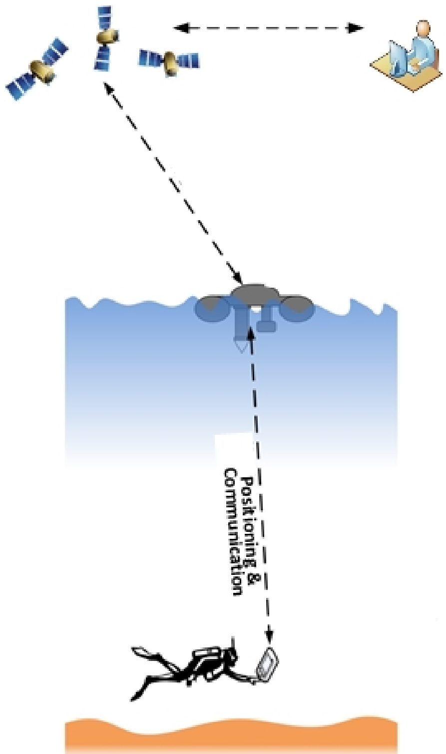

Fig. 3: Diving support, result of the CADDY project.

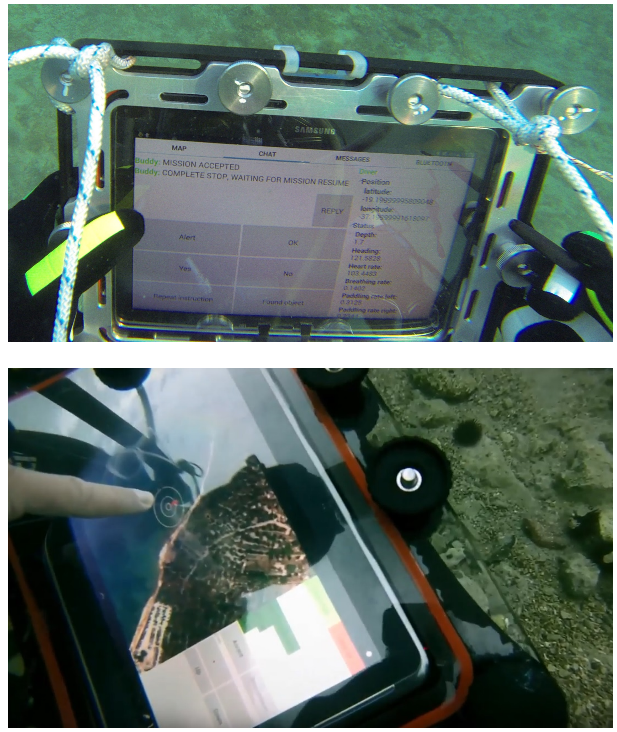

Fig. 4: Diving application that runs on the underwater tablet. Text screen (up) and the navigation screen(down)

support of an underwater vehicles and an underwater wireless sensor networks. While first and second application involve the single ASV able to support one or more underwater agents, the third application involves a multiple ASVs that support network of underwater sensors.

The first application elaborates support to diving operations. The presented study is one of the results of the research project CADDY (Cognitive Autonomous Diving Buddy) [9], funded by the European Commission. Figure 3 presents the concept of the ASV-diver system. Diver is equipped with ordinary mobile device (tablet) enclosed in water- and pressure-proof housing. Tablet is connected to the miniature acoustic modem for communication and positioning. Diver position is estimated by USBL system on-board the ASV and forwarded via acoustic link to the diver's tablet. This low-bandwidth acoustic communication channel is sufficient for regular transfer of diver position messages from an ASV and for two-way data transfer that allows diver to chat with a surface user i.e. for transfer of text messages. The underwater tablet runs a specially developed diving application that supports feature such as displaying the diver's geo-referenced position on overlays within google maps (lower image of figure 4). That allows diver to navigate underwater and to improve its situational awareness. This represents significant benefit for a diver, since situational awareness can often be an issue underwater, especially in low visibility conditions. Other features of the diving application include: chat (upper image of figure 4), dive log, diving tables for decompression and photo log documenting geo-tagged camera images. Another important role of an ASV is to track a diver, based on estimated diver's position [10]. By doing this, ASV indicates divers position on the surface (improve diver safety) and ensures good quality of the communication link.

The second application involves support of autonomous underwater vehicle (AUV) operations. In this study, AUV is assigned to map the underwater area suspected to be contaminated. In complex, rapid response operations, real-time access to underwater contamination data is a priority. Therefore, a second robotic vehicle, ASV is introduced in this cooperative system to act as a positioning and communication satellite between the under- and above-water environments. The presented study is the result of the research project UReady4OS (Underwater Robotics Ready for Oil Spills), funded by the European Commission. The concept is shown in Figure 5 and elaborated in detail in [11] and [12].

ASV performs multiple roles in this cooperative system. It handles acoustic communication with an AUV and radio communication with a ground station that also allows remote via cloud access. Furthermore, ASV acts as an AUV's dedicated positioning satellite and transfers USBL positioning data to an AUV continuously. Within the AUV, received position is fed into the navigation filter together with AUV navigation sensors data, to keep the AUV localization error bounded. Based on AUV position estimate, ASV tracks the AUV, maintaining

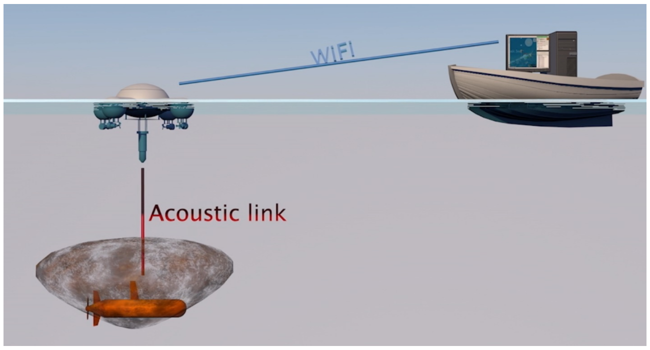

Fig. 5: Concept of project the "UReady4OS", support of AUV underwater operations.

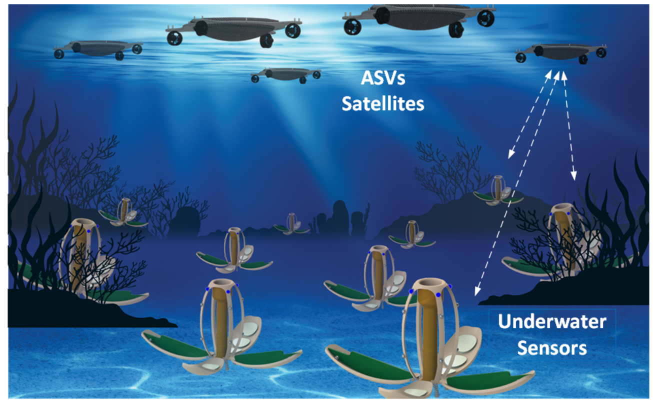

Fig. 6: Localization and communication wireless sensor network of subCULTron project.

the good quality of the acoustic communication channel and ensuring continuous data flow to/from the AUV.

Advantages of such a ASV-AUV fleet are: a.) near real-time transfer of pollution measurements and AUV status to the remote land-based centre; b.) substantial extension of AUV underwater deployment as a result of USBL correction of dead reckoning navigation error and; c.) remote online AUV mission change. In this concept, an operator is able to directly access AUV sensors and AUV control system through the IoUT. As a result, near real-time underwater contamination data from the AUV support the operators' decision-making process. This concept is also known as human-on-the-loop concept, where pilot does not fly the vehicle directly but interfere with autonomous operation only if needed. Therefore, real time availability of the pollution data allows real-time visualisation of the acquired contamination data for any remote end-user, pollution modelling, decision support, and if required, on-line AUV mission change.

The third application is related to data forwarding, deployment and localization in the underwater wireless sensor networks under different environmental conditions [13]. The presented study is the one of the results of the research project subCULTron (Submarine Cultures Perform Long-Term Robotic Exploration of Unconventional Environmental Niches), funded by the European Commission and project CroMarX (Cooperative robotics in marine monitoring and exploration), funded by Croatian Science Foundation. The concept is presented in Figure 6.

In this study, the system consists of two separate agent types: underwater sensors (120 devices) and 5 ASVs in swarm on the surface, that localize Underwater Sensors and enable an exchange of both information and energy [14]. The underwater sensor network nodes are able to wirelessly communicate and interact and they are aided by swarm of ASVs acting as satellites. Furthermore, Underwater Sensors have a buoyancy control system which allows them to sink and collect measurements and to surface when they need a battery charging. ASV again performs different roles in this system. Swarm of ASVs communicate with, localize, recharge and spatially reposition Underwater Sensors. Both ASVs and Sensors are equipped with acoustic nano-modems.

The motivation for localization of underwater acoustic sensor networks comes from the necessity of correlating underwater measurements with the spatial position of the each specific sensor node. Since the goal of the system is long-term monitoring of the underwater environment, the system autonomy is of great importance. Therefore, localization protocols which do not require acoustic communication from underwater sensor nodes, are more suitable for this purpose. The method used in this study is called Basic Synchronization-Free Localization. It does not require any time synchronization between nodes, and uses a silent communication scheme largely contributing to a higher energy efficiency. In this scheme underwater sensor sends an acoustic signal that is received by multiple ASVs. Fusing available sensor depth measurements and Time-Difference-of-Arrival measurements from all ASVs result in underwater sensor localization. ASVs, as mobile surface agents are capable of changing spatial configuration in order to increase localization accuracy of the sensor network. To achieve sufficient localization accuracy, more then three ASVs in the swarm are required. Remote IoUT access is provided to geo-referenced sensor measurements through the acoustic and radio communication available on-board an ASV.

ASV also provides mechanical docking units to capture underwater sensors once they are on the surface as shown in figure 7. The purpose of the docking unit is to recharge underwater sensors battery and to transport the sensor to another location [15].

V. Conclusion

This paper presents versatile application scenarios, results of the research projects that are validated through the field trials. The focus of the current research was on investigating operational support for different underwater agents. The first application is about support to diving operations where a diver tracking and communication link ensures multifunctional support to the diver, i.e. diver following, monitoring, assistance, and improved safety of the diver. The second application involves support of AUVs operations by allowing

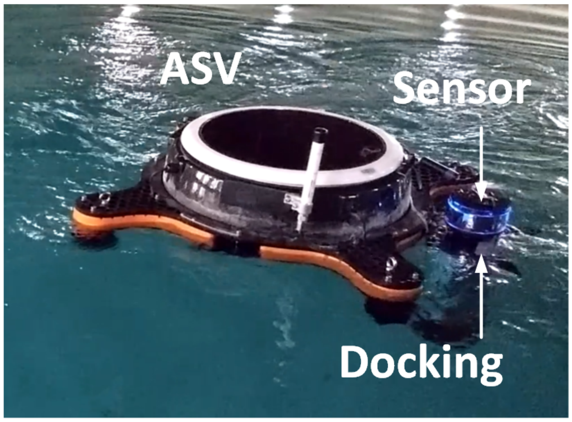

Fig. 7: Docking unit on the ASV for Sensors recharging and repositioning.

real-time transfer of sub-surface data and vehicle status to the land-based centre and extending AUV subsea deployment substantially by correcting the dead reckoning navigation error. The third application is related to data forwarding, localisation, recharging and deployment in the underwater wireless sensor networks under different environmental conditions. The underwater sensor network nodes that are able to wirelessly communicate and interact are aided by swarm of ASVs acting as satellites.

The presented topics are the result of diverse European research projects. The surface-underwater system was awarded a gold medal for innovation at International Trade Fair (IENA 2017) Nuremberg, Germany. The awarded system is now available through the University spinoff company, H2O Robotics.

The future research will be focused more on extension of the wireless underwater networks and setting up the Internet of Underwater Things based on ultra-low-cost wireless communication and sensing nodes.

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