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A REVIEW OF MACHINE LEARNING IN SUSTAINABLEAUTONOMOUS SHIP CONTROL SYSTEM

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ABSTRACT

The rapid development of industry 5.0 has brought the world of sea transportation to challenges that are so speedy and complex in current condition and in the future. Thecondition is supported by the development of artificial intelligence technology which is increasingly being applied to the application of technology. One part of it is machine learningwhich has brought so many changes to the development of unmanned ship technology (or autonomous ship). The ability of machine learning to learn from examples is a massive advantages for autonomous innovation. The massive application of these concepts has resulted in many changes to the applied control system model such as navigation system, detection and navigation system or automation system. This makes researchers have to keep pace with the development of appropriate methods for their implementation. This research aims to map the current condition of the application of machine learning methods, algorithmsand concepts to unmanned ship systems. This study uses a bibliometric analysis approach anda SWOT analysis that is relevant to current conditions. As the result, this study aims and targets to provide an overview of the current conditions for practitioners and researchers in utilizing the concept of machine learning.

***Kata kunci** : machine learning, autonomous ship, swot analysis, artificial intelligence*

INTRODUCTION

Indonesia is a potential maritime sectors development based on the large of its archipelagos country. The existence of coastlines on almost every island in Indonesia (±54,720 km) which makes Indonesia rank third after Canadaand Norway as a country that has the longest coastline in the world (A. Kumar, 2019). Indonesia also conceive with 514 citiesspread over thousands of islands and its population is measured to reach 318.9 millions in 2045 (Sapril, Saputra & Kurniawan, 2022). The geography condition provides an opportunity for Indonesia as one of the strong maritime countries. The growth of development and implementation of advanced technology also give Indonesia the big opportunity to strength their maritime sector (Saputra, R.W. et al., 2019).

The autonomous shipping industry is making waves, as established companies and tech start-ups apply emerging technologies to one of the oldest industries in the world, maritime transport. Control systems for marine vehicles are related to the type of the vehicle (Ocean engineering, 2023). Ships will have different control systems in use. Crude carriers, tankers, drilling ships, gas carriers, or many other types have some systems in common and some systems that differ because of specific features of each. For instance, systems related to the type of cargo will have different control systems for cargo handling and cargo monitoring, while other systems will be very similar such as navigation, guidance, or power generation systems.

Even though we might be years or even decades away from the majority of vessels becoming autonomous, there are certainly artificial intelligence algorithms at worktoday (Marr, 2023). A fully autonomous shipwould be considered a vessel that can operateon its own without a crew. Remote ships are those that are operated by a human from shore, and an automated ship runs software that manages its movements. The research in this area is becoming more interesting with Maritime Autonomous Surface Ships (MASSs) have in recent years emerged as a new application of vehicle automation, in turn presenting new challenges and a productive research community (Veitch et al,2022).

This research studied the actual condition of implementing machine learning concept in automomous vessel. It is intended to inform researchers and decision makers to recognize knowledge areas, evaluate knowledge gaps and identify future development opportunities. The main part of machine learning include the algorithms also will be discussed in this research. This research is consist of five sections. The first section is discussed about introduction as explained. The second section is talking about some literature reviewes that related to this study. The third section will be discussed about research methods that used. And The fourth section is talking about result and discussion of this research and the lastsection is talking about conclussion.

LITERATURE REVIEW

A. Machine Learning

Machine learning is a sub-field of artificial intelligence that remains its focus on system designing and allows them to acquire and make some predictions on the basis of data understandings and experiences. Machine learning enables a machine to act and make data driven conclusions rather than being plainly programmed to carry out a particular job. Machine Learning algorithms are the programs that can learn the hidden patterns from the data, predict the output, andimprove the performance from experiences on their own. Different algorithms can be used in machine learning for different tasks, such as simple linear regression that can be used for prediction problems like stock market prediction, and the KNN algorithm can be used for classification problems (Javatpoint, 2023).

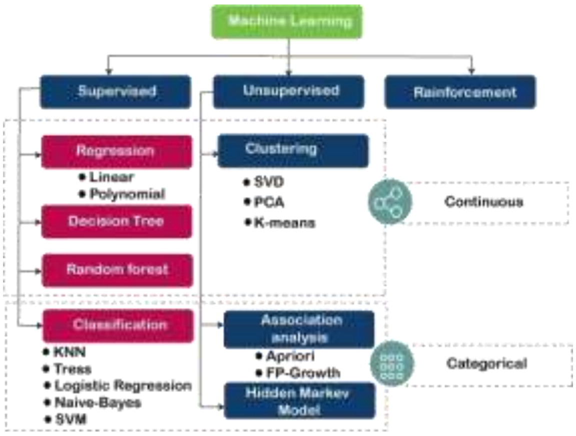


Figure 1: Diagram of different machine learning algorithms with categories (Javatpoint, 2023)

Machine Learning Algorithm can be broadly classified into three types (Suhail et al, 2022)(Huang et al, 2022):

a. Supervised Learning Algorithms. Supervised learning is a type of Machine learning in which the machine needs external supervision to learn. The supervised learning models are trained using the labeled dataset. Once the training and processing are done, the model is tested by providing a sampletest data to check whether it predicts the correct output. The goal of supervised learning is to map input data with the output data. Supervised learning is based on supervision, and it is the same as when a student learns things in the teacher's supervision. The example of supervised learning is spam filtering.

b. Unsupervised Learning Algorithms. It is a type of machine learning in which the machine does not need any external supervision to learn from the data, hence called unsupervised learning. The unsupervised models can be trained using the unlabelled dataset that is notclassified, nor categorized, and the algorithm needs to act on that datawithout any supervision. In unsupervised learning, the model doesn't have a predefined output, and it tries to find useful insights from the huge amount of data. These are used to solve the Association and Clustering problems.

c. Reinforcement Learning Algorithm. In Reinforcement learning, an agent interacts with its environment by producing actions, and learn with the help of feedback. The feedback is givento the agent in the form of rewards, such as for each good action, he gets a positive reward, and for each bad action, he gets a negative reward. There is no supervision provided to the agent.

B. Marine Vessel Control System

Control systems for marine vehicles are related to the type of the vehicle. Ships will have different control systems in use. Crude carriers, tankers, drilling ships, gas carriers, or many other types have some systems in common and some systems that differ because of specific features of each. For instance, systems related to the type of cargo will have different control systems for cargo handling and cargo monitoring, while other systems will be very similar such as navigation, guidance, or power generation systems. The same can be said forsubmarines, underwater vehicles, and other marine vehicles. If it is necessary to somehow present the marine vehicle as a system consisting of many subsystems, thenit seems natural to focus on some "common denominator" for all of them. Figure 2 below shows several groups of different marine vehicle subsystems, which are common to a majority of them. Five main groups can be identified here (Ocean engineering, 2023)(Perera, 2018):

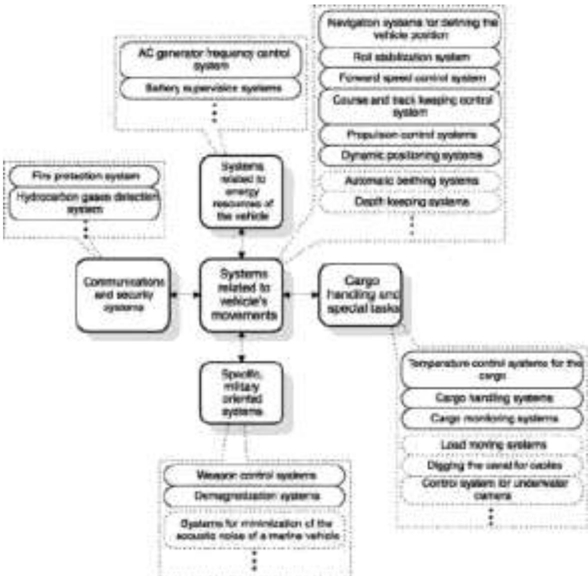


Figure 2: Various control systems for marine vessels (Ocean Engineering, 2023)

a. Systems related to movement of the vehicle. The main purpose of these systems is to help in guiding the marine vehicle from one place to another with improved accuracy, less energy consumption, or some other desired performance specifications.

b. Systems related to cargo handling and special tasks. The main purpose of these systems is to help in handling the cargo or some specific load, so that the cargo is transferred from the port or from the ship (or inside the ship in case of ammunition for instance), as fast as possible or with high accuracy in case of special loads.

c. Systems related to energy resources of the vehicle. Every marine vehicle must have enough energy resources to achieve its goal. The majority of marine vehicles have their own energy source, and only somespecific marine vehicles, such as remotely operated underwater vehicles or tractors, have the energy source in some other place (usually on the command platform).

d. Systems related to communication and security. Communication systems have the role of ensuring open communication channels within the marine vehicle as well as with the world. Here, we can also include the alarm and security systems, such as fire protection systems, because their primary role is to react to everything that may endanger the vehicle, and to pass that information to those responsible for that particular part of the system.

e. Specific military-oriented systems. Weapon control systems on warships, submarines, minehunters, and other navy marine vehicles belong to this category including systems for demagnetization of the warship and systems for minimizing the acoustic noise of the warship or submarine.

There is currently no automation system that monitors or controls the complete ship's operation, replacing the crew onboard. For example, engine control systems may monitor the engine and shut it down if there is a failure, even if this compromises the safety and integrity of the ship. An example is the Viking Sky incident, where the diesel generators were automatically shutdown due to low lubrication oil levels in a severe sea state, which led to a complete blackout and nearly caused the cruise ship with almost 1400 people onboard to ground in storm conditions.

RESEARCH METHOD

To avoid confusion in the use of the terms maritime and marine, this research uses a different approach in interpreting the two terms. Maritime and marine research has different drivers (Saputra et al, 2019). The Maritime industry works to achieve sustainable and efficient operations, and to position the maritime industry to meet challenges, such as competitiveness and cost efficiency. Marine research, on the other hand, is driven by the need to understand ecosystems, how they function and how they change, and to understand the impact of human activities on ecosystems and to develop options for sustainable use. A European association of universities in marine technology (WEGEMT) stipulated the term technology for the safe use, exploitation, protection of, and intervention in, the marine environment (Saputra et al, 2019).

In this research, problems are identified in the first place of the study. Many related papers are collected from IEEE Explorer, Springer and Web of Science. For dataset, this study collected from Dimension.ai as a free recommended research dataset (Saputra, R.W. et al., 2019). The information collected from dataset and related research paper are combined with VosViewer to identified current condition of the research and informed in part result and discussion section on this paper.

RESULT AND DISCUSSION

There are many concepts of autonomous ship implemented by researcher today. The autonomous ship described in this paper are based on related work by (Ilkyun, Im et al, 2018). The researchs focused on the periodically unmanned ship (PUS) defined in the Norwegian Forum for Autonomous Ships in Figure 3: The ship canoperate without crew on the bridge for limited periods, e.g. in open sea and good weather. Crew is on board ship and can be called to the bridge in case of problems.

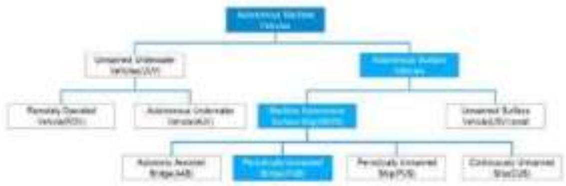


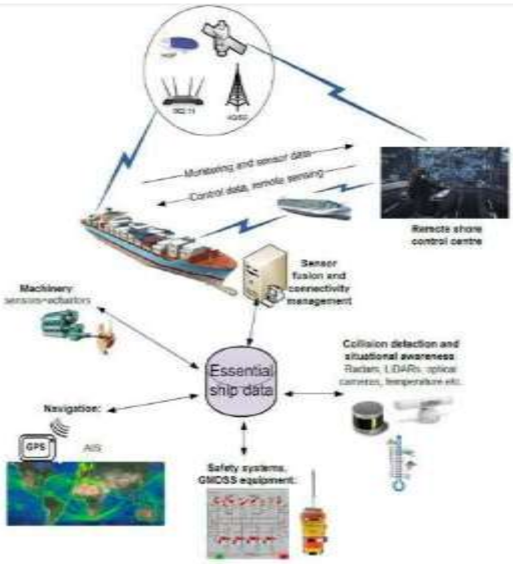
Figure 3: Autonomous ship definition (Ilkyun, Im et al, 2018)

The operation and control methods of autonomous ships can be roughly classified into three categories as shown in Figure 4. First, the ship will safely enter the port under the pilot's embarkation from the port of entry / departure to the point of full away on passage (FAOP) and end of sea passage (EOSP). At this time, the ship's operation control from the autonomous ship is recovered and the ship is controlled in cooperation with the remote operator of the land center. Second, the Deep Sea is operated autonomously by independent judgment of the ship. Third, when an abnormal situation occurs inside or outside the ship, it is controlled by the autonomous ship and controlled remotely. It is possible tomonitor the status of the ship in real time by transmitting the navigation information generated during ship operation to the land center. The analysis of the sensor (camera, various sensor information) in the equipment or facilities in the ship is identified, and the measures are determined to remotely control the ship.

Figure 4: Unmanned freighter navigation area (Ilkyun, Im et al, 2018)

One of the most important parts of an autonomous system is the communication connectivity between each connected device. In previous research, as shown in the figure 5 below, it was found that a lot of connection activities must be connected so that the process can run smoothly. This of coursewill have an impact on the interconnection between one device and another.

Communication systems are essential for these ships to interact with other entities, including other ships, shore-based systems, and satellites. Autonomous ships rely on various sensors, such as radar, lidar, cameras, and sonar, to perceive their environment and make decisions. The information gathered by these sensors needs to be transmitted and exchanged among different onboard systems



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igure 5: Communication architecture of an autonomous ship (Hoyhtya, et al, 2017)

to facilitate navigation and control.

An autonomous ship is equipped with numerous subsystems and computers responsible for different functions, such as navigation, propulsion, and collision avoidance. The communication system allows these components to share data and cooperate seamlessly to ensure the ship's safe and efficient operation.

Machine learning plays a vital role in the development and operation of autonomous ships. It is a core technology that enables ships to become self-navigating and decision-making entities. machine learning is a critical enabler of autonomous ships, allowing them to process sensor data, detect objects, plan routes, make decisions, and continuously improve their performance.The combination of machine learning andother technologies, such as communication systems, sensor fusion, and robotics, ispaving the way for a new era of safe and efficient maritime transportation. Here aresome key aspects of the relationship between machine learning and autonomous ships:

1. Sensor Data Processing: Autonomous ships are equipped with various sensors that continuously collect data about the ship's surroundings, such as radar, lidar, cameras, and sonar. Machine learning algorithms are used to process and interpret this sensor data, enabling the ship to perceive its environment, detect objects, and make sense of complex scenarios.
2. Object Detection and Recognition: Machine learning algorithms, particularly computer vision techniques like convolutional neural networks (CNNs), are used for object detection and recognition. These algorithms canidentify and classify objects, such as other ships, buoys, obstacles, and navigation marks, which are crucial for safe navigation and collision avoidance.
3. Path Planning and Navigation: Machine learning is employed to develop sophisticated algorithms for path planning and navigation. These algorithms take into account the ship's current position, destination, environmental conditions, and any detected obstacles to plan an optimal route. Reinforcement learning is one approach that can be used to train agents to navigate effectively in dynamic and uncertain environments.
4. Decision Making and Control: Autonomous ships need to make decisions in real-time, similar to human operators. Machine learning techniques like reinforcement learning, deep learning, and fuzzy logic are used to create decision-making systems that can adapt to changing conditions and optimize ship operations.
5. Safety and Anomaly Detection: Machine learning models can be trained to

recognize patterns indicative of potential safety risks or anomalies in the ship's behavior or sensor data. By continuously monitoring and analyzing these patterns, autonomous ships can proactivelyrespond to critical situations and ensure safe operation.

6. Performance Optimization: Machine learning can be employed to optimize various aspects of the ship's performance, such as fuel efficiency, speed control, and cargo management. Predictive modeling and data analysis can help improve overall operational efficiency.
7. Learning from Experience: Machine learning enables autonomous ships to learn from their past experiences and improve their decision-making capabilities over time. By accumulating and analyzing historical data, the ship can enhance its performance and adapt to various conditions more effectively.
8. Model Training and Testing: Developing machine learning models for autonomous ships involves training them on vast datasets of simulated or real-world scenarios. The models are tested extensively in virtual or controlled environments before deploying them on actual ships to ensure their reliability and safety.

In the context of autonomous vessel systems, several machine learning algorithms are commonly used to enable various functionalities. Deep Learning and Convolutional Neural Networks (CNNs): Deep learning, particularly CNNs, is widely used for computer vision tasks in autonomous vessel systems. CNNs are effective for object detection, recognition, and classification from sensor data, such as identifying other vessels, obstacles, navigation marks, and buoys. Reinforcement learning is used for training agents to make decisions in dynamic environments. In the context of autonomous vessels, RL can be employed for path planning, navigation, and collision avoidance. RL algorithms enablethe vessel to learn from its actions and the consequences, optimizing its behavior over time.

Supervised learning algorithms are used for various tasks in autonomous vessels, such as predicting vessel behavior based on historical data, weather conditions, or other inputs. It can also be used for predictive maintenance, predicting equipment failures, and optimizing vessel performance. Unsupervised learning algorithms can be applied in autonomous vessel systems for tasks like anomaly detection. These algorithms can help detect unusual patterns or behaviors that might indicate potential safety risks or equipment malfunctions. Semi-Supervised Learning: In scenarios where labeled data is scarce, semi-supervised earning techniques can be utilized to leverage both labeled and unlabeled data to improve model performance in tasks like object detection or classification.

It's important to note that the specificmachine learning algorithms and techniques used in autonomous vessel systems can vary depending on the system's requirements, the type of vessel, and the complexity of thetasks it needs to perform. The field of autonomous vessels is rapidly evolving, and researchers and engineers are continually exploring new approaches and algorithms to enhance their capabilities and safety.

From the picture it can be seen that research on autonomous ships recorded on

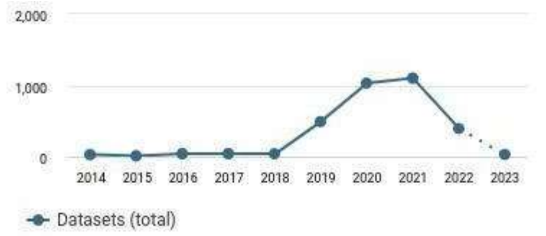

Figure 6: Overview of dataset from Dimension.ai related to research about autonomous ship

Dimension.ai has been going fast since 2018 but has slightly decreased in the last few years. Of course this can be caused by many things, but this is not the main focus of this research.

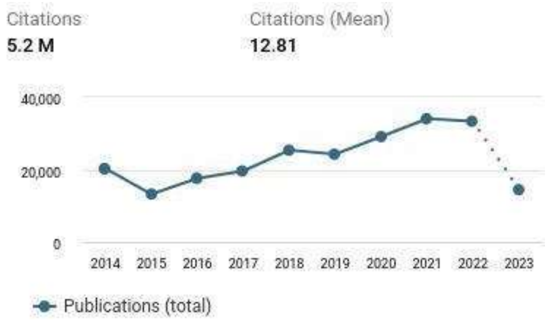

Figure 7: Amount of research recorded based on title and citation in Dimension.ai

The data is not much different when we use title and citation sources as references in data processing. The figure shows thatseveral citations and titles have been recorded since 2014 and have also decreased

CONCLUSSION

The incorporation of machine learning in

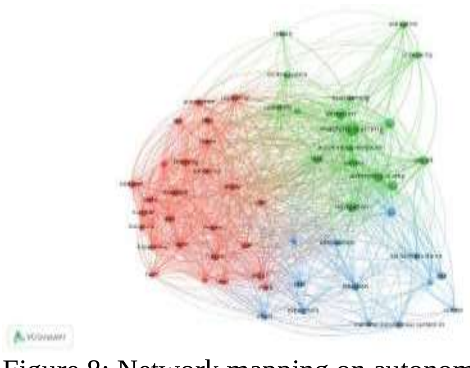

Figure 8: Network mapping on autonomous ship and machine learning research.

in terms of the number of studies in recent years.

In this network analysis using VOSviewer to explore the landscape of research on machine learning and autonomous ship, we identified key themes and relationships within the literature. The analysis revealed a growing interest in the intersection of these two fields, indicatingthe increasing significance of machine learning in shaping the development of autonomous ship technologies.

The network analysis showcased prominent clusters of research that centered around critical topics, such as computer vision techniques, path planning algorithms, and collision avoidance strategies. These clusters signify the core areas of focus within the integration of machine learning in autonomous ship systems. Furthermore, the analysis demonstrated a strong interconnectivity between various research groups and institutions, highlighting collaborative efforts in advancing the understanding and implementation of machine learning in the maritime domain.

sustainable autonomous ship control systems has brought about a transformative shift in the maritime sector. By leveraging advanced algorithms such as deep learning and convolutional neural networks, autonomous vessels can effectively detect and recognize objects, ensuring enhanced collision avoidance and overall safety. Moreover, reinforcement learning empowers ships to learn from experiences and dynamically optimize their routes, leading to improvedfuel efficiency and reduced environmentalimpact.

The deployment of supervised and unsupervised learning algorithms further contributes to the efficiency and safety of autonomous ships. Predictive maintenance, made possible through supervised learning, enables proactive maintenance scheduling, minimizing downtime, and maximizing operational effectiveness. Simultaneously, unsupervised learning aids in anomaly detection, promptly identifying potential safety risks and equipment malfunctions, thereby ensuring early intervention and preventing hazardous incidents.

As the field of autonomous shipping advances, the integration of natural language processing and transfer learning holds immense promise. Enabling intuitive communication between autonomous vessels and human operators facilitates seamless collaboration and information exchange, streamlining operational processes. Additionally, transfer learning allows vessels to leverage knowledge gained from one context to adapt quickly to new and unfamiliar situations, accelerating their learning curve and further improving their performance. This relentless pursuit of innovation in sustainable autonomous ship control systems bodes well for the maritime industry's future, fostering a greener and more sustainable era of global maritime transportation.

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