USE OF THE GEOSPATIAL TECHNOLOGIES AND ITS IMPLICATIONS IN THE MARITIME TRANSPORT AND LOGISTICS

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1. ABSTRACT:

All the shipping industry and also ship building (shipyards) are under a complex process of digital transformation (DT), and so are the maritime ports as part of this logistic chain of significant importance.

This paper aims to review the successive information technology (IT)-based generations that impacted the maritime transport and logistics (computer-based optimization of transport routes; use of intelligent sensors and IoT; position monitoring by using geospatial technologies and databases; intelligence-based decisions), to identify their main features, and to propose an autonomous vessel-port management system that can be implemented in the future. The role of the geographic information system (GIS) is emphasized – as GIS-based electronic route optimization that allows ships to follow new paths and deliver goods in the most economical and efficient way; GIS-based location precision with the use of on board and ashore GIS-based sensors (electro-optics, remote sensing, LiDAR).

The shipping digitalisation process is heading towards a totally autonomous and at the same time safe and reliable ship. Complete autonomy could be reached by adjoining artificial-intelligence controlled systems designed to navigate and operate the ship and that are equipped with sensing and analysis tools, situational awareness, planning, and control capabilities. The Vessel Traffic System (VTS) of the future needs innovative technologies and methodologies to be developed. The desired systems will automatically collect and process data with high precision, will provide input to decision-making systems, and suggest evasive maneuver; to deal with hazards and systems failure without human intervention onboard. The use of new technologies comes with new types of risks specific to maritime transportation and seaports (spoofing, data manipulation, cyber-attacks etc.)

The implications of the findings are important for all stakeholders involved in maritime transport and associated logistics (seaports).

2. INTRODUCTION

Maritime transportation of goods is an essential part of global trade and commerce. It enables the efficient, cost-effective movement of large quantities of goods over long distances. It is also a critical component of global supply chains, providing a low-cost alternative to air transport and ground transportation for many goods. Maritime transport is also important for the transportation of energy resources such as oil and gas, as well as for providing food security and connecting isolated communities. Maritime transportation is by far the most used method of goods transportation today, comprising about 80% of all merchandise transport volume [1]. By playing such a key role in the world's economy, it has been the main focus of many scientists and engineers research on how transportation methods and means can be improved, in order to gain efficiency and security.

The digitalization of the shipping industry is transforming the maritime transport and logistics sector at an unprecedented pace. In this paper, the successive information technology (IT)-based generations that have impacted the industry are reviewed in order to identify their main features and to anticipate what the future could hold. The role of the geographic information system (GIS) is emphasized, as well as the importance of developing innovative technologies and methodologies to achieve complete autonomy. The research objective of this paper is to investigate the impact of digitalization on the shipping industry, with a focus on the role of geospatial technologies in this process. The main research question is: what are the geospatial technologies suitable to be implemented in a fully autonomous system for cargo ships operations? The implications of the findings are discussed with regards to hazards and risks specific to maritime transportation and seaports. This paper aims to provide essential insight into the digital transformation of the shipping industry, and to inform all stakeholders involved in maritime transport and associated logistics.

3. LITERATURE REVIEW

The successive generations of information technology that have impacted the maritime transport and logistics industry include:

- Computer-based optimization of transport routes: This refers to the use of computer algorithms and software to optimize the route and schedule of a vessel, taking into account factors such as cargo volume, weight, destination, and vessel capabilities. This can help reduce fuel consumption and improve efficiency [2].
- Use of intelligent sensors and the Internet of Things (IoT): Sensors and IoT devices can be used to monitor various aspects of a vessel's operation, including cargo temperature, fuel consumption, and engine performance. This data can be used to improve the efficiency of the vessel and reduce costs [2,3].
- Position monitoring using geospatial technologies and databases: Geospatial technologies such as GPS and GIS can be used to track the location and movement of vessels in real-time, allowing for better visibility and coordination within the supply chain [4].
- Intelligence-based decisions: Machine learning and artificial intelligence can be used to analyze large amounts of data and make intelligent decisions based on that data. This can include things like optimizing vessel routes, predicting maintenance needs, and identifying opportunities for cost savings [3].

These four directions combined lead to the vessel of the future: an autonomous surface vessel (defined in different papers as autonomous surface vessels, autonomous surface vehicles, maritime autonomous surface ships, uncrewed surface vessels, unmanned surface vessels etc.). Autonomous surface vessels (ASVs) are self-navigating boats or ships that are able to operate without human intervention. Starting from the 2010s, the main focus in maritime industry research papers was comprised of ASVs and unmanned systems. The majority of efforts in these papers are centered on creating more dependable algorithms for autonomous navigation, guidance, and control [5, 6]. By utilizing these algorithms, the human operator's mistakes can be minimized, leading to increased energy efficiency, safety, and cost-effectiveness in waterborne transportation [7]. In 2019, the Maritime Safety Committee (MSC) [8] – a board of the International Maritime Organization (IMO) that deals with all matters related to maritime safety and maritime security which fall within the scope of IMO, has adopted the "framework for the regulatory scoping exercise for the use of maritime autonomous surface ships (MASS)" (Annex 2) [9]. MSC defines four degrees of autonomy organized as follows:

" Degree one: ***Ship with automated processes and decision support***: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.

Degree two: ***Remotely controlled ship with seafarers on board:*** The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.

Degree three: ***Remotely controlled ship without seafarers on board:*** *The* ship is controlled and operated from another location. There are no seafarers on board.

Degree four: ***Fully autonomous ship:*** The operating system of the ship is able to make decisions and determine actions by itself." [9]

Literature on autonomous vessels presents various type of prototypes with various degrees of autonomy (older prototypes tend to be less autonomous and newer prototypes tend to be fully autonomous) [10-16]. One study [17] reviews many prototypes and projects developed by scholars or private companies (60 prototypes of unmanned vessels are listed and classified by the degree of autonomy). It is noteworthy that the number of autonomous vessel projects and prototypes has increased over the years, with a particularly high concentration of low-level autonomy projects due to their potential for immediate adoption by the industry. The authors present the findings of their experimental study on a nonlinear control logic for autonomous ship maneuvering in [18-20]. In [21], a new autonomous surface unit is designed that can be configured as either a large unit or a fleet of smaller units capable of autonomously transporting a single container [22]. This unit has the potential to significantly impact the shipping industry in a short period of time.

One aspect that is very important for ASVs is the communication infrastructure to deal with all the links between system components (sensors, neural networks and vessel operators). The authors in reference [23] discuss the various Information and Communication Technologies (ICT), communication architectures, and wireless standards that are being considered for the use in autonomous surface vehicles (ASVs). One of these technologies is the Internet of Things (IoT), which is seen as a promising solution for efficient communication management on ships. The authors in reference [24] also highlight the potential of IoT in this context. Although IoT technologies have advanced enough to be used in unmanned navigation systems, these systems also require the support of intelligent algorithms and methods, as well as a platform for managing and coordinating the interactions with these algorithms and dynamically selecting the appropriate level of automation for the ship.

Computing infrastructures are an essential component of ASVs as they provide the necessary computing power and resources to support the various tasks and operations of the ASV. These tasks can include navigation, mapping, data processing, communication, and decision-making. The computing infrastructure of an ASV typically consists of one or more processors, storage devices, and networking equipment [25, 26]. The processor(s) are responsible for executing instructions and performing calculations, while the storage devices are used to store data and programs. The networking equipment is used to connect the ASV to other devices and networks, such as satellite or cellular networks, and to enable communication with other ASVs or control centers [27, 28].

The computing infrastructure of an ASV can be designed in a variety of ways, depending on the specific requirements and constraints of the ASV's mission and operating environment. For example, the ASV may need to have a robust and reliable computing infrastructure to ensure that it can operate continuously for extended periods of time, even in challenging conditions. Alternatively, the ASV may need to have a lightweight and compact computing infrastructure to minimize its size and weight [29], [30].

In the context of ASVs, geospatial technologies can be used to navigate and position the ASV, as well as to map and monitor the surrounding environment. For example, geospatial technologies such as GNSS and GIS can be used to accurately determine the ASV's location, orientation, and movement, as well as to generate maps of the surrounding area [31-33]. These maps can be used to identify potential hazards or to plan the ASV's route. Geospatial technologies can also be used to monitor the environment around the ASV, such as the ocean conditions, weather patterns, and the presence of other vessels. This information can be used to improve the safety and efficiency of the ASV's operations [34-36]. Although the aforementioned papers take in consideration geospatial technologies to be used in ASVs building, there is a gap in the study of the emergent sensors implementation on the future vessel system.

In the development of the next generation of autonomous surface vehicles (ASVs), the incorporation of Artificial Intelligence (AI) and augmented reality (AR) is vital to be used to create reliable, efficient, and comfortable ASVs [37]. When these technologies are combined, they can support the user in performing complex and challenging tasks. Reference [38] presents a decision support system with an AR visualization system as an example of how these technologies can be used in this context.

4. PROPOSED SOLUTION TO OBTAIN FULL AUTONOMY IN TRANSPORT AND PORT OPERATIONS FOR CARGO SHIPS

There are more options to control the traffic near ports and terminals in an autonomous way, and one of them is to have an Ashore Operations Center (AOC) that ensures near shore vessel routes management, either by planning routes in the internal system and sending them to the navigation systems of ASVs to be implemented, or receiving them from the ASVs navigation system and validating or correcting them to ensure safe navigation. For large ports, networked AOCs can handle traffic by sectors, with the ability to hand-over-take-over routes management when a vessel (either autonomous or manned) passes from one sector to another. We can distinguish the following parts for a fully autonomous port and traffic management system: AOC, ships (either manned or ASV), sensors (on-board and ashore), AI/ML neural networks (see Figure 1). One key component in this proposed system are the sensors, as they provide information on location of the ship and environment surrounding the ship. The system can be implemented for a heterogeneous mix of autonomous and manned ships (the major change for interacting with manned ships will be given by the data exchange amounts and type and by the implementing method of the recommended route). Interconnected AI neural networks (ANN), will be used to process data from sensors, develop navigation routes, enable risk management and evasive maneuvers and implement commands to operate the ship on a determined optimized route.

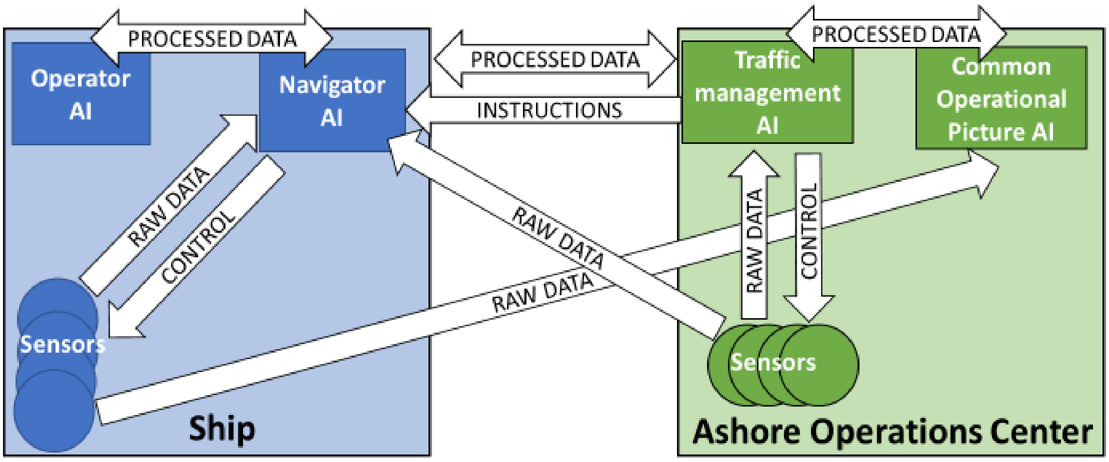

Figure 1: Autonomous port and traffic management system components and interactions.

4.1 Sensors

Sensors in the system will consist of two entities, one controlled by the ship and being positioned onboard and one controlled by the AOC and positioned on land (or sea), air or/and space, near the AOC area of responsibility. Onboard sensors can be classified in two categories: mandatory or permanent sensors, such as GPS sensors, and enhancing, or task specific sensors, used to accurately determine the environment surrounding the ship in specific tasks, such as docking operations.

The main requirements for the onboard sensor are: to be reliable and accurate, to be energy efficient, to be cost effective. In the authors view, the permanent sensors and tracking systems should consist of: GNSS [39], AIS [40], Sonar [41], EO, IR or LiDAR [42] sensors from the geospatial sphere used to compose the gross picture of the surrounding environment for the ship, in order to avoid collision. Other sensors, such as inertial, velocity and acceleration measurement sensors should be integrated too. Task specific sensor requirements are: accuracy and timeliness. These sensors are to be used to accurately determine surrounding objects detected by permanent sensors in order to provide accurate, on time data for the navigation AI system, for it to generate evasive maneuver routes or to establish the optimal route during docking operations or near port operations, in heavy traffic conditions. A mixture of sensors encompassing technologies such as Sonar, IR and LiDAR should be used, that will guarantee accurate detection of surrounding objects and sea bottom, with little or no influence from weather or visibility conditions. Another set of task specific sensors are the one measuring and monitoring internal systems of the ship used for propulsion and maneuver.

The main requirements for the ashore sensors are: to be reliable and accurate. One of the most suitable technology for this task, in the view of the authors, is Synthetic Aperture Radar (SAR) [43] technology, because of its properties to create high resolution images, regardless of visibility conditions, and is not obturated by clouds or smoke. A network of sensors based on land, sea, air or space is desirable to ensure redundancy and desired accuracy for AOC.

4.2 AI neural networks

The proposed architecture of the ANN is based on the principle "many to many" recurrent neural network [44]. This recurrent network will encompass at a minimum the following elements: ship AI (navigation, operation, sensors control) and ashore operations center AI (traffic management, ship control, sensors control, common operational picture). The ANN recurrence is needed to connect the outputs of all neurons to inputs of all neurons and to provide feedback between hidden layers. The proposed hardware implementation is based on Field-Programable Gate Array boards (FPGA), as it offers more robust computation parallelism and low latency needed for time sensitive signals from sensors [45-48]. Figure 2 depicts the proposed architecture for the recurrent neural network to be implemented in the system. CPUs or GPUs hardware solutions are also possible with the proposed architecture with the specified properties. The entire network should be regarded as a network of networks or a system of systems.

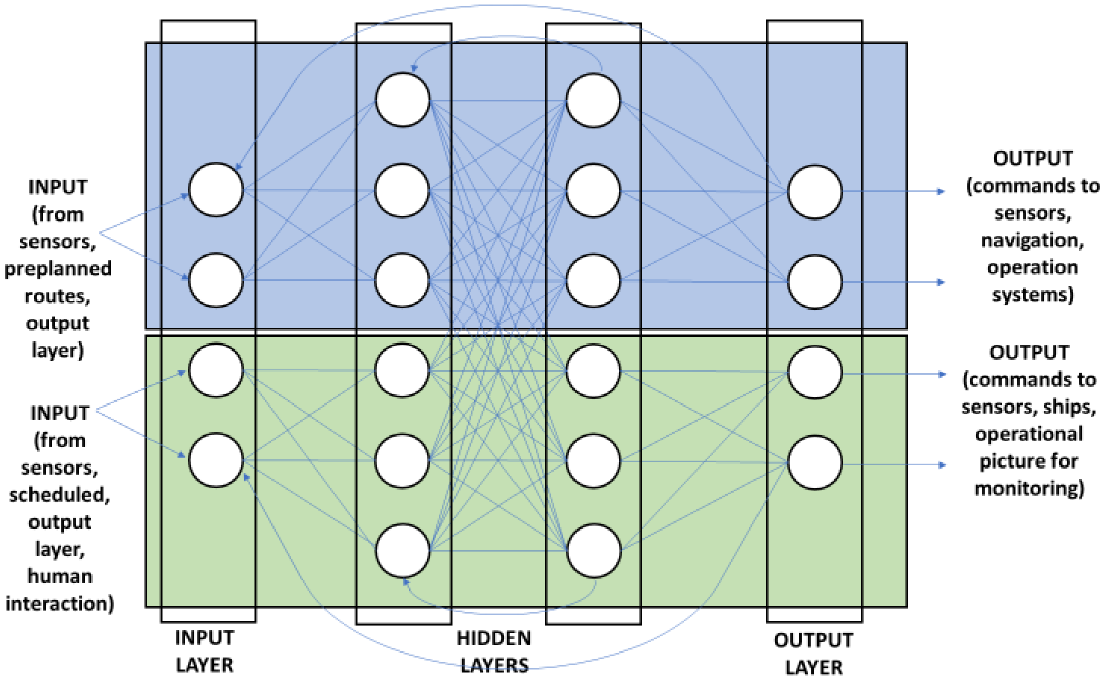

Figure 2: Proposed architecture for the recurrent neural network.

4.3 Working scenarios

The working scenarios that arise in the near future and on long term are as follows: fully automated ships in fully automated ports, fully automated ships in semi-automated or non-automated ports, semi-automated ships or manned ships in fully automated ports and the last case, semi-automated or manned ships in non-automated (manned) ports. In Table 1 is presented a comparison for these four working scenarios, starting from the right column (current state) and progressing to the left towards the end state. As this should be a progressive change, standards need to be adopted as early as possible to ensure interoperability and standardization across the entire field.

Table 1. Comparison between different working scenarios

ASV/AOC	*ASV/ Manned port*	*Manned Ship/Automated port*	*Manned ship/Manned port*
Fully automate system	Autonomous ship in independent mode	Automated routing, manually navigated by ship	Non automated traffic
Supervision may be emplaced	Port manned work required	Ship manned work required	Manual actions mandatory on both sides
Final state	Interim	Interim	Current state

5. CYBERSECURITY CONCERNS

Autonomous surface vessels are becoming increasingly prevalent in various industries, including shipping, oil and gas, and defense. These vessels rely on advanced technology, including sensors, navigation systems, and communication systems, to operate without a human crew on board. While the use of ASVs can bring significant benefits, such as cost savings and increased efficiency, it also introduces new cybersecurity risks that must be carefully managed.

One major risk to ASVs is the potential for cyberattacks on their systems. These attacks could be carried out by hackers or other malicious actors who seek to gain control of the vessel or disrupt its operation. For example, an attacker could manipulate the ASV's navigation system to alter its course or speed, or could interfere with its communication systems to prevent the vessel from communicating with its operators. These types of attacks could have serious consequences, including damage to the vessel and its cargo, injury or death to people in the vicinity, and environmental harm.

To mitigate these risks, it is essential that ASVs are designed and operated with strong cybersecurity measures in place. This can include using secure communication protocols, implementing robust authentication and access controls, and regularly updating and patching software to fix vulnerabilities. It is also important to have backup systems in place to ensure that the ASV can continue to operate safely in the event of a cyberattack or other system failure [49].

In addition to protecting the ASV itself, it is also important to consider the cybersecurity of the broader ecosystem in which the ASV operates. This includes the communication systems used to remotely operate and monitor the vessel, as well as any other systems or devices that may interact with the ASV. Ensuring the security of these systems is critical to preventing attacks that could compromise the ASV [50].

Overall, the use of ASVs brings numerous benefits, but also introduces new cybersecurity risks that must be carefully managed. By implementing strong cybersecurity measures and regularly testing and updating these measures, ASV operators can ensure the safe and reliable operation of their vessels.

6. MANAGERIAL IMPLICATIONS AND RECOMMENDATIONS

The proposed system for autonomous surface vessels has the potential to improve the maritime industry by introducing the concept of dynamic cooperation. It aims to improve existing technology through the use of augmented and virtual reality, machine learning, and artificial intelligence algorithms to provide reliable control of autonomous ships in various navigation scenarios. To effectively extract and clearly represent information, the system will need to be tailored specifically to the maritime context and its challenging environmental conditions while meeting strict safety requirements.

Adopting an autonomous traffic management system the authorities can have several potential benefits including: increased efficiency (fast navigation through ports will reduce the time required for loading and unloading cargo and will minimize delays); improved safety (an autonomous system can reduce the risk of accidents and collisions by providing real time information about the ship's surroundings and automatically adjust the course of the ship or provide evasive maneuvers solutions; the human error risk is also eliminated); reduced costs (an autonomous system can reduce the costs associated with operating ships in ports, such as personnel costs or fuel costs); lower environmental impact (the environmental impact of shipping can be reduced by choosing optimized routes and reducing the amount of time spent in ports).

7. CONCLUSIONS

This system is a unique innovation that does not yet exist in scientific literature or industrial projects, as far as the authors know, and it has the potential to be a game-changer in the maritime industry as it enables ships with different control strategies developed by different automation providers to navigate together with crewed ships. In addition, the use of automatic technologies that support service management can help to rationalize assets and improve the efficiency and environmental sustainability of the industry, while also providing support to workers by predicting hazardous and stressful conditions. By enabling automated interactions among multiple entities, this system can also facilitate the adoption of autonomous ships and simplify the interactions between diverse systems while ensuring optimal performance.

The novelty of this study consists of the proposed architecture for future shipping operations, the proposed model for recurrent neural network to achieve the IoT workflow needed in the system, and the use of FPGA as hardware support for this task.

One key part of the entire system is the proper implementation of sensors that are able to guarantee continuous surveillance and situational awareness, without being perturbed by weather conditions or other visibility disturbing factors.

The proposed software and hardware solution to implement the system brings clear benefits, as shown in section 4.2. Further studies could take in consideration building a model, at first in an enclosed environment, that can be later optimized. One potential approach to implementing the proposed system is to build a model using software such as Python and the TensorFlow library, and then optimize the model for use on FPGA. This approach has several potential benefits.

First, building a model in an enclosed environment, such as a simulated port, can allow for more controlled testing and development of the autonomous system. This can help to identify and address any potential issues or challenges before the solution is deployed in a real-world setting.

Second, optimizing the model for use on an FPGA can help to improve the performance and efficiency of the ASVs and AOCs. FPGAs are specialized devices that can be programmed to perform specific tasks, such as image processing or navigation, more efficiently than general-purpose processors. Using an FPGA to run the proposed model can help to reduce the computational resources required, which can be especially important in a resource-constrained environment such as a ship.

8. CONFLICT OF INTERESTS

The authors declare no conflict of interests.

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