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Drones in Maritime Industry

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ABSTRACT

Drones are remotely or autonomously controlled aircrafts that operate without a pilot. In the maritime industry, drones have found their place to provide an important function in the areas of deliveries, inspections of ships, and safeguarding national security. Drones are increasingly used in the maritime industry for a variety of tasks, including inspection, security, search and rescue, and environmental monitoring. The maritime industry and Navy deploy maritime drones for patrol, reconnaissance, and surveillance. Drone technologies will significantly enhance safety and security in and around ports. Drones are already solving some of shipping's greatest inspection challenges at sea. This paper examines the various uses of drones in the maritime industry.

KEYWORDS: *drones, unmanned aircrafts, unmanned aerial vehicles (UAVs), unmanned aircraft systems (UAS), maritime industry*

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INTRODUCTION

The maritime industry, a global linchpin for trade and economic prosperity, faces a confluence of challenges: soaring operational costs, escalating safety concerns, increasingly complex regulatory landscapes, and the ever-present threat of malicious actors. Amidst these challenges, a technological marvel is emerging as a potent force for transformation: the drone or unmanned aerial vehicle (UAV). Drones do not require a pilot and are often operated remotely. Their development results from the integration of various technologies, including aviation, information, network communication, cloud computing, power, artificial intelligence, and flight control. They are rapidly reshaping maritime operations, enhancing efficiency, bolstering security, and promoting sustainability in ways previously unimaginable [1]. The integration of drones is no longer a futuristic concept; it is a practical reality, impacting nearly every facet of maritime operations.

World nations are building fleets of unmanned robotic boats to perform missions above, on, and under the water. The competition in the maritime drone market has become intense, with several key players gaining traction and carving-out their area of specialization. Key factors driving this include cross-industry, emphasis on maritime surveillance, maritime research and biodiversity, oceanography, cargo and oil rig inspection, drug interdiction, deterring piracy and smuggling activities, etc. Drones within the maritime domain require maintaining hovering stability, ability to withstand extreme wind resistance, adapting to rapidly changing environmental/climatic change, and other challenges that make them distinct from land applications [2].

Autonomous systems across all environments (surface, underwater, ground, and air) have a huge role to play at ports. Introducing drones at ports in a safe, scalable "test and development area" model can bring significant benefits in terms of safety and efficiency of port operations and profitability. Other applications are connecting multimodal transport links, environmental, security and customs enforcement, search and rescue operations, and maintaining and repairing both shipping and port assets [3].

WHAT IS A DRONE?

At least three terms are used to describe drones, depending on how they are operated. The terms include Unmanned Aerial Vehicles (UAVs), Unpiloted Aircraft System (UAS), and Remote Piloted Aircraft System (RPAS). The FAA defines drones, also known as unmanned aerial vehicles (UAVs), as any aircraft system without a flight crew onboard. Drones include flying, floating, and other devices, including unmanned aerial vehicles (UAVs), that can fly independently along set routes using an onboard computer or follow commands transmitted remotely by a pilot on the ground. A typical drone is shown in Figure 1 [4]. A drone is usually controlled remotely by a human pilot on the ground, as typically shown in Figure 2 [4]. Drones can range in size from large military drones to smaller drones. Drones, previously used for military purposes, have started to be used for civilian purposes since the 2000s. Since then, drones have continued to be used in intelligence, aerial surveillance, search and rescue, reconnaissance, and offensive missions as part of the military Internet of things (IoT). Today, drones are used for different purposes such as aerial photography, surveillance, agriculture, entertainment, healthcare, transportation, law enforcement, etc.

Drones work much like other modes of air transportation, such as helicopters and airplanes. When the engine is turned on, it starts up, and the propellers rotate to enable flight. The motors spin the propellers and the propellers push against the air molecules downward, which pulls the drone upwards. Once the drone is flying, it is able to move forward, back, left, and right by spinning each of the propellers at a different speed. Then, the pilot uses the remote control to direct its flight from the ground [5],

Drone laws exist to ensure a high level of safety in the skies, especially near sensitive areas like airports. They also aim to address privacy concerns that arise when camera drones fly in residential areas. These include the requirement to keep your drone within sight at all times when airborne. In the United States, drones weighing less than 250g are exempt from registration with civil aviation authorities. If your drone exceeds 250g in weight, you will also require a Flyer ID, which requires passing a test [6]. It is necessary to register as an operator, be trained as a pilot, and have civil liability insurance, in addition to complying with various flight regulations, and those of the places where their use is permitted.

Most drones have a limited payload, usually under 11 pounds. Drones are classified according to their size. Here are the different drone types:

- Nano Drone: 80-100 mm
- Micro Drone: 100-150 mm
- Small Drone: 150-250 mm
- Medium Drone: 250-400 mm
- Large Drone: 400+ mm

One of the emerging trends in drone use for factories is the utilization of LiDAR technology. LiDAR stands for Light Detection and Ranging. This technology provides accurate depth information essential for understanding the three-dimensional structure of the environment. LiDAR sensors emit laser beams to measure distances to objects, creating high-resolution 3D maps of the surrounding terrain and objects. The ability to capture detailed data through LiDAR technology has opened up opportunities for better predictive maintenance, reduction in inspection times, and overall cost savings [7].

MARITIME DRONES

"Maritime drone" is a general term that refers to remotely controlled tools used in the maritime industry. It includes flying unmanned aerial vehicles (UAVs) and remotely operated vehicles that can move through the water. Maritime drones, also known as sea drones, have emerged as invaluable assets in various maritime operations. A maritime drone is an UAV designed specifically to operate over or under water. What sets maritime drones apart from traditional drones is their durability and specialized features. Equipped with advanced GPS and gyroscopes, they fly steadily over vast water bodies, making them perfect for marine surveillance, research, and search and rescue missions. A typical maritime drone is shown in Figure 3 [8].

Maritime drones operate in many environments that are confined, tough to navigate, and dangerous for crewed inspections or missions. They also help save time on the work it takes to inspect and monitor conditions when sending people into unknown situations. From maritime surveillance and search and rescue missions to surveys and inspections, drones have become an invaluable asset for both professionals and enthusiasts.

TYPES OF MARITIME DRONES

Choosing a maritime drone will ultimately determine whether your intended applications are indoor or outdoor. Figure 4 shows a typical indoor maritime drone [9], while Figure 5 shows a typical outdoor drone [3]. Everybody knows about flying drones, but there are also swimming and diving drones that patrol ports and ships, demine shores, and so on. There are unique drones created to achieve very specific goals. Thus, there are different types of drones for maritime use. They include the following [10,11]:

- *Surface Drones*: Surface drones, also known as boat drones, have become a staple in maritime

applications. These unmanned watercraft are built to glide gracefully on the water's surface, offering versatility in various tasks. They often come equipped with advanced remote control systems, enabling precise maneuvering and seamless operation even from a distance.

- *Underwater Drones*: Underwater drones have taken exploration to new depths. These submersible marvels, also referred to as submaritime drones, are tailor-made for marine surveying, inspection, and environmental research. Armed with high-resolution cameras and sensors, they provide valuable insights into marine ecosystems, shipwrecks, and underwater structures that were once difficult to access.
- *Hybrid Drones:* These drones combine the capabilities of both surface and underwater drones, making them versatile tools for maritime exploration and research. These drones can seamlessly transition between operating on the water's surface and submerging beneath, offering users a comprehensive view of both worlds.
- *Airborne Drones*: While airborne drones are not directly associated with the maritime environment, they play a significant role in supporting maritime operations. Equipped with long-range capabilities and high-resolution cameras, airborne drones are used for aerial surveillance of maritime activities, coastal monitoring, and search and rescue missions.
- *Medical Drones*: When an incident occurs at sea, it is a challenging task to transport injured individuals from sea to somewhere safe, particularly during undersea rescue operations. Conventional transportation methods are often time-consuming and not conducive to prompt treatment. Employing medical drones for transportation purposes can serve as an efficient alternative to traditional ship transport.
- *Naval Drones:* Naval UAV provide tactical situational awareness and ISR (intelligence, surveillance and reconnaissance) to navy vessels and fleets. They may be able to network with other naval assets such as USV (unmanned surface vessels) and AUV (autonomous underwater vehicles) to provide a multi-domain capability that can share information. The size comparison of UAV and USV is made in Figure 6 [12]. The main successes of the Ukrainian efforts against the Russian overwhelming presence at sea were caused by missiles as much as from USVs. The Navy has promised all the right things ("faster, scalable, and distributed decision-making"; "resilience, connectivity, and real time awareness") but provides little granular detail about the differential utility of unmanned systems across mission and warfare areas. Drones play a crucial role in enhancing operations for the Coast Guard and maritime security.

APPLICATIONS OF MARITIME DRONES

Maritime drones have opened up a myriad of applications, ranging from surveillance and search-and-rescue missions to marine inspections and surveying. Drone applications have become increasingly significant in maritime transport, including ship inspections, marine life monitoring, search and rescue operations, and environmental assessments. Common areas of applications include the following [8,10,11,13]:

- *Ship Delivery:* With the continuous growth of global trade, ships play a vital role in maritime transport. Operating ships is expensive, and stopping at ports for parts, important documents, or other essential resources costs time and money. There are also boat delivery services that go out to the ship but still cost thousands of dollars. The ability to assess the interior of a ship before sending in firefighters allows responders to understand if it is safe to enter and what areas of the ship to target to suppress and eliminate any remaining threats. With drones already in use for land deliveries, it only makes sense that drones would be a less expensive and practical option for maritime deliveries. The concept of aerial drone inspections is simple: fly a drone around, and record the flight.
- *Maritime Surveillance:* Maritime patrol drones have become a game-changer in enhancing security and monitoring vast stretches of the ocean. Equipped with high-resolution cameras and infrared sensors, these drones aid in detecting illegal activities, such as smuggling and unauthorized fishing, ensuring the safety and security of maritime borders and waters. Drones have proven to be highly effective in monitoring the perimeter of ports, swiftly detecting any unauthorized access attempts or suspicious activities. This enables security personnel to respond promptly to potential threats, preventing incidents before they occur. Drones can monitor maritime borders, patrol ports, and deter illegal activities like drug trafficking and piracy. They can also be used for surveillance of vessels, identifying threats, and providing real-time data to authorities.
- *Maritime Security:* This is a peacetime endeavor, conducted in congested sea space among

civilians. It refers to constabulary functions such as protecting commerce from terrorists and pirates and preventing illegal behavior such as arms smuggling and drug running. In such operations, small and medium unmanned surface vessels could technically conduct surveillance, issue warnings, or engage threats with small-caliber weapons while under remote human control.

- *Surveying and Inspections:* Inspecting the inside of large maritime cranes is expensive, time-consuming, and physically demanding work. Drones can perform routine inspections of ships, ports, and infrastructure, reducing the need for personnel to work at heights or in hazardous environments. Vessel inspections are crucial to ensure their safety and seaworthiness. Drones can aid in inspecting and surveying hard-to-reach areas, such as crane arms, cargo stacks, and roofs, identifying potential safety hazards such as cracks or corrosion. They offer the advantage of conducting inspections even in challenging weather conditions. The use of drones for maritime surveying and inspections has significantly streamlined these processes. Drones equipped with high-resolution cameras and LiDAR technology can capture detailed images and collect data on maritime infrastructure, such as ports, bridges, and offshore platforms. These inspections are conducted safely and efficiently, reducing costs and minimizing human risk.
- *Marine Search and Rescue*: The existing applications of drones in marine rescue encompass searching for rescue targets, delivering supplies, and path planning for search operations. Drones are deployed far quicker and cheaper than traditional search vehicles like helicopters. In the event of a marine accident, the primary focus is on rescuing survivors. Extensive research has demonstrated that drones can play a crucial role in this regard by swiftly identifying and relaying the precise locations of survivors to command centers. Drone technology has been integrated into marine rescue platforms, successfully locating and planning paths to rescue targets. The three main types of UAVs used in marine rescue are maritime search and rescue UAVs, high-endurance UAVs, and ground-effect UAVs. Drones can quickly locate missing persons or objects at sea, and can even deliver life-saving equipment to those in need. Speed and efficiency are important considerations in this context. If a drone can get to difficult-to-reach parts and identify the problem, it can be fixed more quickly.
- *Asset Management*: Drones can be employed for asset management and inventory control in ports. Equipped with high-quality imaging capabilities, drones assist in monitoring the flow of goods in and out of port, mitigating the likelihood of lost or misplaced shipments.
- *Drug Trafficking*: Maritime drones play a critical, front-end role in drug interdiction to scope-out the activities of the bad guys, without putting patrol agents in dangerous situations. Drug traffickers are using evolving technology including semi-submersibles, narco torpedoes, and full submarines to support their illegal activities. This puts a greater burden on the Coast Guard and other organizations to keep pace to outmaneuver and outwit the bad guys.
- *Marine Communications:* While the existing marine infrastructure generally meets the communication needs of the shipping industry, there are occasions where shore-based wireless communication facilities may fall short, particularly during emergencies. In such cases, drones offer an effective solution to enhancing the quality of wireless communication. In marine communications, drones are mainly applied as communication relay nodes. By being operated at high altitudes, drones can provide extended coverage and establish a reliable communication network between ships and between ships and the shore. This capability ensures that communication remains uninterrupted, even in remote or challenging environments.
- *Military Applications:* Drones have become an integral part of military and naval operations. They are used for surveillance, reconnaissance, and intelligence gathering purposes. Military drones provide real-time aerial imagery, video footage, and sensor data, helping armed forces monitor enemy activities, identify targets, and assess battlefield conditions. They can also be equipped with weapons for offensive operations. Surveillance is a fundamental aspect of military strategies, and drones excel in this domain. In addition to surveillance and reconnaissance, drones play a crucial role in intelligence gathering.
- *Anti-Piracy Applications:* Drones can be used to detect pirates in the same way they are used to look for ice floes. They are increasingly employed in maritime security to combat piracy. They enhance ship and port security by providing surveillance and monitoring capabilities to detect and deter unauthorized access or piracy. They can be used to patrol coastlines and shipping routes,

monitor suspicious activities, and provide early warning systems to prevent pirate attacks. UAV swarm monitoring is emerging as an attractive countermeasure that increases the flexibility of traditional methods and improves mission success. Therefore, the integration of drones into maritime security strategies has revolutionized the fight against piracy.

- *Cargo Operations:* Drones are being explored for cargo operations in maritime settings. They can assist in the efficient loading and unloading of goods on ships or between ships and shores. They facilitate cargo loading and unloading by providing aerial views and real-time data to enhance the precision and efficiency of these operations. They help monitor and guide the process, ensuring proper handling and placement of cargo. Drones equipped with lifting mechanisms or cargo pods can transport small packages or supplies, reducing the need for manual labor and optimizing logistics processes. The utilization of drones in cargo operations brings numerous benefits to the maritime industry. Drones offer increased flexibility and adaptability compared to traditional methods.

BENEFITS

A major benefit is the scaling up of drone usage in shore-ship deliveries and remote ship inspections, which increases industry productivity while improving safety. Drones excel at covering vast areas of water efficiently, making them a valuable asset for monitoring the health of marine ecosystems. They offer advantages like increased safety, efficiency, and cost-effectiveness in these applications. Drone deliveries can reduce cost, time, and CO2 emissions. Other benefits of utilizing drone technology in the maritime sector include the following [10]:

- *Enhanced Safety:* One of the most significant advantages of maritime drones is their ability to perform hazardous tasks without risking human lives. In challenging conditions such as storms or rough seas, sending drones to carry out inspections, surveillance, or search and rescue operations proves to be safer and more efficient than exposing human personnel to potential dangers. Drones eliminate risks to people by cutting exposure to heights, heavy equipment, and dangerous gasses associated with maritime inspections and operations.
- *Cost-Effectiveness*: Maritime operations often involve significant expenses related to manpower and equipment. By leveraging drones, the cost and complexity associated with traditional monitoring methods can be significantly reduced. Drones can cover vast areas in a short amount of time and are relatively less expensive to maintain compared to traditional methods, resulting in substantial cost savings over time. Drone inspections require less personnel and resources, which significantly reduces expenses.
- *Reduced Risk:* Drones can perform dangerous or hazardous tasks that would otherwise require personnel to work in dangerous environments. Drones play a crucial role in addressing the risks associated with maritime transport. The maritime transport industry is facing increasing pressure to mitigate ship emissions for the net zero goal by the IMO. Drones can provide real-time data and visual information, helping to improve situational awareness and safety.
- *Increased Efficiency:* Drones can complete tasks more quickly and with greater precision than traditional methods.
- *Rapid Search and Rescue Operations*: In emergency situations, time is of the essence. Maritime drones can swiftly cover large expanses of water, expediting search and rescue operations. Their ability to reach remote or hazardous locations ensures a quicker response, potentially saving lives.
- *Navigational Assistance:* Drones support navigational operations by providing enhanced situational awareness, particularly in challenging environments such as congested ports, narrow channels, or ice-covered waters. They identify obstacles, other vessels, and hazards in real-time, assisting navigators in making informed decisions to avoid collisions.
- *Efficient Surveys and Inspections*: Traditional maritime surveys and inspections can be time-consuming and costly. However, with the aid of naval UAVs, these tasks can be completed more efficiently. Drones equipped with high-resolution cameras and sensors can capture detailed images and videos of vessels, offshore structures, and coastal areas.
- *Environmental Conservation:* Preserving marine ecosystems is a global priority, and maritime drones play a crucial role in this endeavor. These drones facilitate environmental monitoring, allowing researchers and conservationists to assess water quality, detect oil spills, monitor wildlife, and track changes in marine habitats.
- *Recreational Use:* Beyond professional use, drones find their way into the hands of sailing enthusiasts. The best drones for sailing offer

breathtaking aerial footage of sailing adventures, capturing unforgettable moments on the water and providing a unique perspective for sailors to relive their experiences.

CHALLENGES

As with every technology, there are challenges with drones that must be addressed. Maritime drones present several challenges, including regulatory frameworks, technical limitations, and public acceptance. Maritime environments can be harsh, with strong winds, waves, and salt spray potentially impacting drone performance. Regulations regarding drone operations in maritime areas can vary by location and may be complex. Interoperability of drones from different countries needs to be addressed to ensure effective coordination. Other challenges of maritime drones include [11]:

- *Technical Challenges:* The technical challenges of drones in the maritime transport domain are delineated, encompassing the difficulties in flight control, navigation, power, communication, and vision systems. Shipping companies and port operators can gain insights into the technical challenges and corresponding solutions to integrate drones effectively into their operations.
- *Cost:* When it comes to the price of drones for maritime use, it is essential to consider different types of drones and their respective prices. Generally, the prices can range anywhere from $1,000 to $100,000 or even more, depending on the drone's size, capabilities, and intended applications. As we move up the scale to more advanced professional drones designed for scientific research, marine conservation, and commercial operations, the costs increase substantially. Factors that influence the cost of maritime drone services include the type of drones used, the complexity of the tasks required, the duration of the service, and the location of the operation. On average, basic maritime drone services can start from around $500 to $1,000 per day.
- *Regulations:* Operating maritime drones involves adhering to important laws and regulations. In many countries, maritime drones must be registered with aviation authorities. Countries have set altitude limits for drone operations to ensure airspace safety. Depending on the purpose of your drone operations, you may need certifications or licenses. Certain areas, such as military installations and airports, are restricted or designated as no-fly zones. Follow general safety guidelines, such as maintaining a visual line of sight, avoiding crowded areas, and conducting pre-flight checks. Adhering to these guidelines promotes safe operations. Maritime regulatory authorities can utilize the information on technical challenges and solutions to develop or update regulations and guidelines regarding the use of drones in maritime transport.
- *Safety:* One of the key safety concerns is around the "fly-away" scenario, where the pilot loses control of the drone. In such a scenario, the drone can fly anywhere and may pose a safety risk to manned aircrafts flying into. In some situations, the drone may also fly across borders to another country. Therefore, it is important that drone operators fly their drone safely and responsibly.
- *Security:* On the security front, many drones' control signals are not encrypted, so hackers can easily take control. Drones can be vulnerable to theft, hacking, or misuse, which poses a security risk to maritime operations. Criminals can use spoofing to redirect drones, bypass return-to-base, or even deliberately crash them.

CONCLUSION

The world of maritime drones is continuously evolving, driven by advancements in technology and the growing demand for efficient and sustainable solutions. Drones are quickly becoming ubiquitous around ships and harbors as they are harnessed for inspection, environmental concerns, and delivery. They offer a promising solution to enhance safety, efficiency and cost-effectiveness in port management and maintenance. Drones are used in nations around the world. Figure 7 shows drone privacy laws around the world [10].

The use of drones in the maritime industry is growing daily, with specialized contractors offering marine drone services to assist in inspections, surveys, and general asset management. Drone technology is not merely supplementing existing maritime operations; it is fundamentally transforming them. Maritime drones are used by ship operators and harbor masters for everything from ship and cargo inspection, security, environmental reconnaissance, and even to supply vessels with needed provisions and spare parts. The future of drone technology in maritime operations is characterized by ongoing innovation. More information about drones in the maritime industry can be found in the books in [14,15] and this related journal: *Journal of Maritime Science and Engineering,*

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Figure 1 A typical drone [4].

Figure 2 A drone is usually controlled by operators on the ground [4].

Figure 3 A typical maritime drone [8].

Figure 4 A typical indoor maritime drone [9].

Figure 5 A typical outdoor drone [3].

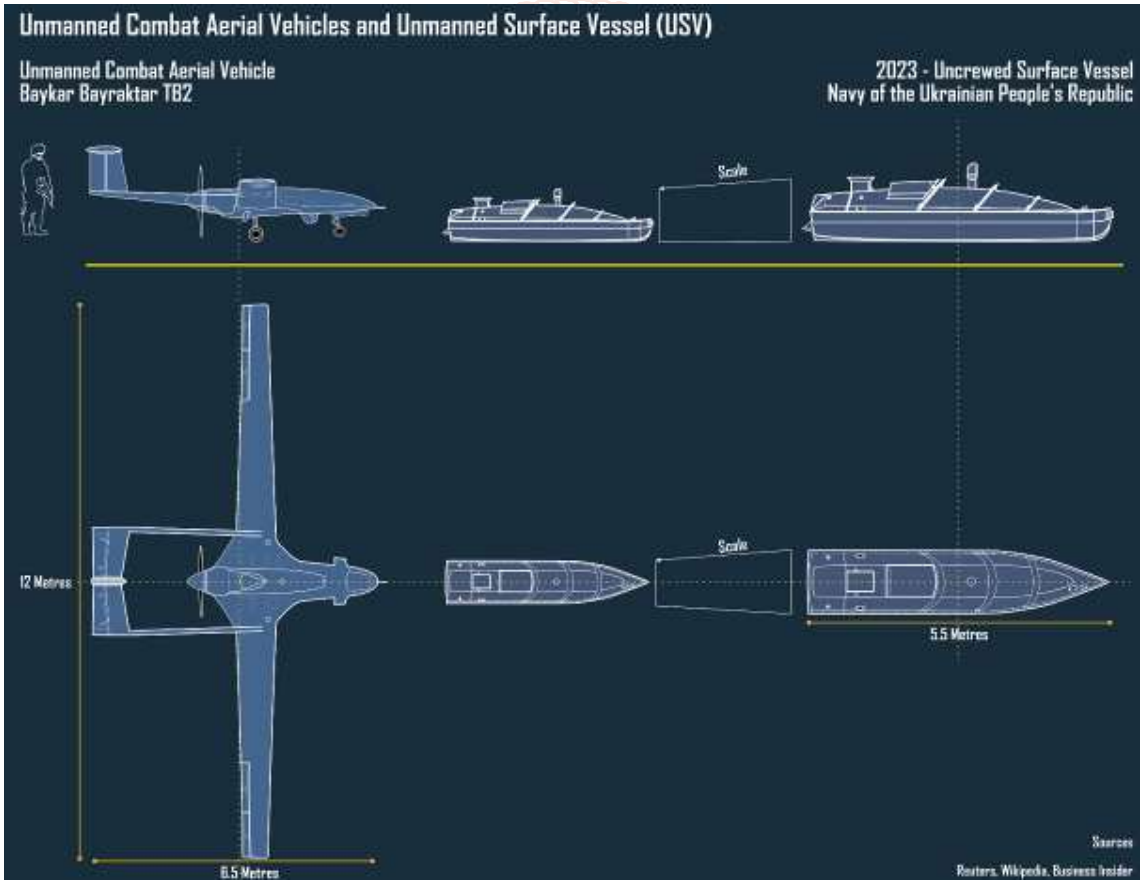

Figure 6 The size comparison of UAV and USV [12].

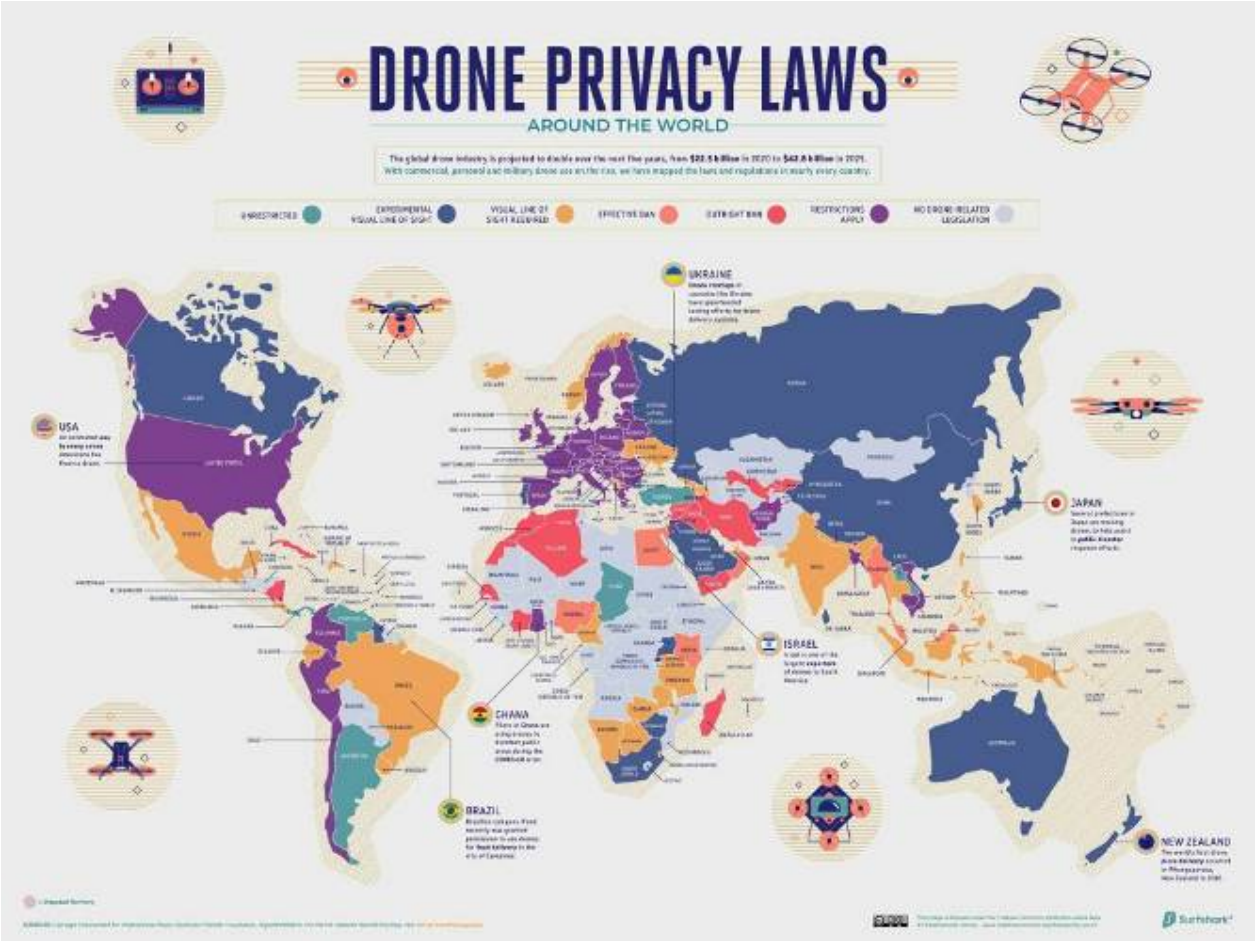

Figure 7 Drone privacy laws around the world [10].