Seabed Surveillance and Underwater Structures Inspection with Remotely Operated Vehicle - Power Ray

Vivien Lorenčič

The marine ecosystem is necessary to be monitored as it is exposed to externalities and pollu-tants that affect biodiversity and the state of the underwater structures. There is a demand for a better, more dynamic, and safe monitoring approach to underwater research and inspection. The unmanned underwater vehicles are becoming a reachable and intuitive tool for underwater inspection, such as for the inspection of the marine hull of vessels, bridges, foundations, piers, pylons, and other support struc-tures in ports. The main advantage of the use of the remotely operated underwater drone is cost and time-efficiency, as they allow to obtain information in a fast and safe way in real-time. In this paper we investigate the possibility of the use of a remotely operated underwater drone Power Ray for seabed observation and underwater structures inspection. It describes the results of the field research collected from the use of low-cost underwater drone Power Ray. The data collected with an underwater drone pre-sents footages of different underwater structures and areas in order to document the seabed state and underwater structures. Additionally, this article provides an overview of the problems in underwater in-spection and monitoring, and possibilities offered by remotely operated vehicle Power Ray in solving them. The results of the paper are not unique to working with a low-cost drone, but are illustrative of the challenges and problems that new users are likely to encounter when using this technology.

KEY WORDS

~ Aquaculture
~ Biosecurity
~ Seabed
~ Inshore inspection
~ Power Ray
~ Underwater drone

University of Ljubljana, Faculty of Maritime Studies and Transport, Slovenia

e-mail: vivien.lorencic@fpp.uni-lj.si

doi: 10.7225/toms.v11.n01.w07

Received on: Aug 3, 2021 / Revised on: Jan 4, 2022 / Accepted on: Feb 1, 2022 / Published online: Feb 19, 2022

1. INTRODUCTION

Inspection and monitoring of marine underwater structures are often presenting a difficult and costly task. Currently, the underwater related activities are primarily performed by divers, who have the proper equipment for the task and are experienced for the most challenging site conditions. However, such tasks can be long lasting and expensive due to the fraction of the cost of a diver over time. The duration of diving and complexity of the diver's tasks make this work extremely dangerous, especially under-ice working (diving). Because of this, those inspections are often not performed at all and, consequently, this can present high risks. Here is also the question of the safety of divers, due to the hazardous environments which can be unpredicted and with limited access. Moreover, the quality of the visual inspection usually depends on the competences of the divers to observe, their knowledge about the research task, objective inspection, experience of the diver, fatigue of the diver, etc. Due to this it is necessary to find and use innovative solutions that can provide cost-effective and accurate information about the circumstances and conditions of the underwater structures.

Therefore innovative research method, tools and studies are necessary. The use of unmanned underwater vehicles for these purposes can become an efficient way to conduct underwater inspections and monitoring. It is due to these considerations that further measurements and studies are necessary to review the usefulness and efficiency of unmanned underwater vehicles (UUVs). We assume that underwater drones will become an important research topic in the academic, as well as in the applicative field.

Unmanned Underwater Vehicles (UUV) are underwater drones that may or may not be operated without human intervention, as explained below: ROV (with human intervention) and AUV (without direct human intervention). UUV is often used as s general term that covers two subcategories of drones: remotely operated underwater vehicles (ROVs), controlled by a remote human operator, and autonomous underwater vehicles (AUVs), which operate independently, with no direct human intervention. AUV classification has a subset known as a diver propulsion device (DPV), also known as swimmer delivery vehicle (SDV), underwater propulsion vehicle (UPV), or underwater scooter (Bernauw, 2016). There is also group of unmanned surface vehicles (USV) or autonomous surface vehicles (ASV) which operate on the surface of the water without a crew. In this research, we have focused on the usefulness of the underwater ROVs; a device that can be operated underwater and controlled via tether by a single person or crew somewhere on the land or a neighboring vessel/floating platform. The tether length defines the size of the ROV's workspace. A large workspace involves a very long cable, which can be difficult to manage. However, ROVs were firstly used by naval military forces (first use of ROV by U.S. Navy in the 1950s) to retrieve torpedoes and clear out underwater mines. Then later they were used for industrial purposes and subsea construction. Nowadays, they are commonly used for oceanic research for various measurements, seabed mapping and exploration, ultrasonic imaging, sampling, digital camera shooting, undersea oil detection, geologic and archaeological surveys, etc.

The classification of the ROVs is an extremely interesting topic of debates, due to the lack of any widely accepted standards on the subject. Therefore, in literature there seem to exist several types and classifications of underwater ROVs. Namely, (Capocci et al., 2017) presented a review of inspection classes of ROVs, and outlined underwater vehicles into two groups: unmanned vehicles and manned vehicles. The unmanned vehicles were further divided into group of AUVs and ROVs, where ROVs were divided into inspection-class and intervention-class. Authors put micro ROVs and medium-sized ROVs into inspection-class, also known as observation-class ROVs; and work-class ROVs (light and heavy) into intervention class. Similarly, (Capocci et al., 2017); (Christ and Robert L. Wernli, 2014; EUROFLEETS+, 2021; Lerus Training, 2021; Norwegian Technology Centre, 2003) also divided ROVs into four classes of underwater ROVs (Table 1). The use of the drone and the size of the drone depends on the task that will be performed. Class I ROVs are used mainly for observation and inspection in the research and military because they have limited deployment (diving depth, etc.), battery and horsepower. In contrast, there are large and most heavy-duty ROVs that are generally more robust machines, and are appropriate for the oil and gas industry. Such ROVs can dive into the deep sea and perform multiple tasks like drilling, lifting and pipeline inspection. However, an example of the Class I ROV is the Power Vision Power Ray drone, which has also been used in this research. This drone has been used to assist with hydrographic survey, i.e. the location and positioning of subsea structures, pipeline inspection, pier condition, and marine hull inspection of vessels. The objective of this research is to present the opportunities of using Power Ray drone in performing underwater observation and monitoring tasks and to present an overview of the challenges and limitations of using this specific underwater drone in field research. The decision to use this specific drone lies in the low-cost, easy control and fast application in the field with minimal resources (vessels, personnel). We have wondered how efficient the use of low-cost drone is in structures (also ship hull) inspection and seabed surveillance. Is it worth using low-cost drones, such as Power Ray underwater drones, to perform those tasks in contrast to the divers? If yes, this can bring a lot of benefits, such as time-saving, lower costs, etc. In this paper, we also discuss general operational issues in the use of the ROV mentioned above.

In general, ROVs presented in Table 1 can perform six tasks: observation, survey, inspection, construction, intervention, burial, and trenching. Observation encompasses tasks where the vehicle moves around an object and situations when it monitors some tasks that are performed by divers (Class I and II). Another task is survey which consists of seabed observation, sometimes also seabed mapping (Class II and III or IV). Surveys are usually undertaken before and after pipeline, umbilical, and cable installation, etc. When performing inspection ROVs are required to be fitted with additional sensors (Class II or III). Construction tasks include physical intervention, including removal of debris, actuation of pipeline valves, etc. Cameras held by manipulators can be used to obtain pictures in areas of restricted access or at difficult angles (Class III). Intervention tasks (Class III and IV) are: support drilling operations by undertaking tasks, such as replacing ring seals, connecting, or disconnecting hydraulic and electrical lines, and operating valves. Some ROVs fitted with suitable trenching equipment are used where soil characteristics are favorable for burial or trenching operations (LerusTraining, 2021).

Over the past decades maritime researchers have extensively used ROVs to explore and monitor the state of the oceans and seas. As a result, the literature on using ROVs has also become quite extensive. This includes academic papers and

Table 1.
ROV classification (Source: Christ and Robert L. Wernli, 2014; EUROFLEETS+, 2021; Lerus Training, 2021; Norwegian Technology Centre, 2003).

Class	Description	Picture
Class I – Pure observation	Small vehicles with camera/lights and sonar only. In-tended for pure observation, although they may be equipped with one additional sensor or additional video camera. Physically they are limited to video ob-servation and cannot undertake any other task with-out considerable modification. These vehicles go from the smallest micro-ROVs to a vehicle weighing 100 kg. Limited to depth ratings of less than 300 m. This class is also known as low-cost ROVs - LCROV.	
Class II – Observation with payload option	Vehicles with two simultaneously viewable camer-as/sonars as standards and can handle several addi-tional sensors. They should be able to operate with-out loss of original function while carrying two addi-tional sensors/manipulators. This vehicles weigh from 100kg to 1,000kg and are electrically powered. This class is also known as light work class ROVs. Limited to depth ratings of less than 1,000 m.	
Class III – Work class vehicles	Vehicles are large enough to carry additional sensors and manipulator. These vehicles have multiplexing capability that allows the use of additional sensors and tools. They are generally larger and more power-ful than Class I and II, but also have wide capability, depth, and power variations. This vehicles are heavy electromechanical vehicles running on high-voltage (up to 3000V). Limited to depth ratings of less than 3000 m.	
Class IV – Seabed-working vehicles	Vehicles are pulled through the water by a surface craft or winch. They can have limited propulsive power and are capable of limited manoeuverability. They use a wheel or track system to move ROV Class III across the seafloor, although some may be able to 'swim' limited distances. These vehicles are typically large and heavy and are often designed for one specific task, such as cable burial.	

reports with various research areas, such as ecology and water quality monitoring (Lima, Boogaard, Graaf-van Dinther, 2020; Lima, Boogaard, De Graaf, Dionisio Pires, et al., 2015), underwater archeology (Menna, Agrafiotis, Georgopoulos, 2018), underwater inspection (Meng, Hirayama, Oyanagi, 2018; O'Byrne, Ghosh, Schoefs, Pakrashi, 2015), seabed mapping (Erena, Atenza, García-Galiano, Domínguez, et al., 2019), fish recognition and machine learning (Meng et al., 2018; Salhaoui, Molina-Molina, Guerrero-González, Arioua, et al., 2020), etc. Especially concerning seabed and aquaculture monitoring, the researchers have made efforts to estimate the location of underwater drones in a given environment (Maurelli, Krupiński, Xiang, Petillot, 2021; Pham, Soriano, Van Hien, Gies, 2020) etc. It can be concluded that ROVs are truly becoming an interesting research topic if we just highlight the most important research papers related to the underwater seabed monitoring and underwater structures inspection. (O'Byrne et al., 2015) researched underwater inspection with ROVs, and established that monitoring of marine structures was often based on reduced visibility, limited access, and high costs. They presented an image processing protocol for underwater inspection of structures, which can be used in a variety of situations within a range of image scenes and environmental conditions affecting the imaging conditions. In contrast, (Lima et al., 2020; Lima et al., 2015) researched effects of floating structures on water quality and ecology by the use of underwater drone. The results showed that underwater drones exhibited a high potential as water quality monitoring tools, considering that they can easily reach limited-access zones to collect data. In their research, they compared eight different small ROVs (also Power Ray) for underwater data collection. The research has also shown multiple advantages and disadvantages of the use of small ROVs in water quality and ecology monitoring. (Meng et al., 2018) also researched ecology, water quality and aquaculture (fish species), conducting the monitoring, using underwater drone as well. They developed a small underwater drone with a 360-degree panoramic camera for fish recognition, based on deep learning and designed for investigating fish species in a lake. Another example of seabed monitoring and marine organisms' observation, using a small ROVs, was described by (Pacunski, Palsson, Greene, Gunderson, 2008). The authors used small ROVs (Class I) to conduct quantitative fishery and habitat investigations with a video camera. It has been noticed that the response of fishes to the ROV can be positive or negative, depending upon whether they are attracted to or avoid the vehicle, and may vary considerably between species. However, they showed the ability of a small ROV to collect quantitative data for analysing marine communities in depths up to 160 meters. One of the exposed advantages of small ROVs consisted in reducing operating costs compared to manned submersible or large-ROVs surveys, which may also cost as much as 10.000€ per day. Nonetheless, in recent years it can be noted that unmanned underwater vehicles are becoming extensively used by water managers, marine biologists, archaeologists, and also by fishery manager, as well as by port authorities for ship hull inspections when entering the port. This is the result of a rapid development and price reduction of drone components (sensors, etc.), consequently reducing drone prices. Consequently, this has also impacted researchers, to whom the drones have suddenly become more accessible. (Song and Cui, 2020) reviewed and analyzed various underwater vessel hull cleaning methods and devices. This paper has surveyed the details of a series of underwater hull cleaning robots, noting that underwater cleaning of a vessel hull can be done with ROVs, equipped with rotary brushes that are used for cleaning the hulls of a vessel. For continuous underwater infrastructure inspection and monitoring, (Matsuda, Maki, Masuda, Sakamaki, 2019) proposed an autonomous underwater vehicle (AUV) system with a seafloor station, where AUV charges its batteries wirelessly. It has been shown that the proposed method is robust against low visibility and complicated sea current, and can be used for completely unmanned underwater surveying. An interesting paper related to the research in question is (Raoult et al., 2020), where the authors compared ROVs with snorkelers for video-based marine research. The study shows that the video obtained from the mini ROV has produced the results comparable to the ones obtained by snorkelers.

Recently the ROVs have become more and more accessible to broader users, due to their rapid development and price reduction. Yet ROVs are not yet part of common monitoring tools as used by port authorities or other managers. Mainly because they are still prioritizing human work and conventional methods. But also because they are not familiar with drone work, and it is not yet clear if the use of drones can complement the existing subsea works. In this context, the main purpose of the work reported in this review paper is to explore the application of the ROVs for seabed observation and underwater structures inspection, as demonstrated in the case of the low-cost drone Power Ray. Port operators and water managers need to recognise this tool as valuable in obtaining a quick insight into the condition of the underwater infrastructure and ship hull condition, as the available alternative option for divers or dry dock. There seem to be technical, legislative, and operational limitations for a larger-scale use of the ROVs.

2. METHODS

This review paper aims at investigating the use of unmanned underwater drone in seabed observation and underwater structures inspection, such as piers and underwater parts of vessels. For this purpose, different ROVs could be used, but we have decided to use the Power Vision PowerRay drone (Figure 1). This device is capable of floating or diving within a depth capacity of 30 meters (100 meters of cable) and a maximum sailing time of four hours. It is a battery powered system with a capacity of 6,400 mAh, which can be recharged many times. On the front of the drone there is a high-definition video camera and two adjusted LEDs, helping to observe deep water areas with less light. It is also equipped with a 4K UHD camera to capture the condition of the seabed and underwater infrastructure. The footage is captured (video resolution 4K and image size 12M) directly into solid-state hard drive without any signal loss and can be transferred onto any computer or mobile device. It provides valuable information which can be analyzed after the inspection has been completed. The underwater images provide information for observing and monitoring the underwater environment.

Figure 1.
Power Vision PowerRay drone (Source: author).

The drone is sending real-time videos to human operators, who supervise the task at hand. It is also equipped with PowerSeeker, which has powerful sonar detection capability with a precise detection of fish distribution up to 80 meters underwater, as well as the water temperature, water depth, underwater topology, etc. The sonar ensures a precise navigation in murky water and transmits a real-time seabed map (Figure 2) to the Vision+ App, without a need to use the camera (Power Vision, 2021).The sonar mounted on PowerRay drone can be used for navigation by recognizing underwater landmarks, or it can be used to search for lost objects on the seabed. The high frequency multibeam can even inspect small structures with an impressive millimeter resolution. Some sonars work like police speed guns angled in four directions towards the sea floor. They measure the change in frequency (pitch), exploiting the Doppler Effect to calculate the speed and direction (velocity) of the underwater ROV. Additionally, they measure the response time of these sonar pings and can calculate the altitude above the bottom. This can be used for autonomous depth holding and its position in all three directions. Regarding the sonar images, those are low in resolution, lack fine detail, are not colored, and thus require a training to read (Ho, Pavlovic, Arrabito, 2011). However, this drone and sonar are unsuitable for precision mapping of the seabed due to inaccuracies in navigation and the fact that the drone weighs just 3.9 kg, so the thrust to weight ratios can reduce the handling of control characteristics. Therefore, movements negatively affect sonar, and objects that absorb sound will not appear on the sonar (Christ and Robert L. Wernli, 2014).

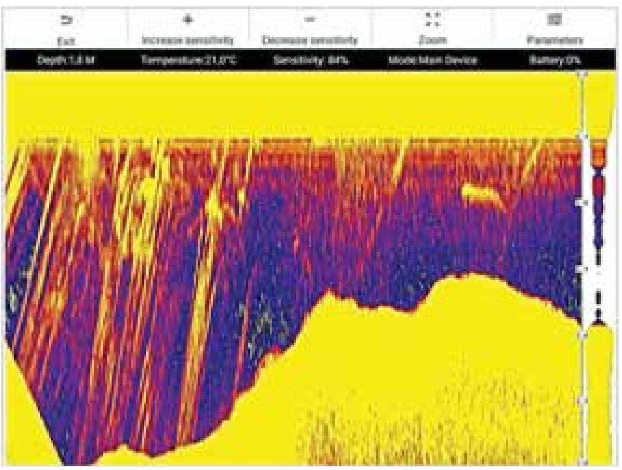

Figure 2.
Sonar real-time seabed map from Power Ray drone (Source: author).

When an ROV navigates under the sea, its motions and stability are affected by the forces produced by its mass, propellers, and the surrounding water. The propulsion and diving configuration of the drone consists of two horizontal thrusters and one vertical thruster. Horizontal thrusters are used for heading, whereas the vertical thrusters are used to control over heave. The maximum speed that a drone can reach is 1.5m/s (Power Vision, 2021). When the research area was not reachable from the coast, we used a boat, from where the drone was controlled. The test of the application of the underwater ROV Power Ray has been performed for three research areas related to the seabed and underwater structures, namely for the following: a) aquaculture and ecology; b) biosecurity inspection and marine hull inspection of vessels; c) pipelines and inshore inspection.

3. RESULTS

To conduct this research, several locations in the Slovenian sea have been used. The average depth of the Slovenian sea is 17 meters, and the deepest point of the sea is 37 meters. In deep and murky water the underwater visibility is low, for which reason the underwater ROV is equipped with sonar to identify fishes and the depth of the sea. In contrast, ROV is capable of operating in shallow water areas. Underwater footages have been captured in 4K resolution, but the quality depends on water visibility (murky water). The most common activity in marine environment research is the underwater visual census (UVC) approach, which aims at quantifying biodiversity, abundance, and coverage of a variety of organisms. Therefore, in order to inspect underwater infrastructure and aquaculture, an image processing is required as an important tool since it often relies on visual descriptions of divers. The skills and knowledge of the divers affect the quality of the obtained information. Therefore, to increase the reliability of visual inspection, photographs are necessary to be captured. Here the underwater imaging must try to overcome the challenging environmental conditions, as even in a perfectly clear water, there is a loss of color and contrast. Water absorbs the red component of light to a greater extent, resulting in underwater subjects having a blue-green tinge. Therefore, the photos captured in this research have a blue-green tinge. The images captured underwater are not only affected by the water itself, but also by the diverse suspended particles that increase the effect of absorption and scattering. Occasionally, high turbidity is caused by the ROVs itself, as its thrusters stir up the sediment on the seabed (Ho et al., 2011). Moreover, these particles themselves are usually viewed in the picture, causing the spot noise signal to interfere with the target objects. But also sand, underwater plants, water particles, etc., may cause scattering and absorption of light (Jiang, Chen, Wang, Ji, 2020). The results of the seabed observation and structures inspection give insights into a practical feasibility, versatility, and accessibility of the underwater ROV, but also the challenges of using the ROV. The usefulness of the ROV for seabed observation and infrastructure inspection have been structured and categorized into three research areas.

3.1. Aquaculture and Ecology

Visual observation and monitoring of fish behavior and their habitats form the standard methodology of many ecological studies. Therefore for visual observation it is necessary to use effective monitoring devices that are not harmful to the sea environment, especially for the water, which is the most important element for all kinds of beings essential to the existence of life. Marine pollution, which is a combination of chemical and rubbish being washed into the sea, is damaging the aquaculture and the health of all water beings. Therefore, the monitoring of the water quality and the seabed is important to ensure adequate environmental management and decision making in order to face ecological problems. The inspection of the underwater objects and aquaculture is often performed by divers or SCUBA divers, using underwater visual census (UVC) methods and manual collection of samples (Lima et al., 2020). To enhance the environmental reports ROV can assist to take an accurate underwater look at the problems in time to find a solution and to capture high-definition video and photographic surveys. In this context, we have performed an identification of aquatic fauna and characterization of local habitats in the Slovenian Sea. Habitat location mapped on the marine chart presents valuable information to understand and manage the underwater ecosystems. It is therefore important to observe and document (with footage and video) the movements of marine fishes in their natural environment without frightening them, which is why small ROV are more convenient for the survey than divers. Underwater footages from Power Ray drone video camera have revealed multiple fishes and aquatic organisms attached to the underwater structures (Figure 3 and 4).

Figure 3.
Underwater images of aquatic fauna (fish, jellyfish, vegetation, mussels) (Source: author).

Visual survey (monitoring) can play an important role in the long-term monitoring of seafloor communities and species-habitat interaction, as it has a significant potential to contribute towards a better understanding of species-habitat dynamics. To investigate and observe aquaculture in seawater, automatic fish and other aquatic species recognition is the basis of underwater research. Efficient fish detection and tracking plays one of the most fundamental roles in the description of fish behavior (Nian, He, Yu, Bao, & Wang, 2013). Advances in object recognition and machine learning can be used for deep learning for recognizing

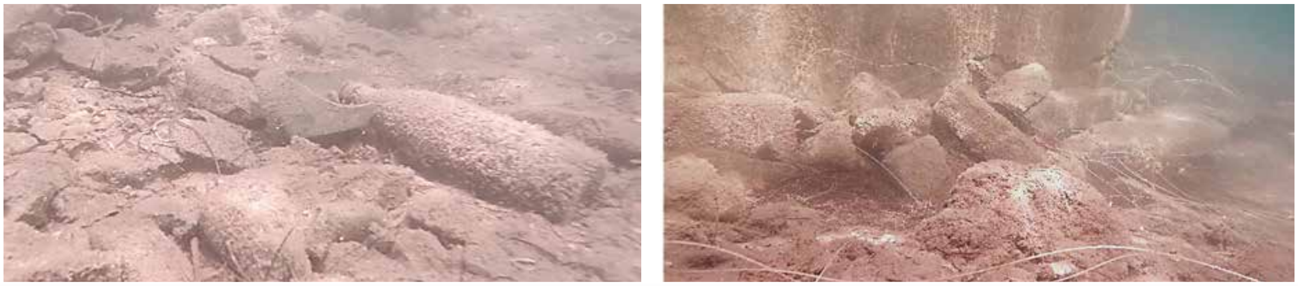

Figure 4.
Underwater images of seabed pollution (bottles, wire) (Source: author).

and classifying objects in the aquatic world. Some authors have already researched this field of use of UAV, such as (Meng et al., 2018; Nian et al., 2013). Other researchers have compared ROVs over snorkelers and divers for underwater video-based marine research (Raoult et al., 2020), concluding that ROV has detected significantly more fish (39% higher abundance) and greater diversity (24% higher). Snorkelers were equipped with hand-held Go Pros and ROV with full HD low light camera, and GoPro mounted on the front of the battery tube of the ROV. The study shows that the video obtained from mini ROVs can be used for research in shallow marine environments when direct intervention is not needed. Based on Figure 3, it can be concluded that underwater footages of fish and vegetation depends not only on the quality of the camera, but also on the underwater visibility and strong waves, affecting the operation of the drone.

The fundamental importance of the ecological status of aquaculture and human survival is the state of the water quality. Thus it becomes important to assess the health status of water and of the marine environment. Ecological inspection of the state of the seabed and underwater structures is usually carried out by divers by visual observation and by manual sampling. However, ROVs can be also used for underwater environmental monitoring and inspection of the water state. For this purpose different types of underwater drones, combined with water quality sensors and cameras, can be used. The combination of underwater drones with a variety of equipment has allowed the collection of high-frequency multi-dimensional data of multiple environmental and water quality parameters, as well as to obtain visual insights into underwater environments (Lima et al., 2020). Such a survey can expose garbage or all sorts of marine debris (Figure 4). On this basis it can become possible to reduce pollutants in seas and other waters. ROVs provide researchers with a powerful tool for oceanographic research. If we compare the results of research by Lima et al. (2015), where Power ray drone was used, with our field result, it can be noticed that we have come to similar results. While the Power Ray has proved good in performing underwater inspection, it can also auto depth hold and transmit real-time video and navigation data to enclose quick insight into the condition of underwater sites.

3.2. Biosecurity Inspection and Marine Hull Inspection of Vessels

Inspecting ships hulls and underwater parts of the vessels for defects or damage poses several challenges, and ROV are increasingly being used to perform hull inspection as an alternative to human divers. Biosecurity inspection of vessels is normally undertaken to ensure that there are no invasive species attached to the vessel when it enters the port. However, marine hull inspection of the vessels is important for many reasons, particularly because it gives insight into whether the structure of the ship is compromised, as an inspection of hull damages and marine life attached to the vessel, etc., as well as taking the vessel out of the water, when it is not required to be expensive or laborious, while diving inspection can pose a potential danger to humans in addition to being costly and time-consuming. Thus, the underwater ROVs allows easy access and data collection underneath floating structures and ships, without dry-docking of the ship (Figure 5). By conducting a regular ROV inspection of the vessel, hulls can proactively manage fuel efficiency by determining optimal cleaning and paint schedules. ROVs can easily confirm that the hull is clear of invasive species attached to the vessel and other marine life when entering the port. Otherwise, drones can also be used to remove (also collect) biofouling from the vessel hull. The vessel hull can be cleaned with various cleaning methods and devices e.g., dry-dock cleaning and underwater cleaning. (Song and Cui, 2020), with reviewing and analysing various underwater vessel hull cleaning methods and devices, as high-pressure and cavitation water jet technology, ultrasonic technology, laser cleaning technology, and rotary brushes. The most common method for biofouling removal is dry-docking, antifouling paint (coating), and periodic underwater cleaning. All the mentioned methods are manly performed by workers to remove biofouling surface by hand.

However, ROVs can be also used as underwater cleaning method, where ROVs are adapted (or attached) with rotary brushes that are used for cleaning the hulls of a vessel. Such brushes are electric-powered rotating cleaning brush devices that can use different brushes to remove marine organisms attached to the vessel. Another cleaning methods used by underwater drones are high pressure seawater jets (Hull Wiper, 2021). Some drones e.g., HullWiper, can clean the hull and also simultaneously collect biofouling removals from a vessel. Such approaches provide environmental-friendly, cost-effective, and diver-free underwater hull cleaning of vessels.

In case when a vessel (ship) touches seabed or collides with another vessel or pier, underwater ROVs e.g. Power Ray, are an ideal tool for a quick, easy, and safe establishing an initial assessment of the extent of the damage. Immediately inspected cracks and damages on a ship or vessel would reduce undesirable risk. Exploring partial underwater parts of a ship and structures is dangerous and impractical for human. Especially in the case of hazardous (oil spill) and risk to life, ROV can provide urgent and critical feedback to the first responder.

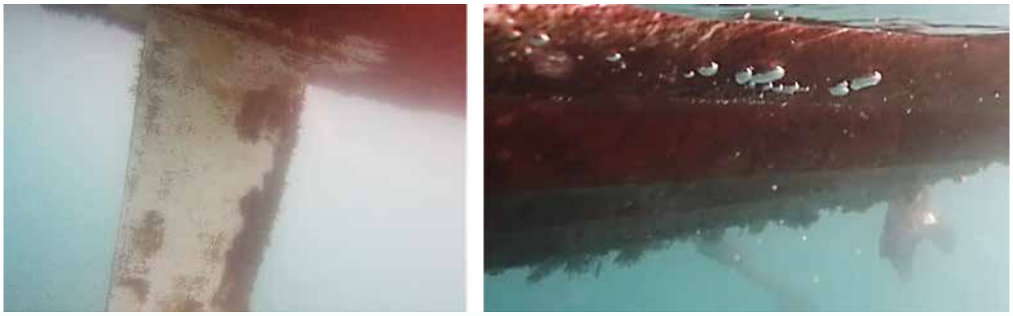

Figure 5.
Underwater images of vessel hull inspection (the keel of a sailboat, boat hull algae) (Source: author).

Figure 6.
Underwater images of vessel elements (anchor rope and chain, boat propeller) (Source: author).

Underwater ROV, equipped with HD camera, makes underwater drones great for checking anchors or a yacht's (vessel) undercarriage, inspecting a dive site. Figure 6 presents an anchor rope and chain inspection, and propeller state. Sometimes it has happened that vegetation or rope gets intertwined with the propeller, in such a case, a fast and safe inspection can be performed with underwater ROV, before the divers arrive.

3.3. Pipelines and Inshore Inspection

As pipelines deteriorate and start to degrade over time, maintenance issues arise, and monitoring lines and pumps become essential to avoiding malfunctions that put employees and the environment at risk. The said inspections of pipelines are unsafe and inaccessible for divers, so to enable visual inspection ROVs are used.. They are commonly used to perform corrosion inspection of subsea pipelines, and support pilings (Figure 7). Because pipelines are monitored with pressure sensors, engineers can easily and quickly locate the section of the line with a spike-pressure increase/decrease or a leak. Pipelines can be inspected internally or externally, depending on the work task (corrosion, searching for leaks, valve condition, etc.). Also, storage tanks which contain water, fuel or other liquids, are necessary to be inspected for corrosion, cracks, and other defects. These tasks usually require getting empty and being taken out of service for inspection. ROVs and robots can overcome these problems, by filming and scanning the walls and ground. Hence the use of drones becomes of high importance, as it has a greater access to narrow pipelines and reservoirs. Especially in the oil and gas industry, it plays a vital role because safety and environmental protection are of crucial importance. Therefore the industry is obviously seeking new robotic technologies for underwater applications.

Figure 7.
Underwater image of the pipeline (Source: author).

Ports are facing water erosion causing large damages to underwater infrastructures. They also have problems with the corrosion of metal structures. Here can be underwater ROVs, such as Power Ray, used for detailed inspection of the inshore infrastructure of ports, such as bridges, foundations, piers (Figure 8), pylons, and other underwater support structures. It is important to regularly inspect such structures, especially because of infrastructure ageing and designated lifespan. As these structures frequently and invariably age, they require severe inspections and maintenance. Another important task is monitoring infrastructural elements underneath the floating structures, which usually presents a difficult task due to the access (small free space between the floating platform and the seabed). Therefore, such tasks are usually performed with underwater ROVs, rarely with divers, or not at all.

Figure 8.
Underwater images of inshore infrastructure (pier) (Source: author).

4. DISCUSSION

A crucial concern with UUV is communication between the operator and unmanaged vehicle (distortion of transmissions underwater, communication delay, etc.), as the only way of underwater communication, are underwater sound and fibre. Another option of the communication is optical fiber, which is used for the underwater drones ROV equipped with cables and optical transceiver (water surface), as well as Underwater optical transceiver and an optical cable. The advantage of the optical fiber is the big data rate (100Mbit/s) and good anti-interference ability. The most serious disadvantage of the ROV is limited working distance and maneuverability. One of the concerns related to the cable of the ROV is a possibility of getting stuck in an unknown obstacle or intertwined with a mooring rope. If the underwater ROV is given too much cable, it can slack, and the cable can get stuck. Also the battery system itself and the battery capacity present a disadvantage due to the operating time, depending on the battery output and lifespan. Another disadvantage of using UUV, and consequently ROV, consists in the difficulty in receiving the position of the drone at each observation, as the GPS is not working underwater. We recognize that in the future it will be necessary to improve the underwater georeferencing of data collection to estimate the size of the organisms and underwater structures' location. Few of the researchers have dealt with underwater drone positioning and navigation (Capocci et al., 2017; Pham et al., 2020). Moreover, the success of using unmanned aquatic drones to inspect underwater infrastructure or to study underwater ecosystems has been observed to be highly dependent on the turbidity/transparency of the water. As the mapping of the seafloor plays an important role in the efficient survey design and monitoring, high-resolution bathymetric maps of areas are also needed, especially for ecosystem management. Moreover, when using the

Power Ray drone, we have noticed that the drone is not capable of diving vertically, as it needs to glide to be able to dive efficiently. This causes a problem with maintaining the position of the drone at a specific depth. Additionally, when performing a dive, the distance between the drone and the seabed is unknown and we only have the depth of the drone dive. Therefore one needs to be careful when approaching the seabed. If you hit the bottom, the sediments are lifting, causing murky water (poor visibility). Here can be addressed the problem of using Power Ray drone, namely, the collision and obstacle avoidance. Therefore, is necessary that underwater drones have a collision-avoidance system and stable formation control. Another advantage of ROV use, in comparison to divers, are costs. A greater number of divers are required for diver-based monitoring and sampling due to the limitations on dive time, depth, etc. Therefore, ROV is more cost-efficient, but it takes much greater post-processing time for video.

However, there is a lot of advantages of using UUVs and underwater ROVs: they can reach places and depths that are not possible for humans (beyond safe diving limits ~25 m depth); they can decrease costs for many activities that are currently performed by humans; improve safety in dangerous tasks and increase performance for underwater related activities. They enable to cover wide areas also with submarine obstacles and a close-up examination of the seabed. Underwater ROVs are allowing marine research to be efficient and safe performed from shore or boat. ROV also requires fewer field personnel as diver-based team. One of the main advantages is also that they can be used in delicate environments like near corals or other seascapes without damaging the environment. Moreover, drones are generally also more environmentally friendly, as they are often electrically powered (battery). Another advantage of ROV is the access to deeper bottom depths and longer diving time to monitor more deeply species in deep sea areas.

5. CONCLUSION

At the beginning of the ROV era, some people thought the ROV could replace the divers. However, ROVs and divers complement each other. In some cases, divers are necessary to do some tasks which cannot be done with ROV, and in contrast, ROVs are more suitable for hazardous areas. The monitoring of the seabed, underwater areas, port infrastructure and hull of vessels, are important to understand different problems and challenges in the underwater area of the port and to ensure adequate decision-making in port development. Underwater monitoring (lifespan of structures) and inspections are vital components to underwater construction and maintenance. This review paper exposes the use of the remotely operated vehicle Power Ray as a research approach in seabed observation and structures inspection. The insights of this paper have shown that, in many cases, small ROVs are a valuable complement to the divers, as they contribute towards providing video/image insight into the underwater ecosystem and a visual inspection of underwater structures. Furthermore, they can be used without divers' intervention. This paper has highlighted the research question, i.e. whether low-cost drones, such as Power Ray underwater drone, can perform tasks of seabed monitoring and ship hull inspection like divers. It has been noticed that underwater drones show high potential as monitoring and inspection tool that they can easily reach limited-accessed areas to collect data (video, photo), that otherwise would cost a lot or be a dangerous task for divers. Especially small ROVs have a potential in enclosed underwater structures penetration, where ROVs may be the only way of surveying the site. However, from the discussion it can be evident that there are still some challenges in future research, such as the positioning of the underwater drone.

This review paper has reported experiences and observations collected from the application of underwater drone in practice. The versatility and flexibility of the ROV allow us to obtain visual insight into underwater aquatic ecosystems and the state of the underwater infrastructure. This is especially important for floating structures of the wider areas, such as Venice. The water body underneath the structures is usually difficult to access (small free space between the floating platform and the seabed). Therefore, innovative research methods and further measurements and studies are necessary. With ROVs it will be easier to perform such a task, and to inspect the under-ice situations. We can conclude that new technologies such as ROVs will in the near future play an important role in observing and surveying the seabed, e.g. for the inspection of the marine hull of vessels, bridges, foundations, piers, pylons, and other support structures in ports. The use of the ROVs for exploration, rescue, military, or defense, will in the near future expand. But the performance at the sea remains a challenging task, and the potential for future innovations is still wide-ranging. From all of the above, one thing seems to emerge and seems to be clear: advanced technologies used in underwater drones will continue to develop.

CONFLICT OF INTEREST

The author declares that she has no known competing financial interests or personal relationships that could influence the work reported in this paper.

REFERENCES

Capocci, R. et al., 2017. Inspection-Class Remotely Operated Vehicles—A Review. Journal of Marine Science and Engineering, 5(1), p.13. Available at: http://dx.doi.org/10.3390/jmse5010013.

Christ, R. D. & Wernli, R. L., 2014. The ROV Manual: A User Guide for Remotely Operated Vehicles. Second Edition Elsevier. Available at: https://www.sciencedirect.com/book/9780080982885/the-rov-manual.

Erena, M. et al., 2019. Use of Drones for the Topo-Bathymetric Monitoring of the Reservoirs of the Segura River Basin. Water, 11(3), p.445. Available at: http://dx.doi.org/10.3390/w11030445.

EUROFLEETS+, 2021. Project Name: An alliance of European marine research infrastructure to meet the evolving needs of the research and industrial communities. Coordinator: Marine Institute (IE). Available at: https://www.eurofleets.eu/wp-content/uploads/2020/07/ROV-Types.pdf.

Ho, G., Pavlovic, N. & Arrabito, R., 2011. Human Factors Issues with Operating Unmanned Underwater Vehicles. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 55(1), pp.429–433. Available at: http://dx.doi.org/10.1177/1071181311551088.

Jiang, Q. et al., 2020. A novel deep neural network for noise removal from underwater image. Signal Processing: Image Communication, 87, p.115921. Available at: http://dx.doi.org/10.1016/j.image.2020.115921.

Bernauw, K., 2016. Drones: The emerging era of unmanned civil aviation. Zbornik Pravnog Fakulteta u Zagrebu, 66(2/3), 223-248. Available at: https://hrcak.srce.hr/157605.

Lerus Training Blog, 2021. ROV: Classifications, Tasks, Tools. Available at: https://www.lerus-training.com/blog/offshore-operations.

De Lima, R.L.P., Boogaard, F.C. & de Graaf-van Dinther, R.E., 2020. Innovative Water Quality and Ecology Monitoring Using Underwater Unmanned Vehicles: Field Applications, Challenges and Feedback from Water Managers. Water, 12(4), p.1196. Available at: http://dx.doi.org/10.3390/w12041196.

Lima, R. et al., 2015. Monitoring the impacts of floating structures on the water quality and ecology using an underwater drone.

Matsuda, T. et al., 2019. Resident autonomous underwater vehicle: Underwater system for prolonged and continuous monitoring based at a seafloor station. Robotics and Autonomous Systems, 120, p.103231. Available at: http://dx.doi.org/10.1016/j.robot.2019.07.001.

Maurelli, F. et al., 2021. AUV localisation: a review of passive and active techniques. International Journal of Intelligent Robotics and Applications. Available at: http://dx.doi.org/10.1007/s41315-021-00215-x.

Meng, L., Hirayama, T. & Oyanagi, S., 2018. Underwater-Drone With Panoramic Camera for Automatic Fish Recognition Based on Deep Learning. IEEE Access, 6, pp.17880–17886. Available at: http://dx.doi.org/10.1109/access.2018.2820326.

Menna, F., Agrafiotis, P. & Georgopoulos, A., 2018. State of the art and applications in archaeological underwater 3D recording and mapping. Journal of Cultural Heritage, 33, pp.231–248. Available at: http://dx.doi.org/10.1016/j.culher.2018.02.017.

Nian, R. et al., 2013. ROV-based Underwater Vision System for Intelligent Fish Ethology Research. International Journal of Advanced Robotic Systems, 10(9), p.326. Available at: http://dx.doi.org/10.5772/56800.

NorwegianTechnologyCentre, 2003. Remotely operated vehicle (ROV) services Remotely operated vehicle (ROV) classification Website: Norwegian Technology Centre, Oscarsgt. 20, Postbox 7072 Majorstuen, N-0306 Oslo, Norway. Available at: https://www.standard.no/pagefiles/978/u-102r1.pdf.

O'Byrne, M. et al., 2015. Protocols for Image Processing based Underwater Inspection of Infrastructure Elements. Journal of Physics: Conference Series, 628, p.012130. Available at: http://dx.doi.org/10.1088/1742-6596/628/1/012130.

Pacunski, R. et al., 2008. Conducting Visual Surveys with a Small ROV in Shallow Water. Marine Habitat Mapping Technology for Alaska, pp.109–128. Available at: http://dx.doi.org/10.4027/mhmta.2008.08.

Pham, H.A. et al., 2020. Distributed Adaptive Neural Network Control Applied to a Formation Tracking of a Group of Low-Cost Underwater Drones in Hazardous Environments. Applied Sciences, 10(5), p.1732. Available at: http://dx.doi.org/10.3390/app10051732.

PowerVision., 2021. PowerVision. Available at: https://www.powervision.me/en/.

Raoult, V. et al., 2020. Remotely operated vehicles as alternatives to snorkellers for video-based marine research. Journal of Experimental Marine Biology and Ecology, 522, p.151253. Available at: http://dx.doi.org/10.1016/j.jembe.2019.151253.

Salhaoui, M. et al., 2020. Autonomous Underwater Monitoring System for Detecting Life on the Seabed by Means of Computer Vision Cloud Services. Remote Sensing, 12(12), p.1981. Available at: http://dx.doi.org/10.3390/rs12121981.

Song, C. & Cui, W., 2020. Review of Underwater Ship Hull Cleaning Technologies. Journal of Marine Science and Application, 19(3), pp.415–429. Available at: http://dx.doi.org/10.1007/s11804-020-00157-z.