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The use of drones in the maritime sector – areas and benefits

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Abstract

Drones are entering the maritime sector and have successfully increased safety and security. They can effectively replace humans, and where life and health are at risk during operations such as tank or hull inspections, they can be used in a fully remote capacity. They are used to transport spare parts, documents, medicine, etc. between land and ships at sea or on the roadstead, which may increase safety during the COVID-19 pandemic. Drones can control traffic and the emission of pollutants from ships, detect pirates, monitor areas, and support operations. They are used in search and rescue missions and also provide modern technologies like 5G and others. Drones are reliable and effective, and their use minimizes costs and reduces time.

This paper presents a current review of the state of knowledge on the use of drones in the maritime sector. It takes into consideration the opportunities of their utilisation and presents possibilities and examples of successful drone exploitation by various entities such as classification societies, shipyards, search and rescue (SAR) missions, and others. The benefits and limitations and a roadmap for drones in shipping are also analysed. An application forecast for the Polish maritime sector in the West Pomeranian and Pomeranian Regions is also delivered in the paper.

Desk research methodology was used to review the literature to identify the set goals by analysing literature reports, articles, and materials published by beneficiaries using drones successfully, as well as inquiries and market offers.

Introduction

Unmanned aerial vehicles (UAVs), commonly called drones, have become an increasingly important part of the maritime sector. Thus, it is not surprising that they have successfully performed increasingly complex tasks with an increasing degree of autonomy. Drones are used for missions that are too "dull, dirty, or dangerous" for humans in military and government applications. Nowadays, they are present in different civil and military missions for the transport of goods, people, in emergency services, in tourism, in cities and suburbs, and other regions such as mountains or seas.

It is estimated that the industrial drone fleet in Europe and the US will be $50B by 2050 (Castellano, 2020), but the COVID-19 crisis might change this prediction. Nowadays, drones are more common than ever. The aviation domain is the 2nd largest industry in the world after oil and gas, accounting for $650B. The flight inspection market, as part of the aviation industry, is expanding. In 2018, it occupied a share of $1.5B and is expected to exceed $1.8B by 2025 according to a 2019 Global Market Insights report. The autonomous last-mile delivery market size is expected to grow to $91.5B by 2030.

The use of UAV carriers in the maritime sector began in January 2016, when the first drone delivered

a box of Maersk-branded Danish butter cookies, weighing about 1.2 kg, from a tugboat to a tanker off the Danish Island of Zealand (Cage, 2016; Downs, 2016; Paris &Wall, 2016; West Coast Sailors, 2016). The cookies were dropped from a height of about five meters and did not break. In fact, many years before, in 1898, Nikola Tesla foretold maritime drones in his patent for "Method Regulating Drones in Maritime and Energy Sectors 3 of and apparatus for controlling, of moving vessels or vehicles" (Tesla, 1898).

Operating drones are usually components of unmanned aircraft systems (UASs), which include a UAV, a ground-based controller, and a system of communications between a base and operator, two or a swarm of drones. UAVs may fly with various degrees of autonomy: either under remote control by a human operator or autonomously by onboard computers.

The maritime industry is an important one for the expansion of drone applications. Almost 90% of external and 40% of internal EU freight trade by volume is carried by sea. European ports are the hubs of this arterial transport network and are responsible for the safety and mobility of 400 million passengers and 4 billion tonnes of freight every year. 52,000 merchant ships need regular hull-condition assessments, and more than 1000 ship casualties occur in EU waters annually (with 42% of accidents occurring in port areas). Innovative drone services are required to optimise both routine and emergency surveys and other services (EMSA, 2018). Drones offer several benefits to the maritime sector, including cost and time reductions, as well as safety and security, efficiency, reliability, and reduced environmental impacts, e.g., CO_2 emission reductions.

Drones in the maritime sector act as the eyes and ears of crews, shipowners, experts, class societies, surveyors, and other stakeholders. They are being increasingly used in the open oceans, and also near and in harbours and shipyards.

The purpose of this manuscript is to investigate the feasibility of using drones in the maritime sector. The author's goal is to study the literature, in which there are reports of successful projects and missions, as well as currently implemented shipping projects using drones. The results of this research will allow for the classification of potential beneficiaries and the recording of tasks that can be carried out with drones. Gathering information on the acquired and negative experiences of entities will permit the determination of the advantages and barriers to the use of drones. This can be used to set the research directions that must be undertaken to better match drones to missions in the maritime sector.

Special attention will be placed on the possibility of using drones by Polish entities involved in the shipping industry. The possibilities of using drones will also be considered in the context of the COVID-19 epidemic.

Methodology

The literature research was carried out for the following keywords: drones, unmanned aerial vehicles, maritime sector, safety in the maritime sector, ship safety.

The research aimed to identify the possibilities of using drones in the maritime sector and determine in which areas they have already been utilised. Thus, successful examples of their use were searched for. The aim of the research was also to identify factors that limit the possibilities of using drones in shipping.

The materials provided by potential beneficiaries such as classification societies, shipowners, ports, shipyards, drone producers, and spare parts manufacturers were analysed, as were articles whose subject matter matched the manuscript's focus. The market offer and industry demand were recognized.

As a result of the conducted analyses, the areas of drone applications were classified for the maritime sector. The detailed tasks for which they can be used were specified, and examples of their use by various beneficiaries were presented. Advantages and limitations of the use of drones for tasks carried out in the maritime sector were also identified.

The literature research on the possibility of using drones during the COVID-19 pandemic was executed.

Identifying drone applications in the maritime sector

In the maritime sector, drones safely go where humans cannot or should not. During the COVID-19 pandemic, when maintaining safety rules, including social distancing, the use of drones significantly reduces risks and should be considered as frequently as possible. Moreover, it should be remembered that drones are more effective in monitoring and in some kinds of inspections too. Drones can have a tremendous positive impact on safety standards. For example, they can replace the need for human inspection and exploration of the most dangerous and inaccessible places, such as cargo and water ballast tanks, and can also be used to verify the proper application

of coatings systems, structural integrity, and loaded cargoes. Currently used drones allow for real-time inspections, which reduces the risk, time, and cost of a wide range of operations. In the maritime sector, they are successfully exploited in (Frederiksen & Knudsen, 2018; Hines, 2018):

- routine inspections such as: hull surveys, cargo and water ballast tanks, coating systems, structural integrity etc.;
- inspections of flare stacks, tops of cranes, and confined spaces;
- remote inspections of the hull exterior or the interior of tanks and other areas where surveyors cannot reach during typical on/off-hire condition surveys or routine inspections;
- inspection during repair, conversion, and newbuilding of ships or prior to handover;
- damage surveys after an incident;
- inspection prior to reactivation of ships;
- inspections of moorings and anchorages;
- inspection of tow arrangements from tow lines through to an unmanned towed object;
- aerial inspections with sensors, which allows pictures and videos to be taken.

Drones equipped for and adapted to these special purposes can be used to inspect hard-to-reach places and transfer pictures in real-time to a dedicated inspector's device. Moreover, transmissions can be recorded for further detailed analyses of the condition of an examined object.

Inspections are not the only tasks realized by drones – they are increasingly used in (Frederiksen & Knudsen, 2018; Hines, 2018; Ship Technology, 2018; Gupta, 2019):

- support for operations on the open seas and in ports;
- search and rescue operations, such as finding lost people, assisting with a man overboard, and delivering a life jacket or a life raft;
- delivering an early warning system;
- detecting large and small objects at sea under a variety of conditions;
- delivering goods, documents, spare parts, or emergency supplies of medicine to ships at sea and at anchorage in harbours and *vice versa*
- border coastal/offshore control to prevent illegal immigration;
- harbour monitoring (aerial videography for loading operations, thermographic cameras for detecting people (those hiding inside or under trucks or those who fell into the water);
- testing entering port ships' emissions;
- piracy hazard areas control;
- detection of incidents over the open ocean such as illegal fishing or drug trafficking;
- allowing seamless communication;
- testing and calibrating ships' antennas;
- pollution monitoring (mainly sulphur and carbon dioxide).

Figure 1. Drone in action – Maersk Group (Cage, 2016)

Moreover, the maritime sector, due to its specificity, provides for the future combining services of self-sailing unmanned surface vehicles (USV) with swarms of autonomous unmanned aerial systems (ILO, 1996; Coastguard New Zealand, 2014; Ball, 2016; Maersk, 2016; Explicit, 2020; Quadsat 2020). They will enable fully automated and safe inspections.

During the COVID-19 pandemic, the use of drones can help reduce the virus expansion threshold, allowing the implementation of missions that would otherwise have to be suspended for safety reasons. During the lockdown, drones can and should be a commonly used tool to help supply ship crews with necessary items, such as spare parts, medicines, food, and hygiene items. They can and should also be widely used in inspections to minimize interpersonal contact.

Drone types available for the maritime industry and their expected advantages

Available drone types

Semi- or fully-autonomous drone solutions are currently available. Nowadays, fixed-wing drones, single and multi-rotor drones, and fixed-wing hybrid VTOLs are in use. Multi-rotor drones are the most common UAVs, and they are usually used for photography and video. They are classified by the number of propellers such as tricopter (3), quadcopter (4), hexacopter (6), and octocopter (8). Each drone has advantages and disadvantages. For example, fixed-wing drones are able to fly longer distances, larger areas, and monitor for a longer time. Single rotors are best for heavy payloads (e.g., an aerial

Table 1. Drone characteristics (Chapman, 2016; Chakrasthitha, 2019; The Aircraft Compare, 2019)

Drone type	Pros	Cons	Utylisation	Example
Multirotor	Accessibility Easy use Good camera control Operation in a confined area	Short flight Small payload capacity	Aerial photography Video aerial inspections	
Fixed-wing	Long endurance Large area coverage Fast flight speed	Need large spaces Harder to fly More training needed Expensive	Aerial mapping	
Single rotor	Long endurance Havier payload capacity	More dangerous Harder to fly More training needed Expensive	Aerial laser scanning	
Fixed-wing hybrid	Long endurance flight	Not perfect either for hovering or forward flight Still in development	Drone delivery	

laser scanner) or missions that involve a mixture of hovering with long endurance or fast forward flight (Chapman, 2016). Fixed-wing drones cannot hover, and they fly on a set course till their energy source is depleted. Some pros and cons are presented in Table 1.

A well-chosen type of drone and its equipment enable the implementation of various tasks in the maritime sector.

Time, cost, and risk reduction in the maritime sector

Entering and working in enclosed or confined spaces, e.g., tanks of ships, is a high-risk operation. A set of procedures is required to enable crew members to carry out scheduled tasks. Before a space is entered, in accordance with International Labour Organization (ILO) regulations, the following precautions should be taken, as appropriate, to ensure safe entry without the need for a breathing apparatus and to ensure that it remains safe whilst seafarers are inside. A competent person should make an assessment of the space, and a responsible officer should be appointed to take charge of the operation; potential hazards should be identified; the space should be prepared and secured for entry; the atmosphere should be tested; a "permit-to-work" system should be used; entry procedures should be established and followed; continuous ventilation should be maintained throughout (ILO, 1996). Breathing apparatuses and resuscitation equipment should be prepared. As the described procedure requires lots of time and results in high costs; thus, replacing the need for human inspections can minimise danger, costs, and time.

Det Norske Veritas (DNV) calculated the total cost of a single survey to be $1,000,000 (including vessel preparation, the use of a yard's facilities, cleaning, ventilation, and provision of access arrangements). It must be remembered that shipowners lose the opportunity to earn while a ship is inoperable. DNV also presented some examples to illustrate costs: scaffolding erection: $200,000; 1–2 days in dock: $100,000 for an oil tanker on good rates; emptying tanks for methane gas and replace with inert gases and oxygen: $100,000 for LNG/LPG ships (DNV-GL, 2018b; Vessel Performance Optimisation, 2020). Similar savings for large vessels were predicted by Maersk Tanker (Paris & Wall, 2016).

The use of drones can reduce the duration of remote infrastructure inspection surveys by 90–95%, reducing 2–3 days down to 2–3 hours. This translates into a savings of €20,000 – €30,000 per large asset survey.

DNV GL is currently testing autonomous drones with hyperspectral cameras for use in ship tank inspections. The autonomous drone-based surveys of ships in operation (ADRASSO) project takes into consideration the quality of such inspections. It

Figure 2.Current inspections and drones for future use (visual representation of the autonomous drone under development as part of the ADRASSO project) (DNV-GL, 2018b; Vessel Performance Optimisation, 2020)

plans to use drones to detect cracks using computer vision. Semi and fully autonomous drones that can manoeuvre alone and find their way around a ship tank without a professional pilot are under consideration (Figure 2) DNV-GL, 2018b; Vessel Performance Optimisation, 2020).

Although drones provide a much more efficient way to carry out inspections on board ships, they still require a professional pilot and live surveyor. Additionally, according to DNV GL's Smogeli, drones can be hard to manoeuvre (Vessel Performance Optimisation, 2020).

Nevertheless, the classification society Lloyd's Register (LR), has successfully realized over 50 remote inspections and published guidance on UAS in inspections (Lloyd's Register, 2016), recognizing the benefits of safe and effective UAV inspections (Lloyd's Register, 2018; 2020).

Nowadays, one of the disadvantages of drones is the need to be controlled by an operator and the need for manual steering according to an inspection regime. In the future, it will be possible to pre-programme a drone with a map of the relevant marine asset and conduct inspections fully automatically. It may also be possible to use pre-loaded 3D models of ships. This allows a drone to autonomously work its way around a vessel, stopping at a point of interest to obtain more detailed video or image data prepared by a drone before an inspection (Martek Marine, 2017).

Examples of drones used in the maritime sector

Although drones are still seen as a novelty in the maritime sector, they have been successfully used for many different tasks (Figure 3).

Airbus, Wilhelmsen, EMSA, Martek Marine, Maersk, the Maritime and The Port Authority of Singapore, The Port of Hamburg and Amsterdam, US Navy, and the Remontowa ship repair yard, are some examples of beneficiaries of drone use in the

Figure 3. Drone over a maritime horizon (Lavars, 2019)

maritime industry. Table 2 presents various examples of drone uses in the maritime sector.

Drones on the Polish maritime horizon

There are at least 11 entity types potentially interested in the use of drones for the maritime sector in the Polish West Pomeranian and Pomeranian regions. The list of these entities and the categories of usage are presented in Table 3.

Some of the presented entities have already successfully used drones in everyday operations. One of the main entities is the DNV-GL classification society. Its team from Gdynia, which started a drone survey in June 2016, can deploy its drones anywhere in the world. Drones are equipped with a high-definition camera and can remotely assess structural components and verify their condition. Such drone-assisted surveys have been carried out on tankers, bulk carriers, ore carriers, container carriers, etc. (DNV-GL, 2018a; 2020). DNV GL has four drone types: custom drones, the DJI Phantom, the Mavic drone, and the Flyability Elios drone. Each has unique capabilities and areas of application (Figure 4).

In 2017, the Polish Register of Shipping, in cooperation with domestic partners, began drone inspections. Inspections in confined spaces such as ship

Table 2. Drone uses in the maritime sector (Ship Technology, 2016; Cheeseman, 2020; Hakirevic, 2020; O'Dwyer, 2020; safety4sea, 2020)

Beneficiary	Use example
• Airbus with Wilhelmsen Ships Services and the Maritime Port Authority of Singapore	• Depositing packages onto ships anchored offshore by unmanned aircraft
• Wilhelmsen Ship Service	• Delivering spare parts and documents to ships (cost reduction from $1500 to $150)
• The UK Royal Navy	• Identifying ship defects (of the HMS Diamond)
• EMSA	• Border control, pollution monitoring, detection of illegal activities such as fishing and drug trafficking
• Martek Marine	• Security and safety activities, reconnaissance, search and rescue (SAR), illegal pollution detection and monitoring, illegal drug and people trafficking, fisheries protection, offshore assistance, infrastructure inspection
• US Navy	• Identifying and monitoring ships from many miles away, automatically sending information to officials in near real-time
• Airbus and Wilhelmsen	• Delivering by Airbus built 1.36 kg payload of consumables produced by Wilhelmsen's 3D printing "micro-factory"
• The Maritime and Port Authority of Singapore, Infocomm Media Development Authority and M1, Airbus	• Testing of 4G and 5G networks*, to pilot innovative use cases for 5G technology in the maritime industry*
• Start-up F-drones, product tanker operator Hafnia, MOU, Wilhelmsen	• Delivering by drones 3D-printed spare parts; long-term ambition: developing a larger-scale drone capable of delivering 100 kg to vessels up to 100 km away
• Natilus - start-up	• Shortening the delivery time: 17 times faster than a cargo ship
• Intel	• Providing artificial intelligence and drone technologies
• Maersk	• Delivering packages
• Remontowa Shiprepair shipyard	• Looking at conditions of protective coatings and detecting corrosion and cracks; hold inspections by drones
• Istanbul- Metropolitan Municipality's Marine Service Directorate	• Monitoring Bosporus for marine pollution, taking photographs and video footage
• EMSA, European Space Agency	• Monitoring the English Channel, North Sea, Baltic Sea, and the Gulf of Bothnia
• The Spanish Maritime Safety Agency	• Using EMSA's Remotely Piloted Aircraft Systems (RPAS) in the southern province of Huelva to identify and monitor oil spills; assist during SAR missions.
• Norway authorities	• Using drones which measure the sulphur content in the exhaust emissions from ships (since 2018)
• China authorities	• Monitoring strategic parts of Chinese maritime claims in the South China Sea
• The Port of Amsterdam	• Aerial and marine drones used for different operations, supporting the Port by monitoring legal and illegal flights across its land by detecting and identifying drones within a 5 km range, providing GPS positioning of both drones and pilots together
• The Port of Hamburg	• Testing the use of autonomous surface vehicles (ASVs) for hydrography
• Essex Police, the UK Maritime & Coastguard Agency, the Royal National Lifeboat Institution	• Support vital search and rescue operations around the coast of Essex
• Israel's new Gulf Port in Haifa, the authorities	• Monitoring construction taking place, as well as measuring stockpiles

holds, fuel tanks, and ballast tanks became possible (Gospodarka Morska, 2017).

In addition to classification societies, shipyards use UAVs. In September 2015, the Remontowa shipyard used a UAV to inspect work carried out on the vessel 'CPO Japan'. It was the first drone used in a Polish shipyard (Andruszkiewicz, 2015). The inspection of internal surfaces of tanks, such as ballasts and slop tanks, were carried out (Latarska & Stareńczak, 2015). The Remontowa Shipyard also cooperated with DNV-GL in field inspections (Figure 5).

In October 2020, the Port of Gdynia (Poland) began a cooperation with the company Pelixar. Pelixar used delivery UAVs adapted to the specific port conditions and requirements, such as strong wind, high air salinity, and disturbances in drone-operator communication. The drone was equipped with

Table 3. Polish entities interested in using drones in the maritime sector

Type of entity	Area of use
• Classification societies	• Vessel inspections
• Shipyards	• Vessel inspections, shipyard infrastructure inspections
• Shipowners	• Vessel inspections, document deliveries, spare parts deliveries, medicine deliveries
• Ports	• Vessel traffic coordination support, vessel inspections, port infrastructure inspections, logistics inspections, testing entering port ships' emissions
• SAR	• Searching for people at sea, assisting survivors, providing rescue means, guiding rescue units, communicating with survivors
• Maritime academies and research institutes	• Research in inspections, communication, searching survivors, etc.
• Maritime office	• Inspections of vessels and waterway infrastructure
• Insurance agencies	• Inspection of vessels and other objects
• Manufacturers and suppliers of spare parts	• Spare parts deliveries
• Medical support entities	• Delivery of medicine and other items to ships

Figure 4. Flyability Elios and DJI Phantom drones (DNV-GL, 2018a)

Figure 5. Tests in the Remontowa Shipyard by DNV-GL-tests with drones inside a tanker (poland@sea, 2016)

a zoom camera and air pollution sensors. It will be used to observe the area of the port and detect environmental pollution caused by ships entering the port (Figure 6) (Walas, 2020).

Figure 6.The drone mission in the Port of Gdynia (Walas, 2020)

Research institutes in the Maritime University of Szczecin (Poland) are working on a project involving a rescue search on the water using a drone. The training ship Navigator XXI was used for this test. The University of Gdynia (Poland) research institute is also engaged in a project involving the use of drones to search for missing persons, including survivors.

Conclusions

Based on the results of desk research, this article presented the possibilities and examples of the use of drones in the maritime sector. UAV technology is currently primarily used for inspection and surveillance (Martek Marine, 2018). Drones are successfully used by entities such as classification societies, shipowners, SARs, manufacturers of spare parts, and other actors.

The advantages and limitations of drone uses were also identified in the paper. It can be concluded that they are well recognized in the maritime sector.

Overall, drones are used because they can reduce time and cost. They can also ensure human safety and operational efficiency during transportation from port to ship. They can be used for reducing the carbon footprint when used over the sea, real-time traffic flow management, infrastructure management and intervention, monitoring material defects, improving the accuracy of hazard identification, quality air imaging, precise operation, accessibility to hard-to-reach areas, and reliability.

There are still many barriers to overcome, for instance improving the distance a drone can travel or its ability to handle heavy and large cargoes. The most important limitations are:

- limited operation time due to its battery power;
- difficulties during operation in poor weather conditions;
- less ability to handle heavier loads;
- risk of hacking;
- safety and security depend on operator skills;
- privacy put at risk;
- national and international regulations still in progress.

Despite these limitations, drones have successfully carried out many maritime missions, some of which have been described in the paper. Analysing them shows that drones are the best solutions for:

- carrying out inspections and calibrations;
- transporting on-demand supplies such as documents, spare parts, medical equipment, or medicine;
- pollution detection;
- monitoring;
- border and illegal activities control;
- traffic control support;
- SAR mission support;
- validation of key infrastructure;
- operation of quasi-autonomous water-buoyant and aerial drones within off-shore port services
- and others.

Additionally, hybrid drones are soon expected to carry out inspections both above and below the waterline. This very promising solution is dedicated to hazardous inspections and may reduce the time spent in dry docks.

The conducted analyses lead to the conclusion that to better utilise drones, the technology must be further developed and matured. Some of the identified components of a future roadmap are listed below:

- focusing on the end-user to replace ground deliveries by aerial ones;
- the more frequent use of drone in coastal and off-shore environments (e.g., SAR missions);
- improve docking mechanisms/platforms for drones;
- increase safety, security, and social acceptance;
- advance traffic control systems, define safety and security requirements;
- use drones as 'flying IoT' (Internet of Things);
- develop image analysis solutions;
- develop telecommunication solutions;
- develop computer vision, collision sensing and avoidance, and real-time paths;
- develop reliable 5G wireless communication;
- develop operational procedures and business models;
- balance the needs of the drone sector and air traffic;
- develop management;
- validate vision-aided landing and emergency landing;
- develop failure detection, isolation, and recovery systems.

The long-lasting COVID-19 pandemic will certainly affect decisions regarding the implementation of drones by many entities in the maritime sector. Drones can successfully replace humans and limit the spread of the virus. A noticeable increase in interest in their use and the implementation of subsequent projects was observed.

During the COVID-19 pandemic, which shipowners and other players in the maritime sector have had to deal with for over a year, drones are the optimal tool for many missions, such as delivering necessary items to a ship such as spare parts, as well as inspecting and observing.

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