BEA: Overview of a multi-unmanned vehicle system for diver assistance

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Abstract. This paper presents an overview of a solution to address the issue of marine traffic endangering scuba diving and free diving. Diving is a popular recreational activity, and it is estimated that there are around six million active scuba divers worldwide. When diving, it is essential to signal one's presence with universal markers, however, boat drivers do not always recognize them and can speed too close to dive zones, posing a risk to divers. To mitigate these risks, a multi-unmanned vehicle system consisting of an Unmanned Aerial Vehicle (UAV), an Unmanned Surface Vehicle (USV), and an Unmanned Underwater Vehicle (UUV) has been developed. The proposed system works in synergy to monitor and protect divers. The UAV monitors the surface of the sea near the dive zone for any traffic, while the USV tracks the UUV, communicates with the other unmanned vehicles, and provides a takeoff/landing surface for the UAV. The USV can also be used to tow divers and equipment to/from the shore. Finally, the UUV tracks the diver and warns them if it is unsafe to surface. The paper provides an overview of the design and system's architecture, algorithms for boat detection, precision landing and UUV tracking, as well as preliminary tests carried out on the prototype. The proposed system is found to be suitable for the intended application. The BEA (Buoy Eau Air) system is the first in the world to use a multi-drone system to create a geo-fence around the diver and monitor the area within it. The paper also highlights the potential benefits of such a system for the touristic sector, especially for countries where diving is a popular recreational activity.

Introduction

The project presented in this paper develops the first system in the world composed of a multi-drone system: BEA. Before the global pandemic due to Covid-19, the touristic sector in Malta contributed to approximately 25% of GDP and to 28% of fulltime employment. Around 5% of inbound tourists have engaged in diving activities such as snorkelling, scuba diving and freediving [1]. However, such activities have an element of risk. With the recovery of the economic situation worldwide it is important to investigate ways to reboost the touristic sector with new solution to improve the safety at sea. To mitigate the risks associated, BEA proposes a system of drones, one operating in the air, one on the water surface and one underwater to support and monitor the safety of divers. While the hovering UAV creates a geo-fence around the diver, therefore offering protection against boat incursions [2, 3]. The self-propelled Buoy acts as a resting platform while hosting critical support. It also acts as the communication link between the hovering drone and the underwater ROV. Finally, the ROV is able to follow the diver emulating the "buddy philosophy", while providing reassurance to the diver. The multi-drone system works in synergy, with the sub-systems being in communication with each other, and have the ability to relay a message to the

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diver. The buddy system is set of safety procedures to improve the chances of avoiding accidents in or under water by having divers in a group of at least two. The group dive together and co-operate, so that they can help or rescue each other in the event of an emergency. The key point is to respond in time, which is related with the experience of the divers. The multi-drone system enhances this, working in synergy, with the sub-systems being in communication with each other, and having the ability to relay a message to the diver.

The use of a group (or swarm) of unmanned vehicles to perform a task is advantageous because it makes it possible to overcome the limitations of individual vehicles and improves overall performance, flexibility and fault-tolerance, amongst other things. Various instances of collaboration between unmanned aerial, ground, surface and underwater vehicles are available in the literature. For instance, collaborations are reported between Unmanned Ground Vehicles (UGVs) and UAVs [4-7]; between USVs and UAVs [8-10]; and between UAVs, USVs and UUVs [11, 12]. The applications for such collaborations are endless and include: maritime patrol [10], power pylon inspection [7], search and rescue [11], object transportation [5] and terrain navigation [6]. BEA will contribute towards maintaining the safety track record of the local Maltese industry while offering a novelty which boosts the diving experience.

The rest of the paper is organized as follows. Section 2 describes the BEA concept overview while Sections 3 detail the architecture of the proposed system and, finally, Section 4 concludes the paper and describes future work.

BEA concept overview

The BEA system is composed of 3 main modules, the Buoy, developed from scratch, a drone monitoring the geo-fence around the diver and an underwater drone.

More in detail, the primary objectives of BEA are to develop a functional prototype of the multi-drone system and to conduct comprehensive testing under various ambient conditions, including different sea and diving scenarios. By capturing data from test campaigns, divers, and engineers, the secondary objective of BEA is to facilitate design improvements and industrialization while creating a valuable database of average diving safety conditions.

The engineering and divers' requirements have been captured to ensure the system's effectiveness and usability. Figure 1 illustrates the conceptual architecture of the system, outlining the roles and interactions of each component.

The UAV plays a critical role in detecting boat traffic through an onboard camera. It takes off from the Unmanned Surface Vehicle (USV) and hovers at a specified altitude. The UAV can initiate its flight either at the beginning of a dive or a few minutes prior to the expected end, during the divers' safety stop. Upon detecting a boat or vessel, the UAV transmits a warning signal to the USV, which subsequently activates a light indicator located on its underside. The warning signal is also relayed to the Underwater Unmanned Vehicle (UUV), triggering a light indicator for the divers. This system ensures that divers are visually alerted to the presence of boats, enabling them to exercise caution before surfacing.

Throughout the dive, the UUV closely follows the divers, detecting their movements and adapting its speed and direction accordingly, while avoiding obstacles such as rocks. Simultaneously, the USV tracks the UUV's position, maintaining a fixed distance from it by maneuvering and propelling itself. Furthermore, the UAV continuously tracks the current position of the USV. These three vehicles maintain mutual tracking during the dive, ensuring comprehensive surveillance and support.

At the conclusion of the dive, as the divers surface, the UAV descends and lands on the USV by accurately detecting and tracking fiducial markers. Additionally, the UUV docks with the USV, facilitating seamless retrieval. Prior to or after a dive, the USV can be manually operated by the divers, allowing them to tow themselves and their equipment to or from the shore or a boat. In rescue situations, the USV can also serve as a towing mechanism for divers requiring assistance.

Figure 2 shows the 3D model of the finalized conceptual design.

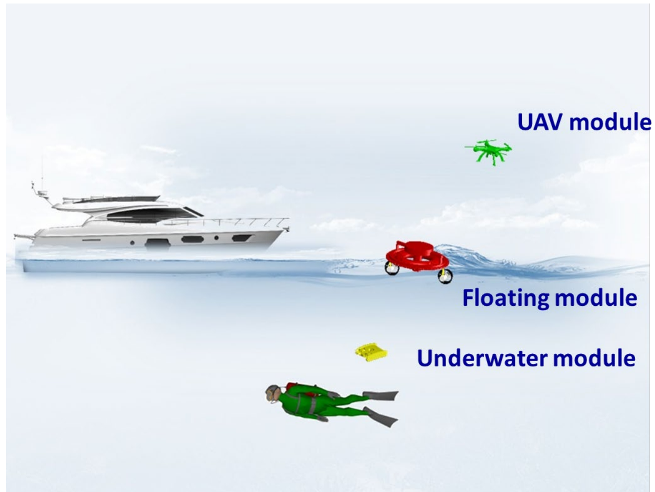

Fig 1: BEA system concept

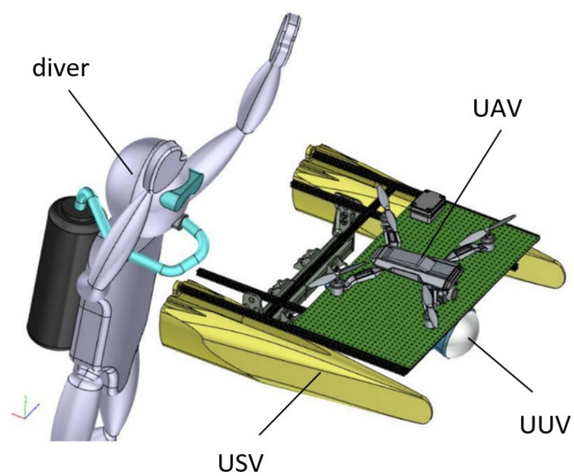

Fig 2: BEA conceptual design

System architecture

This paragraph will describe in detail the system architecture.

UAV: The UAV is the Cuta-Copter EX-1 drone. This quadcopter has an IP67 rating, a payload capacity of 2 kg and an endurance of 23 minutes (without a payload). It is equipped with a Pixhawk 2.4.8 flight controller (running ArduPilot autopilot software) and supports manual and automatic flight. For this application, additional components were added to the Cuta-Copter. The first of these is a Raspberry Pi 4 (Model B) companion computer with 8 GB of RAM. This computer exchanges MAVLink messages with the flight controller via a Universal Asynchronous Receiver-Transmitter (UART) communication interface. It also exchanges data with the USV via a wireless, half-duplex, serial communication link. Two sensors are connected to the Raspberry Pi: a visible light camera module and a distance sensor. The camera is a Raspberry Pi camera module (v1) with a weight of 3 g, a sensor resolution of 2592 x 1944 pixels, a horizontal Field of View (FoV) of 53.5 degrees and a vertical FoV of 41.4 degrees. The camera is mounted beneath the Cuta-Copter and points downwards. It is used both for boat detection and precision landing. The distance sensor is a Benewake TF02-Pro IP65 LiDAR with an outdoor range of 13.5 m and a weight of 50 g. This sensor is mounted next to the camera and measures the height of the UAV above the USV. This sensor is used for precision landing.

USV: The USV was custom-built for this work (Fig. 3). It is made of fiberglass and consists of two hulls; a takeoff/landing pad measuring 1 x 1 m; a waterproof compartment for the electronics; and a handle bar for manual control. Its overall size is 110 x 80 x 15 cm. The USV is controlled by an Arduino Mega 2560 microcontroller and is powered by a 14.8 V 46 Ah LiPo battery pack, complete with a Battery Management System (BMS). Propulsion is provided by four BlueRobotics T200 thrusters at the bottom of the USV – two in front and two at the back. The speed and direction of the USV is controlled by varying the Pulse Width Modulation (PWM) signals to these thrusters. The GPS position of the USV is determined by an Adafruit Ultimate GPS module which provides the controller with NMEA-0183 messages. The position of the USV is transmitted to the UAV via the wireless communication link, and this position is sent to the UAV's autopilot as a new waypoint. Thus, the UAV can follow the USV and remain overhead. Two BlueRobotics ping sonar altimeters and echosounders are mounted in front of the USV, 70 cm apart. Each sensor operates at 115 kHz and has a beam width of 30 degrees and can detect objects up to 50 m underwater. The output of each sensor consists of a distance measurement and a confidence value. These sensors are used to estimate the position of the UUV. An underwater Light Emitting Diode (LED) – whose brightness can be controlled by means of a PWM signal – is mounted beneath the USV. This LED can be turned on by the controller to warn the divers in the event of boat traffic. The USV and UUV communicate via Water Linked M64 underwater modems which provide a wireless half-duplex acoustic communication link.

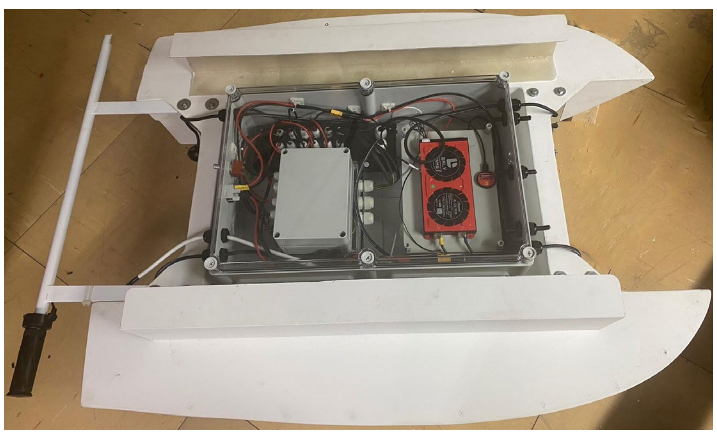

Fig 3: USV

UUV: The UUV is the iBubble Evo. This is an untethered drone with seven thrusters, an endurance of one hour, and a maximum operating depth of 60 m. The iBubble has a proprietary sonar positioning system. This is capable of tracking a diver by using four hydrophones to pick up the acoustic signal transmitted by a remote controller worn by the diver. The iBubble can also detect and avoid obstacles by means of an integrated visible light camera module. As in the case of the UAV, additional electronic components were added to the iBubble. A Water Linked M64 acoustic modem relays warning messages from the USV to an Arduino Mega 2560 microcontroller which, in turn, turns on an LED indicator to warn the diver in the event of marine traffic.

Fig 4: BEA system with Cutacopter, iBubble EVO, Buoy (from left to right)

Conclusions

This paper presented a multi-unmanned vehicle system consisting of a UAV, a USV and a UUV, to assist divers and warn them of boat traffic in their proximity. By integrating the Buoy, UAV, and ROV modules, this multi-drone system, Figure 4, effectively tracks and supports divers throughout their underwater activities. The requirements capture process, functional architecture and versatile surface operation capabilities collectively position BEA as a promising solution for improving diving safety conditions. The initial simulations and real-world test results have showcased the system's suitability and effectiveness for the intended application. Future developments will focus on the full integration of the three vehicles, enabling further real-world testing with divers to evaluate the system's performance in a wider range of diving scenarios.

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