UNDERWATER ROBOTICS: A PRIMER

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ABSTRACT

An underwater robot is a vehicle that can go anywhere from the water surface to full ocean depth. Underwater robots do work that is too dangerous or too expensive for human divers. They perform different functions such as inspecting ships, repairing underwater structures, mapping the oceans, performing scientific research, and cleaning up oil spills. They can replace or accompany human beings to complete underwater missions in unknown and complex marine environments. They are making exploration cheaper and more accessible. This paper reviews space robots and their applications.

Key Words: robots, robotics, underwater robotics, marine robots, marine engineering, exploration.

I. INTRODUCTION

An industrial revolution is unfolding under the seas. Although humans have explored the Earth, we know little about our oceans. The ocean is a fascinating domain, and relatively unexplored compared to the land masses. It covers more than 70 percent of the planet's surface. It has always been critical to human welfare by being a source of food and other resources such as oil and gas. Oceans are a major food source and play a central role in regulating the planet's climate, regulating temperature, and ultimately supporting all living organisms. They represent a largely untapped source. Due to overfishing, acidification, and pollution, the ocean ecosystem is changing rapidly [1].

With the technological development and the emergence of many problems that need to be solved by using the technology of robots, marine technology, and artificial intelligence, such as monitoring and following-up water and sea pollution. As the ocean attracts great attention on environmental issues and resources as well as scientific and military tasks, the need for underwater robotic systems has become more apparent. Underwater robots, also called unmanned underwater vehicles (UUVs), have become important tools in many fields. Since the first remotely operated underwater vehicle, POODLE, was first launched in 1953, underwater robots began to evolve through the 1960s and 1970s, mostly for military purposes. Unmanned underwater robotics opens the door to new possibilities across all marine sectors. Many countries have implemented research and development on underwater robots. For instance, the US military designed the "bluefin" autonomous underwater vehicle (AUV), which can perform autonomous underwater navigation [2].

II. WHAT ARE ROBOTS?

The word "robot" was coined by Czechriter Karel Čapek in his play in 1920. Isaac Asimov coined the term "robotics" in 1942 and came up with three rules to guide the behavior of robots [3]:
(1) Robots must never harm human beings,
(2) Robots must follow instructions from humans without violating rule 1,
(3) Robots must protect themselves without violating the other rules.

Robotics has advanced and taken many forms including fixed robots, collaborative robots, mobile robots, industrial robots, medical robots, police robots, military robots, officer robots, service robots, space robots, social robots, personal robots, and rehabilitation robots [4,5]. Robots are becoming increasingly prevalent in almost every industry, from healthcare to manufacturing. Figure 1 indicates that robotics is one of the branches of artificial intelligence.

Special forms of robots in common use include drones and chatbots. Drones are flying robots, a type of robots, that are poised to proliferate in certain commercial sectors. Drones can help utility crews after a storm by quickly and safely identifying areas in need of repair. Drones can also help with maintenance tasks, such as surveying solar panels for damage.

Chatbots have empowered the banks and other financial institutions by simplifying the complex processes. We interact with Facebook Messenger bots all the time. Messenger bots are revolutionizing the small business world. Messenger bots can answer customers' questions, collect user's info, organize meetings, reduce overhead costs, and engage in other business tasks. Big companies like Walmart, Alibaba, and Amazon have been benefitting the help of bots.

III. UNDERWATER SPACE ROBOTICS

Robotics is a branch of engineering that involves the concept, design, manufacture, and operation of programmable machines. Underwater robots are machines designed to explore the mysteries and beauty of the ocean. They are often equipped with a video camera, propulsion system, and lights. They are increasingly used to relieve the burden on human operators. Underwater applications require robots that can withstand the incredibly challenging environment as well as deliver improvements in efficiency, safety, and reduced carbon emissions. It is hoped that underwater robots will have the ability to move quietly and efficiently like fish, and have the ability to move in all directions like rotor robots to complete complex tasks.

Underwater robots operate in ocean and lake environments. There are two categories of UUVs: autonomous underwater vehicles (AUVs), which operate independently, and remotely operated vehicles (ROVs), which a person controls from a distance. AUVs can be programmed by engineers to perform specific tasks. ROVs shine in situations that require close observation [6]. Figure 2 shows the classification of UUVs [7]. Initially, these robots were used mainly for military and scientific purposes. Today, they are being used in scientific research, defense, surveying, and industry.

Here are some interesting facts about these robots [8]:

1. Underwater robots can be referred to as sea gliders or Autonomous Underwater Vehicle (AUV).
2. They are relatively small and lightweight.
3. Underwater robots can dive more than 300feet deep in water unlike humans who only dive 130feet deep.
4. Underwater robots can be designed to be mechanical replicas of sea creatures.
5. They are used to explore the ocean, gather data about ocean currents, seawater temperatures, and sound of a sea creature.
6. Underwater robots can operate independently and dependently; some need a physical connection to their operator who may be on a ship.
7. Underwater robots can fit into small spaces such as small holes, which humans cannot enter.
8. These robots are essential, they inspect and clean water tanks without the need to drain and by so doing remove any risk to human life.
9. The robots can be used to repair damage to pipelines and oilrigs under the sea.

10. In the world today, researchers use underwater robots to discover the mysteries of the sea.

IV. TYPES OF UNDERWATER ROBOTS

Robots are usually broken into size categories. Modern autonomous remotely operated underwater vehicles (ROVs) are categorized based on their size, depth capability, on-board horsepower, and whether they are all-electric or electro-hydraulic as follows [9]:

1. *Micro:* Micro class ROVs are very small in size and weight. They weigh less than 3kg and are used as an alternative to a diver, specifically in places where a diver might not physically enter.
2. *Mini:* Mini Class ROVs weigh around 15kg. A single person can transport the complete ROV system on a small boat, deploy it, and complete the job without outside help.
3. *General:* They typically have less than 5HP (propulsion), manipulators, grippers, and a sonar unit. They are used on light survey applications.
4. *Light Work Class:* They typically have less than 50HP (propulsion). They carry manipulators and are made from polymers such as polyethylene.
5. *Heavy Work Class:* They typically have less than 220HP (propulsion) with the ability to carry at least two manipulators.
6. *Trenching/Burial:* They typically have more than 200HP (propulsion) and not usually greater than 500 HP with an ability to carry a cable laying sled.

V. EXAMPLES OF UNDERWATER ROBOTS

Underwater robots play an important role in the offshore oil and gas industry, the defense sector, maritime search and rescue, oceanographic research, underwater archaeology and environmental monitoring . They are now finding growing uses, driven largely by the improved capabilities arising from various technological developments [10]. Humans have developed different underwater robots for various reasons. We will consider four examples here.

1. *Iver3:* This is the first commercially developed family of low-cost AUVs. They are ideal for coastal applications such as sensor development, general survey work, sub-surface security, research and environmental monitoring. The Iver system offers the widest range of world-class sensors and sonar packages with simple operation in near coastal environments. It is capable of diving up to 100m, has battery life that can last approximately 24 hours, and is programmable to carry out autonomous missions. Figure 3 shows Iver3 [11].

2. *Eelume:* This is a self-propelled snake-shaped robot that spends all of its time underwater. It stays on location on the sea floor, ready for subsea inspection, maintenance, and repair. It can be used in offshore wind, oil and gas production, and any type of underwater inspection. A pilot program for Eelume is being completed in the Norwegian Sea. Figure 4 shows Eelume [12].

3. *Mesobot:* This is an innovative underwater robot capable of tracking and recording high-resolution images of animals and particles in the mid-ocean region known as the twilight zone. This robot will enable commercial exploitation of twilight zone fisheries. It greatly expands scientists' ability to observe creatures in their habitat with minimal disturbance. Mesobot is shown in Figure 5 [13].

4. *Nereus:* On its first mission, Nereus explored the deepest part of the ocean, In the future, Nereus could also be used under ice-capped polar waters. Nereus, an unmanned vehicle, can swim freely as an autonomous underwater vehicle (AUV) to survey large areas of the depths, map the seafloor, and give scientists a broad overview. Nereus can transmit high-quality, real-time video images and receive commands from skilled pilots on the ship to collect samples or conduct experiments with a manipulator arm. Nereus is shown in Figure 6 [14].

VI. APPLICATIONS

Underwater robots are currently used for military, commercial, scientific, and exploration applications. Scientific applications for underwater robots include survey, inspection, and sampling tasks previously performed by human-occupied submersibles or towed vehicles. Common areas of applications of underwater robots include the following [9]:

- *Ocean Exploration:* Underwater robots help study areas of the ocean that are inaccessible to humans. They are used in ocean or deep-sea exploration for resources like oil, gas and metals, pipeline repair, shipwreck investigation, surveys, oceanographic sampling, underwater archaeology. Ocean exploration provides the data, information, and tools needed to increase our understanding of ocean processes and ecosystems.

- *Offshore Oil and Gas Industry:* One of the primary uses for underwater robots is in the oil and gas industry. They can inspect and maintain offshore pipelines and rigs, allowing for safer and more efficient operation of these facilities. The oil and gas industry heavily relies on underwater robots for installation, inspection, and servicing of platforms, pipelines, and subsea production facilities. As the search for oil and gas goes deeper, this trend can only continue.

- *Robotics Education:* Robotics education uses robotics projects to encourage youths to build critical thinking, problem-solving, and teamwork skills as they become effective engineers. Getting exposed to robotics is good for elementary and high school students. Young people considering entering any engineering or industrial field will benefit from robotics education [15]. For example, at the University of Delaware, the ocean robotics laboratory is home to 10 underwater robots.

- *Student Competition:* Underwater robotics unifies all of the topics of STEM education – the sciences, the technological advances, the engineering behind the new technology, and mathematics used to analyze the data collected on each mission. Underwater robot competition challenges student teams to design and build underwater robots that can complete a series of tasks while submerged. This gives students the opportunity to connect ideas across a variety of disciplines through experiential learning, all while building a vehicle, a team, and a dream to be the next underwater robotics competition world champion. Figure 7 shows an underwater robotic design competition [16].

- *Military:* The military has always been a leader in the development of underwater robotic capabilities. In military applications, autonomous underwater vehicles (AUVs) are often referred to as unmanned undersea vehicles (UUVs). Many nations operate underwater robots for military surveys.

- *Underwater Drones*: Underwater drones are unlocking a whole new world beneath the surface for sub sea exploration, underwater cinematography and fishing. They have been used to explore the most extreme depths of the world's oceans. These drones can open up a whole new world of underwater exploration and photography for one. Underwater drones are nowadays very capable and surprisingly affordable. A typical underwater drone is displayed in Figure 8 [17].

BENEFITS

Great efforts have been made in developing underwater vehicles to overcome challenging problems caused by the unstructured and hazardous ocean environment. Underwater robots currently play important roles in several scientific, commercial, and military tasks. Their goal is not only for these robotic vehicles to replace human divers but also to enable an entirely new generation of subsea equipment serviced without intervention. Autonomous underwater robots can improve productivity and data quality compared to towed and tethered systems. They can dive to depths humans cannot endure.

CHALLENGES

Although a lot of progress has been achieved for underwater robotics technology, there are still some challenges. Due to the complex underwater environment, the state-of-the-art sensing technologies cannot handle all the needs of underwater observations. For the same reason, capturing a clear underwater images is still a challenging problem. Robots that collect images do not have the ability to recognize objects or make decisions based on what they see. Although underwater acoustic and optical sensing technologies have been widely used in underwater robots, there still exist many challenging problems such as acoustic multipath effects, acoustic reverberation, and optical attenuation [20]. The electrical conductivity of saltwater makes radio communication very difficult underwater. Government support for exploratory science is not what it used to be. New hope for ocean exploration often comes via the largesse of billionaire philanthropists, who have poured money into a range of projects.

CONCLUSION

Robotics is a branch of engineering concerned with the conception, design, manufacture, and operation of programmable machines capable of developing autonomy while performing a specific task. Robots make subsea operations safer and less expensive than requiring human divers. Underwater robotics have always been the primary mode for exploring the depths of the ocean. The autonomous underwater robot travels hydrodynamically at the surface or through the depths of the sea. We have slowly begun to see its widespread use in a variety of commercial, naval, offshore, scientific, and military applications. It holds the promise of efficient survey from small vessels of opportunity with minimal infrastructure. The future of underwater robots is bright with almost limitless applications. For more information about underwater robotics, one should consult the books in [18-30] and the following related journals devoted to robotics:

- *Robotica*
- *Robitics and Autonomous*
- *Robotics and Computer-Integrated Manufacturing,*
- *Advanced Robotics*
- *Autonomous Robots*
- *Journal of Robotics*
- *Journal of Robotic Systems*
- *Journal of Robotic Surgery*
- *Journal of Robotics and Mechatronics*
- *Journal of Field Robotics*
- *Journal of Intelligent & Robotic Systems*
- *Journal of Mechanisms and Robotics-Transactions of the ASME*
- *Journal of Automation, Mobile Robotics and Intelligent Systems*
- *Journal of Future Robot Life*
- *Journal of Marine Science and Engineering*
- *IEEE Robotics and Automation Letters*
- *IEEE Transactions on Robotics and Automation*
- *International Journal of Medical Robotics and Computer Assisted Surgery*
- *International Journal of Robotics Research*
- *International Journal of Social Robotics*
- *International Journal of Humanoid Robotics*
- *International Journal of Advanced Robotic Systems*

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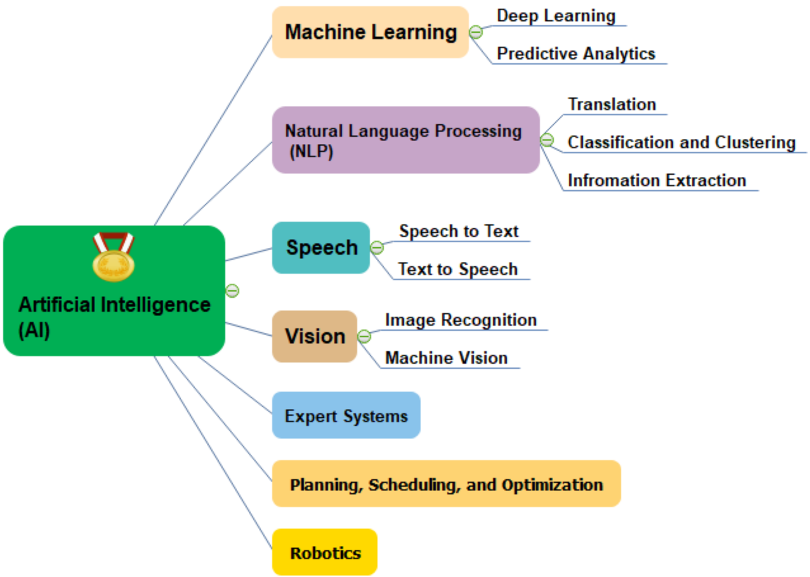

Figure 1 Robotics is one of the branches of artificial intelligence.

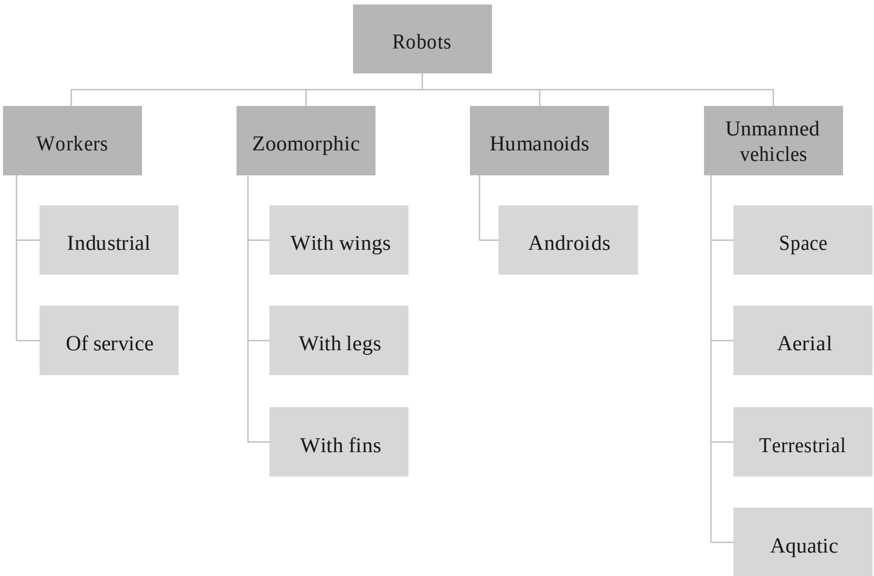

Figure 2 Classification of unmanned underwater vehicles (UUV) [7].

Figure 3 Iver3 AUV [11].

Figure 4 Norwegian Eelume [12].

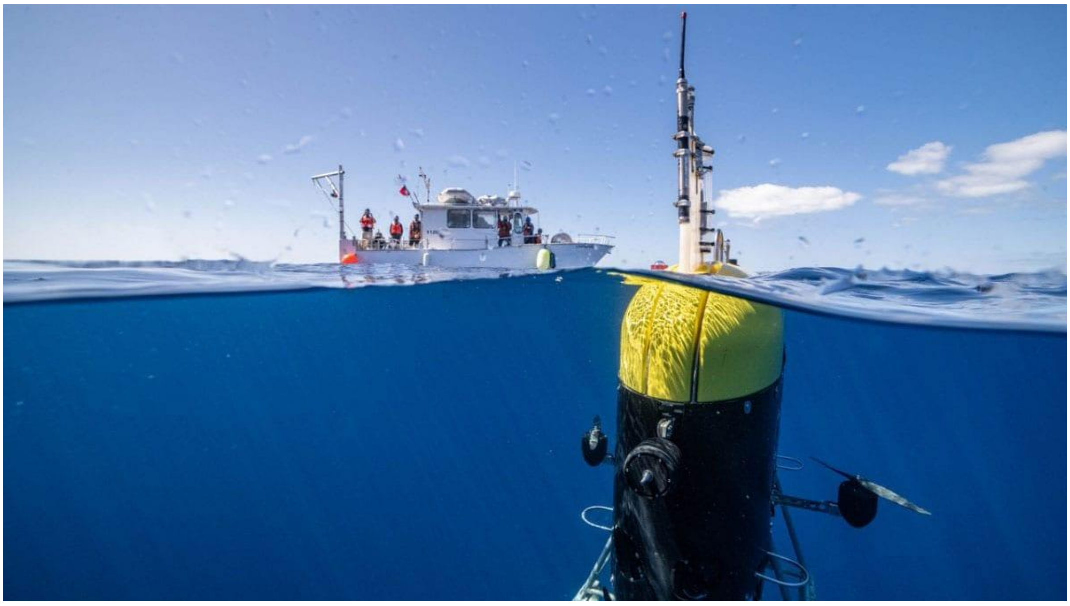

Figure 5 Mesobot [13].

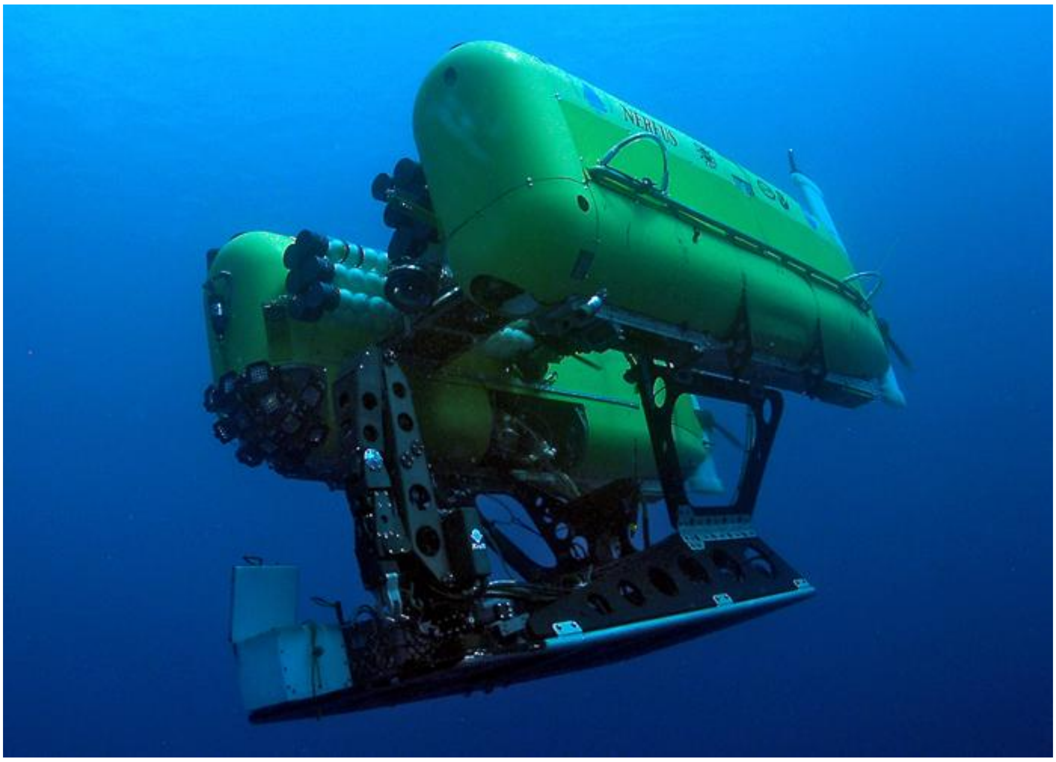

Figure 6 Nereus [14].

Figure 7 Underwater robotics design competition [16].

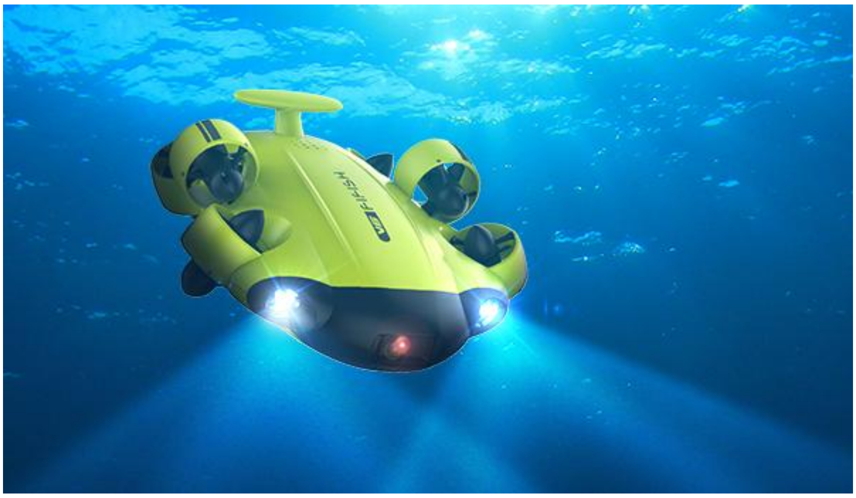

Figure 8 A typical underwater drone [17].