electronics

Article

Trend Research on Maritime Autonomous Surface Ships (MASSs) Based on Shipboard Electronics: Focusing on Text Mining and Network Analysis

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Abstract: The growing adoption of electric propulsion systems in Maritime Autonomous Surface Ships (MASSs) necessitates advancements in shipboard electronics for safe, efficient, and reliable operation. These advancements are crucial for tasks such as real-time sensor data processing, control algorithms for autonomous navigation, and robust decision-making capabilities. This study investigates research trends in MASSs, using bibliographic analysis to identify policy and future research directions in this evolving field. We analyze 3363 MASS-related articles from the Web of Science database, employing co-occurrence word analysis and latent Dirichlet allocation (LDA) topic modeling. The findings reveal a rapidly growing field dominated by image recognition research. Keywords such as "datum", "image", and "detection" suggest a focus on collecting and analyzing marine data, particularly with deep learning for synthetic aperture radar imagery. LDA confirms this, with "image analysis and classification research" as the leading topic. The study also identifies national and organizational leaders in MASS research. However, research on Arctic routes lags behind that on other areas. This work provides valuable insights for policymakers and researchers, promoting a deeper understanding of MASSs and informing future policy and research agendas regarding the integration of electric propulsion systems within the maritime industry.

Keywords: Maritime Autonomous Surface Ships (MASS); research trends; text mining; latent Dirichlet allocation (LDA) topic modeling; shipboard electronics; shipping industry

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1. Introduction

1.1. Background

Advancements in automation systems and the integration of IoT technology are ushering in a transformative era for maritime operations [1]. This paradigm shift has given rise to innovative ship operations, including smart ships, remotely operating vessels, and digital twin ships [2,3]. Maritime Autonomous Surface Ships (MASSs), analogous to self-driving cars, rely heavily on innovations in electronics, which enable them to operate safely and efficiently in complex maritime environments. The integration of sensor technology, data processing, communication systems, and power management enables ships to sense their surroundings, gather and process the necessary information, and make appropriate decisions [4]. This implies that electronics play an essential role in the operation and safety management of autonomous ships. It is crucial to monitor the latest developments in autonomous ships from an electronics perspective in order to comprehend and capitalize on the innovative advancements in this field. The primary advantages of electronics-based autonomous ships are as follows. The first is enhanced safety. Advanced sensor technology and data processing systems enable autonomous ships to operate safely in a variety of ocean and weather conditions. This reduces the number of accidents caused by human operator errors and enables a swift and accurate response in the event of an incident. Secondly, the implementation of electronics-based autonomous navigation technology results in a reduction in operating costs and an increase in the overall operational efficiency. This is achieved through the use of optimal routing and the minimization of fuel use. In response to dynamic conditions, adjustments in speed are made, thereby improving the energy efficiency. Thirdly, the development and implementation of autonomous ships serves to fuel technological innovation. This is not limited to the field of electronics, but also encompasses related industries such as communications technology, artificial intelligence, and machine learning. This provides opportunities for the further development of these technologies and the exploration of new technological possibilities. It is anticipated that these effects will significantly enhance the sustainability and economic benefits of the shipping industry, with positive implications for the future [4].

In light of the potential of these technological advances, the International Maritime Organization (IMO) has been engaged in discussions surrounding the safe operation of Maritime Autonomous Surface Ships (MASSs). In 2017–2018, the IMO proposed a new action plan for MASSs and drafted relevant conventions and regulations to address several issues, including safety and environmental protection. The IMO refers to MASSs as ships that, to varying degrees, can operate independently of human involvement [5,6]. MASS research has emerged as a significant area of interest within the international maritime field. The research, development, and adoption of MASSs are becoming a prominent trend within the shipbuilding industry. The shipping industry and relevant scientific research institutions have invested in research on autonomous ships with varying degrees of autonomy and intelligence [7].

MASSs are essential because they have a variety of commercial [7] and military [8,9] applications, and they are very attractive in that they can enable safe navigation [10], especially because most ship accidents arise from human errors [11,12]. According to Wrobel et al., boarding crews have an advantage in responding to a ship accident, but MASSs can significantly reduce the risk of an accident occurring in advance [13]. The objective of MASSs is to facilitate autonomous decision-making. Consequently, AI-powered embedded software serves as the foundation for MASSs, with the potential to ultimately replace human mariners. Further research in this area is likely, and it is therefore advisable to monitor the emerging trends.

From a scientific and econometric perspective, examining the research that has been conducted in a field can reveal important topics, concepts that are currently popular, and the most prevalent research areas. A careful search of the relevant literature is the most important method in enabling such research. As illustrated in Figure 1, the number of papers on autonomous ships grew exponentially over the five-year period from 2018, when MASSs were first mentioned by the IMO, to 2022. This growth can be observed in the number of studies on MASSs at sea, which has increased annually [14]. An analysis of the number of papers related to autonomous ships by year reveals that there were 368 papers in 2018, the first year of analysis; 531 papers in 2019; 584 papers in 2020; 836 papers in 2021; and 1049 papers in 2022. This represents an average annual growth rate of 30%, as illustrated in Figure 1. In particular, the highest growth rate of 29.9% was recorded from 2018 to 2019, when the concept of MASSs was first established.

The rapid increase in research in the field of MASSs is due to a number of factors, including advances in artificial intelligence, robotics, sensor technology, and communication technologies; industrial demands for increased efficiency in the shipping industry; changes in the safety and regulatory environment; increasing investment; and the need for technological approaches to minimize environmental impacts [11]. These technical and industrial motivations drive research on MASSs, which is reflected in the rapid increase in the number of research papers. The fundamental research conducted in the early stages has provided an important foundation to overcome technical applicability, legal, and operational challenges.

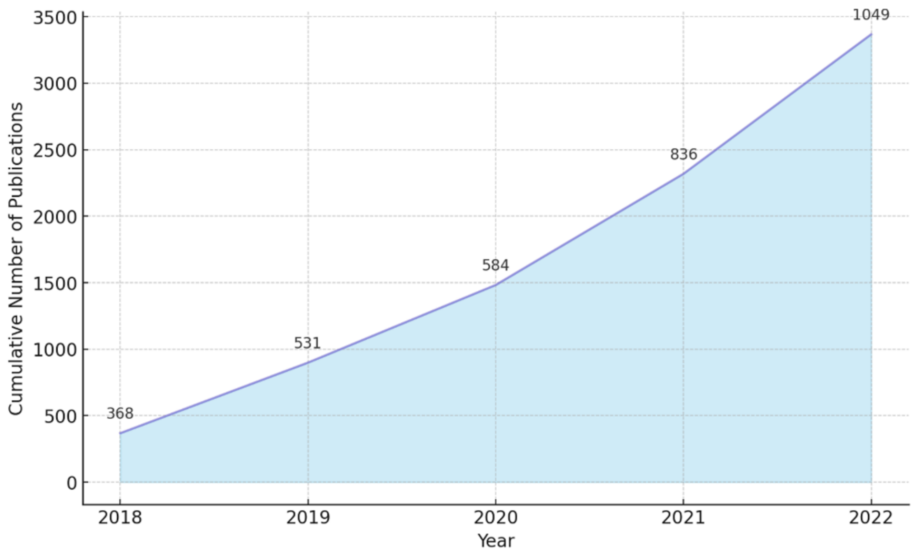

Figure 1. The increase in the number of MASS-related research articles searched on Web of Science.

However, complex systematic reviews can take more than a year to complete, with half of this time spent searching and ensuring proper scanning. This presents a significant challenge, as policymakers and practitioners frequently require research results within a much shorter time scale than allowed by manual methods [15]. In this study, a systematic review with text mining is proposed for the current literature—an operation that is almost impossible to perform manually—to determine the critical topics and trends in the field of MASSs. This allows for the identification of topics, frameworks, future challenges, and expectations that are of worldwide importance.

The application of data mining techniques for the discovery of information from structured data has recently attracted the interest of a considerable number of researchers and industry professionals [16]. The main reason for the increasing usage of data mining techniques is that data can be easily stored and processed in a digital medium; manually processing and interpreting large amounts of data is expensive and time-consuming. Although structured and numerical data are commonly used in data mining studies, various research articles, comments, and discussions may contain unstructured textual data about a specific field. Text mining, a data exploration method, is a popular tool as it eliminates errors, saves time, and provides more precise information from unstructured text. It employs word-indexing methods to exploit the vast amount of information available in text documents. A number of text mining techniques have been established in the literature for the purpose of information discovery in both academic and industrial contexts [17]. The objective of this study is to identify important and popular topics by examining academic articles on the subject of MASSs using the text mining method. The findings are expected to inform the selection of new research topics. The absences and major topics in the literature are identified by mining the enormous and increasing number of articles in a fast, systematic, and subjective manner. Consequently, it will be possible to appropriately allocate funds by giving priority to more important and popular issues.

1.2. Previous Research on Maritime Autonomous Surface Ships and Bibliometrics

The literature on MASSs is divided into two categories: engineering and maritime law. First, there are articles in maritime law that deal with the application of international maritime conventions to autonomous ships with navigational and structural characteristics that differ from those of existing ships and normative responses to them. Secondly, there are engineering articles on the development of autonomous systems and related technologies, such as AI. Under these two categories, previous studies on the technical and normative aspects of autonomous ships published in prominent journals were outlined. Furthermore, previous studies analyzing promising future technologies, such as autonomous ships, using scientific metrics such as text mining and networking analysis were also outlined.

According to Rodseth and Burmeisterl, the development and introduction of unmanned ships could provide new career opportunities for highly qualified and maritime-experienced sailors. The ability to supervise and control ship operations from land, without being aboard the vessel, is worthy of consideration as a new high-value occupation in the maritime industry [18].

In a 2022 study, T. Kim and colleagues observed that despite advances in autonomous ship technology, manned (conventional) vessels will continue to play a role in the maritime sector. They further predicted that not all ships will become fully autonomous, suggesting the potential for sustained employment in the maritime industry. However, they did not provide specific estimates on the number or types of jobs in the sector. Instead, they offered insights at the macro level [19].

As argued by Eric Van Hooydonk, the aforementioned contractual matters pertaining to maritime law, the continued presence of sailors on board, the delineation between the responsibilities of an autonomous ship and that of its flag state, and whether autonomous ships can be considered vessels in their own right will continue to apply to these vessels in the future, regardless of whether they are manned or autonomous. This paper was written at a time when autonomous ships were being increasingly recognized by the international community. Rather than focusing on one area, it provides a comprehensive discussion of the general issues and challenges facing autonomous ships in the future [20].

Robert Veal et al. conducted an interpretative review of the appropriateness of applying the international maritime conventions applicable to conventional ships in the context of the introduction of autonomous ships—specifically, the UN Convention on the Law of the Sea; the International Convention for the Safety of Life at Sea; the International Convention for the Training, Credentialing, and Standards of Watchkeeping of Sailors; and the International Rules for the Prevention of Collisions at Sea. They concluded that the current norms can be applied to autonomous ships in the same category as conventional ships, provided that navigational safety and airworthiness are ensured [21].

The paper by Kuntao Cui et al. proposes an optimized offloading mechanism to minimize computation task offloading delays for unmanned surface vehicles (USVs) in rapidly changing marine environments. They developed the Adaptive Upper Confidence Boundary (AUCB) algorithm based on multi-armed bandit (MAB) theory. This algorithm aids USV clusters in effectively adapting to maritime vehicular fog computing networks. The simulation results demonstrate that the AUCB algorithm quickly converges to the optimal computation task offloading strategy under varying data load conditions [22].

Kim et al. investigated the legal concerns arising in the shipping and shipbuilding industries using MASSs. This transition to highly autonomous, software-centric structures necessitates a new legal framework. The study anticipates legal concerns in MASSs' commercial operation by comparing the Republic of Korea and the United Kingdom. The results contribute to defining the manufacturing responsibility for autonomous ship-embedded software and proposing legal policy changes. The identified legal concerns include software product liability and broader legal policy directions. This study proposes practical solutions to balance damage relief and technological progress for maritime safety [11].

A number of previous studies have analyzed various industries from a scientific and econometric perspective, including text mining.

Santha Kumar and Kallyaperumal conducted a bibliometric analysis using the Web of Science database, focusing on mobile technology research. They quantitatively assessed the publication trends, growth rates, and collaboration patterns to identify numerical trends in the field [23].

Xiao et al. employed the Web of Science database to analyze the development of organic photovoltaic technology, devising search expressions to encompass related technologies such as polymer solar cells and organic solar cells and examining the research patterns from various perspectives, including keyword trends, citation relationships, and collaborative research [24].

In 2020, Yilong Hao conducted a quantitative analysis of 513 articles on aquaponics, covering the period of 2000 to 2019, within the Web of Science database. The findings of the study emphasize system components, wastewater treatment, nutrient management, and production. There are evident differences in regional research fields, with a particular focus on technology application, system optimization, and role exploration in China, the United States, and Europe [25].

In a study conducted by Eunhye Park, the factors influencing the citation counts in academic publications within the tourism and hospitality literature were investigated. This study employed an unsupervised topic modeling approach, utilizing a corpus of 9910 articles from first-tier journals on the Web of Science, spanning over a decade. The findings indicated that articles related to the online media and sharing economy received high citation rates, while recently published articles on specific topics, including rural tourism and ecotourism, were often cited frequently. This study makes a significant contribution to the hospitality and tourism literature by examining the impact of the topic structure and originality, as identified through text mining, on citation counts [26].

1.3. Theoretical Background of Maritime Autonomous Surface Ships

1.3.1. Definition of Maritime Autonomous Surface Ships

Before 2017, the terminology and concept of autonomous ships were used in various contexts within the International Maritime Organization (IMO), a specialized agency of the United Nations (UN) with a strong influence on the shipbuilding and shipping industry, encompassing the concepts of smart ships, digital ships, unmanned ships, remote ships, and automated ships. In 2017, eight countries, including Korea, proposed a new review of the IMO laws governing the operation of autonomous ships at sea in the 20th agenda of the 98th session of the IMO Maritime Safety Committee (MSC) [27]. The term MASSs was used for the first time in this study. Since then, numerous terms have been used interchangeably to define and describe MASSs, although the implied meaning of the term may be the same and disputes have continued, without the term being clearly defined. As a result of discussions at the IMO MSC's 99th meeting in 2018, it was decided that "MASS definitions and concepts of different types and levels of autonomy, automation, operation, and manning should be provisional, neutral in terms of technology, and developed for exercise only". The definition has been agreed as "a vessel capable of operating independently without human interference at various levels of automation" [28]. Even now, the names and concepts of autonomous ships differ slightly depending on the industry and research group. However, ultimately, regardless of the form that they take, autonomous ships are characterized by the fact that they operate in the absence of human factors, unlike conventional ships. They are ships that operate independently, without human interference [28]. A summary is provided in Table 1.

Table 1. The glossary of terms regarding Maritime Autonomous Surface Ships.

Term	Description
Maritime Autonomous Surface Ship	Operates autonomously, with or without crew.
Smart Ship	Enhances safety and efficiency through connectivity and automation.
Digital Ship	Operates using digital and IT-based systems.
Unmanned Ship	Controlled remotely without an onboard crew.
Autonomous Ship	Functions based on remote or automated commands.
Remote Ship	Directly controlled by an onshore operator.

1.3.2. Stages of Autonomy for Maritime Autonomous Surface Ships

The IMO MSC's 99th meeting, which agreed on the definition of Maritime Autonomous Surface Ships (MASSs), classified ship autonomy into four stages, as shown in Table 2. The four stages of ship autonomy are based on the ship's operator and the type of system (automated, unmanned, and fully autonomous), but, given the current level of technological development regarding AI systems, these stages could change at any time as the related technologies develop. However, because such a conceptual distinction may be helpful in future code application and technological development, it is considered reasonable to follow the IMO's four-stage distinction, based on a comprehensive consideration of the international impacts and potential future use of the autonomy stages, rather than adopting an overly granular, technical distinction.

Table 2. The levels of Maritime Autonomous Surface Ships.

Level	Description
1	Ship with automated processes and decision support. Seafarers are present on board to operate and control the shipboard systems and functions. Some operations may be automated.
2	Remotely controlled ship without seafarers on board. The ship is controlled and operated from another location.
3	Remotely controlled ship without seafarers on board. The ship is controlled and operated from another location.
4	Fully autonomous ship. The operating system of the ship can make decisions and determine actions by itself.

1.4. The Need to Develop Maritime Autonomous Surface Ships

The benefits of constructing MASSs for the shipbuilding and shipping industries include the ability to build eco-friendly ships depending on the method of construction. The air environment is protected using technologies such as electric propulsion; since there is no crew on board, little waste, such as sewage and gray water, is generated, contributing to the protection of the maritime environment [29]. Second, it can significantly reduce the ship operating costs by reducing the crew costs [30]. The crew costs account for a significant proportion of the ship operating costs, and MASS operations can reduce the crew costs for ship owners. Furthermore, it is not necessary to carry survival supplies or design a separate living area for the crew, which can contribute to cost savings in terms of space, as well as significant savings in fuel oil [31]. Third, MASSs can contribute significantly to maritime safety and the reduction and prevention of marine pollution. Many maritime accidents are directly or indirectly caused by sailors' inattention, intentional negligence, and breaches of the duty of care; hence, eliminating the human factor can help to prevent maritime accidents from occurring in the first place [32]. Finally, MASSs can significantly contribute to improving sailors' working conditions. If autonomous ships are commercialized, a new working environment will arise in which sailors can live with their families while monitoring the ship's operational status from an onshore control center and being guaranteed a set commute time [33].

2. Materials and Methods

2.1. Research Subjects

2.1.1. Collecting Research Data

Clarivate's Web of Science database was used to construct the analysis data for this study. Web of Science is a scholarly citation indexing database that was first developed in the 1950s and provides full-text access to SCI(E) research publications [34]. To extract data from the research papers on autonomous ships, we used the search expression "'Maritime Autonomous surface ship' (All Fields) or 'Smart ship' (All Fields) or 'Unmanned Ship' (All Fields) or 'Automated Ship' (All Fields) or 'Remote Ship' (All fields)", which includes all of the common terms in Table 1, given that the names and concepts of Maritime Autonomous Surface Ships differ slightly across industries and research groups. The search period was set to five years beginning in 2018, the year of the IMO MSC's 99th meeting, when the concept of autonomous ships was agreed upon, and ending in 2022, resulting in an analysis database of 3363 papers.

2.1.2. Refining Research Data

Before the analysis, the generated database was subjected to the following data pretreatment procedures. Because the keyword data of articles are calculated as entered by the authors, they are often entered differently despite referring to the same concepts, due to distinctions across papers and subscripts [34]. Therefore, if the data are used without processing, errors will arise in the analysis. Hence, errors were minimized by refining the keyword data. Next, Clarivate's Incites was used to analyze the number of articles published by major countries and research institutes in the field of MASSs, to derive trends and identify domestic and international institutions with a strong focus on autonomous ships. Furthermore, the keywords of the articles were analyzed periodically to scientifically identify the research trends. NetMiner 4, a Python-based analytic program, was used, and a co-occurrence word analysis was conducted on the abstracts of the bibliographic information to derive the main keywords. Furthermore, topic modeling was conducted to analyze eight major topics.

2.2. Research Methods

This research used NetMiner4.4.3 (Cyram Inc., Seongnam, Republic of Korea), a software tool used for network analysis and visualization. Along with UCINET and Pajek, NetMiner is a representative tool for social network analysis [35]. A research model was designed for this study, as shown in Figure 2. First, the concept and characteristics of autonomous ships were analyzed based on previous studies, and then bibliographic data on autonomous ships were collected from the Web of Science database. The collected data were refined by unifying the terms, removing unused terms, and filtering them with a dictionary. The number of papers published per year was computed, and the abstracts, author keywords, and titles of the papers were extracted [26].

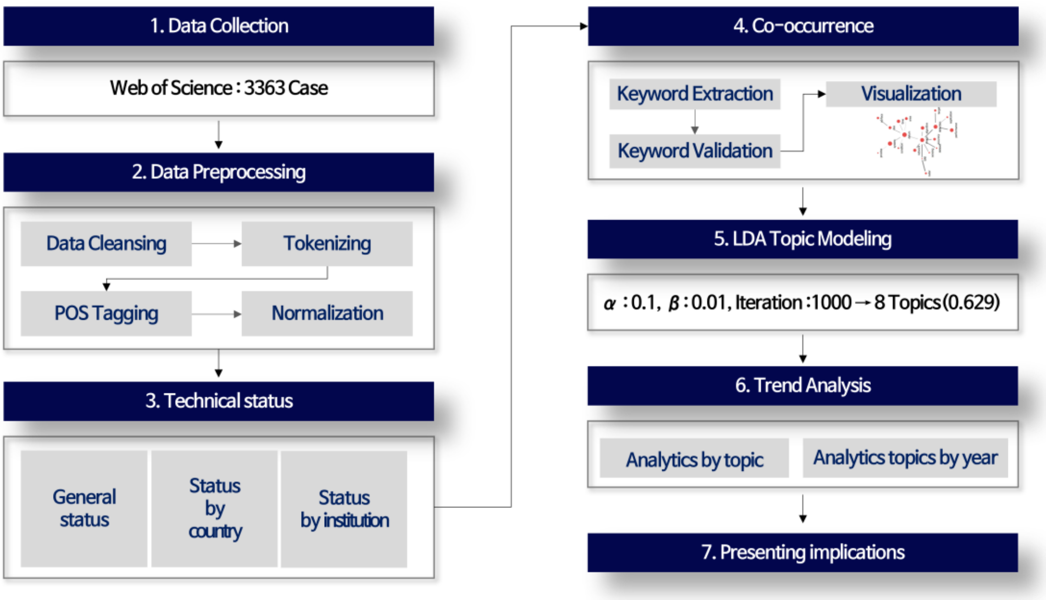

Figure 2. An overview of the research process.

2.2.1. Co-Occurrence Analysis

Co-occurrence word analysis is a means of visually representing the topics in a set of documents by using the co-occurrence frequency of major keywords or classification codes, and it is used to identify topic trends and temporal changes in various fields [36]. In particular, n-gram analysis, which is often used in text mining, has the advantage of being useful in identifying the relationships between adjacent keywords. However, its disadvantage is that the correlations between the keywords cannot be confirmed if the keywords that co-occur frequently in the same document do not appear one after another. Therefore, in this study, a co-occurrence network analysis was conducted to check the correlations between the co-occurring keywords in a document.

In co-occurrence network analysis, a network comprises nodes and the connections (links) between the nodes, with each node representing a keyword and each link representing a relationship between the keywords. To visually represent the relationships between the keywords, each keyword is represented by a dot, the link between them is represented by a line, and the thickness of the line varies depending on how often the two keywords are used together [37]. If a network analysis is conducted for all keywords, it becomes difficult to grasp the meaning due to the excessive number of nodes and connections; hence, the range of nodes to be included in the analysis must be determined [38]. In this study, the top 20 keywords were subjected to a pathfinder network (PFNet), and the complex network represented by the input matrix was reduced, leaving only the most important links for each node, so that the overall structure could be understood at a glance [39].

2.2.2. LDA Topic Modeling

Depending on the calculation method used, various types of algorithms, including individual analysis techniques, can be used for topic modeling. In this study, the latent Dirichlet allocation (LDA) technique was used. LDA is commonly used when the subject areas across articles have a strong tendency to be reduced to a single contact point; it is also used to derive topic modeling results for information technology articles containing specific domain information, such as papers, news, and patents [40,41]. To derive analysis results using topic modeling, the parameter values of alpha and beta and the number of topics must be arbitrarily specified in the settings. However, both alpha and beta range from 0.01 to 0.99 and can be divided into thousands of digits [42]. Furthermore, determining the number of papers, calculating the number of topics, and finding the best topic organization can be challenging. These challenges can be overcome by using the coherence coefficient to determine the appropriate number of topics and the keywords within topics [43].

The coherence coefficient is a virtual proxy for the number of papers with the above-mentioned alpha, beta, and number of topic settings, and it uses the number of cases with coherence values close to 1. To determine the best number of topics and parameters for the topic modeling results, the number of papers for the alpha and beta values in this study was set to 0.01–0.99. Considering the total number of articles, the number of topics ranged from two to ten, and the consistency index was calculated for the total number of papers. Therefore, by comparing the topic composition according to the number of topics, core topics that showed a high-density keyword composition in any setting and variable topics that indicated changes depending on the setting were derived, and the meanings and implications of the subject areas implied by each topic were proposed. Figure 3 shows the conceptual model of LDA topic modeling used in this study.

The most challenging and trial-and-error aspect of LDA topic analysis is determining the number of topics [44]. Therefore, the coherence score is often used as a reference index to determine the number of topics. In this study, topic cohesion was used to determine the number of topics, and the 'Cv' metric was applied, which is considered to have excellent performance among several similar indices. Topic cohesion is a technique used to determine the interpretability of an extracted topic from the words comprising the topic, reflecting the way in which humans interpret text, and it assumes that the higher the average of the pairwise similarity between words in an extracted topic's word set, the higher the topic's cohesion [45]. 'Cv' is a concept proposed by Röder et al. [46] that depicts a keyword as a context vector expressing its co-occurrence frequency with the surrounding terms, and it arithmetically averages the pairwise similarity between keywords by calculating the cosine similarity. The formula for calculating this 'cv' value is shown in Equation (1) [46]. It is a more accurate measure of similarity because it takes into account the relationship among neighboring words, rather than calculating the direct similarity between words [46].

$$C_v = \frac{1}{N \times K} \sum_{k=1}^{K} \sum_{n=1}^{N} \mathrm{scos}\left(\vec{w_{n,k}} \cdot \vec{w_k^*} \right) \tag{1}$$

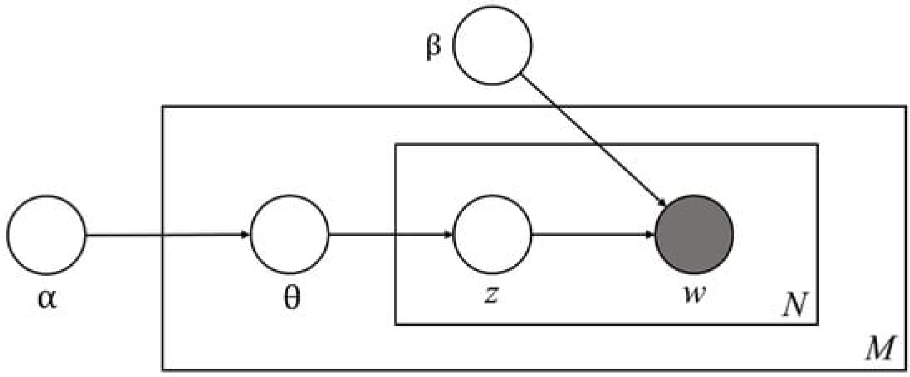

Figure 3. The conceptual model of LDA topic modeling.

3. Results

3.1. Descriptive Statistics Analysis Results

3.1.1. Status by Country

A review of the status of the publications by country reveals an increase in the number of MASS research articles in most countries. As shown in Table 3, China has the highest proportion (560 articles as of 2022), followed by the United States of America (95 articles) and South Korea (76 papers). In particular, in 2018, the number of articles from China, which ranked first, and the United States of America (USA), which ranked second, was approximately 1.4 times higher. However, in 2022, the difference increased substantially to 5.9 times. China's MASS research is increasing rapidly, with an average annual growth rate of 47%.

Table 3. The research status by country.

Status	2018	2019	2020	2021	2022	2018~2022
1	CHINA (120 papers)	CHINA (204 papers)	CHINA (246 papers)	CHINA (381 papers)	CHINA (560 papers)	CHINA (1511 papers)
2	USA (85 papers)	USA (104 papers)	USA (90 papers)	USA (91 papers)	USA (95 papers)	USA (465 papers)
3	S. KOREA (29 papers)	GERMANY (45 papers)	S. KOREA (56 papers)	S. KOREA (67 papers)	S. KOREA (76 papers)	S. KOREA (255 papers)
4	GERMANY (25 papers)	CANADA (32 papers)	ENGLAND (34 papers)	ENGLAND (43 papers)	NORWAY (50 papers)	GERMANY (185 papers)
5	CANADA (24 papers)	ITALY (28 papers)	ITALY (32 papers)	GERMANY (41 papers)	GERMANY (47 papers)	CANADA (162 papers)

China continues to publish the most papers, with an increase from 120 in 2018 to 560 in 2022. The cumulative number of publications from 2018 to 2022 was 1511. China consistently appears as the country with the highest number of publications, reflecting its technological leadership and rapid development in the field. China's high research productivity is indicative of its strategic investment and strong government support for R&D at the national level, which could lead to the country playing a leading role in the commercialization of autonomous vessel technologies and the development of regulatory frameworks. The United States of America (USA) published the second-highest number of papers each year, with 85 in 2018 and 95 in 2022, for a cumulative total of 465 over the five-year period. South Korea (S. KOREA) published the third-highest number of papers in 2018, but it then dropped briefly in the rankings in 2019. However, it returned to being the third most prolific from 2020 to 2022. Its cumulative number of publications from 2018 to 2022 was 255. Germany and Canada consistently appeared in the top five countries from 2018 to 2022, with 185 and 162 papers published, respectively. England and Italy were among the top five countries in specific years, but they did not appear in the top five in terms of their cumulative publications. Norway reached the top five for the first time in 2022. The number of research papers can be considered an indicator of a country's interest in the research and development of MASS technology, as well as the extent to which they are engaged in research activities. A high number of research papers suggests that the researchers in a country are actively conducting research in this area, which could potentially influence the development and adoption of MASS technology. For instance, the considerable number of papers published by China may indicate that there is substantial investment in research and development (R&D) at the national level, which has the potential to influence not only the development of the technology but also domestic policies and international maritime regulations surrounding the technology. In other countries, such as the USA, South Korea, Germany, and Canada, the increase in the number of research papers reflects national interest in the technology and the pace of technological advancement. It can also provide insights into the research capabilities and technological advancements exhibited by different countries in the field of MASS.

3.1.2. Status by Institution

The institutional analysis, as detailed in Table 4, reveals a consistent upward trend in research activity across various organizations. Notably, in China, prominent entities such as the Chinese Academy of Sciences and the University of the Chinese Academy of Sciences, both governmental institutions, lead in this domain. This trend indicates a government-driven expansion in MASS research, emphasizing the significant role of state-led research and development efforts.

The Chinese Academy of Sciences was consistently identified as the organization with the highest number of publications from 2018 to 2022. Notably, there was a particularly large year-on-year increase in 2022. This suggests that the Chinese Academy of Sciences is playing a central role in autonomous vessel research. Furthermore, Dalian Maritime University also appears at the top of the list, with a particularly high number of papers published in 2021 and 2022. This indicates that the institution is conducting important research in maritime technology and shipbuilding, contributing to the advancement of technical and practical knowledge related to autonomous ships. Several other institutions in China, including Wuhan University and the University of the Chinese Academy of Sciences, are also in the top five, contributing to MASS research. The work of these domestic institutions is paving the way for the rapid development of autonomous vessel technology in China, reflecting the country's desire to secure leadership in global maritime technology. This unparalleled activity of Chinese institutions is underpinned by policy support from the Chinese government and intensive R&D investment in the field. It is also indicative of China's growing influence in the international maritime and shipbuilding industry. The findings of Chinese institutions are likely to have a significant impact on the adoption, standardization, and regulatory framework for MASS technology at home and abroad.

Table 4. The research status by institution.

Status	2018	2019	2020	2021	2022	Cumulative Number of Papers
1	CHINESE ACADEMY OF SCIENCES (19 papers)	CHINESE ACADEMY OF SCIENCES (33 papers)	CHINESE ACADEMY OF SCIENCES (38 papers)	CHINESE ACADEMY OF SCIENCES (50 papers)	CHINESE ACADEMY OF SCIENCES (65 papers)	CHINESE ACADEMY OF SCIENCES (205 papers)
2	UNIVERSITY OF CHINESE ACADEMY OF SCIENCES (14 papers)	UNIVERSITY OF CALIFORNIA SYSTEM (25 papers)	WUHAN UNIVERSITY (30 papers)	DALIAN MARITIME UNIVERSITY (46 papers)	DALIAN MARITIME UNIVERSITY (47 papers)	DALIAN MARITIME UNIVERSITY (132 papers)
3	HELMHOLTZ ASSOCIATION (13 papers)	HELMHOLTZ ASSOCIATION (24 papers)	DALIAN MARITIME UNIVERSITY (21 papers)	WUHAN UNIVERSITY (29 papers)	UNIVERSITY OF CHINESE ACADEMY OF SCIENCES (40 papers)	UNIVERSITY OF CHINESE ACADEMY OF SCIENCES (115 papers)
4	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE (11 papers)	UNIVERSITY OF CHINESE ACADEMY OF SCIENCES (16 papers)	UNIVERSITY OF CHINESE ACADEMY OF SCIENCES (20 papers)	XIDAN UNIVERSITY (26 papers)	WUHAN UNIVERSITY (38 papers)	WUHAN UNIVERSITY (111 papers)
5	NATIONAL UNIVERSITY OF DEFENSE TECHNOLOGY CHINA (11 papers)	WUHAN UNIVERSITY (16 papers)	SEOUL NATIONAL UNIVERSITY (13 papers)	UNIVERSITY OF CHINESE ACADEMY OF SCIENCES (25 papers)	XIDAN UNIVERSITY (33 papers)	XIDAN UNIVERSITY (86 papers)

3.2. Results of Co-Occurrence Analysis

A word network was created to convert the bimodal network between words and articles into a unimodal network between words and words to analyze the relationships between the main keywords. The top 20 main keywords were selected based on the number of articles and converted into a network structure based on the co-occurrence of words, resulting in 19 links. The results are shown in Table 5.

Table 5. The results of the co-occurrence analysis.

Status	Main Keywords (Frequency of Occurrence)	Status	Main Keywords (Frequency of Occurrence)
1	detection (3428)	11	time (1178)
2	datum (2991)	12	water (1166)
3	image (2876)	13	area (1101)
4	system (2590)	14	surface (1096)
5	SAR (1901)	15	control (991)
6	target (1708)	16	accuracy (976)
7	network (1653)	17	radar (950)
8	algorithm (1625)	18	dataset (944)
9	sea (1430)	19	object (929)
10	performance (1383)	20	sensing (882)

Because converting the binary mode between a thesis and word into a unimodal mode between a word and n-word may result in too many links, Path-Finder Network Scaling (PFnet) was used to visually represent the network between the words, leaving only highly relevant relationships between words, as described previously by Im et al. [47]. The result of reducing the network to 19 links with a strong correlation between words is shown in Figure 4. The wider the circle, the more frequently the keywords are used based on the number of articles, and the thicker the connection line, the stronger the link strength [36].

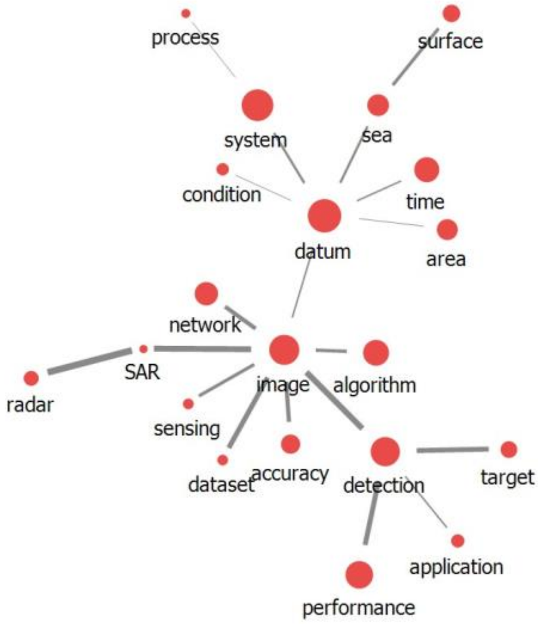

Figure 4. The visualization of the co-occurrence analysis results.

Looking at the network structure of the most relevant keywords, it can be seen that there is a high concentration of keywords related to situational awareness, which is a key concept for autonomous ships, such as 'datum', 'image', and 'detection'. 'Datum' is connected to 'sea', 'condition', 'surface', 'area', etc., and can be seen as including all types of data, such as sea currents and areas. Furthermore, in the papers related to 'image', it seems that deep learning algorithms such as Convolutional Neural Networks (CNNs) based on Synthetic Aperture Radar (SAR) images are used to train the computer with various image data situation recognition technologies. In the papers related to 'detection', it is clear that the researchers mainly conduct 'performance' tests regarding the detection and location of the various objects that already exist in the water. Conversely, deep learning technology is being used by researchers in the field of autonomous ships to learn SAR images while collecting various marine data.

Upon closer inspection, the co-occurrence analysis conducted in this study reveals the interconnectedness of the keywords within the autonomous vessel research: 'detection' (3428 occurrences) has the highest frequency, highlighting the importance of environmental awareness and obstacle avoidance as the core functions of autonomous vessels. 'Datum' (2991 times) refers to the importance of the data that the ships collect, while 'algorithm' (1625 times) refers to the role of the complex algorithms that process these data to make decisions. 'Accuracy' (976 times) and 'target' (1708 times) emphasize the accuracy of algorithms and their ability to track targets, which are essential criteria for safe navigation. 'Control' (991 times) and 'performance' (1383 times) refer to the control of autonomy and the efficiency of the ship's operations, respectively, suggesting that technological advances must be aligned with ethical standards. 'Network' (1653 times) and 'system' (2590 times) reflect the development of integrated management systems and communication networks for autonomous ships. 'SAR' (1901 occurrences), 'radar' (950 occurrences), and 'sensing' (882 occurrences) represent the advanced sensor technologies used for object detection and surveillance at sea, the integration of which contributes to the enhancement of a ship's autonomous navigation capabilities. 'Area' (1101 occurrences), 'water' (1166 occurrences), and 'sea' (1430 occurrences) refer to the legal and environmental conditions associated with operating in the marine environment, which provide a basis for policy decisions that can be applied to the operation of autonomous ships. As such, the keywords identified through the co-occurrence analysis clarify how the algorithmic, ethical, technological, and policy aspects of MASS development are interconnected, and these connections have practical implications for the development of MASS technology.

3.3. Results of LDA Topic Modeling

3.3.1. Coherence Score Measurement Results

To determine the ideal number of topics, α was set to 0.1, β to 0.01, and iteration to 1000, according to W. Zhao et al. [48]. The number of topics was then increased from two to ten to simulate the coherence score, and the eight topics with the highest scores (0.629) were determined, as shown in Figure 5.

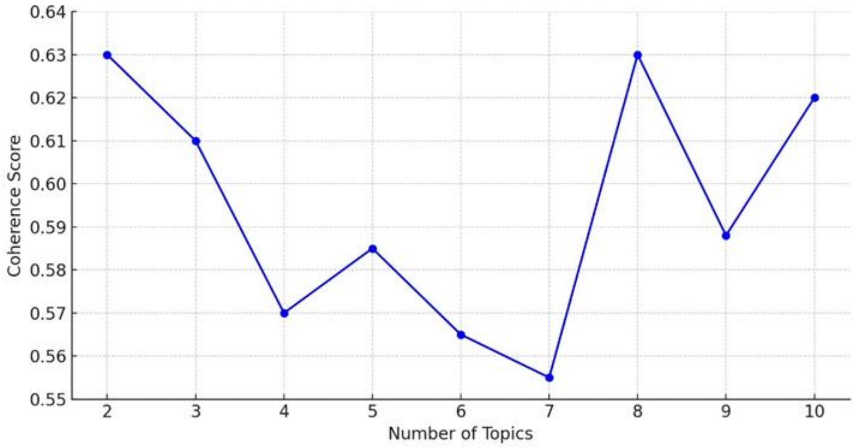

Figure 5. The coherence score measurement results.

Following this, the top 10 keywords with the highest frequency for each topic were summarized, as shown in Table 6, and a comprehensive topic name was assigned by reviewing the topic's keywords and the abstracts from the research bibliographies. We received assistance in determining the topic names through collaborations with researchers who had worked in maritime public institutions for more than five years and professors who had conducted text mining research.

Table 6. A summary of the topic modeling analysis results.

Topic 1 (11.98%)			**Topic 2 (9.28%)**			**Topic 3 (7.94%)**			**Topic 4 (13.83%)**		
Rank	Keyword	Prob	Rank	Keyword	Prob	Rank	Keyword	Prob	Rank	Keyword	Prob
1	detection	0.035	1	datum	0.037	1	ice	0.031	1	system	0.033
2	target	0.034	2	measurement	0.019	2	concentration	0.02	2	control	0.026
3	image	0.03	3	satellite	0.018	3	water	0.015	3	navigation	0.015
4	SAR	0.028	4	wave	0.017	4	sea	0.014	4	algorithm	0.015
5	radar	0.027	5	surface	0.016	5	Arctic	0.012	5	collision	0.013
6	sea	0.02	6	water	0.016	6	region	0.011	6	datum	0.012
7	datum	0.018	7	ocean	0.015	7	emission	0.01	7	motion	0.008
8	algorithm	0.015	8	wind	0.014	8	cloud	0.009	8	simulation	0.008
9	wake	0.011	9	observation	0.012	9	surface	0.009	9	surface	0.008
10	clutter	0.011	10	sensing	0.011	10	particle	0.009	10	path	0.008
Situational awareness technology research			Ocean observation and sensing research			Arctic navigation research			Navigation decision-making and control technology research		

Table 6. *Cont.*

Topic 5 (14.87%)			Topic 6 (8.15%)			Topic 7 (19.60%)			Topic 8 (14.36%)		
Rank	Keyword	Prob	Rank	Keyword	Prob	Rank	Keyword	Prob	Rank	Keyword	Prob
1	system	0.022	1	area	0.021	1	detection	0.059	1	system	0.014
2	energy	0.017	2	oil	0.018	2	image	0.049	2	technology	0.012
3	design	0.013	3	datum	0.013	3	network	0.031	3	shipping	0.011
4	power	0.013	4	water	0.012	4	SAR	0.028	4	datum	0.01
5	structure	0.01	5	marine	0.01	5	object	0.02	5	service	0.008
6	condition	0.009	6	activity	0.009	6	dataset	0.02	6	port	0.007
7	performance	0.008	7	monitoring	0.008	7	target	0.018	7	development	0.007
8	process	0.008	8	fishing	0.007	8	performance	0.015	8	industry	0.007
9	fuel	0.008	9	spill	0.007	9	classification	0.015	9	management	0.007
10	load	0.008	10	island	0.007	10	accuracy	0.014	10	time	0.006
Research on energy and high-efficiency navigation technology			Research on the derivation of autonomous ships			Research on image analysis and classification			Research on port connectivity		

The topics were ① situational awareness technology research (11.98%), ② ocean observation and sensing research (9.28%), ③ Arctic route research (7.94%), ④ route decision and control technology research (13.83%), ⑤ energy and high-efficiency navigation technology research (14.87%), ⑥ autonomous ship derivation research (8.17%), ⑦ image analysis and classification research (19.6%), and ⑧ port connectivity research (14.36%). Similar to the results of the co-occurrence analysis, ⑦ image analysis and classification research (19.6%) was found to have the highest proportion.

3.3.2. Topic Classification Results

In order to facilitate the interpretation of the results of the topic classification, the subsequent paragraphs are organized as follows. Firstly, the main keywords for each topic are presented, along with an explanation of the rationale behind the topic name. Secondly, the main articles on the topic are introduced.

The first topic, titled 'situational awareness technology research', contains the keywords 'detection', 'target', 'image', 'SAR', and 'radar'. Situational awareness technology detects and recognizes maritime fixtures and floating objects by fusing onboard data such as AIS, radar, and SAR images to provide risk warnings, and it is a core technology for autonomous ship operation [39]. Extensive research has been conducted on it. Lee et al. is a representative study, in which ship monitoring using satellite SAR imagery is classified into three stages: ship detection, ship discrimination, and ship identification. However, because there are many studies on ship detection and identification worldwide but only a few studies on ship identification, this study applies recent identification concepts that have shown high performance in existing airborne SAR target identification to the OpenSARShip database to perform ship identification, and it then analyzes the performance to investigate the utility of the OpenSARShip database [49].

The main keywords for the second topic are 'datum', 'measurement', 'wave', 'water', 'ocean', and 'wind', and it is titled 'ocean observation and sensing research'. The process of observing and predicting the state of the marine environment is essential for the operation of autonomous ships. Furthermore, considering ship communication, it is necessary to produce marine environment information so that decisions can be made by analyzing only the information onboard the ship [50]. It appears that extensive research has been conducted on this. Yucheng Zhou et al. is an example of a representative study. In general, the authors point out that, in existing studies, external factors such as wind, waves, and currents are not considered in the route planning of autonomous ships, which affects the navigation safety. They propose a PSO optimization algorithm that considers external factors such as wind, waves, and currents [51].

The third topic, titled ‘Arctic route research’, has the following main keywords: ‘ice’, ‘concentration’, and ‘Arctic’. The Arctic Ocean route represented a turning point in the Fourth Industrial Revolution because of its high economic efficiency when used as a regular route for logistics transport, as it reduces the distance by 4000 to 7000 km and shortens the voyage by approximately 13 days compared to the existing southern sea route via the Suez Canal [52]. However, unlike other oceans, the Arctic Ocean is characterized by a high probability of ship accidents and casualties due to iceberg collisions and difficulties in rescuing people due to the harsh climate; thus, at present, many shipping companies tend to avoid Arctic routes. However, autonomous ships are expected to use the Arctic route in the future because they can ensure crew safety and use optimized routes that can be traveled with minimal energy. Ziaul Haque Munim et al. proposed that the three most important criteria for the deployment of autonomous ships on Arctic routes are the operating costs, operational aspects, and environmental protection. Later, the International Maritime Organization (IMO)’s Polar Code stated that “autonomous ships are not included in the category of ships that can operate in polar waters, hence they cannot yet operate, and further discussion is needed” [53].

The fourth topic is titled ‘research on navigation decision-making and control technology’ and contains the following keywords: ‘system’, ‘control’, ‘navigation’, and ‘collision’. Route decision-making and control technology research is key in determining the autonomy levels of autonomous ships, as it enables autonomous ships to find autonomous and economical routes in consideration of various situations (traffic conditions, weather, routes, etc.) and determine the best route that can be operated autonomously [39]. Extensive research has been conducted on it. Xinyu Zhang et al. is a representative article that reviews the main trends in the MASS R&D industry and collision-avoidance navigation technology from academia to industry. It also analyzes the concepts of collision-avoidance navigation, cognitive navigation using the brain, and e-navigation technology to systematically reveal the mechanisms and principles behind efficient operation in a typical maritime environment, thereby analyzing the trends of maritime collision-avoidance navigation systems [54].

The fifth topic, titled ‘research on energy and high-efficiency navigation technology’, has the following keywords: ‘system’, ‘energy’, ‘power’, and ‘condition’. Autonomous ships not only use optimized routes that can be navigated with minimum energy but also have the advantage of integrated on-board data management, which allows for energy optimization via the management of all energy systems (fuel storage, fuel supply, power generation, energy storage, and energy consumption systems) installed on the ship in an integrated manner for their efficient use [39]. Konstantinos et al. propose a system that automates the energy management of propulsion engines, the largest energy producers on ships [55].

The sixth topic, titled ‘autonomous ship derivative research’, includes ‘area’, ‘oil’, ‘fishing’, and ‘monitoring’. Deep learning, the basic technology of autonomous ships, can be applied not only to ships but also to many other marine fields. For example, fully connected neural networks (FNNs) and convolutional neural networks (CNNs) are used to identify red tides, oil spills, and illegal fishing boats, etc., which are deadly to fisheries and aquaculture. Meanwhile, linear regression, recurrent neural networks (RNNs)/LSTM, etc., are used to estimate seaweed, the sea water temperature, and the salinity at the sea surface. Choiproposes a deep learning-based methodology to predict the occurrence of anomalous high-temperature phenomena using LSTM models [56].

The seventh topic is titled ‘image analysis and classification research’, with the following keywords: ‘detection’, ‘image’, ‘network’, and ‘SAR’. The perception of the surrounding environment, including the detection and classification of objects, is one of the essential skills required for autonomous ships [57]. Although computer vision research for ship image classification has been steadily progressing, it suffers from a lack of properly labeled databases for ship classification, although this appears to have been improved. José is an exemplary work that used the Mask-CNN and OMRCNN-SHD techniques for small vessel detection with autonomous ship technology. Data augmentation was conducted to solve the problem of the limited number of real image samples of small ships [58].

The eighth topic is titled 'research related to port connectivity' and contains the following keywords: 'system', 'technology', 'shipping', 'service', and 'port'. When autonomous ships are unmanned, advanced port infrastructure that can be linked to port management, fueling, optimal loading and unloading, etc., is required, and substantial research has been conducted on this. Anastasia Tsvetkova's is an example of a study that analyzed how autonomous ships create value and for whom, and how various actors in the maritime logistics ecosystem can monetize or otherwise benefit from the innovation. Interviews were conducted with port logistics experts and relevant innovation leaders to analyze different aspects of value creation in autonomous ships [59].

3.3.3. Topic Analysis by Year

Figure 6 is a graph showing the share of each topic from 2018 to 2022.. The number of articles in all eight topics increased at a compound annual growth rate (CAGR) of 33.2% from 2018 to 2022. In particular, ⑦ image analysis and classification research increased the most, at 65.4%, followed by ④ route decision and control technology research, at 52.4%, and ⑤ energy and high-efficiency navigation technology research, at 35.1%. On the other hand, ③ research on Arctic routes increased the least, at 3.3%. For Arctic routes, reliable sea ice information detection technology is needed to analyze the size, thickness, and ice concentration of drift ice during navigation [60]. However, data collection in this area is relatively difficult compared to other areas of the world, which is why the research has stagnated.

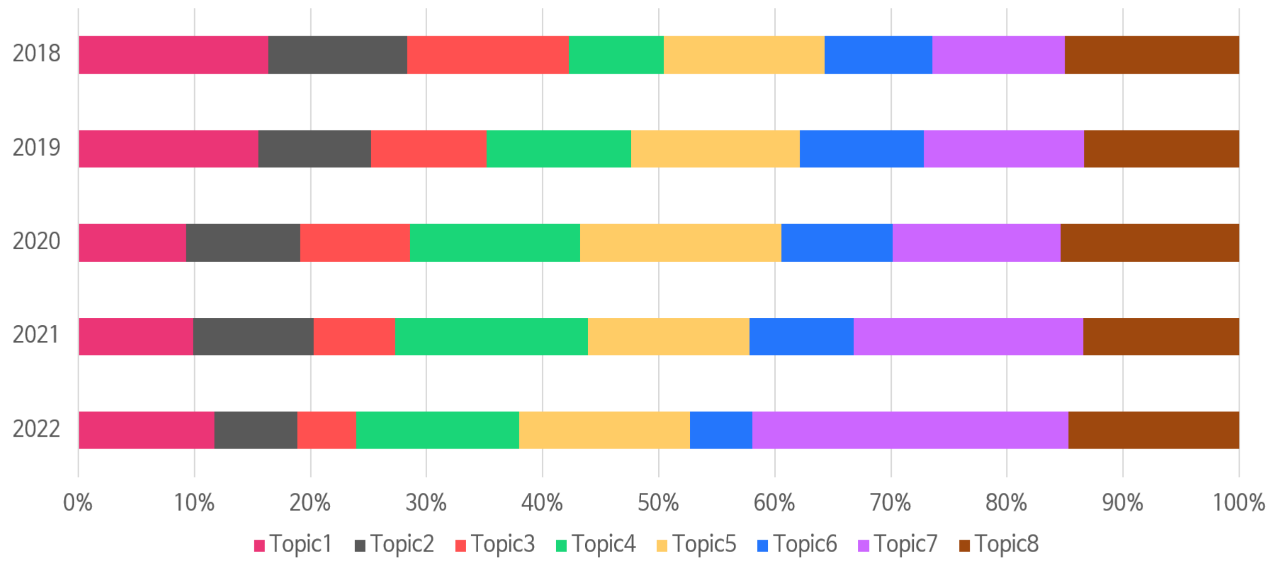

Figure 6. Changes in the topics over the years.

4. Discussion

The number of MASS research articles has grown at a CAGR of 30%. MASS research is expected to grow further as the policy paradigms change and related industries grow.

The analysis shows that China is conducting the largest amount of MASS research, followed by the United States and South Korea, which are actively conducting MASS research. The network structure between the most relevant keywords was found to be centered on keywords related to situational awareness technology, which is the basic technology in autonomous ships, including terms such as 'datum', 'image', and 'detection'. Similarly, research on autonomous ships is mainly conducted using deep learning technology to learn

SAR images while collecting various marine data. Before conducting LDA topic modeling, the optimal number of topics, 8, was derived through Cv measurement. Finally, the following were obtained: ① situational awareness technology research (11.98%), ② ocean observation and sensing research (9.28%), ③ Arctic route research (7.94%), ④ route decision and control technology research (13.83%), ⑤ energy and high-efficiency navigation technology research (14.87%), ⑥ autonomous ship derivation research (8.17%), ⑦ image analysis and classification research (19.6%), and ⑧ port linkage-related research (14.36%). As in the results of the co-occurrence analysis, ⑦ image analysis and classification research (19.6%) had the highest share, indicating that research on this topic is the most active. Meanwhile, ③ Arctic route research increased the least. This is because Arctic routes require reliable sea ice information detection technology that can be used to analyze the size, thickness, and density of ice floes during navigation [60]. However, data collection in this area is difficult compared with other areas of the world, impeding further research.

The significant share of 'image analysis and classification research' in the MASS category, reaching 19.6%, suggests that this technology plays a pivotal role in the development of autonomous navigation capabilities for ships. This technology is key to enabling ships to precisely perceive the marine environment and make appropriate navigational decisions, and it has the potential to significantly improve maritime safety and efficiency. As such, intensive investment in video analytics technology is needed for several reasons. First, in terms of technological importance, precise image analysis and classification will enable autonomous vessels to automatically make decisions, such as recognizing and avoiding obstacles in complex maritime environments. Second, in terms of safety enhancement, highly advanced image recognition technologies can contribute to the prevention of maritime accidents, minimizing the loss of life and property. Third, in terms of operational efficiency, video analytics contribute to reducing the operational costs by optimizing the route decisions and reducing the energy consumption. Fourth, highly precise video analytics technology is essential to meet the stringent requirements of international shipping regulations. Finally, in terms of competitiveness, investing in image analytics and classification will help to establish technological leadership in the global market and give the shipping industry a competitive edge. For these reasons, more intensive investment in research on image analysis and classification is required, which will play an important role in promoting the development of autonomous ship technology and laying a solid foundation for its eventual commercialization. Next, research on energy and high-efficiency navigation technology (14.87%) and research on port connectivity (14.36%) were the most common. This means that MASSs are expected to affect not only the shipbuilding industry but also the port industry and the shipping industry. In this process, the introduction and operation of radical MASSs may bring various negative consequences. For example, due to the lack of port infrastructure, safety accidents may occur due to confusion with manned vessel operations. In the event of an accident, legal liabilities, insurance issues, and ethical issues, are expected, so a step-by-step and cautious approach is needed [11]. Therefore, it is proposed to promote policies that include the broad consensus and participation of all stakeholders related to MASSs. On the other hand, the growth rate of Arctic route research is relatively low. This is because Arctic shipping routes are challenged by the need for precise knowledge of the sea ice characteristics, such as the size, thickness, and density [60]. Reliable sea ice detection technology is essential for safe navigation, but the harsh environment of the Arctic region makes data collection difficult and research progress has been slow. This suggests that additional resources and technological innovations are needed for Arctic navigation research, and specific efforts should be made to accelerate research and development in this area.

5. Conclusions

This study is academically significant because it is the first to analyze the group of papers related to autonomous ships and explore their implications. It is difficult to predict how the introduction of MASSs will affect policy, society, and international security.

However, it is necessary to discuss which research should be conducted in anticipation of these modifications. It is hoped that this study can be used as a preliminary work in the research on Maritime Autonomous Surface Ships.

Papers analyzing the research trends in MASSs make an important contribution to the systematic understanding of the technological progress and industrial prospects in this field. Such research can have a number of positive effects. Firstly, the analysis of research trends can provide a direction for the development of MASS technology and help to set priorities for future research. This enables academia and industry to identify gaps in technology development, identify necessary research topics, and guide investment. Secondly, it provides important information for industry development strategies. By analyzing the commercial applicability of MASS technology and market introduction strategies, companies and governments can formulate more effective industrialization strategies. This contributes to the acquisition of a technological advantage and the enhancement of the competitiveness in the global market. Third, it supports the formulation of policy. By understanding the maturity of the technologies, safety concerns, and the regulatory needs related to MASSs, policymakers can create more effective policies and regulations. This is important for the sustainability of the industry and the fostering of technological advancement. Fourth, it contributes to the improvement of education and training programs. The development of educational curricula and training programs that reflect the research trends enables educational institutions to create a professional workforce that is responsive to the market needs. This provides students and professionals with the latest knowledge and skills required in the workplace and contributes to the production of the talent that is essential for industry development. Finally, it fosters international collaboration. The sharing of research results provides a platform for international cooperation in global problem-solving and technology standardization, which promotes the global integration and development of autonomous ship technology. Consequently, papers analyzing the research trends in autonomous ships have a multifaceted positive impact on academia, industry, policymakers, and educational institutions, and they play an important role in the development of the field.

The limitations and recommendations of this study are as follows. First, this study was limited to the literature on MASSs in the Web of Science. Although the search expression "Maritime Autonomous Surface Ships" (All Fields), "Smart Ship" (All Fields), "Unmanned Ship" (All Fields), "Automated Ship" (All Fields), and "Remote Ship" (All Fields) was used in previous studies, there may have been some articles in other fields that were not included. Furthermore, the words most frequently expressed in autonomous ship-related studies were pretreated after a list of unused words was drafted using a keyword frequency analysis and topic modeling. However, it should be noted that the researchers' views may also have been included.

Secondly, this study only analyzed bibliographic data on MASSs, which may be a limitation. As the analysis of bibliographic data alone may not be sufficient to comprehensively understand the overall trend of technological development and the market trends, future studies should address this by further analyzing the data from various perspectives. Patent data are useful in understanding the current state of technological development and trends in intellectual property rights, and they can be an important indicator for the quantitative assessment of progress in the field. Media data analysis can be employed to monitor fluctuations in societal interest and the market demand for autonomous vessel technology, as well as to assess the perceptions of policymakers and the general public. Qualitative research, including expert interviews and Analytic Hierarchy Process (AHP) assessments, can also contribute to a broader comprehension of the trajectory of technology development, prioritization, and the viability of policy proposals. These methods will complement the information available from quantitative data analyses and provide deeper insights into autonomous ship technology.

Third, this study exploratively analyzed the initial challenges of MASSs by collecting bibliometric data over a five-year period, from 2018 to 2022, when autonomous navigation was discussed in earnest at the IMO. As the number of published papers is growing at an average annual rate of 30%, a future study could extend the analysis period to provide a more in-depth examination of the research trends.

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Abbreviations

CNN	Convolutional Neural Network
IMO	International Maritime Organization
LDA	Latent Dirichlet Allocation
MASS	Maritime Autonomous Surface Ships
MSC	Maritime Safety Committee
PFnet	Path-Finer Network Scaling
SAR	Synthetic Aperture Radar
UN	United Nations

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