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Robotics in Maritime Industry

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ABSTRACT

Modern robotics is spreading across almost all sectors, including the maritime industry. Robotics is rapidly transforming the maritime industry, offering solutions for a wide range of applications from maintenance and repair to exploration and environmental monitoring. Robotization in the maritime industry can help accomplish a number of important tasks with greater efficiency and safety. The key direction of using robots is the execution of situations that are dangerous or potentially hazardous to human health. Robots are used for many purposes in the maritime industry, from cleaning and maintenance to fully autonomous vessels with no pilot, no captain, and no crew on board. For example, a robot can be used to carry out preventive cleaning to maintain the working capacity of ships without long-term work hazardous to humans. In this paper, we highlight the main use cases and trends of robotics in the maritime industry.

KEYWORDS: *robots, robotics, space robotics, maritime industry*

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INTRODUCTION

The ocean represents a large untapped source. Ocean exploration aligned with sustainable development warrants at least as much attention as space flights. The undersea work needed to investigate and tap into ocean energy and resource potential can be dangerous. Mankind has been able to set foot on the moon, land rovers on Mars, and discover the existence of a supermassive black hole at the center of the Milky Way. Yet, our oceans remain an enigma to us. The oceans cover more than 70% of the earth's surface and support an estimated 90% of the life forms on our planet. They even provide employment and alternative sources of energy, and generate revenue for the scores of people that live along its shores. Some scientists argue that it is a herculean task to send people to the bottom of the ocean and then into space. From a scientific point of view, the deep ocean is thought to hold the secret to the origin of life. The bottom of the oceans is the largest component of the surface of our planet and yet it is also the least known. Thus, there is currently worldwide interest in the development of new tools to support the exploration, observation, sampling, and persistent monitoring of the marine environment [1].

The digital revolution has dramatically changed our lives. A huge number of online services, devices, software and, of course, robots have become the drivers of economic and social development. Many digital services, devices, and robots are driving economic and social progress. Technology is undoubtedly a catalyst of change. Due to technological advancement, machines have made our lives easier and better. We have gone from assembly-line equipment and repetitive operators to full-on autonomous robots. Industries around the world are now showing more interest in robotics because it represents the key to future medicine, warfare, better economy, and well-being. With the introduction of a variety of new robotic technologies, the day is not far when robots will carry out several important jobs both at sea and on shore [2].

Modern robotics is sweeping across nearly every sector, including the maritime world. Robotic systems are being used to enhance safety, efficiency, and sustainability in maritime operations. As such, robotics companies in the shipping industry are now changing the way that goods are transported globally.

By replacing humans with robotics, shipping and crating operations have become much safer, streamlined and more efficient.

WHAT IS A ROBOT?

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 and later added the zeroth law [3]:

- Law 0: A robot may not injure humanity or through inaction, allow humanity to come to harm.
- Law 1: Robots must never harm human beings,
- Law 2: Robots must follow instructions from humans without violating rule 1,
- Law3: Robots must protect themselves without violating the other rules.

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.

Although there are many types of robots designed for different environments and for different purposes/applications, they all share four basic similarities [4]:

1. All robots have some form of mechanical construction designed to achieve a particular task;
2. They have electrical components which power and control the machinery;
3. All robots must be able to sense its surroundings; a robot may have light sensors (eyes), touch and pressure sensors (hands), chemical sensors (nose), hearing and sonar sensors (ears), etc.
4. All robots contain some level of computer programming code.

Programs are the core essence of a robot since they provide intelligence. There are three different types of robotic programs: remote control, artificial intelligence, and hybrid. Some robots are programmed to faithfully carry out specific actions over and over again (repetitive actions) without variation and with a high degree of accuracy.

Robotics is an interdisciplinary field that involves the design, construction, operation, and use of robots. It is a branch of engineering and computer sciences that includes the design and use of machines that are capable of performing programmed tasks without human involvement. The field develops machines that can efficiently carry out various tasks, can automate tasks, and do various jobs that a human might not be able to do. Robots could someday be our drivers, companions, collaborators, teachers, specialists, and exploration pioneers [5].

MARITIME ROBOTS

Robots are used for many purposes in the maritime industry, from cleaning and maintenance to fully autonomous vessels with no pilot, no captain, and no crew on board. The key direction of using robots is the execution of situations that are dangerous or potentially hazardous to human health. For example, building robotic vessels for oil refining is dangerous for workers who are regularly exposed to chemicals, toxic fumes and have a constantly high risk of fire or explosion.

Robots are used for many things in the maritime industry, from cleanup and maintenance to full-on driverless craft, such as the Maxlimer. Marine robotics encompasses an extremely wide range of topics that are usually defined as application domains. In each domain, autonomous marine systems play a key-role in the achievement of specific challenging scientific, commercial, and societal goals. Marine robotics has steadily emerged as a key enabling technology for the execution of increasingly complex and challenging missions at sea. Tasks such as water sampling, monitoring, and exploration are extremely simplified by the exploitation of robotic teams of heterogeneous and complementary agents, implying also great improvements in results with less effort in terms of time and human resources and being able to obtain better performance in terms of accuracy on gathered data. Figure 2 shows a typical example of maritime robot [2].

TYPES OF MARITIME ROBOTS

Marine robots fall into two major categories: remotely operated and autonomous. The first include Remotely Operated Vehicles (ROVs), while a representative group of the latter consists of Autonomous Underwater Vehicles (AUVs), often referred to as Unmanned Underwater Vehicles (UUVs). The following types of robots are commonly used in maritime industry [6-8]:

- *Underwater Robots:* An underwater robot is a technologically advanced machine designed for submerged operations. These robots range from remotely operated vehicles (ROVs) to autonomous underwater vehicles (AUVs), each equipped with specialized functionalities to perform tasks beneath the water surface. Underwater robots are often equipped with cameras, sensors, and application-specific tools (grippers, welding torches, etc.), enabling them to navigate, gather data, and sometimes manipulate objects in the aquatic environment. They have emerged as pivotal tools in various sectors for work that is considered too dangerous or expensive for human divers. These sophisticated machines, often referred to as underwater drones, subsea robotics, remotely operated vehicles (ROVs), and autonomous underwater vehicles (AUVs), have significantly expanded our capacity to explore and interact with the underwater world. Underwater vehicles are used for exploration and mapping, military and defense, salvage operations, and industrial applications. An example of undersea robot is shown in Figure 3 [9].

- *Fire Robots:* These are firefighter robots on ships. Robots are designed to detect and extinguish fires alongside human firefighters onboard. In the event of a fire on a ship, these robots are capable of performing tasks such as turning valves, collecting and dragging fire hoses, searching for survivors, and can withstand temperatures up to 500 degrees Celsius. Robots can respond to gestures and commands, and its sensor package includes a camera and gas sensor. For example, the SAFFiR Firefighter Robot, developed by the Naval Research Laboratory, is an autonomous humanoid robot capable of detecting and extinguishing fires aboard a ship and working side by side with human firefighters using advanced technology. The fire robot SAFFIR is shown in Figure 4 [2]
- *Anti-Piracy Robots:* These are used to watch out for pirate attacks. They use advanced infrared cameras that capture footage in the dark. Recon Scout developed by Recon Robotics, is an anti-piracy robot which will fight against maritime piracy. It can be controlled by joystick from the nearby command center. The robot can keep eye on piracy activities using its cameras that can see even in darkness using infrared camera. The Recon robot is displayed in Figure 5 [2].
- *Cleaning Robots:* Hulls tend to accumulate debris as they move through the oceans, including some live creatures that form colonies. Usually, cleaning a hull requires a ship to be dry-docked, and the process can take days or even weeks to complete. Hull-cleaning robots have become a major trend in marine robotics. They can be remote-controlled or autonomous and usually use a magnet system to stick to the side of the hull. The robot scrubs away debris throughout a ship's voyage to prevent biofouling. Samsung has already launched an underwater robot for cleaning the hulls of ships. Water pollution is one of the most pressing environmental issues today. Water pollution is a major public health problem in many areas of the world. Some engineers and designers are working on making pollution cleaning robots solar-powered so they can be fully autonomous and independent.

APPLICATIONS OF ROBOTICS IN MARITIME

Marine robotic vehicles, like ROVs (Remotely Operated Underwater Vehicles), AUVs (Autonomous Underwater Vehicles), and USVs (Unmanned Surface Vessels), are useful subsea tools with endless capabilities, from inspecting shipwrecks to monitoring ecosystems to recovering missing objects to mapping the seafloor. Although the types of services provided by these tools vary, there are some core capabilities that many of them offer that can be used in a wide range of applications. Here are some different ways robotics is being used in the maritime industry [10-12]:

- *Shipbuilding*: Automated technology and robotic systems play an important part in modern shipbuilding. Robots, which perform tasks such as welding, blasting, and heavy lifting, can help fill the labor gap at shipyards, freeing human counterparts from the most dangerous tasks. Recently, Rolls-Royce put forth the designs of unmanned remote controlled cargo ships. The world's first remote-controlled unmanned cargo ship by Rolls-Royce is shown in Figure 6 [2].
- *Maintenance and Repair:* Marine maintenance is a major concern, something that is difficult to do even after vessels dock. This is a task that can be dangerous, challenging, and tedious. Maintaining a vessel's performance takes a lot of resources from fuel and oil maintenance to regular cleanings. A lot goes into keeping a boat healthy, from fuel and oil service to regular cleanings. A large number of parts and equipment also need to be serviced or replaced to keep the ship in good condition. Robots are being deployed for tasks that are dangerous or difficult for humans, such as hull cleaning, painting, and welding. Underwater robots, or ROVs (remotely operated vehicles), are used for inspecting submerged structures and pipelines, assessing corrosion, and identifying marine growth. Autonomous underwater vehicles (AUVs) can also be used for more in-depth inspections and repairs. Finding cracks, corrosion, and other serious complications can be difficult for large ships, especially underwater, where it is dark and cloudy. This means that inspectors have to spend a lot of time on every meter of the vessel. Sarcos robotic systems are designed to carry out maintenance, inspection, and repair activities, on and around ships that are underway and pier side.

- *Ship Inspections:* In the rapidly evolving maritime industry, vessel inspection and maintenance have traditionally been labor-intensive, costly, and occasionally hazardous processes. Huge ships such as cargo or shipping vessels are difficult to inspect because of the surface area of the boat and its materials and colors. It can be challenging to detect cracks, corrosion, and other serious complications, especially under the water where its dark and murky. Hence, robots are deployed to spot cracks, corrosion, and serious complications on a regular basis. Performing subsea inspections of ships and boats is important to ensure they remain functional and safe. Inspecting pipelines in various industries and locations, such as sewers, potable water pipes, rainwater drainage pipes, and oil and gas pipelines is neither an easy nor safe task. Like pipe inspections, tunnels are another hard-to-reach space. Tunnels can include mining operations, large draining channels, aqueducts, and culverts. Autonomous inspection technologies eliminate these risks by sending robots into potentially dangerous areas instead of human inspectors. For shipping companies, the ability to conduct in-water inspections rather than dry-docking vessels could save millions of dollars annually. For example, SmartBot is working on an underwater robot, called ROBOSHIP, which can inspect ballast tanks and perform maintenance underwater. Figure 7 shows a ship inspecting robot [2]. This robot can be controlled via a wireless transmitter with live video feed and its four infrared distance sensors help in detecting edges and obstacles.
- *Marine Surveying:* Marine surveying, the practice of assessing and inspecting maritime vessels and structures, has always been a cornerstone of the maritime industry. Marine surveying has historically been a labor-intensive and time-consuming task. Surveyors would physically inspect ships, offshore platforms, and underwater structures to assess their condition and compliance with safety regulations. Artificial intelligence and robotics are transforming marine surveying by enhancing data analysis and decision-making processes. AI algorithms can process vast amounts of data collected from various sensors and sources, identifying patterns and anomalies that might be missed by human surveyors. One of the most significant applications of AI in marine surveying is in the realm of image recognition. Robotics is another key player in the future of marine surveying. Autonomous robots, both aerial and underwater, are revolutionizing the way inspections are conducted. The future of marine surveying lies in the continued integration of AI and robotics. Figure 8 shows a surveyor [13].
- *Marine Exploration:* The past two decades have witnessed growing interest in ocean exploration and exploitation for scientific and commercial purposes. Underwater robots are crucial for ocean exploration, including mapping the seafloor, studying marine life, and investigating shipwrecks. Unmanned aerial vehicles (UAVs), or drones, are used for aerial inspections of maritime structures, providing detailed imagery and data for surveyors. During aquaculture and environmental surveys, water sampling can be used to test the water quality for pollutants, salt levels, and other water quality parameters. Aquaculture is the breeding, raising, and harvesting of fish, shellfish, and aquatic plants. Maritime and naval applications such as ship monitoring and maintenance and offshore inspections can benefit from scientific and technological improvements on advanced technologies for ocean exploration.
- *Environmental Monitoring:* Robots are used for environmental monitoring, including tracking pollutants, monitoring ecosystems, and collecting samples. AUVs and ROVs can be deployed for these tasks, providing real-time data and imagery. Environmental monitoring helps us understand what is affecting our waters when it comes to pollution, hazardous substances, climate change, and more. They can also be used to monitor ecosystems and study marine organisms and their habitats,
- *Autonomous Operations:* Autonomous surface vessels (USVs) are being developed for various applications, including transportation, cargo handling, and research. These vessels can operate without human crew, potentially leading to increased efficiency and reduced costs.
- *Security and Surveillance:* Robots are being used for maritime surveillance, including patrolling ports and coastal areas, and monitoring for illegal activities. USVs and other robotic systems can be equipped with sensors and cameras to collect data and provide real-time information.
- *Underwater Photography*: Cameras on both remotely operated and autonomous underwater vehicles provide high resolution images and video footage and allow users to perform visual inspections. Commercial divers can also use vehicles equipped with cameras to inspect areas for safety before sending divers down.

Photogrammetry is the art and science of extracting 3D information from photographs. Now with numerous camera and sensor options, ROVs can be transformed into high-tech photography machines, capturing images from under the sea and transforming them into 3D models.

- *Bathymetry/Hydrography*: It is often necessary to determine water depths or properties while performing many of the above-mentioned surveys, which is where bathymetry and hydrography come into play. Bathymetry is the depth measurement of oceans, seas, and lakes. Hydrography includes bathymetry, but also the shape and features of the shoreline and the chemical properties of the water itself. Both can be used for charting and navigation purposes, determination of marine boundaries, investigation into beach erosion and sea level rising, understanding ocean currents, and more.

BENEFITS

Advanced robotics is already impacting maritime operations from the environmental benefits provided by regular hull cleaning to safer waters achieved through anti-piracy measures. Of particular importance is their use during hazardous or potentially dangerous situations. By replacing human laborers with robotics, the operations instantly become safer and often more streamlined. Other benefits of robotics in the maritime industry:

- *Automation:* Industries across the globe have witnessed the transformative power of automation and robotics, and the maritime sector is no exception. With the increasing demands of global trade and the need for efficient supply chain management, automation and robotics have emerged as game-changers. One of the key advantages of automation and robotics in smart ports is the ability to streamline operations. Modernizing so-called naval sustainment through robotics and automation can help meet demand for warfighting assets as naval shipyards experience tight deadlines, aging facilities, and limited access to dry docks. Ship welding, sanding, and painting are some of the activities that meet the "Three Ds of Automation." They are dirty, dull, and dangerous tasks.
- *Increased Safety*: Robots can perform dangerous tasks, reducing the risk to human workers. Human errors can have significant consequences in the maritime supply chain, leading to delays, damages, and potential safety hazards. Automation and robotics offer a solution by reducing dependency on human intervention and minimizing the risk of errors. This reduces the likelihood of accidents, improves safety conditions, and protects both personnel and cargo.
- *Enhanced Collaboration:* Smart ports leverage automation and robotics to create a connected ecosystem that promotes collaboration among stakeholders. Integration of systems and processes allows seamless data sharing and communication between port authorities, shipping companies, logistics providers, and other entities involved in the supply chain. Collaboration between public and private sectors is essential. Partnerships with educational institutions can facilitate the development of training programs to equip the workforce with the necessary skills to adapt to the changing landscape.
- *Enhanced Efficiency:* Robotic systems can operate continuously and cover large areas, saving time and resources. Smart robots inspect offshore facilities around the clock, detecting the smallest weaknesses before they become costly problems and minimizing downtime. This results in more safety, lower costs, and greater efficiency. Drones and autonomous robots are taking over ship handling, optimizing logistics processes and making procedures more efficient than ever before. Robots are a driver for resource-conserving and economically efficient processes. Robotization in the maritime industry can help in accomplishing a variety of important tasks with greater efficiency and safety.

CHALLENGES

As is the case with space exploration, the oceans pose their own set of challenges to the advancement of marine robotics. The integration of robotics in maritime technology brings forth a unique set of challenges. These challenges encompass technical, regulatory, and ethical aspects, including issues related to safety, cyber security, legal frameworks, and public acceptance. Although the already high level of autonomy reached by current marine robotic platforms, there is still an impressive number of scenarios and applications that require the skills and adaptation capabilities towards unpredictable conditions that only expert human operators can provide. Other challenges of robotics in maritime industry include the following [14-16]:

- *High Cost:* The implementation of these technologies requires significant investments in infrastructure, equipment, and workforce training.
- *Job Displacement:* Concerns regarding job displacement and the need for re-skilling the

workforce arise with the increasing automation. The World Economic Forum estimates 85 million jobs will be displaced. On the other hand, 97 million new jobs will be created. Balancing the benefits of automation with the social impact on employment is a crucial aspect that requires careful consideration.

- *Flexible Robots:* While flexible marine robots surpass rigid ones in their adaptability to the complexities of undersea operations, scientific research, and exploration applications, they also come with their own set of challenges. For instance, the use of rigid materials for the hull of the marine robot limits the robot volume and mass, making operations in confined seabed environments inconvenient compared to their flexible counterparts. Flexible robots have better adaptability to complex and changing underwater environments and are more eco-friendly, thus showing great potential in applications such as seabed complex terrain detection and biological observation.
- *Buoyancy Regulation:* The wide use of throwaway and oil-bladder buoyancy regulation devices poses challenges. Throwaway buoyancy regulation, which adjusts gravity by adding or reducing the weight of the ballast carried on the submersible, is a simple and straightforward technology. However, it can only be adjusted in one direction, and as more ballast is discarded, the submersible's ability to regulate its buoyancy gradually diminishes, until it is completely lost. This technology is generally used for unpowered uplifting of submersibles or as an emergency uplift measure.
- *3D Mapping Capabilities:* Another important challenge is related to achieve 3D mapping capabilities of high interest for the scientific and industrial applications. While during the last decade there has been a significant advance in the techniques for 3D mapping (stereo, structure from motion, visual SLAM) very little work has been done on the development of the algorithms and methodologies required to bring the AUVs close enough to the 3D structures in order to gather optical imagery.
- *Ocean Cleanup:* Marine debris contaminates water and threatens aquatic beings and their habitat. Sustainable efforts to reduce their impact are already underway but more can be done to remove the debris. Clear Blue Sea, a nonprofit in California, has developed robotic solutions like the Floating Robot for Eliminating Debris (FRED), which removes plastic content from the oceans. ROVs have helped the police and fire departments in many search and rescue operations and the retrieval of lost objects.
- *Compliance with Regulations:* The current regulatory landscape that applies to maritime service robotics, aptly termed as robotics and autonomous systems (RAS), is quite complex. When it comes to patents, there are multifarious considerations in relation to vessel survey, inspection, and maintenance processes under national and international law. Adherence is challenging, given that the traditional delivery methods are viewed as unsafe, strenuous, and laborious. The ways forward include strategic actions to remove data barriers towards overall efficacy of maritime RAS operations. Once fully integrated, RAS would eventually replace traditional human-led survey, inspection, and maintenance.
- *Data Preservation:* In terms of data preservation, a topic that also needs attention is the duration aspect. As is tradition, once the data acquisition tasks are complete, the operator is under obligation to provide those videos and still images and data in a format acceptable to the attending surveyor for review and examination. The current practice gives copyright ownership to the service providers, which is also coupled with the right to retain data for a limited duration within which data need to be communicated subject to request from the concerned classification society. The vessel itself is a business asset, and from that standpoint, adequate protection should be given to safeguard the information so gathered in the operational process. Figure 9 shows the visual-cycle of data elements [16].

CONCLUSION

Robots are really changing the marine sector. With all of the customizations and modifications possible, the world of marine robotics is forever evolving. Robotics has emerged as a disruptive force in the maritime sector, offering promising solutions for various applications, including underwater exploration, offshore operations, port logistics, and vessel maintenance. Emerging marine robotic developments will afford scientists advanced tools to explore and exploit the oceans at an unprecedented scale, in a sustainable manner. The further development of robotics and AI is not only creating more powerful solutions for the maritime industry, but also economically viable ones.

One of the emerging and most intriguing future trends in the robotic community consists in the development of effective robotic teams to be deployed in harsh and remote environments for complex autonomous operations to be cooperatively performed by agents. The future belongs to those who can build new and improved robots that can easily adapt to harsh sea conditions, devices with increased strength and accuracy, and improved sensors and battery technologies. Marine robotics will allow the marine industry to tackle some daunting challenges in innovative ways. More information on robotics in the maritime industry can be found in the books in [17-21] and the following related journals:

- Robotica
- Robotics
- Robitics and Autonomous
- Robotics and Computer-Integrated Manufacturing,
- Advanced Robotics
- Autonomous Robots
- Automation in Construction
- Journal of Robotics
- Journal of Robotic Systems
- Journal of Robotic Surgery
- Journal of Robotics and Mechatronics
- 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
- IEEE Robotics and Automation Letters
- IEEE Transactions on Robotics
- International Journal of Robotics Research
- International Journal of Social Robotics
- International Journal of Humanoid Robotics
- International Journal of Advanced Robotic Systems
- Science Robotics
- Soft Robotics

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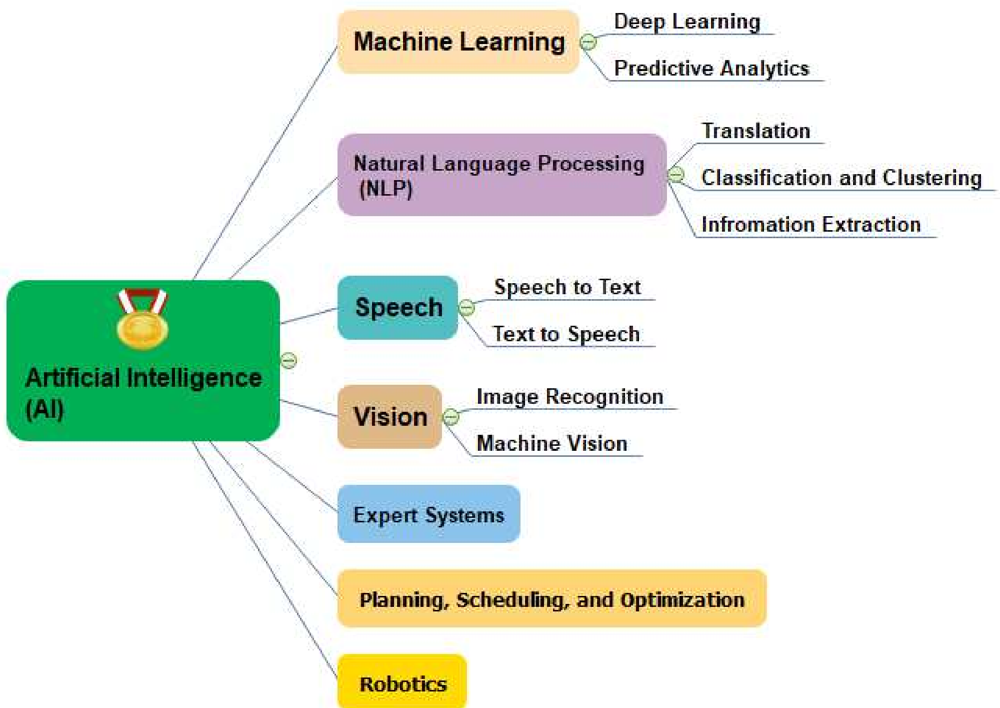

Figure 1 Robotics is one of the branches of artificial intelligence.

Figure 2 A typical example of maritime robot [1].

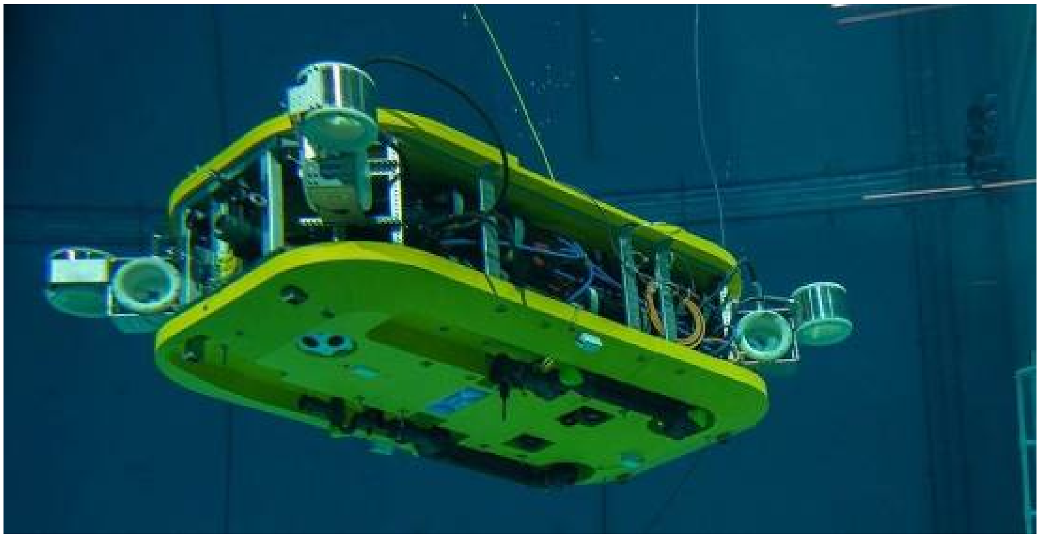

Figure 3 An undersea robot [9].

Figure 4 The fire robot SAFFIR [2]

Figure 5 The Recon robot [2].

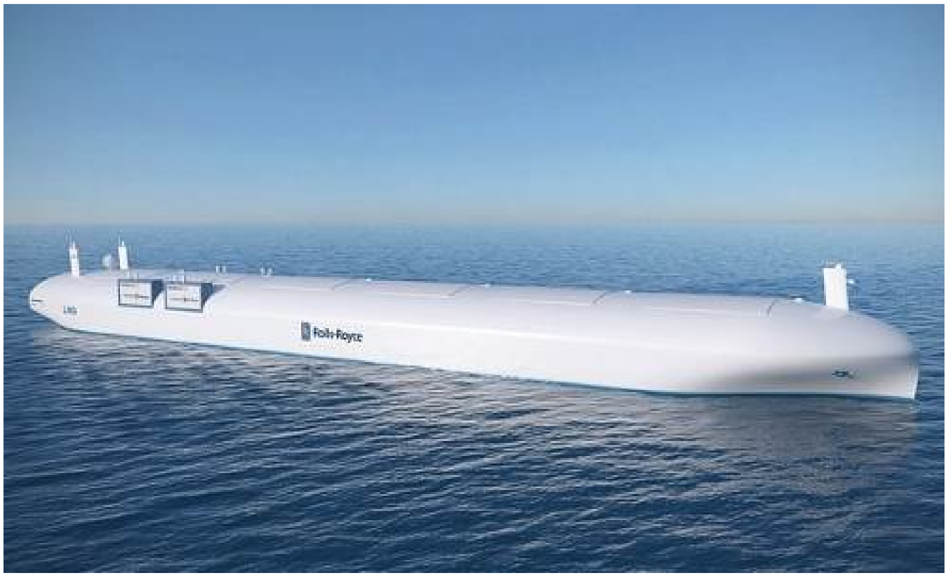

Figure 6 Rolls-Royce's unmanned remote controlled cargo ship [2].

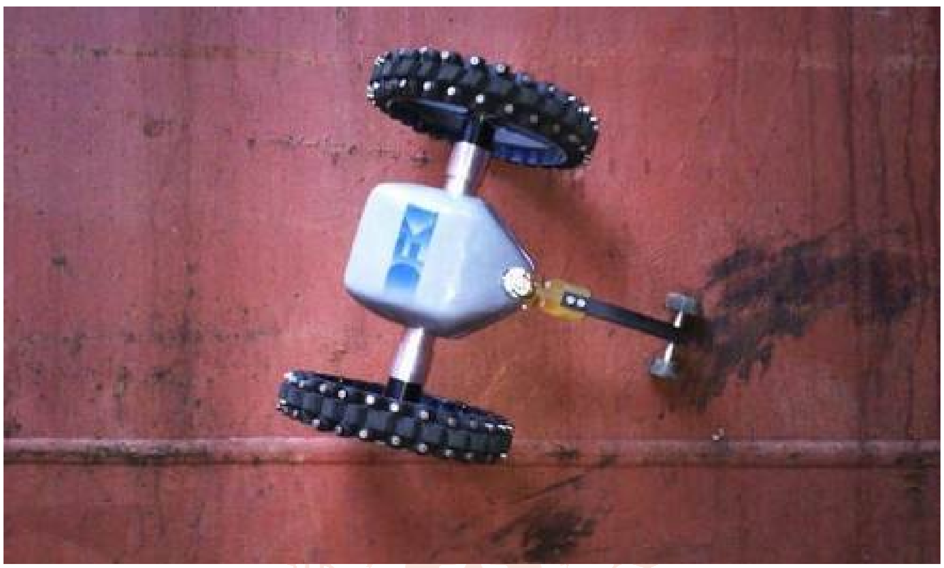

Figure 7 A ship inspecting robot [2].

Figure 8 A surveyor [13].

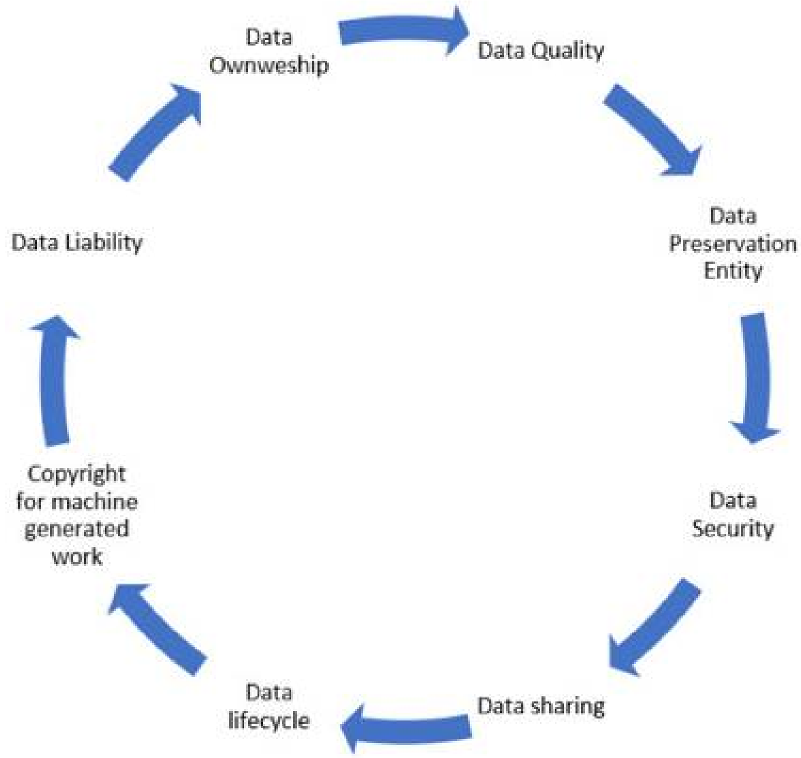

Figure 9 The visual-cycle of data elements [16].