applied sciences

MDPI

Systematic Review

Evolution of Algorithms and Applications for Unmanned Surface Vehicles in the Context of Small Craft: A Systematic Review

Luis Castano-Londono [1,*], Stefany del Pilar Marrugo Llorente [2], Edwin Paipa-Sanabria [2,3], María Belén Orozco-Lopez [4], David Ignacio Fuentes Montaña [2] and Daniel Gonzalez Montoya [1]

1 Faculty of Engineering, Instituto Tecnológico Metropolitano—ITM, Medellín 050013, Colombia; danielgonzalez@itm.edu.co
2 Corporación de Ciencia y Tecnología para el Desarrollo de la Industria Naval Marítima y Fluvial—COTECMAR, Cartagena 130001, Colombia; smarrugo@cotecmar.com (S.d.P.M.L.); epaipa@cotecmar.com or epaipa@cuc.edu.co (E.P.-S.); dfuentes@cotecmar.com (D.I.F.M.)
3 Faculty of Administration, Universidad de la Costa, Barranquilla 080002, Colombia
4 Faculty of Engineering, Universidad Tecnológica de Bolívar, Cartagena 130001, Colombia; maorozco@utb.edu.co
* Correspondence: luiscastano@itm.edu.co

Abstract: The development of autonomous vessels and unmanned surface vehicles (USVs) has generated great interest in the scientific community due to their potential and advantages for use in various environments and applications. Several literature review papers have been produced from different perspectives, contributing to a better understanding of the topic and to the analysis of advances, challenges, and trends. We hypothesize that the greatest attention has been focused on the development of high-impact applications in the maritime sector. Additionally, we depart from the need to investigate the potential and advances of USVs in fluvial environments, which involve particular operating conditions, where there are different socio-environmental conditions and restrictions in terms of access to conventional energy sources and communication systems. In this sense, the main objective of this work is to study USVs in the particular context of small craft. The search for records was conducted in Scopus and Web of Science databases, covering studies published from 2000 to May 16, 2024. The methodology employed was based on the PRISMA 2020 guidelines, which is a widely recognized protocol that ensures quality and rigor in systematic reviews and bibliometric analyses. To optimize the data collection and selection process, the semaphore technique was additionally implemented, allowing for an efficient categorization of the studies found. This combined methodological approach facilitated a systematic and transparent evaluation of the literature. This study was developed based on three research questions about the evolution of research topics, areas of application, and types of algorithms related to USVs. The study of the evolution of works on USVs was carried out based on the results of the meta-analysis generated with the Bibliometrix tool. The study of applications and developments was carried out based on information obtained from the papers for six study categories: application environment, level of autonomy, application area, algorithm typology, methods, and electronic devices used. For each of the 387 papers identified in the databases, labeling was performed for the 359 screened papers with six study categories according to the availability of information in the title and abstract. In the categories application sector, autonomy level, application area and algorithm type/task, it was identified that most studies are oriented toward the maritime sector, the developments to achieve full autonomy for USVs, the development of designs or algorithms at the modeling and simulation level, and the development and implementation of algorithms for the GNC subsystems. Nevertheless, this research has revealed a much wider range of environments and applications beyond maritime, military, and commercial sectors. In addition, from the mapping of the types of algorithms used in the GNC architecture, the study provides information that can be used to guide the design of the subsystems that enable USV autonomy for civilian use in restricted environments.

Keywords: unmanned surface vehicles; bibliometric analysis; autonomy; GNC architecture

check for updates

Citation: Castano-Londono, L.; Marrugo Llorente, S.d.P.; Paipa-Sanabria, E.; Orozco-Lopez, M.B.; Fuentes Montaña, D.I.; Gonzalez Montoya, D. Evolution of Algorithms and Applications for Unmanned Surface Vehicles in the Context of Small Craft: A Systematic Review. *Appl. Sci.* **2024**, *14*, 9693. https://doi.org/10.3390/app14219693

Academic Editor: Zaopeng Dong

Received: 20 August 2024
Revised: 5 October 2024
Accepted: 17 October 2024
Published: 23 October 2024

1. Introduction

The development of autonomous vessels and unmanned surface vehicles (USVs) has generated a significant amount of research due to their potential applications in the naval sector and the maritime, fluvial, and lacustrine industries as well as in studies associated with environmental monitoring. Additionally, the development of these types of systems involves addressing aspects related to route planning, navigation systems, automatic control, object and environment recognition, communications, safety, and regulation. According to [1], the growth period of studies related to autonomous and unmanned surface vehicles began in 2010 with a substantial increase in recent years.

Although previous advances in aerial and ground vehicles have provided a fundamental basis for the development of USVs, there are various challenges linked to the particularities of the different types of vehicles as well as to the complexity of the environments, contexts, and applications [2]. Numerous studies have contributed to the field of USVs, covering topics including literature reviews, bibliometric analysis, applications, vessel design, GNC system development, communications, risk management, cooperative systems, and regulatory and normative frameworks.

This work has been developed within the framework of the project "BERCO—Development of a boat focused on remote-controlled electromobility for the transport of logistic supplies from TRL 3 to TRL 5, as a strategy to validate the functionality of charging stations that use second-life batteries", which is part of the program "TULATO—Technologies for the adoption of efficient energy and mobility systems that promote sustainable development oriented towards regions with high biosocial and energy potential such as Tumaco, Nariño". Our hypothesis is that most of the research and industry efforts on USVs are concentrated on maritime, military, and commercial applications. This study seeks to explore the development of USVs for civilian use in confined environments, especially rivers. The main objective of this work is to identify the evolution of studies related to USVs, focusing on advancements in algorithms for achieving USV autonomy and the applications related to small craft, to guide the development of future USV technologies for the specific context of interest. The autonomy capabilities of the USV are highly dependent on the guidance, navigation, and control (GNC) architecture. While several literature reviews on USVs focus on specific subsystems or task, a comprehensive mapping of the entire GNC architecture remains lacking. Our review aims to address this gap. The review works presented in [1,3] are mainly focused on the bibliometric analysis of the identified documents. The authors present the main topics of the state of the art and establish future research directions based on the analysis performed. In our work, in addition to bibliometric analysis, the collected information is organized in such a way that it is possible to map the selected works within the framework of the GNC architecture. In addition, while the work presented in [4] focuses on civilian USV applications in disaster management, our study presents a wider range of both civilian and military applications.

To achieve the goals of this research, the study is developed based on the following research questions:

RQ1: What has been the evolution of studies on unmanned surface vehicles regarding the applications and the achievement of autonomous capabilities?

RQ2: What are the general areas in the civil and military fields in which unmanned surface vehicles are used?

RQ3: What types of algorithms have been the subject of research for achieving unmanned surface vehicles autonomy?

The main contributions made in this work, achieved through the development of these three research questions, are the following:

- A perspective of the evolution of USV studies is presented based on the information obtained with the bibliometrix analysis tool. The bibliometric analysis shows the evolution over time of academic production from 2004. Trends are identified in terms of the number of papers published per year, academic production in the five most relevant journals in which the topic has been published, and the most relevant topics.

- A mapping of the different areas of application in the civil and military fields is carried out.
- A mapping of the different task and types of algorithms used to achieve USV autonomy is carried out.
- A labeled dataset, comprising papers indexed in Scopus and Web of Science, that features six study categories: application sector, autonomy level, application case or area, algorithm type or task, methods developed or implemented, and electronic devices used in the system implementation. This dataset enables a variety of analyses of USV literature.

This document is organized as follows. Section 2 describes relevant works of literature review and bibliometric analysis, published in the last six years. Section 3 describes the methodology used for the development of the systematic literature review (SLR). Section 4 presents the results of the SLR through the development of each research question. Section 5 presents the discussion of the results obtained. Section 6 presents some study limitations ans draw the lines of future work. Finally, Section 7 presents the conclusions.

2. Previous Works of Bibliometric Analysis and Literature Review

The volume of publications in the literature on USV is quite extensive, and the topics are very varied. Several authors have contributed valuable literature review and bibliometric analysis works, which have allowed the establishment of concepts and the identification of trends and taxonomies, facilitating the study and understanding of the subject. Two types of literature review works can be identified. One group of works develops the current state of developments and trends in ASV and USV. The other group consists of studies that address specific topics related to USV. A summary of some literature reviews conducted in recent years for USV-relevant topics is provided in Table 1, outlining the respective topic and publication year.

Table 1. Literature reviews for USV-relevant topics.

Review Topics	References	Year
Current state and trends of autonomous vessels and USV	[1,3] [2] [5]	2024 2023 2022
Path planning	[6] [7] [8]	2024 2023 2021
Path-following control systems	[9]	2023
Adaptive control	[10]	2024
Autonomous docking	[11]	2024
Deep learning in Maritime Autonomous Surface Ships (MASSs)	[12]	2023
Decision making in MASS operations	[13]	2024
Regulation of remotely controlled and autonomous commercial vessels	[14]	2023

2.1. Literature Reviews on the Current State and Trends of USV

Several literature reviews address the developments and trends of USV in general, as in [1–3,5]. In [1], the authors present an analysis of the advances in the development of autonomous and unmanned vessels based on a search of papers conducted in the Scopus database and using the bibliometric analysis tools VOSviewer and CiteSpace. For each of these tools, the data analysis is presented, describing the divisions of the field obtained in each case. In [2], the topic of USVs is developed within the framework of a broader review on unmanned maritime vehicles (UMVs), which also includes unmanned underwater vehicles (UUVs). The authors present for each type of UMV the fields of application, developments carried out in different countries, and technologies used in the navigation system. In addition to addressing the past and present challenges of UMVs, the authors present an analysis of the current state and trends focused on the use of artificial intelligence for the development of autonomy and cooperation in multi-vehicle systems. The work presented in [3] describes the results of a systematic literature review on USVs with papers published between 2000 and 2023 found in the Web of Science (WoS) database. The authors used the VOSviewer tool to perform the corresponding bibliometric analysis. As part of the results, six future research lines were identified. In [5], the topic of USVs is approached by presenting a context of the needs and levels of automation, the applications, the advantages and implications of their use, and some of the main technologies used in the development of USVs and their applications.

2.2. Literature Reviews on Specific Topics Related to USV

Several review papers focus on specific aspects associated with different tasks or components of the vessel's control architecture, such as path planning [6–8], path-following control systems [9], adaptive control [10], autonomous docking [11], deep learning in Maritime Autonomous Surface Ships (MASSs) [12], decision making in MASS operations [13], and the regulation of remotely controlled and autonomous commercial vessels [14].

Path planning is fundamental in the context of USVs and has been widely studied. Various review papers on path planning can be found in the literature. In [6], the authors provide a chronological overview of eight previous literature review papers related to path planning, which were published from 2006 to 2023. They also present a taxonomy of path planning, categorizing algorithms into global path planning and local path planning. This article also presents a state-of-the-art review of path-planning algorithms in chronological order, which were divided into four time intervals starting from the year 2000, specifying whether the implementation was in simulated conditions or validated in real-world scenarios. The work presented in [7] conducts a state-of-the-art review of global and local planning algorithms using the same taxonomy found in [6]. Additionally, it includes the state of the art of algorithms for proximity risk avoidance and cluster path planning. The authors state that their contribution lies mainly in including aspects related to complex maritime environmental conditions in their analysis. In [8], the authors present various aspects related to autonomous surface vehicles (ASVs). This article provides a context for ASVs, the conceptual elements associated with path planning, and a timeline of literature reviews on path planning and collision avoidance. Furthermore, sections are dedicated to the regulatory framework, the architecture of the guidance, navigation, and control (GNC) system, and the path planning algorithms classified into classical, advanced, and hybrid approaches.

Path following is related to the component that various authors define as the central element for the autonomy of USVs and ASVs, which is known as the guidance, navigation, and control system [8,9]. In the literature review presented in [9], the authors explain the trajectory-tracking problem, focusing on the vessel's guidance and control subsystems. They also present the state of the art of guidance laws and motion control systems. An important contribution of this article is the comparison of algorithms found in the literature based on the architecture structure, simulation or experimental results, guidance law used, consideration of environmental disturbances, type of controller, consideration of vessel dynamics, type of stability analysis, and consideration of degrees of freedom for the control problem.

Among the many challenges associated with the development and operation of USVs, selecting an appropriate control strategy to respond to the complexities of the environment in real-world applications is crucial. Among the approaches found in the literature, ref. [10] presents a review of Model-Free Adaptive Control (MFAC). The article provides a context for MFAC, highlighting its characteristics and advantages over conventional control schemes. The authors describe and present the state of the art of three data-driven approaches, which use neural networks, reinforcement learning, and fuzzy logic.

Autonomous docking is essential for the development of fully autonomous USVs. The developments and challenges of this specific aspect of USV operation are studied in [11]. The authors provide a description of the process and components of the architecture for autonomous docking. Additionally, the article presents a state-of-the-art review of existing methods for autonomous docking, considering aspects such as sensors, decision making, path planning and collision avoidance, and control. Based on the study conducted, the authors present the opportunities and challenges of the technology for autonomous docking, including the development of control algorithms, operation in complex environments, hardware/software integration, vessel modeling, multi-USV cooperative work, and efficient use of the existing knowledge and development framework for advancing future developments.

Artificial intelligence is a field that plays a significant role in developing autonomy for vessels and surface vehicles. Among its most notable contributions is the implementation of GNC systems that do not require complex models for vessel control and adapt to operation in dynamic environments. In [12], a literature review on the use of deep learning in MASS is presented. The authors develop a comprehensive state-of-the-art review of the works that have used deep learning in control and navigation systems, identifying the advantages and types of applications. Additionally, reference is made to works related to transport and logistics, a comparison with traditional methods developed for autonomous vessels is made, and the trends of deep learning in autonomous vessels are analyzed.

The analysis of factors involved in decision making and the role of the human component in MASS operations is addressed in the systematic literature review presented in [13]. The authors use the PRISMA methodology to select papers obtained from the Google Scholar, Research Gate, Scopus, and Web of Science databases, which is related to decision making in teams composed of autonomous systems and humans. The authors identify seven themes associated with decision making, for each of which they present the state of the art. Based on these themes, a series of design recommendations for MASSs is made, and a decision-making model based on the interaction of these seven factors is proposed. This model is validated through its application to a UAV accident situation as a case study.

One of the issues that has received less attention in the context of autonomous vessels is the regulatory and normative framework for the commercial operation of such systems. In [14], the authors present a systematic quantitative literature review on the regulatory framework applicable to autonomous vessels, using a hybrid methodology that combines traditional narrative review and the PRISMA method. The selection of papers used in this work is based on searching scientific literature in the Google Scholar, HeinOnline, and Scopus databases. The authors develop this work based on three research questions aimed at investigating the regulatory framework for autonomous vessels in Australia and other countries. Additionally, the article outlines the main lessons learned and open topics as input for future research developments.

3. Methodology

We followed the PRISMA 2020 guidelines for conducting this systematic review. PRISMA is a reporting guideline for systematic reviews and meta-analyses that is designed to ensure transparency, integrity, and accuracy in literature review or bibliometric studies [15]. The steps taken for the development of this methodology are shown in the flow chart in Figure 1.

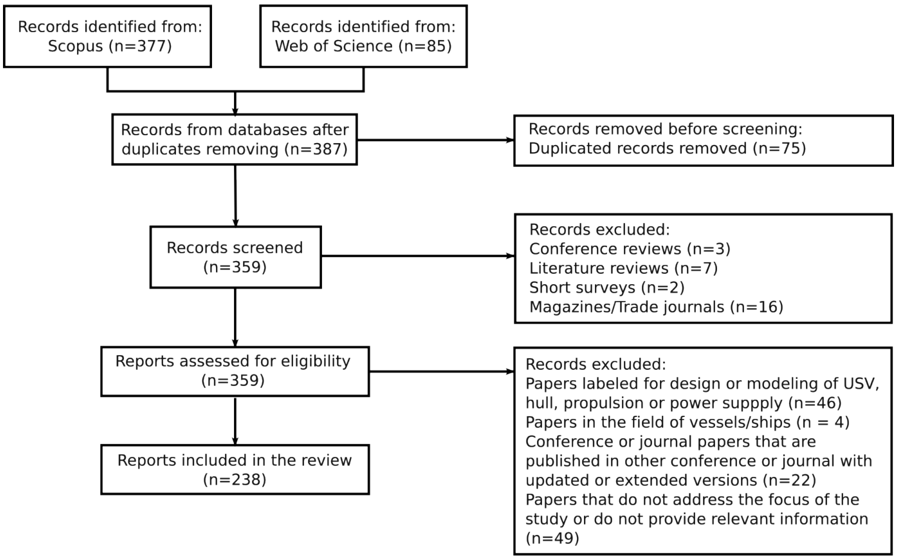

Figure 1. Flow chart for the development of the methodology.

3.1. Databases

For the search, the indexed academic databases Scopus and Web of Science (WOS) were chosen due to their ease of generating search equations and being processed jointly through analysis tools such as Bibliometrix. The databases were consulted on 16 May 2024. The databases and access information are shown in Table 2.

Table 2. Databases consulted for the development of the literature review.

Data Source	URL
Scopus	www.scopus.com (accesed on 16 May 2024)
Web of Science	access.clarivate.com (accesed on 16 May 2024)

3.2. Search Strategy

During this phase, the keyword groups to be used in the search equations were defined. In line with the research objective, keywords were classified into 2 groups, which are described in Table 3. The first group consists of keywords that refer to the product: small craft. The second group describes the characteristics and types of use expected in this product: unmanned surface vehicles. In this way, the search is aimed at retrieving documents that contain information about unmanned surface vessels, leaving the search open to the sectors of application of these vessels and the different algorithms and technologies employed.

Table 3. Groups of keywords for the search.

Group	Keywords
Group 1	boats, boat, small boats, riverboat, small boat, small craft
Group 2	Unmanned Surface Vehicles, Unmanned Surface Vehicle, Autonomous Vehicles, Autonomous Surface Vehicles, Unmanned Surface Craft, Unmanned Maritime Vehicle, Remotely Operated Surface Vehicles, Unmanned Surface Vessels, USV

Once the keyword groups were defined, search equations were constructed using the Boolean operators available in the databases. Given the research objective of focusing on unmanned surface vessels within the context of small craft, the decision was made to combine both groups using the “AND” operator. This operator narrows down the search results as it moves through the keyword clusters, as detailed in Table 4 for each database.

Search terms were applied to the "title, keywords, and abstract" fields in Scopus and "all fields" in WOS.

Table 4. Database search equations.

Database	Algorithm Search
Scopus	(TITLE-ABS-KEY ("boats" OR "boat" OR "small boats" OR "riverboat" OR "small boat" OR "small craft") AND TITLE-ABS-KEY ("Unmanned Surface Vehicles" OR "Unmanned Surface Vehicle" OR "Autonomous Surface Vehicles" OR "Unmanned Surface Craft" OR "Unmanned Maritime Vehicle" OR "Remotely Operated Surface Vehicles" OR "Unmanned Surface Vessels" OR "USV"))
WOS	"boats" OR "boat" OR "small boats" OR "rivercat" OR "small boat" OR "small craft" (All Fields) and "Unmanned Surface Vehicles" OR "Unmanned Surface Vehicle" OR "Autonomous Surface Vehicles" OR "Unmanned Surface Craft" OR "Unmanned Maritime Vehicle" OR "Remotely Operated Surface Vehicles" OR "Unmanned Surface Vessels" OR "USV" (All Fields)

The bibliographic data were consolidated and analyzed using Bibliometrix 4.3.3 in the R environment, supplemented by Microsoft Excel. The database of the papers is in spreadsheet format, containing information on authors, abstract, article type, DOI, journal, title and year of publication. Duplicate records were eliminated to maintain data integrity. Table 5 presents the number of papers retrieved from each database and the total number of academic papers obtained after duplicate removal.

Table 5. Number of papers found in the databases with the equation "group 1 AND group 2".

Data Source	Number of Papers
Scopus	377
Web of Science	85
Total after duplicates removing	387

3.3. Selection Criteria

In order to select the appropriate papers to address the questions and contribute to the objective, inclusion and exclusion criteria were established for the documents to be reviewed. The main inclusion criterion pertains to academic documents (journal papers, book chapters, and conference papers).

Two main approaches were considered for defining the inclusion/exclusion criteria: classification based on hull length and the primary architecture components required for autonomy and the USV application. The distinction criterion between small craft and larger vessels/ships is primarily based on the length of hull (LH), as established by the ISO 8666 standard [16]. This standard defines small craft as those with a hull length not exceeding 24 m. Consequently, if a craft exceeds this measurement, it is considered a vessel or ship, according to its length. Through this differentiation, applicable regulations, safety requirements, and technical specifications that various vessels must comply with are determined. In most cases, information regarding hull length is unavailable, and the identified studies are considered consistent with the context of small craft based on the search criteria.

To establish the components of interest, we relied on the architecture description presented in [17], as shown in Figure 2. The guidance, navigation, and control (GNC) subsystem is a critical component for autonomous maritime vehicles [8,9]. Moreover, the specific application of a USV is heavily influenced by the modules and equipment used for data acquisition in a given environment, upon which various types of studies are conducted or specific sector-based problems are solved. In this regard, the GNC subsystem and data acquisition are considered the key components for this study on the evolution of USV development.

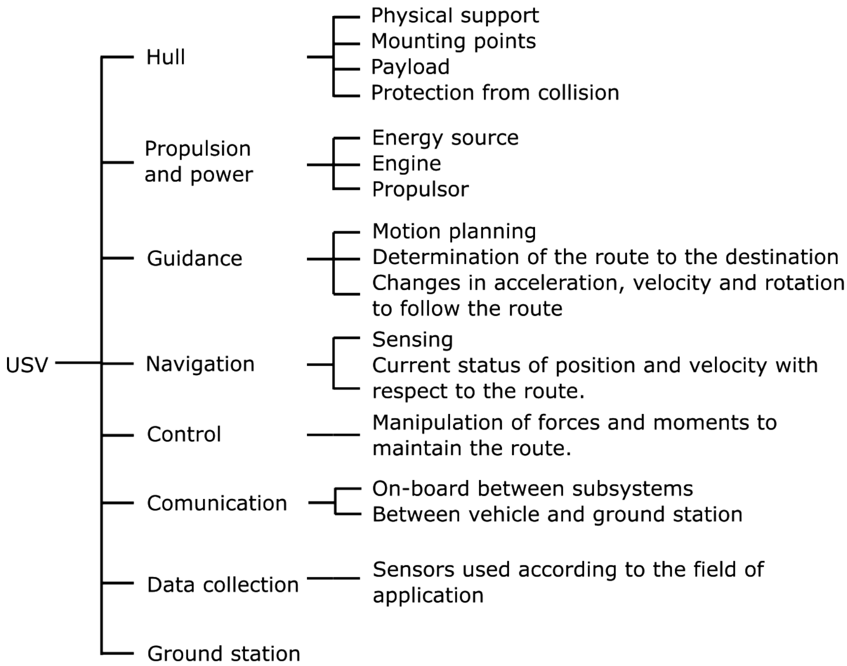

Figure 2. USV architecture components.

Given the aforementioned considerations, the following exclusion criteria were applied according to the corresponding stage of the methodology:

- Identification: duplicate records.
- Screening: literature reviews, conference reviews, short surveys and weekly magazines.
- Eligibility: items with the following conditions.
  - Labeled for the design of USV, hull, propulsion or power supply.
  - Works in the field of major vessels.
  - Conference or journal papers that are published in other conference or journal with updated or extended versions.
  - Items that do not address the focus of the study or do not provide relevant information. This criterion includes works in the preconceptual phase with no clear indication of technological maturity level scaling.

3.4. Data Collection Process

This work studies the thematic areas and algorithms employed in the development of unmanned surface vehicles, aiming to consolidate existing literature, identify research gaps, and propose future research directions. The data collection process is performed in the eligibility stage, after having excluded duplicate items in the identification stage and items corresponding to conference reviews, short surveys and weekly magazines in the screening stage. To explore environments, application areas and algorithm types, six columns were added to the database spreadsheet to extract relevant information from papers titles and abstracts. These columns were used to label each of the papers considering the following six categories: application sector (maritime, riverine, or lacustrine), IMO autonomy level, application case or area, algorithm type or task, methods developed or implemented, and electronic devices used in the system implementation. The labeling was carried out by two members of the work team. This process also included a review and validation stage by one of the labeling managers. In cases where doubts arose, the validation was carried out with all the members of the team considering the selection criteria established for this work. Due to insufficient information in most cases, complete categorization was challenging.

Nevertheless, the extracted data enabled the formulation of the proposed research questions. Table 6 summarizes the number of papers categorized by study category.

Table 6. Number of papers labeled by category.

Category	Number of Labeled Papers
Application Environment	239
Level of Autonomy	198
Application Area	359
Algorithm Type	338
Method Used	174
Electronic Devices	127

Some of the defined study categories do not directly contribute to the development of the research questions. However, they provide relevant information about the context of the reviewed works and can contribute to the identification of approaches for the development of future works.

3.5. Selection Process

As part of the paper labeling process, a color-coded system was employed to categorize papers based on their perceived contribution to the current study, specifically regarding USV application fields and the guidance, navigation, and control architecture. Papers were assigned colors as follows: green for clear and direct contributions, yellow for potential contributions, and red for those with no apparent relevance. This categorization was determined by analyzing the title and abstract of the papers. A summary of the number of papers labeled according to the contribution to the object of study is shown in the Table 7.

Table 7. Number of items prioritized using the semaphore technique.

Color	Number of Papers	% Over Screened Papers
Green	238	66.30
Yellow	28	7.80
Red	93	25.91

The 238 papers assigned with the green color are selected for inclusion in the literature review. The distribution of papers across the categories, within this subset of the database, is presented in the Table 8. In light of research questions 2 and 3, it is noteworthy that the categories related to application area and algorithm type exhibit labeling rates of 100% and 94.54%, respectively.

Table 8. Number of papers included in the review labeled by category.

Category	Number of Labeled Papers	% over Included Papers
Application Environment	160	67.23
Level of Autonomy	141	59.24
Application Area	238	100.00
Algorithm Type	225	94.54
Method Used	147	61.76
Electronic Devices	107	44.96

4. Results

This section presents the results of the systematic literature review (SLR) to answer the research questions posed. Initially, Section 4.1 presents the results obtained for the study categories “Application Environments”, “Autonomy Levels”, “Application Areas”, and “Algorithm Typology”. Subsequently, Section 4.2 shows the results of the review in terms of the three research questions.

4.1. Classification of Papers According to Study Categories

This subsection presents the results of five categories considered to be the most generic, corresponding to application environments, level of autonomy, application area, algorithm typology, and methods. For each of these categories, the number of labeled items and the different subcategories identified in the study are presented for the 238 selected papers.

4.1.1. Application Environments

In the "Application Environment" category, 191 papers were labeled from the selected papers. Most papers refer to the marine environment with 89 papers. Applications for lacustrine and coastal environments are in second and third place with 22 and 20 papers, respectively. The fluvial environment occupies the fourth place with 18. Finally, there is a group of papers that refers to applications in environments such as ponds, reservoirs, and wetlands, which contributes 42 papers. In 28 papers, two or more application environments were identified. On the other hand, a total of 78 papers were not tagged, as the environment information was not found explicitly. In this case, it is considered that most of these works are carried out on topics applicable to any of the environments. However, further in-depth study is required to perform an adequate classification. The distribution of the number of categorized papers according to the application environment is shown in Table 9.

Table 9. Number of papers labeled in the category "Application Environments".

Application Environments	Number of Papers
Maritime	89
Lacustrine	22
Coastal	20
Fluvial	18
Other (ponds, pools, reservoirs)	42

4.1.2. Autonomy Levels

In the "Autonomy Levels" category, 141 papers were tagged, of which 126 were classified as "IMO: fully autonomous vessel" and 23 as "IMO: remotely controlled uncrewed vessel". The remaining 97 papers lacked explicit information on autonomy levels. It is assumed that most of these studies contribute to developing fully autonomous USVs, but further research is needed for a more accurate classification. Table 10 presents the distribution of papers by autonomy level.

Table 10. Number of papers labeled in the category "Autonomy Levels".

Level of Autonomy (IMO)	Number of Papers
Fully autonomous vessel	126
Remotely controlled uncrewed vessel	23

4.1.3. Application Areas

In the "Application Areas" category, the 238 selected papers were tagged based on information extracted from their titles and abstracts. This category directly provides the data needed to address the research question concerning the general civil and military application areas of unmanned surface vehicles. The identified areas were classified into 10 groups, as presented in Table 11. Firstly, there is a group of 128 papers categorized as purely academic works. These papers focus on designs or algorithms at the modeling and simulation level without specifying a particular application field. Furthermore, the lower construction and operational costs of USVs, coupled with their ability to access restricted areas, have driven the development of studies with practical real-world applications, such as data acquisition for environmental monitoring, bathymetry, oceanography, and hydrography. Additional practical applications are directed toward the naval, fishing, disaster management, and transportation sectors.

Table 11. Number of papers labeled in the "Application Areas" category.

Application Area	Number of Papers
Academic	128
Environmental Monitoring	30
Naval/Security	24
Bathymetry/Cartography	22
Risk and Disaster Management	13
Aquaculture/Fishing	8
Oceanography	8
Hydrography/Hydrology	5
Transportation/Tourism/Ports	3

4.1.4. Algorithm Typologies

The "Algorithm Typologies" category was assigned to 194 of the selected papers based on information extracted from their titles and abstracts. This category directly provides the data needed to address the research question concerning the types of algorithms used in the development and operation of unmanned surface vehicles. The works are mostly related to path-planning algorithms. In total, 24 types of algorithms were identified, as shown in Table 12. The information obtained indicates that the tagged papers can be grouped based on the USV architecture. This grouping is developed in Section 4.2.3, which addresses the research question about the types of algorithms used in USVs.

Table 12. Types of algorithms identified.

Algorithm Type	Number of Papers
Data collection	40
Path planning	32
Cooperative robotics systems	26
Obstacle avoidance	17
Environment perception	16
Trajectory tracking	16
Collision avoidance	15
Obstacle detection	15
Path following	14
USV state estimation	13
Control	11
Object detection	9
Position control	8
Target tracking	8
Heading control	6
Motion control	6
Course control	5
Autonomous docking	4
Trajectory planning	3
Target detection	3
Sensor fusion	2
Remote control	2
Heading and speed control	2
Mission planning	2
Target localization	2
Application-specific task	8

4.2. Research Questions Results

In this subsection, the results for the development of the three research questions are presented, which are based on the information obtained from the papers labeled in the database according to the study categories. To address research questions 1 and 2, we analyzed all labeled articles. For research question 3, given the specific selection criteria related to USV autonomy algorithms, the analysis was centered on the selected articles. This focused approach allowed us to identify the different approaches used in studies within the GNC architecture framework.

4.2.1. What Has Been the Evolution of Studies on USV Regarding the Applications and the Achievement of Autonomous Capabilities?

The results obtained show that the topic is relatively recent. The first documents in the databases are recorded from the year 2004. Starting in the year 2015, they began to increase significantly, and most of the production has occurred in the last 5 years (2019–2024) with 54.43% of the total as shown in Figure 3. The trend is expected to continue in 2024.

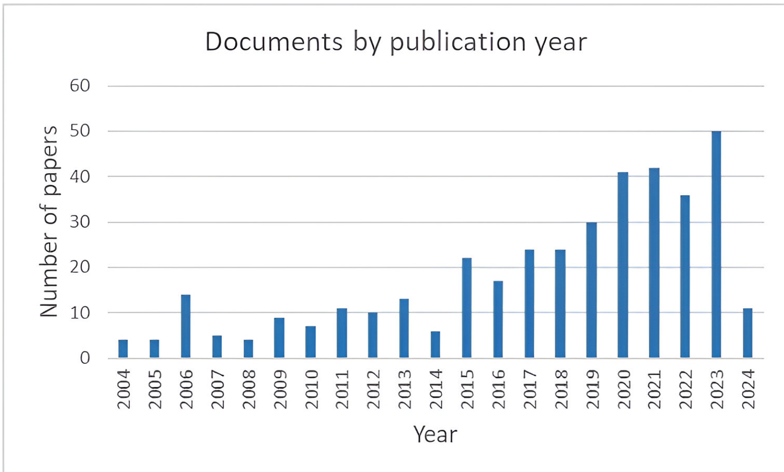

Figure 3. Production of documents over time.

The produced documents have been published through various sources, as shown in Figure 4. Initially, the journal dedicated to strategic and military security issues, *Jane's Defence Weekly*, was the only one; in 2007, production on this topic ceased. Subsequently, in 2010, *The IEEE International Conference of Intelligent Robots and Systems*, a journal on robotics, began publishing and has since maintained relevance, with a higher cumulative total compared to the rest, along with *Ocean Engineering*, which is dedicated to research and development in naval engineering. Based on this, it is pertinent to appreciate that unmanned vehicles encompass a broad scope of interest that includes the naval industry, intelligent systems, and strategic military purposes.

The thematic evolution confirms the aforementioned. Figure 5 shows that initially, the trending topic was military operations. Subsequently, hulls, navigation systems, and unmanned vehicles gained relevance along with the introduction of the term "ocean engineering" to categorize the research carried out in this field. Since 2008, remotely operated vehicles have maintained their presence in the thematic, alluding to the importance of these vehicles being able to operate without an onboard crew. For the years 2011–2015, robotics in this area began to be discussed as well as oceanography and autonomous navigation. Finally, for the years 2015–2017, the term "unmanned surface vehicles/vessels" was introduced, and with it, terms such as "obstacle avoidance", "maneuverability", "object detection", "controllers", and others, indicating evidence of the growing interest in achieving autonomy in these vehicles through navigation and control technologies.

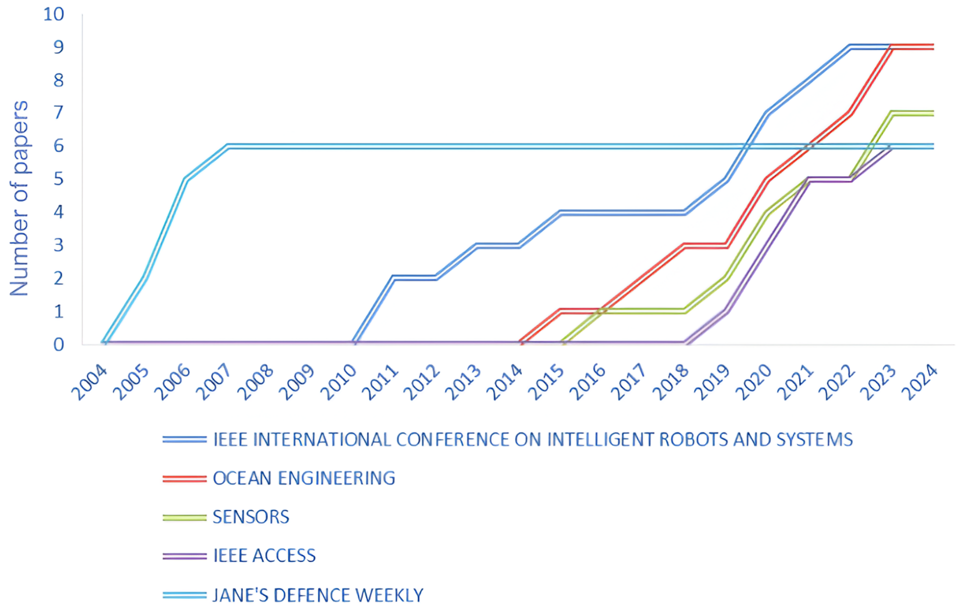

Figure 4. Production from the most relevant sources over time.

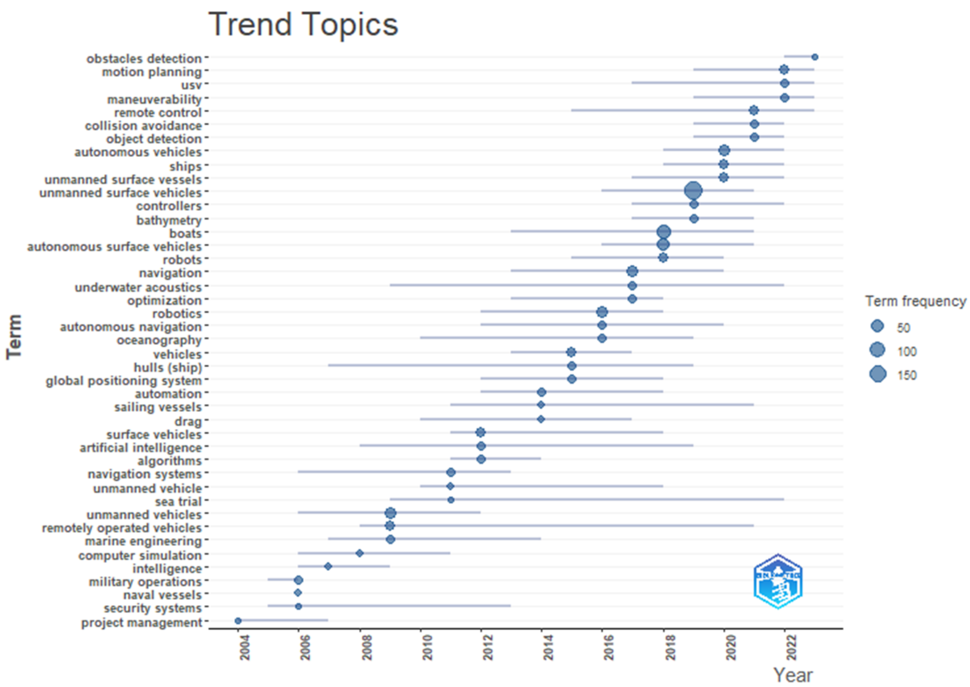

Figure 5. Most relevant topics over the years.

The evolution of academic production, considering the document type, shows an increasing trend in the number of articles, both journal and conference papers, with a more pronounced growth starting from 2010. Figure 6 shows the chronological evolution of the quantity of journal and conference articles. It can be observed that in most years, more conference papers have been published than journal articles. Additionally, fluctuations in both cases are evident. In this systematic review, starting from the screening stage, according to the document type, 206 conference papers, 150 journal articles, 2 book chapters, and 1 editorial were used.

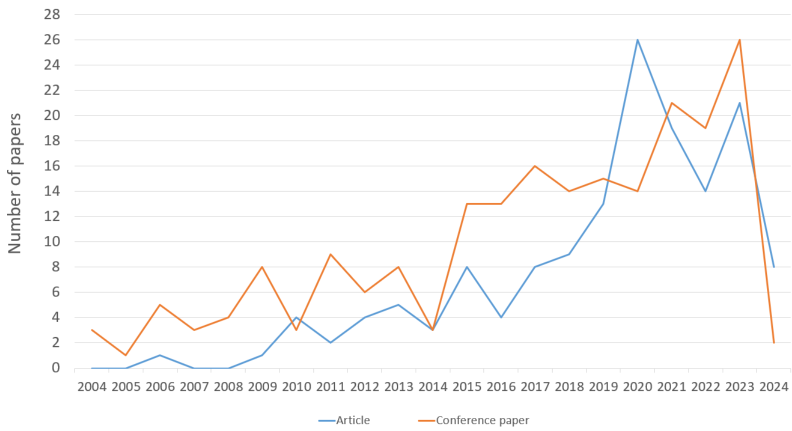

Figure 6. Document type over the years.

4.2.2. What Are the General Areas in the Civil and Military Environments Where Unmanned Surface Vehicles Are Used?

Hydrodynamic modeling technology and marine vehicle control systems have progressed significantly in recent years. In particular, USVs have found a number of fields where their application is highly useful [18]. In fact, they have gone from being considered as heavy and expensive equipment to viable instruments for multiple scientific and commercial applications [19].

In this sense, based on the bibliographic review carried out, it is identified that civil applications are more widely disseminated in the scientific field; in fact, more than 80% of the reviewed works, which corresponds to approximately 334 references, present applications of unmanned vehicles in the civil environment, while only 51 works describe applications in the military or defense field. Figure 7 illustrates the percentages of the identified applications.

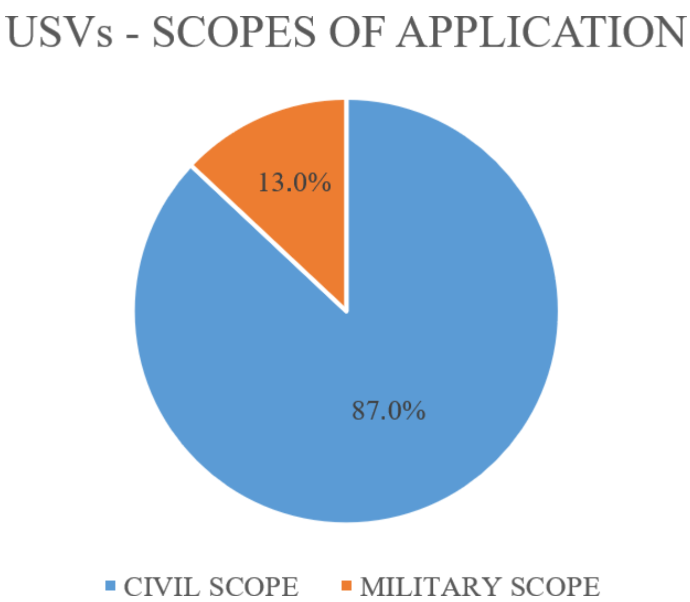

Figure 7. Scope of application of autonomous and unmanned surface vehicles.

When reviewing applications in the civil field, it was identified that the largest proportion of works related to USVs has been developed in the academic field, which is followed by works in the areas of environmental monitoring and bathymetry. Some minor applications correspond to the areas of disaster management [4,20], fishing [21] and hydrography [22]. Figure 8 presents the percentage distribution of the main application areas of USV technologies in the civil field.

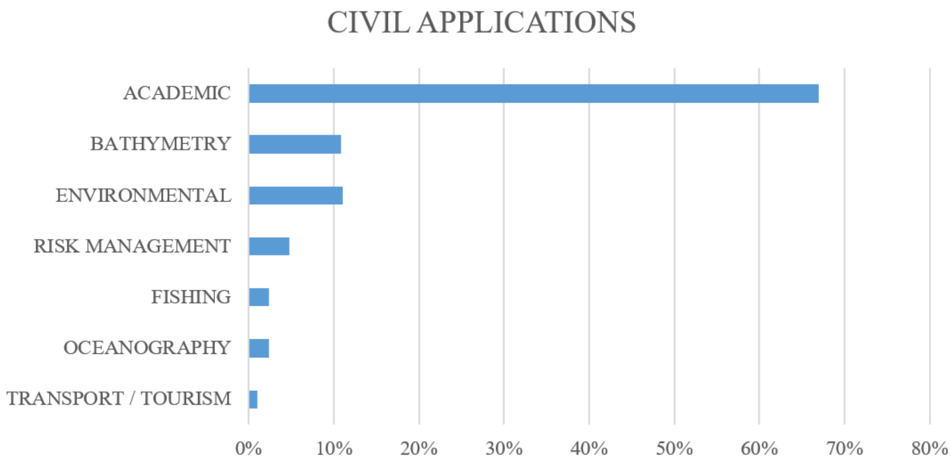

Figure 8. Application areas of autonomous and unmanned surface vehicles in the civil field.

Within the applications in the academic area, works related to target tracking [23,24] and trajectory tracking [25], obstacle avoidance [26], path planning [27–29] and control techniques [30,31] stand out.

On the other hand, in the environmental area, works stand out in the lines of water sampling/water quality [32,33], nuclear/oceanic radiation [34,35], current studies [36] and ecological protection [37], among others.

Likewise, as part of the main applications of bathymetry, some works developed in the Arctic environment [38], in lakes [39,40] and in the marine/coastal environment [41–43] stand out.

In the military field, the largest proportion of works developed are related to applications focused on security and defense, surveillance and reconnaissance, interception/interdiction, and intruder detection. Figure 9 presents a summary of the main application areas of USVs in the military environment.

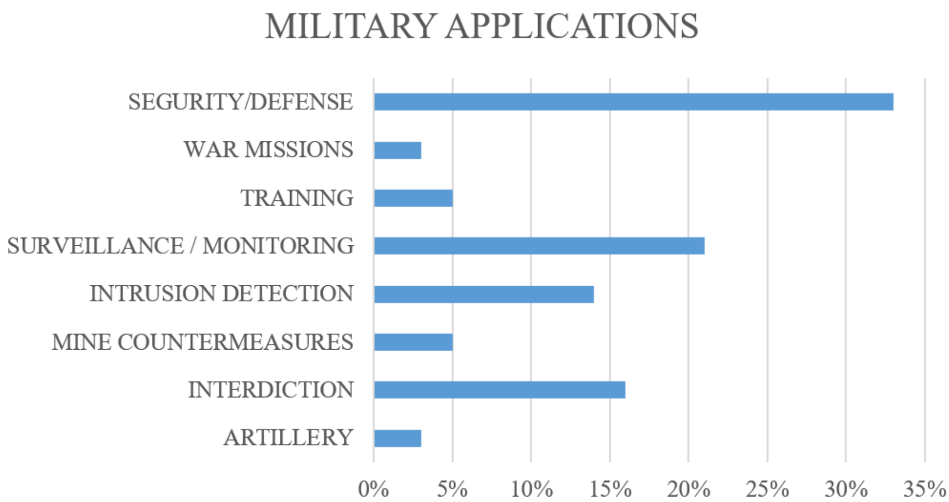

Figure 9. Application areas of unmanned vehicles.

In the area of security and defense, works related to maritime border security [44], port security [45] and merchant escort [46] stand out. As part of the works in the area of surveillance and reconnaissance, some are focused on patrolling hostile environments with civilian traffic [47] and coastal surveillance [48], among others.

The distribution of applications identified in the selected articles is presented in Figure 10.

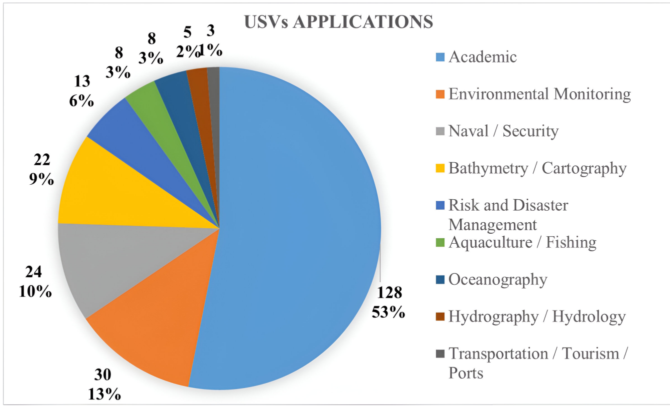

Figure 10. General application areas of unmanned surface vehicles .

For applications related to monitoring and data collection, the studies shown in Table 13 were identified, according to their application areas in the civil environment.

Table 13. References for the papers labeled in the "Application Areas" category related to data acquisition for specific applications.

Application Area	Number of Papers	References
Environmental Monitoring	30	[12,32,35,37,41,49–73]
Bathymetry/Cartography	22	[38–43,74–89]
Risk and Disaster Management	13	[20,34,52,88,90–97]
Aquaculture/Fishing	8	[21,98–104]
Oceanography	8	[36,105–111]
Hydrography/Hydrology	5	[112–116]
Transportation/Tourism/Ports	3	[117–121]

4.2.3. What Types of Algorithms Have Been the Subject of Research for Achieving USV Autonomy?

In the process of labeling the papers according to the algorithm type, 22 subcategories were identified. However, some of them can be grouped considering the relationship between them in terms of the USV development stage, the type of task, or the component of the USV GNC system architecture. Table 14 presents the references related to GNC architecture systems, which are categorized by subsystem.

Table 14. References of the identified types of algorithms grouped according to the GNC architecture subsystems.

Algorithm Type	Papers	References	Subsystem
Environment perception	16	[25,49,82,118,122–133]	Navigation (69)
Obstacle detection	15	[26,49,122,134–145]	
USV state estimation	13	[56,70,119,146–155]	
Object detection	9	[44,150,156–162]	
Target tracking	8	[23,24,160,163–167]	
Target detection	3	[24,168,169]	
Sensor fusion	2	[170,171]	
Target localization	2	[99,172]	
Path planning	32	[20,28,29,36,37,45,47,76,118,128,129,132,141, 150,164,173–189]	Guidance (71)
Obstacle avoidance	17	[25,31,45,121,139,140,156,160,167,181–183,186,190–193]	
Collision avoidance	15	[27,164,174,179,180,187,190,194–201]	
Trajectory planning	3	[165,193,202]	
Mission planning	2	[203,204]	

Table 14. *Cont.*

Algorithm Type	Papers	References	Subsystem
Trajectory tracking	16	[25,31,62,98,118,165,193,203–211]	Control (74)
Path following	14	[56,76,77,84,187,189,201,212–218]	
Control	11	[42,97,104,116,128,150,219–223]	
Position control	8	[23,31,39,112,221,224–226]	
Heading control	6	[36,62,227–230]	
Motion control	6	[119,204,212,231–233]	
Course control	5	[66,173,217,234,235]	
Autonomous docking	4	[156,236–238]	
Remote control	2	[146,239]	
Heading and speed control	2	[43,240]	

The control subsystem emerged as the most prevalent research topic with 74 papers primarily focused on trajectory tracking. Guidance systems constituted the second category, encompassing 71 studies. Path-planning algorithms were the core focus of nearly half of these papers. While obstacle and collision avoidance was addressed in 32 papers, it is inherently linked to path planning. Trajectory planning, considering both spatial and temporal dimensions, was explored in a smaller subset of four papers. Navigation subsystem research comprised the third category with 69 studies predominantly focused on environment perception.

The developed database also provides information about the methods used to address the corresponding tasks. This information was identified for 147 articles. Table 15 presents information on articles related to environment perception and obstacle detection. The remaining information is available in the database and is not included in this article due to its length and quantity.

Table 15. Methods implemented for environment perception and obstacle detection.

Task	Method/Algorithm	Reference
Waterline detection/Obstacle detection	Image segmentation	[49]
Wind speed and direction estimation	Neural networks–Perceptron	[124]
Estimation of meander parameters	Gaussian filters/Restricted interval Kalman filter	[125]
Navigable waterway detection	Deep learning-based semantic segmentation/Planar homography/Line detection	[128]
Background segmentation and change detection	Background subtraction	[130]
Coastline-water detection and recognition	Line segment detection/coarse-to-fine strategy	[133]
Obstacle detection	Sensor fusion/Weighted ELM binary classifier	[134]
Miltimodal perception for obstacle detection	CNN–YOLO V7	[135]
LiDAR-based ambient detection	Sensor data fusion/Voxel filtering	[136]
Hallucinating hidden obstacles	Compositional model	[137]
Temporal context for obstacle detection	Temporal context extraction from image sequences for ambiguity reduction	[138]
Obstacle avoidance system	CNN–YOLO V4/Vector Field Histogram (VFH)	[139]
Obstacle detection/Obstacle distance ranging	Fuzzy Kohonen Network (FKN)	[140]
Obstacle detection	Segmentation	[141]
Stereo obstacle detection	Semantic segmentation	[26]
Real-time stationary obstacle detection and localization	Robust two-step outlier rejection method	[143]

Table 15. *Cont.*

Task	Method/Algorithm	Reference
Real-time obstacle detection	SKIP-ENET segmentation model	[144]
Small obstacle segmentation/Obstacle map estimation	Efficient semantic segmentation networks/Efficient Multi-Feature Aggregation (MFA) module/Gaussian mixture model-based Feature Separation (FS) loss function/FASNET	[145]

5. Discussion

This literature review examines the evolution and development of two key aspects of USVs: applications and algorithms used for achieving USV autonomy. While the work presented in [4] is focused on civilian USV applications in disaster management, our study presents a wider range of both civilian and military applications. Other review works, presented in [1,3], provide a comprehensive overview of the main topics of the state of the art and the future research directions based on the bibliometric analysis. In our work, the collected information is organized in such a way that it is possible to map the selected works within the framework of the applications and the GNC architecture. The state of the art is further enriched by analyzing data collected from the review based on our three research questions and six study categories. The results of this systematic literature review on USVs in the context of small craft allow us to identify several relevant aspects for defining guidelines oriented toward the development of USVs and applications for the specific context of fluvial environments in areas with technological and socio-environmental constraints. The methodology used, in addition to obtaining relevant bibliometric information, allowed us to identify key information to support needs in terms of research and development. To answer the three research questions, six study categories were proposed, of which three were used as the main input. The remaining three categories provided complementary information or can be used in future work to expand the present study and identify potential lines of future work. In general terms, based on these categories, it was identified that most of the reviewed works are oriented toward developments for marine environments and systems to achieve the full autonomy of vessels. In addition, applications in the civilian field are identified, which are focused mainly on data acquisition for environmental scientific studies. Furthermore, there is a marked interest in developing path-planning algorithms, particularly those related to obstacle and collision avoidance. The discussion related to each of the research questions follows.

5.1. Evolution of USV Studies

Research in the field of USV is a relatively recent development, gaining significant interest in the last 10 years. In review papers such as the one presented in [1], the authors identify a period of growth in academic production related to autonomous and unmanned vessels starting in 2010. In our study, this growth stage is clearly evident from 2014 onwards. This trend is more similar to the phase of rapid growth between 2014 and 2019 reported in [3]. There is a coincidence of these years with some critical points observed in the graph of production of the most relevant sources over time shown in Figure 4. According to the trends shown in Figure 5, it is identified that in the early years, there are mainly reports of applications in the military field. Subsequently, in 2016, there are applications in the civil field related to oceanography and three years later with bathymetry. On the other hand, the trend in terms of focus allows us to identify the following order of trend topics in terms of the GNC architecture: navigation system between 2011 and 2018, control system in 2019 and guidance systems from 2021 onwards. With respect to the level of autonomy, remotely controlled unmanned vessels appear in 2009 and 2021, while the term autonomous navigation appears from 2016 onwards.

5.2. Areas of Application in the Military and Civilian Fields

The majority of the reviewed papers focus on designing or implementing algorithms to achieve vessel autonomy. Consequently, these papers were classified as primarily academic. Such works can contribute to both naval and civilian applications. While these studies have the potential to significantly advance real-world applications, many remain at the simulation or early prototype stage. Conversely, this study reveals a substantial body of literature where the specific application of the USV is explicitly identified. Civilian applications significantly outnumber military ones, with a primary focus on data collection for environmental monitoring and aquatic ecosystem studies. Bathymetry has emerged as a recent trend, as illustrated in Figure 5 around 2019. The extensive use of USVs in bathymetric surveys, as well as other environmental and oceanographic studies, is primarily due to their cost-effectiveness, operational safety, and ability to access restricted areas.

5.3. Types of Algorithms Used for USV Development and Operation

The review results show the navigation system addresses different challenges associated with data acquisition and environmental perception, having a considerable participation among the studies found. On the other hand, works related to guidance system and control systems have a greater development related to path-planning and collision avoidance algorithms, which is followed by control strategies associated with path or trajectory tracking. In addition to the works that involve the different components of the GNC architecture, two more groups related to applications stand out. On the one hand, there are works related to missions that address general aspects such as planning and others more specific such as target detection and tracking. Due to their characteristics, these developments are associated with the military field. On the other hand, cooperative systems constitute the other group, where systems with multiple unmanned vehicles are proposed that can be homogeneous or heterogeneous. In these collaborative robotics works, algorithms for formation control are found and have applicability in both the civilian and military fields.

6. Limitations and Future Work

This systematic literature review has resulted in a database of scientific papers on USVs, focusing on applications and algorithms for small craft. In addition to the corresponding bibliometric information, the elaborated database contains information on environments and application areas, level of autonomy, algorithms, and electronic devices. In the present article, some of these categories are analyzed to answer the research questions, but the different relationships that may exist between them are not explored. Furthermore, the database could be enriched by a more in-depth review of the selected papers due to limitations in abstract information. Given the significant amount of papers in the database, automated tools can be valuable for extracting and validating information. In addition, the scope of this study is limited to the Scopus and Web of Science databases. The database and analysis could be expanded by applying the methodology to other scientific databases.

The volume of research dedicated to maritime applications is substantial compared to other domains. A promising avenue for future research involves a more in-depth analysis of works focusing on riverine, lacustrine, and other confined aquatic environments. This analysis aims to identify the unique needs, challenges, and distinct requirements of these settings compared to maritime environments.

7. Conclusions

This systematic literature review investigates the evolution of Unmanned Surface Vehicle (USV) developments and applications in small craft. Employing the PRISMA methodology, the study analyzes scientific publications retrieved from Scopus and Web of Science. Three research questions guide the investigation: the evolution of USV research, civil and military applications, and the algorithms used in USV development and operation. Bibliometric analysis and manual categorization were used to answer these questions.

The results identify trends in USV research, map applications, and analyze the algorithms used in USV guidance, navigation, and control (GNC) systems. Numerous civil applications, particularly data acquisition for environmental and oceanographic studies, were identified. Additionally, the study highlights the significant development of path-planning and collision avoidance algorithms. This research contributes to the state-of-the-art in autonomous and unmanned vessels, providing a baseline for researchers seeking to develop USVs for applications in technologically and socio-environmentally constrained contexts.

Author Contributions: Conceptualization, E.P.-S., D.I.F.M. and L.C.-L.; methodology, E.P.-S., M.B.O.-L. and L.C.-L.; software, M.B.O.-L.; validation, M.B.O.-L., S.d.P.M.L., L.C.-L., E.P.-S., D.I.F.M. and D.G.M.; formal analysis, M.B.O.-L., S.d.P.M.L., E.P.-S. and L.C.-L.; investigation, M.B.O.-L., S.d.P.M.L., E.P.-S., D.I.F.M. and L.C.-L.; resources, M.B.O.-L., S.d.P.M.L., L.C.-L., E.P.-S., D.I.F.M. and D.G.M.; data curation, M.B.O.-L., S.d.P.M.L. and L.C.-L.; writing—original draft preparation, E.P.-S. and M.B.O.-L.; writing—review and editing, M.B.O.-L., S.d.P.M.L., E.P.-S. and L.C.-L.; visualization, M.B.O.-L. and L.C.-L.; supervision, E.P.-S., D.I.F.M. and D.G.M.; project administration, E.P.-S., D.I.F.M. and D.G.M.; funding acquisition, L.C.-L., E.P.-S., D.I.F.M. and D.G.M. All authors have read and agreed to the published version of the manuscript.

Funding: This study and APC were funded with resources from the Fondo Nacional de Financiamiento para la Ciencia, la Tecnología y la Innovación Francisco José De Caldas provided by Ministerio de Ciencia, Tecnología e Innovación through the call 938 of 2023 (Program code 100864 and project code 105897).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Castano-Londono, L., del Pilar Marrugo Llorente, S., Paipa-Sanabria, E., Orozco-Lopez, M. B., Montaña, D. I. F., & Montoya, D. G. Algorithms and applications of unmanned surface vehicles in the context of small craft. Retrieved from osf.io/yk86n (accessed on 8 September 2024).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Jovanović, I.; Perčić, M.; BahooToroody, A.; Fan, A.; Vladimir, N. Review of research progress of autonomous and unmanned shipping and identification of future research directions. *J. Mar. Eng. Technol.* **2024**, *23*, 82–97. [CrossRef]
2. Bae, I.; Hong, J. Survey on the developments of unmanned marine vehicles: Intelligence and cooperation. *Sensors* **2023**, *23*, 4643. [CrossRef]
3. Yang, P.; Xue, J.; Hu, H. A Bibliometric Analysis and Overall Review of the New Technology and Development of Unmanned Surface Vessels. *J. Mar. Sci. Eng.* **2024**, *12*, 146. [CrossRef]
4. Jorge, V.A.; Granada, R.; Maidana, R.G.; Jurak, D.A.; Heck, G.; Negreiros, A.P.; Dos Santos, D.H.; Gonçalves, L.M.; Amory, A.M. A survey on unmanned surface vehicles for disaster robotics: Main challenges and directions. *Sensors* **2019**, *19*, 702. [CrossRef]
5. Bai, X.; Li, B.; Xu, X.; Xiao, Y. A review of current research and advances in unmanned surface vehicles. *J. Mar. Sci. Appl.* **2022**, *21*, 47–58. [CrossRef]
6. Hashali, S.D.; Yang, S.; Xiang, X. Route Planning Algorithms for Unmanned Surface Vehicles (USVs): A Comprehensive Analysis. *J. Mar. Sci. Eng.* **2024**, *12*, 382. [CrossRef]
7. Xing, B.; Yu, M.; Liu, Z.; Tan, Y.; Sun, Y.; Li, B. A review of path planning for unmanned surface vehicles. *J. Mar. Sci. Eng.* **2023**, *11*, 1556. [CrossRef]
8. Vagale, A.; Oucheikh, R.; Bye, R.T.; Osen, O.L.; Fossen, T.I. Path planning and collision avoidance for autonomous surface vehicles I: A review. *J. Mar. Sci. Technol.* **2021**, *26*, 1292–1306. [CrossRef]
9. Xu, H.; Guedes Soares, C. Review of path-following control systems for maritime autonomous surface ships. *J. Mar. Sci. Appl.* **2023**, *22*, 153–171. [CrossRef]
10. Wang, Y.; Shen, C.; Huang, J.; Chen, H. Model-free adaptive control for unmanned surface vessels: A literature review. *Syst. Sci. Control Eng.* **2024**, *12*, 2316170. [CrossRef]
11. Wu, G.; Li, D.; Ding, H.; Shi, D.; Han, B. An overview of developments and challenges for unmanned surface vehicle autonomous berthing. *Complex Intell. Syst.* **2024**, *10*, 981–1003. [CrossRef]
12. Ye, J.; Li, C.; Wen, W.; Zhou, R.; Reppa, V. Deep learning in maritime autonomous surface ships: Current development and challenges. *J. Mar. Sci. Appl.* **2023**, *22*, 584–601. [CrossRef]
13. Lynch, K.M.; Banks, V.A.; Roberts, A.P.; Radcliffe, S.; Plant, K.L. What factors may influence decision-making in the operation of Maritime autonomous surface ships? A systematic review. *Theor. Issues Ergon. Sci.* **2024**, *25*, 98–142. [CrossRef]

14. Horne, R.; Deane, F.; Joiner, K.; Tranter, K. Navigating to smoother regulatory waters for Australian commercial vessels capable of remote or autonomous operation: A systematic quantitative literature review. *Aust. J. Marit. Ocean. Aff.* **2023**, *15*, 496–517. [CrossRef]
15. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. Declaración PRISMA 2020: Una guía actualizada para la publicación de revisiones sistemáticas. *Rev. Esp. Cardiol.* **2021**, *74*, 790–799. [CrossRef]
16. *ISO 8666:2020*; Small Craft–Principal Data. International Organization for Standardization: Geneva, Switzerland, 2020.
17. Shetty, N.B.; Umesh, P.; Gangadharan, K. Multi-role remotely operated marine surface vehicle. *J. Mar. Sci. Appl.* **2022**, *21*, 219–227. [CrossRef]
18. Gallo Aguilar, J. *Modelado y Control de un Vehículo Marino de Superficie no Tripulado*; Universidad de Sevilla: Sevilla, Spain, 2021.
19. Munim, Z.H. Autonomous ships: A review, innovative applications and future maritime business models. *Supply Chain Forum Int. J.* **2019**, *20*, 266–279. [CrossRef]
20. Ozkan, M.F.; Carrillo, L.R.G.; King, S.A. Rescue boat path planning in flooded urban environments. In Proceedings of the 2019 IEEE International Symposium on Measurement and Control in Robotics (ISMCR), Houston, TX, USA, 19–21 September 2019; IEEE: Piscataway, NJ, USA, 2019; pp. B2-2-1–B2-2-9.
21. Matsushita, Y.; Onuma, A.; Takeshita, C.; Shiramizu, R.; Izu, T.; Matsuno, Y.; Takagi, N. Unmanned surface vehicle (USV) with a fish attraction lamp to assist the purse seine operations. *Fish. Sci.* **2024**, *90*, 357–367. [CrossRef]
22. Makhsoos, A.; Mousazadeh, H.; Mohtasebi, S.S. Increasing the energy efficiency of an autonomous solar hydrographer boat. *Int. J. Electr. Hybrid Veh.* **2022**, *14*, 296–313. [CrossRef]
23. Cui, Y.; Xu, K.; Zheng, C.; Liu, J.; Peng, L.; Li, H. Flexible unmanned surface vehicles control using probabilistic model-based reinforcement learning with hierarchical Gaussian distribution. *Ocean Eng.* **2023**, *285*, 115467. [CrossRef]
24. Jin, J.; Zhang, J.; Liu, D.; Shi, J.; Wang, D.; Li, F. Vision-based target tracking for unmanned surface vehicle considering its motion features. *IEEE Access* **2020**, *8*, 132655–132664. [CrossRef]
25. Xiao, G.; Zheng, G.; Tong, C.; Hong, X. A virtual system and method for autonomous navigation performance testing of unmanned surface vehicles. *J. Mar. Sci. Eng.* **2023**, *11*, 2058. [CrossRef]
26. Bovcon, B.; Mandeljc, R.; Perš, J.; Kristan, M. Stereo obstacle detection for unmanned surface vehicles by IMU-assisted semantic segmentation. *Robot. Auton. Syst.* **2018**, *104*, 1–13. [CrossRef]
27. Liu, X. Research on Unmanned Ship Collision Avoidance Algorithm Based on Improved Particle Swarm Optimization Algorithm. In Proceedings of the International Conference on Bio-Inspired Computing: Theories and Applications, Wuhan, China, 16–18 December 2022; pp. 196–209.
28. Xu, S.; Li, W.; Zhang, Z.; Wu, J.; Long, C. Global Path Planning for Unmanned Surface Vessels based on Risk-Penalty-related A* Algorithm. In Proceedings of the 2022 41st Chinese Control Conference (CCC), Hefei, China, 25–27 July 2022; IEEE: Piscataway, NJ, USA, 2022; pp. 2422–2427.
29. Wengang, L.; Liujiang, W.; Dexiang, F.; Yuwei, L.; Jun, H. Path planning algorithm combining A* with DWA. *Syst. Eng. Electron.* **2021**, *43*, 3694-3702.
30. Priandana, K.; Kusumoputro, B. Performance analysis of a backpropagation neural controller system for a double-propeller boat model. In Proceedings of the 2017 International Seminar on Application for Technology of Information and Communication (iSemantic), Semarang, Indonesia, 7–8 October 2017; IEEE: Piscataway, NJ, USA, 2017; pp. 221–226.
31. Pshikhopov, V.; Medvedev, M.; Soloviev, V. Multi-mode control system of an unmanned vessel with fuzzy hybridization of controllers. In Proceedings of the 2019 6th International Conference on Control, Decision and Information Technologies (CoDIT), Paris, France, 23–26 April 2019; pp. 1221–1226. [CrossRef]
32. Powers, C.; Hanlon, R.; Schmale III, D.G. Remote collection of microorganisms at two depths in a freshwater lake using an unmanned surface vehicle (USV). *PeerJ* **2018**, *6*, e4290. [CrossRef]
33. Sornek, K.; Wiercioch, J.; Kurczyna, D.; Figaj, R.; Wójcik, B.; Borowicz, M.; Wieliński, M. Development of a solar-powered small autonomous surface vehicle for environmental measurements. *Energy Convers. Manag.* **2022**, *267*, 115953. [CrossRef]
34. Sakaue, T.; Nagakita, T.; Kaneda, T.; Yamashita, Y.; Nishizawa, K.; Kanbara, K.; Hanaoka, H.; Shirai, S.; Kikuchi, S.; Uchijima, D. Development of USV Used in Underground Floors Surveying of the Contaminated Buildings at Fukushima Daiichi NPS. In Proceedings of the 2022 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR), Sevilla, Spain, 8–10 November 2022; IEEE: Piscataway, NJ, USA, 2022; pp. 224–229.
35. Lee, S.; Lee, J.; Kim, H.; Park, J.; Baek, S.; Song, Y.; Seo, J.M.; Kim, S.M. In-situ remotely controllable ocean radiation monitoring system. *J. Instrum.* **2020**, *15*, P06027. [CrossRef]
36. Govindarajan, K.; Haydon, B.; Mishra, K.; Vermillion, C. Coverage-Maximizing Solar-Powered Autonomous Surface Vehicle Control for Persistent Gulf Stream Observation. In Proceedings of the 2022 American Control Conference (ACC), Atlanta, GA, USA, 8–10 June 2022; pp. 3675–3681. [CrossRef]
37. Huang, Z.; Chen, N.; Yan, Y.; Yan, K.; Chen, X.; Zheng, X.; Yin, H.; Xie, K.; Zhang, L. Dynamic Path-Planning Approach of Garbage Cleanup Oriented Unmanned Ship Based on Simplified Flow Velocity Prediction. *Contemp. Math.* **2024**, *5*, 1672–1694. [CrossRef]
38. Carlson, D.F.; Fürsterling, A.; Vesterled, L.; Skovby, M.; Pedersen, S.S.; Melvad, C.; Rysgaard, S. An affordable and portable autonomous surface vehicle with obstacle avoidance for coastal ocean monitoring. *HardwareX* **2019**, *5*, e00059. [CrossRef]

39. Sotelo-Torres, F.; Alvarez, L.V.; Roberts, R.C. An unmanned surface vehicle (USV): Development of an autonomous boat with a sensor integration system for bathymetric surveys. *Sensors* **2023**, *23*, 4420. [CrossRef]
40. Ronda, J.; Benabdeloued, B.; Tent-Manclús, J. Development of a superficial autonomous vehicle for aquatic environments study: Example of the Rabasa lagoons | Desarrollo de una nave superficial autónoma para el estudio de ambientes acuáticos: Ejemplo de las lagunas de Rabasa. *Geogaceta* **2023**, *74*, 115–118. [CrossRef]
41. Giordano, F.; Mattei, G.; Parente, C.; Peluso, F.; Santamaria, R. Integrating sensors into a marine drone for bathymetric 3D surveys in shallow waters. *Sensors* **2015**, *16*, 41. [CrossRef] [PubMed]
42. Zakki, A.F.; Triwiyatno, A.; Sasmito, B.; Budiono, K. Design and control of autonomous surface vehicle to support bathymetry survey in the coastal environment. *Adv. Sci. Technol. Eng. Syst.* **2019**, *4*, 458–461. [CrossRef]
43. Raygosa-Barahona, R.; Garcia-Terán, M.Á.; Enriquez, C.; Olguín-Díaz, E. Experimental evaluation of an autonomous surface craft for shallow-water bathymetry. *Mar. Technol. Soc. J.* **2017**, *51*, 59–67. [CrossRef]
44. Handayani, A.N.; Pusparani, F.A.; Lestari, D.; Wirawan, I.M.; Fukuda, O.; Aqthobirrobbany, A. Robot Boat Prototype System Based on Image Processing for Maritime Patrol Area. In Proceedings of the 2022 2nd International Seminar on Machine Learning, Optimization, and Data Science (ISMODE), Jakarta, Indonesia, 22–23 December 2022; IEEE: Piscataway, NJ, USA, 2022; pp. 310–315.
45. Casalino, G.; Turetta, A.; Simetti, E. A three-layered architecture for real time path planning and obstacle avoidance for surveillance USVs operating in harbour fields. In Proceedings of the Oceans 2009-Europe, Bremen, Germany, 11–14 May 2009; IEEE: Piscataway, NJ, USA, 2009; pp. 1–8. [CrossRef]
46. Zixiao, W.; Zhenyu, X.; Qiang, Z.; Yulei, L.; Ye, L.; Bo, W. Threat Targets Clustering Method of Unmanned Surface Vessel Cluster for Merchant Ship Escort. In Proceedings of the International Conference on Marine Equipment & Technology and Sustainable Development, Beijing, China, 1–2 April 2023; pp. 515–530.
47. Raboin, E.; Švec, P.; Nau, D.S.; Gupta, S.K. Model-predictive asset guarding by team of autonomous surface vehicles in environment with civilian boats. *Auton. Robot.* **2015**, *38*, 261–282. [CrossRef]
48. Prabhu, T. Unmanned surface vehicle (USV) for coastal surveillance. *Int. J. Mech. Eng. Technol.* **2017**, *7*, 13–28.
49. Steccanella, L.; Bloisi, D.D.; Castellini, A.; Farinelli, A. Waterline and obstacle detection in images from low-cost autonomous boats for environmental monitoring. *Robot. Auton. Syst.* **2020**, *124*, 103346. [CrossRef]
50. Montemayor, M.M.L.; Bautista, A.J. Development of Remote Controlled Skimmer for Waste Collection on Waterbodies. In Proceedings of the 2022 IEEE 14th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM), Boracay Island, Philippines, 1–4 December 2022; IEEE: Piscataway, NJ, USA, 2022; pp. 1–4.
51. Kim, D.; Kim, H.; Jung, S.; Koo, J.; Kim, J.; Shin, J.U.; Myung, H. Development of a jellyfish reconnaissance and removal robot system using unmanned aerial and surface vehicles. In Proceedings of the 2015 12th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI), Goyangi, Republic of Korea, 28–30 October 2015; IEEE: Piscataway, NJ, USA, 2015; p. 101.
52. Powers, C.; Hanlon, R.; Schmale, D.G. Tracking of a fluorescent dye in a freshwater lake with an unmanned surface vehicle and an unmanned aircraft system. *Remote Sens.* **2018**, *10*, 81. [CrossRef]
53. Pinto, E.; Santana, P.; Barata, J. On collaborative aerial and surface robots for environmental monitoring of water bodies. In *Technological Innovation for the Internet of Things; Proceedings of the 4th IFIP WG 5.5/SOCOLNET Doctoral Conference on Computing, Electrical and Industrial Systems, DoCEIS 2013, Costa de Caparica, Portugal, 15–17 April 2013*; Proceedings 4; Springer: Berlin/Heidelberg, Germany, 2013; pp. 183–191.
54. Karapetyan, N.; Braude, A.; Moulton, J.; Burstein, J.A.; White, S.; O'Kane, J.M.; Rekleitis, I. Riverine Coverage with an Autonomous Surface Vehicle over Known Environments. In Proceedings of the 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Macau, China, 3–8 November 2019; pp. 3098–3104. [CrossRef]
55. Watanabe, K.; Utsunomiya, K.; Harada, K.; Watanabe, Y. A Concept of Coastal Sea Monitoring System from Sky to Water. In Proceedings of the Proceedings of the 3rd World Congress on Civil, Structural, and Environmental Engineering (CSEE'18), Budapest, Hungary, 8–10 April 2018; pp. 8–10.
56. Paez, J.; Villa, J.; Cabrera, J.; Yime, E. Implementation of an Unmanned Surface Vehicle for Environmental Monitoring Applications. In Proceedings of the 2018 IEEE 2nd Colombian Conference on Robotics and Automation (CCRA), Barranquilla, Colombia, 1–3 November 2018. [CrossRef]
57. Odetti, A.; Altosole, M.; Caccia, M.; Viviani, M.; Bruzzone, G. Wetlands monitoring: Hints for innovative autonomous surface vehicles design. In *Technology and Science for the Ships of the Future*; IOS Press: Amsterdam, The Netherlands, 2018; pp. 1014–1022. [CrossRef]
58. Arko, S.R.; Issa, R.B.; Das, M.; Rahman, M.S. Autonomous surface vehicle for real-time monitoring of water bodies in Bangladesh. In Proceedings of the Global Oceans 2020: Singapore—US Gulf Coast, Biloxi, MS, USA, 5–30 October 2020; IEEE: Piscataway, NJ, USA, 2020; pp. 1–7.
59. Kemna, S.; Caron, D.A.; Sukhatme, G.S. Constraint-induced formation switching for adaptive environmental sampling. In Proceedings of the OCEANS 2015, Genova, Italy, 18–21 May 2015; IEEE: Piscataway, NJ, USA, 2015; pp. 1–7.
60. Ferri, G.; Manzi, A.; Fornai, F.; Ciuchi, F.; Laschi, C. The HydroNet ASV, a small-sized autonomous catamaran for real-time monitoring of water quality: From design to missions at sea. *IEEE J. Ocean Eng.* **2014**, *40*, 710–726. [CrossRef]

61. Duranti, P. CatOne, multitask unmanned surface vessel for hydro-geological and environment surveys. In *Engineering Geology for Society and Territory*; River Basins, Reservoir Sedimentation and Water Resources; Springer: Cham, Switzerland, 2015; Volume 3, pp. 647–652.
62. Xiong, Y.; Zhu, H.; Pan, L.; Wang, J. Research on Intelligent Trajectory Control Method of Water Quality Testing Unmanned Surface Vessel. *J. Mar. Sci. Eng.* **2022**, *10*, 1252. [CrossRef]
63. Li, C.; Weeks, E.; Huang, W.; Milan, B.; Wu, R. Weather-induced transport through a tidal channel calibrated by an unmanned boat. *J. Atmos. Ocean. Technol.* **2018**, *35*, 261–279. [CrossRef]
64. Cuppens, A.; Menesse, G.; Caligaris, E.; Marecos, O.; Wyseure, G. A low-cost, open-source autonomous surface vehicle as a multipurpose waste stabilization pond monitoring platform. *J. Water Sanit. Hyg. Dev.* **2019**, *9*, 172–180. [CrossRef]
65. Schwermann, R.; Effkemann, C.; Hein, N.; Kutschera, G.; Blankenbach, J. Riverview—Monitoring of water parameters in small and medium-sized water bodies using USV; [Riverview - Monitoring von gewässerparametern an kleinen und mittleren fließgewässern mit USV]. *AVN Allg.-Vermess.-Nachrichten* **2019**, *126*, 136–146.
66. Nikishin, V.; Durmanov, M.; Skorik, I. Autonomous unmanned surface vehicle for water surface monitoring. *TransNav* **2020**, *14*, 853–858. [CrossRef]
67. Powers, C.W.; Hanlon, R.; Grothe, H.; Prussin, A.J.; Marr, L.C.; Schmale III, D.G. Coordinated sampling of microorganisms over freshwater and saltwater environments using an unmanned surface vehicle (USV) and a small unmanned aircraft system (sUAS). *Front. Microbiol.* **2018**, *9*, 1668. [CrossRef] [PubMed]
68. Dunbabin, M.; Grinham, A. Quantifying spatiotemporal greenhouse gas emissions using autonomous surface vehicles. *J. Field Robot.* **2017**, *34*, 151–169. [CrossRef]
69. Carlson, D.F.; Akbulut, S.; Rasmussen, J.F.; Hestbech, C.S.; Andersen, M.H.; Melvad, C. Compact and modular autonomous surface vehicle for water research: The Naval Operating Research Drone Assessing Climate Change (NORDACC). *HardwareX* **2023**, *15*, e00453. [CrossRef] [PubMed]
70. Hitz, G.; Pomerleau, F.; Colas, F.; Siegwart, R. Relaxing the planar assumption: 3D state estimation for an autonomous surface vessel. *Int. J. Robot. Res.* **2015**, *34*, 1604–1621. [CrossRef]
71. Caccia, M.; Bibuli, M.; Bono, R.; Bruzzone, G.; Bruzzone, G.; Spirandelli, E. Aluminum hull USV for coastal water and seafloor monitoring. In Proceedings of the OCEANS 2009-EUROPE, Bremen, Germany, 11–14 May 2009; IEEE: Piscataway, NJ, USA, 2009; pp. 1–5.
72. Beshah, W.T.; Moorhead, J.; Dash, P.; Moorhead, R.J.; Herman, J.; Sankar, M.; Chesser, D.; Lowe, W.; Simmerman, J.; Turnage, G. IoT based real-time water quality monitoring and visualization system using an autonomous surface vehicle. In Proceedings of the OCEANS 2021: San Diego–Porto, San Diego, CA, USA, 20–23 September 2021; IEEE: Piscataway, NJ, USA, 2021; pp. 1–4.
73. Lin, C.C.; Hung, C.H.; Huang, S.H.; Chang, K.C. Study on Robust Design for Underwater Identification of Multi-Functional Small Surface Vehicles. *J. Taiwan Soc. Nav. Archit. Mar. Eng.* **2022**, *41*, 131–139.
74. Bibuli, M.; Bruzzone, G.; Caccia, M.; Fumagalli, E.; Saggini, E.; Zereik, E.; Buttaro, E.; Caporale, C.; Ivaldi, R. Unmanned surface vehicles for automatic bathymetry mapping and shores' maintenance. In Proceedings of the OCEANS 2014-TAIPEI, Taipei, Taiwan, 7–10 April 2014; IEEE: Piscataway, NJ, USA, 2014; pp. 1–7.
75. Sandoval-Erazo, W.; Toulkeridis, T.; Morales-Sanchez, A.; Mora, M.J.M. Sedimentological study of the reservoir of the Manduriacu hydroelectric project, northern Ecuador. *IOP Conf. Ser. Earth Environ. Sci.* **2018**, *191*, 012119. [CrossRef]
76. Bakar, M.F.A.; Arshad, M. ASV data logger for bathymetry mapping system. In Proceedings of the 2017 IEEE 7th International Conference on Underwater System Technology: Theory and Applications (USYS), Kuala Lumpur, Malaysia, 18–20 December 2017; pp. 1–5. [CrossRef]
77. Fu, C.; Yuan, M.; Lin, D.; Jian, F. Research on Control Algorithm of Unmanned Surface Vehicle Line Tracking Based on FPGA. In Proceedings of the 2023 4th International Seminar on Artificial Intelligence, Networking and Information Technology (AINIT), Nanjing, China, 16–18 June 2023; IEEE: Piscataway, NJ, USA, 2023; pp. 320–328.
78. Kapetanović, N.; Kordić, B.; Vasilijević, A.; Nađ, Đ.; Mišković, N. Autonomous Vehicles Mapping Plitvice Lakes National Park, Croatia. *Remote Sens.* **2020**, *12*, 3683. [CrossRef]
79. Suhari, K.; Gunawan, P. The anyar river depth mapping from surveying boat (SHUMOO) using ArcGIS and surfer. In Proceedings of the 2017 International Conference on Control, Electronics, Renewable Energy and Communications (ICCREC), IEEE, Yogyakarta, Indonesia, 26–28 September 2017; pp. 227–230.
80. Sahalan, M.; Idris, M.M.; Abidin, Z.; Kamarudin, M.C. Tilt compensated mechanical measurement mechanism for very shallow water USV bathymetry. In Proceedings of the 2016 IEEE International Conference on Underwater System Technology: Theory and Applications (USYS), Penang, Malaysia, 13–14 December 2017; pp. 48–54. [CrossRef]
81. Madusiok, D. A bathymetric unmanned surface vessel for effective monitoring of underwater aggregate extraction from the perspective of engineering facilities protection. *Arch. Min. Sci.* **2019**, *64*, 375–384.
82. Makar, A. Determination of the Minimum Safe Distance between a USV and a Hydro-Engineering Structure in a Restricted Water Region Sounding. *Energies* **2022**, *15*, 2441. [CrossRef]
83. Mancini, A.; Frontoni, E.; Zingaretti, P. Development of a low-cost Unmanned Surface Vehicle for digital survey. In Proceedings of the 2015 European Conference on Mobile Robots (ECMR), Lincoln, UK, 2–4 September 2015; IEEE: Piscataway, NJ, USA, 2015; pp. 1–6.

84. Mousazadeh, H.; Kiapey, A. Experimental Evaluation of A New Developed Algorithm for An Autonomous Surface Vehicle and Comparison with Simulink Results. *China Ocean. Eng.* **2019**, *33*, 268–278. [CrossRef]
85. Mohd Adam, M.A.; Zainal Abidin, Z.; Ibrahim, A.I.; Mohd Ghani, A.S.; Anchumukkil, A.J. Design and development of mini autonomous surface vessel for bathymetric survey. In Proceedings of the Proceedings of the 11th National Technical Seminar on Unmanned System Technology 2019: NUSYS'19, Kuala Lumpur, Malaysia, 2–3 December 2021; pp. 189–203.
86. Silva, S.R.; Cunha, S.; Matos, A.; Cruz, N. Shallow water surveying using experimental interferometric synthetic aperture sonar. *Mar. Technol. Soc. J.* **2009**, *43*, 50–63. [CrossRef]
87. Kapetanović, N.; Vasilijević, A.; Zubčić, K. Assessing the current state of a shipwreck using an autonomous marine robot: Szent Istvan case study. In Proceedings of the Distributed Computing and Artificial Intelligence, Special Sessions, 17th International Conference, Salamanca, Spain, 6–8 October 2021; pp. 126–135.
88. Zhou, Z.; Cheng, X.; Shangguan, D.; Li, W.; Li, D.; He, B.; Wang, M.; Ling, Q.; Zhang, X.; Wang, X.; et al. A Comparative Study of a Typical Glacial Lake in the Himalayas before and after Engineering Management. *Remote Sens.* **2023**, *15*, 214. [CrossRef]
89. Villarroel, J.L.; Lera, F.; Tardioli, D.; Riazuelo, L.; Montano, L. RoboBoat: A robotic boat for 3D mapping of partially flooded underground sites. *J. Field Robot.* **2024**, *41*, 1029–1053. [CrossRef]
90. Giron-Sierra, J.M.; Gheorghita, A.T.; Angulo, G.; Jimenez, J.F. Preparing the automatic spill recovery by two unmanned boats towing a boom: Development with scale experiments. *Ocean Eng.* **2015**, *95*, 23–33. [CrossRef]
91. Andreotti, M.; Peixoto, A.J.; Monteiro, J.C.; Halfeld, R.; Azambuja, I.; Vargas, L.; Neves, A.F.; Costa, R.R.; Ouvinã, R.; Valentim, S.S.; et al. ARIEL: An autonomous robotic system for oil spill detection. In Proceedings of the Offshore Technology Conference, OTC, Houston, TX, USA, 4–7 May 2020; p. D011S006R007.
92. Sanada, Y.; Miyamoto, K.; Momma, H.; Miyazaki, N.; Nakasone, T.; Tahara, J.; Baba, S.; Furuyama, H. Development of a radiation survey device for a multipurpose unmanned surface vehicle. *Mar. Technol. Soc. J.* **2021**, *55*, 222–230. [CrossRef]
93. Scerri, P.; Kannan, B.; Velagapudi, P.; Macarthur, K.; Stone, P.; Taylor, M.; Dolan, J.; Farinelli, A.; Chapman, A.; Dias, B.; et al. Flood disaster mitigation: A real-world challenge problem for multi-agent unmanned surface vehicles. In *Advanced Agent Technology; Proceedings of the AAMAS 2011 Workshops, AMPLE, AOSE, ARMS, DOCM 3 AS, ITMAS, Taipei, Taiwan, 2–6 May 2011*; Revised Selected Papers 10; Springer: Cham, Switzerland, 2012; pp. 252–269.
94. Shih, H.; Lee, C.; Ho, M.; Kuo, C.; Liao, T.; Chen, C.; Yeh, T. Monitoring and risk assessment of Taoyuan ponds using an unmanned surface vehicle with multibeam echo sounder, ground-penetrating radar, and electrical resistivity tomography. *Geomat. Nat. Hazards Risk* **2024**, *15*, 2323598 . [CrossRef]
95. Shankar, V.; Onuoha, C.; Pozniak, E.; Song, P.; Tetteh-Wayoe, D. Innovative Solutions for Water Crossing Pipeline Inspections. In *Pipelines 2021*; ASCE: Reston, VA, USA, 2021; pp. 98–106.
96. Barilaro, L.; Gauci, J.; Galea, M.; Filippozzi, A.; Vella, D.; Camilleri, R. BEA: Overview of a multi-unmanned vehicle system for diver assistance. In *Aeronautics and Astronautics: AIDAA XXVII International Congress*; Materials Research Forum LLC: Millersville, PA, USA, 2023; Volume 37, p. 243.
97. Kang, C.M.; Yeh, L.C.; Jie, S.Y.R.; Pei, T.J.; Nugroho, H. Design of USV for Search and Rescue in Shallow Water. In *Intelligent Robotics and Applications, Proceedings of the 13th International Conference, ICIRA 2020, Kuala Lumpur, Malaysia, 5–7 November 2020;* Springer: Cham, Switzerland, 2020; Volume 12595 LNAI, pp. 351–363. [CrossRef]
98. Guo, Z.; Zhang, J.; Zeng, F.; Zuo, Z.; Pan, L.; Li, H. A trajectory tracking control system for paddle boat in intelligent aquaculture. *PLOS ONE* **2023**, *18*, e0290246. [CrossRef] [PubMed]
99. Klahn, D.; Gillespie, F.; Monsalvo, S.; Dapoz, A.; Bennett, A.; Triantafyllou, M.S. Oyster Farming by Autonomous Surface Vehicles: An Implementation of Control and Perception Systems. In Proceedings of the OCEANS 2023-Limerick, Limerick, Ireland, 5–8 June 2023; IEEE: Piscataway, NJ, USA, 2023; pp. 1–8.
100. Osen, O.L.; Havnegjerde, A.; Kamsvåg, V.; Liavaag, S.; Bye, R.T. A low cost USV for aqua farm inspection. In Proceedings of the 2016 Techno-Ocean (Techno-Ocean), Kobe, Japan; 6–8 October 2016; IEEE: Piscataway, NJ, USA, 2016; pp. 291–298.
101. Evans, T.M.; Rudstam, L.G.; Sethi, S.A.; Warner, D.M.; Hanson, S.D.; Turschak, B.; Farha, S.A.; Barnard, A.R.; Yule, D.L.; DuFour, M.R.; et al. Fish avoidance of ships during acoustic surveys tested with quiet uncrewed surface vessels. *Fish. Res.* **2023**, *267*, 106817. [CrossRef]
102. Goulon, C.; Le Meaux, O.; Vincent-Falquet, R.; Guillard, J. Hydroacoustic Autonomous boat for Remote fish detection in LakE (HARLE), an unmanned autonomous surface vehicle to monitor fish populations in lakes. *Limnol. Oceanogr. Methods* **2021**, *19*, 280–292. [CrossRef]
103. Dabit, A.S.; Lianto, A.E.; Branta, S.A.; Laksono, F.B.; Prabowo, A.R.; Muhayat, N. Finite Element Analysis (FEA) on autonomous unmanned surface vehicle feeder boat subjected to static loads. *Procedia Struct. Integr.* **2020**, *27*, 163–170. [CrossRef]
104. Thianwiboon, M. Parameter tuning of the autonomous boat in fish farming industry with design of experiment. *Eng. J.* **2020**, *24*, 218–225. [CrossRef]
105. Kimball, P.; Bailey, J.; Das, S.; Geyer, R.; Harrison, T.; Kunz, C.; Manganini, K.; Mankoff, K.; Samuelson, K.; Sayre-McCord, T.; et al. The WHOI Jetyak: An autonomous surface vehicle for oceanographic research in shallow or dangerous waters. In Proceedings of the 2014 IEEE/OES Autonomous Underwater Vehicles (AUV), Oxford, MS, USA, 6–9 October 2014.
106. Pandey, J.; Hasegawa, K. Study on manoeuverability and control of an autonomous Wave Adaptive Modular Vessel (WAM-V) for ocean observation. In Proceedings of the 2015 International Association of Institutes of Navigation World Congress (IAIN), Prague, Czech Republic, 20–23 October 2015. [CrossRef]

107. Shelley, T. Autonomous boat defies the waves. *Eureka* **2006**, *26*, 13–14.
108. Chupin, C.; Ballu, V.; Testut, L.; Tranchant, Y.T.; Calzas, M.; Poirier, E.; Coulombier, T.; Laurain, O.; Bonnefond, P.; Project, T.F. Mapping sea surface height using new concepts of kinematic GNSS instruments. *Remote Sens.* **2020**, *12*, 2656. [CrossRef]
109. Fumagalli, E.; Bibuli, M.; Caccia, M.; Zereik, E.; Del Bianco, F.; Gasperini, L.; Stanghellini, G.; Bruzzone, G. Combined acoustic and video characterization of coastal environment by means of unmanned surface vehicles. *IFAC Proc. Vol.* **2014**, *19*, 4240–4245. [CrossRef]
110. Son, N.S.; Park, H.S.; Pyo, C.S. On the sea trial test of the autonomous collision avoidance among multiple unmanned surface vehicles. In Proceedings of the OCEANS 2023-Limerick, Limerick, Ireland, 5–8 June 2023; IEEE: Piscataway, NJ, USA, 2023; pp. 1–6.
111. Howden, S.; Change, G.; Currier, B.; Grant, C.; Jurisich, J.; Kim, M.; Kirkpatrick, B.; Simon, N.; Spada, F. Offshore Demonstration of an Unmanned Surface Vehicle for Autonomous Hypoxia Monitoring. In Proceedings of the OCEANS 2023—MTS/IEEE U.S. Gulf Coast, Biloxi, MS, USA, 25–28 September 2023. [CrossRef]
112. Sanjou, M.; Shigeta, A.; Kato, K.; Aizawa, W. Portable unmanned surface vehicle that automatically measures flow velocity and direction in rivers. *Flow Meas. Instrum.* **2021**, *80*, 101964. [CrossRef]
113. Kamarudin, M.K.A.; Mustapha, M.F.H.; Abd Wahab, N.; Saad, M.H.M.; Toriman, M.E.; Hamzah, F.M.; Armi, M.; Samah, A.; Hassan, M.S.N.A.; Bati, S.N.A.M. Assessment of Hydrological Inspection Using Development Low-Cost Boat Application in University Sultan Zainal Abidin (UniSZA) Lake, Terengganu, Malaysia. *Int. J. Recent Technol. Eng.* **2019**, *8*, 205–212.
114. Regina, B.A.; Honório, L.M.; Pancoti, A.A.; Silva, M.F.; Santos, M.F.; Lopes, V.M.; Neto, A.F.S.; Westin, L.G. Hull and aerial holonomic propulsion system design for optimal underwater sensor positioning in autonomous surface vessels. *Sensors* **2021**, *21*, 571. [CrossRef] [PubMed]
115. Orthmann, A.; Ziegwied, A. The force multiplier effect: Using autonomous surface vehicles for hydrographic survey. In Proceedings of the AUVSI XPONENTIAL 2017, Anchorage, AK, USA, 18–21 September 2017.
116. da Silva, M.F.; de Mello Honório, L.; dos Santos, M.F.; dos Santos Neto, A.F.; Cruz, N.A.; Matos, A.C.; Westin, L.G.F. Project and control allocation of a 3 DoF autonomous surface vessel with aerial azimuth propulsion system. *IEEE Access* **2020**, *9*, 5212–5227. [CrossRef]
117. de Andrade, E.M.; Fernandes, A.C.; Junior, J.S. Decentralized floating object transportation using a swarm of autonomous surface vehicles. *J. Ocean. Eng. Mar. Energy* **2024**, *10*, 509–521. [CrossRef]
118. Wang, W.; Shan, T.; Leoni, P.; Fernandez-Gutierrez, D.; Meyers, D.; Ratti, C.; Rus, D. Roboat II: A novel autonomous surface vessel for urban environments. In Proceedings of the 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Las Vegas, NV, USA, 24 October 2020–24 January 2021; pp. 1740–1747. [CrossRef]
119. Herlambang, T.; Rahmalia, D.; Suryowinoto, A.; Yudianto, F.; Susanto, F.; Anshori, M. H-infinity for autonomous surface vehicle position estimation. *J. Phys. Conf. Ser.* **2022**, *2157*, 012022. [CrossRef]
120. Hou, L.; Chen, S.; Png, Q.S. Design of a Deployable Cargo Vessel Based on Autonomous Surface Vehicle to Aid Offshore Maritime Shipping: A Robotic Solution for Insufficient Manpower in Maritime Shipping Industry Under Singapore's Context. In Proceedings of the 8th International Conference on Robotics and Artificial Intelligence, Singapore, 18–20 November 2022; pp. 59–63.
121. Plonski, P.A.; Vander Hook, J.; Peng, C.; Noori, N.; Isler, V. Navigation around an unknown obstacle for autonomous surface vehicles using a forward-facing sonar. In Proceedings of the 2015 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR), West Lafayette, IN, USA, 18–20 October 2015. [CrossRef]
122. Jeong, M.; Li, A.Q. Efficient LiDAR-based In-water Obstacle Detection and Segmentation by Autonomous Surface Vehicles in Aquatic Environments. In Proceedings of the 2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Prague, Czech Republic, 27 September–1 October 2021; pp. 5387–5394. [CrossRef]
123. Njogu, P.; Jablonski, P.; Shastri, A.; Sanz-Izquierdo, B. Origami Boat Sensing Antenna. In Proceedings of the 2021 15th European Conference on Antennas and Propagation (EuCAP), Dusseldorf, Germany, 22–26 March 2021. [CrossRef]
124. Monteiro, J.; Suetake, M.; Paula, G.; Almeida, T.; Santana, M.; Romero, G.; Faracco, J.; Monaco, F.; Pinto, R. Wind velocity neural estimator for small autonomous surface vehicles. In Proceedings of the 2012 Second Brazilian Conference on Critical Embedded Systems, Sao Paulo, Brazil, 20–25 May 2012; pp. 6–11. [CrossRef]
125. Qin, K.; Shell, D.A. Robots going round the bend—A comparative study of estimators for anticipating river meanders. In Proceedings of the 2017 IEEE International Conference on Robotics and Automation (ICRA), Singapore, 29 May–3 June 2017; pp. 4934–4940. [CrossRef]
126. Xu, H.; Geng, Z.; He, J.; Shi, Y.; Yu, Y.; Zhang, X. A Multi-Task Water Surface Visual Perception Network for Unmanned Surface Vehicles. In Proceedings of the 2023 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC), Zhengzhou, China, 14–17 November 2023. [CrossRef]
127. Dong, H.; Xu, P.; Liu, Q.; Xu, H. The water coastline detection approaches based on USV vision. In Proceedings of the 2015 IEEE International Conference on Cyber Technology in Automation, Control, and Intelligent Systems (CYBER), Shenyang, China, 8–12 June; IEEE: Piscataway, NJ, USA, 2015; pp. 404–408.
128. Kim, J.; Lee, C.; Chung, D.; Kim, J. Navigable Area Detection and Perception-Guided Model Predictive Control for Autonomous Navigation in Narrow Waterways. *IEEE Robot. Autom. Lett.* **2023**, *8*, 5456–5463. [CrossRef]

129. Gadre, A.; Kragelund, S.; Masek, T.; Stilwell, D.; Woolsey, C.; Horner, D. Subsurface and surface sensing for autonomous navigation in a riverine environment. In Proceedings of the Association of Unmanned Vehicle Systems International (AUVSI) Unmanned Systems North America Convention, Washington, DC, USA, 10–13 August 2009; Volume 2, pp. 1192–1208.
130. Chan, Y.T. Comprehensive comparative evaluation of background subtraction algorithms in open sea environments. *Comput. Vis. Image Underst.* **2021**, *202*, 103101. [CrossRef]
131. Aldegheri, S.; Bloisi, D.; Blum, J.; Bombieri, N.; Farinelli, A. Fast and Power-Efficient Embedded Software Implementation of Digital Image Stabilization for Low-Cost Autonomous Boats. In Proceedings of the Field and Service Robotics: Results of the 11th International Conference, Zurich, Switzerland, 12–15 September 2018; Volume 5, pp. 129–144. [CrossRef]
132. Izzo, P.; Veres, S.M. Intelligent planning with performance assessment for Autonomous Surface Vehicles. In Proceedings of the 2015 IEEE OCEANS, Genova, Italy, 18–21 May 2015; IEEE: Piscataway, NJ, USA, 2015; pp. 1–6. [CrossRef]
133. Zou, X.; Xiao, C.; Zhan, W.; Zhou, C.; Xiu, S.; Yuan, H. A novel water-shore-line detection method for USV autonomous navigation. *Sensors* **2020**, *20*, 1682. [CrossRef] [PubMed]
134. Chen, J.; Wang, H. An Obstacle Detection Method for USV by Fusing of Radar and Motion Stereo. In Proceedings of the IEEE 16th International Conference on Control & Automation (ICCA), Singapore, 9–11 October 2020; IEEE: Piscataway, NJ, USA, 2020; pp. 159–164. [CrossRef]
135. Douguet, R.; Heller, D.; Laurent, J. Multimodal perception for obstacle detection for flying boats-Unmanned Surface Vehicle (USV). In Proceedings of the OCEANS 2023-Limerick, Limerick, Ireland, 12 September 2023; IEEE: Piscataway, NJ, USA, 2023; pp. 1–8.
136. Karez, I.; Marx, J.R.; Jeinsch, T. LiDAR-based ambient detection for surface vehicles in conurbations. In Proceedings of the OCEANS 2023, Limerick, Ireland, 5–8 June 2023. [CrossRef]
137. Muhovič, J.; Koporec, G.; Perš, J. Hallucinating hidden obstacles for unmanned surface vehicles using a compositional model. In Proceedings of the 26th Computer Vision Winter Workshop, Krems, Austria, 15–17 February 2023; Volume 3349.
138. Zust, L.; Kristan, M. Temporal Context for Robust Maritime Obstacle Detection. In Proceedings of the 2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Kyoto, Japan, 23–27 October 2022; IEEE: Piscataway, NJ, USA, 2022; pp. 6340–6346. [CrossRef]
139. Xu, Z.; Duan, K.; Li, D. Autonomous obstacle avoidance assistant system for unmanned surface vehicle based on Intelligent Vision. In Proceedings of the 2022 IEEE Asia-Pacific Conference on Image Processing, Electronics and Computers (IPEC), Dalian, China, 14–16 April 2022; IEEE: Piscataway, NJ, USA, 2022; pp. 1396–1405. [CrossRef]
140. Passarella, R.; Zarkasi, A.; Maghfur, H.; Sutarno.; Exsaudi, K.; Prasetyo, A.; Veny, H. Autonomous Surface Vehicle (ASV) Obstacle Avoidance Using Fuzzy Kohonen Network (FKN). *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *648*, 012023. [CrossRef]
141. Plumet, F.; Pêtrès, C.; Romero-Ramirez, M.A.; Gas, B.; Ieng, S.H. Toward an Autonomous Sailing Boat. *IEEE J. Ocean. Eng.* **2015**, *40*, 397–407. [CrossRef]
142. Ha, J.S.; Im, S.R.; Lee, W.K.; Kim, D.H.; Ryu, J.K. Radar based Obstacle Detection System for Autonomous Unmanned Surface Vehicles. In Proceedings of the 21st International Conference on Control, Automation and Systems (ICCAS), Jeju, Republic of Korea, 12–15 October 2021; IEEE: Piscataway, NJ, USA, 2021; pp. 863–867. [CrossRef]
143. Gong, X.; Xu, B.; Reed, C.; Wyatt, C.; Stilwell, D. Real-time robust mapping for an autonomous surface vehicle using an omnidirectional camera. In Proceedings of the 2008 IEEE Workshop on Applications of Computer Vision, Copper Mountain, CO, USA, 7–9 January 2008; IEEE: Piscataway, NJ, USA, 2008. [CrossRef]
144. Kim, H.; Koo, J.; Kim, D.; Park, B.; Jo, Y.; Myung, H.; Lee, D. Vision-Based Real-Time Obstacle Segmentation Algorithm for Autonomous Surface Vehicle. *IEEE Access* **2019**, *7*, 179420–179428. [CrossRef]
145. Liu, J.; Li, H.; Luo, J.; Xie, S.; Sun, Y. Estimating Obstacle Maps for USVs Based on a Multistage Feature Aggregation and Semantic Feature Separation Network. *J. Intell. Robot. Syst. Theory Appl.* **2021**, *102*, 21. [CrossRef]
146. Zhang, Y.; Yu, J.; Zhang, W.; Dai, C.; Yuan, R. Design of ARM-based Intelligent Unmanned Surface Vehicle Control and Acquisition Module. In Proceedings of the IEEE 4th Advanced Information Management, Communicates, Electronic and Automation Control Conference (IMCEC), Chongqing, China, 18–20 June 2021; IEEE: Piscataway, NJ, USA, 2021; pp. 1100–1103. [CrossRef]
147. Song, G.; Ko, N.Y.; Choi, H.T.; Sur, J. Fault Detection in Inertial Measurement Unit and Global Navigation Satellite System of an Unmanned surface vehicle. In Proceedings of the 22nd International Conference on Control, Automation and Systems (ICCAS) Jeju, Republic of Korea, 27 November–1 December 2022; IEEE: Piscataway, NJ, USA, 2022; pp. 1066–1068. [CrossRef]
148. Sardemann, H.; Blaskow, R.; Maas, H.G. Camera-Aided Orientation of Mobile Lidar Point Clouds Acquired from an Uncrewed Water Vehicle. *Sensors* **2023**, *23*, 6009. [CrossRef] [PubMed]
149. Dos Santos, D.S.; Nascimento, C.L.; Cunha, W.C. Autonomous navigation of a small boat using IMU/GPS/digital compass integration. In Proceedings of the IEEE International Systems Conference (SysCon), Orlando, FL, USA, 15–18 April 2013; IEEE: Piscataway, NJ, USA, 2013; pp. 468–474. [CrossRef]
150. Kim, J.; Lee, C.; Chung, D.; Cho, Y.; Kim, J.; Jang, W.; Park, S. Field experiment of autonomous ship navigation in canal and surrounding nearshore environments. *J. Field Robot.* **2024**, *41*, 470–489. [CrossRef]
151. Cahyadi, M.; Asfihani, T.; Mardiyanto, R.; Erfianti, R. Loosely Coupled GNSS and IMU Integration for Accurate i-Boat Horizontal Navigation. *Int. J. Geoinform.* **2022**, *18*, 111–122. [CrossRef]
152. Li, X.; Wang, W.; Ke, J.; Zhang, X.; Luo, J. Research on $\alpha - \beta$ filter in the course angle navigation of unmanned surface vehicle. *Yi Qi Yi Biao Xue Bao/Chin. J. Sci. Instrum.* **2017**, *38*, 1747–1755.

153. Kiefer, B.; Hofer, T.; Zell, A. Stable Yaw Estimation of Boats from the Viewpoint of UAVs and USVs. In Proceedings of the European Conference on Mobile Robots, Coimbra, Portugal, 4–7 September 2023; IEEE: Piscataway, NJ, USA, 2023. [CrossRef]
154. Pamadi, K.B. Evaluating the feasibility of a particle filtering approach for tracking Unmanned Surface Vehicles. In Proceedings of the AIAA Guidance, Navigation, and Control Conference, Chicago, IL, USA, 10–13 August 2009. [CrossRef]
155. Kolev, G.; Solomevich, E.; Rodionova, E.; Kopets, E.; Rybin, V. Sensor subsystem design for small unmanned surface vehicle. In Proceedings of the 3rd International Conference on Information Processing and Control Engineering, Moscow, Russian Federation, 4–7 August 2019; IOP Science: Bristol, UK, 2019; Volume 630. [CrossRef]
156. Wu, J.; Song, Y.; Song, C.; Xu, Z. A Method with Improved Accuracy and Robustness for Object Detection in Wharf Scenarios. In Proceedings of the IEEE Radar Conference (RadarConf22), New York City, NY, USA, 21–25 March; IEEE: Piscataway, NJ, USA, 2022. [CrossRef]
157. Sun, B.; Zuo, Z.; Wu, P.; Tong, X.; Guo, R. Object detection for environment perception of unmanned surface vehicles based on the improved SSD. *Chin. J. Sci. Instrum.* **2021**, *42*, 52–61.
158. Lee, S.J.; Roh, M.I.; Lee, H.W.; Ha, J.S.; Woo, I.G. Image-based ship detection and classification for unmanned surface vehicle using real-time object detection neural networks. In Proceedings of the 28th International Ocean and Polar Engineering Conference, Sapporo, Japan, 18 June 2018; pp. 726–730.
159. Li, C.; Cao, Z.; Xiao, Y.; Fang, Z. Fast object detection from unmanned surface vehicles via objectness and saliency. In Proceedings of the Chinese Automation Congress (CAC), Wuhan, China, 27–29 November; IEEE: Piscataway, NJ, USA, 2016; pp. 500–505. [CrossRef]
160. Huntsberger, T.; Aghazarian, H.; Howard, A.; Trotz, D.C. Stereo vision-based navigation for autonomous surface vessels. *J. Field Robot.* **2011**, *28*, 3–18. [CrossRef]
161. Duarte, D.F.; Pereira, M.I.; Pinto, A.M. Multiple Vessel Detection in Harsh Maritime Environments. *Mar. Technol. Soc. J.* **2022**, *56*, 58–67. [CrossRef]
162. Omrani, E.; Mousazadeh, H.; Omid, M.; Masouleh, M.T.; Jafarbiglu, H.; Salmani-Zakaria, Y.; Makhsoos, A.; Monhaseri, F.; Kiapei, A. Dynamic and static object detection and tracking in an autonomous surface vehicle. *Ships Offshore Struct.* **2020**, *15*, 711–721. [CrossRef]
163. Matveev, K.I. Modeling of Autonomous Hydrofoil Craft Tracking a Moving Target. *Unmanned Syst.* **2020**, *8*, 171–178. [CrossRef]
164. Kuwata, Y.; Wolf, M.T.; Zarzhitsky, D.; Huntsberger, T.L. Safe maritime autonomous navigation with COLREGS, using velocity obstacles. *IEEE J. Ocean. Eng.* **2014**, *39*, 110–119. [CrossRef]
165. Švec, P.; Thakur, A.; Raboin, E.; Shah, B.C.; Gupta, S.K. Target following with motion prediction for unmanned surface vehicle operating in cluttered environments. *Auton. Robots* **2014**, *36*, 383–405. [CrossRef]
166. Sinisterra, A.J.; Dhanak, M.R.; Von Ellenrieder, K. Stereo vision-based target tracking system for an USV. In Proceedings of the Oceans, St. John's, NL, Canada, 14–19 September 2015; IEEE: Piscataway, NJ, USA, 2015. [CrossRef]
167. Wang, G.; Shi, F.; Xiang, X. Unmanned boat design for Challenges and verification of unmanned surface ship intelligent navigation. In Proceedings of the IEEE 8th International Conference on Underwater System Technology: Theory and Applications (USYS), Wuhan, China, 1–3 December 2018; IEEE: Piscataway, NJ, USA, 2018. [CrossRef]
168. Zhang, W.; Yang, C.F.; Jiang, F.; Gao, X.Z.; Yang, K. A Water Surface Moving Target Detection Based on Information Fusion Using Deep Learning. In Proceedings of the 2020 International Conference on 5G Mobile Communication and Information Science (MCIS-5G), Guangzhou, China, 26–28 June 2020; IOP Science: Bristol, UK, 2020; Volume 1606. [CrossRef]
169. Stateczny, A.; Kazimierski, W.; Gronska-Sledz, D.; Motyl, W. The empirical application of automotive 3D radar sensor for target detection for an autonomous surface vehicle's navigation. *Remote Sens.* **2019**, *11*, 1156. [CrossRef]
170. Cahyadi, M.N.; Asfihani, T.; Mardiyanto, R.; Erfianti, R. Performance of GPS and IMU sensor fusion using unscented Kalman filter for precise i-Boat navigation in infinite wide waters. *Geod. Geodyn.* **2023**, *14*, 265–274. [CrossRef]
171. Lu, Z.; Li, B.; Yan, J. Research on Unmanned Surface Vessel Perception Algorithm Based on Multi-Sensor Fusion. In Proceedings of the 4th International Conference on Frontiers Technology of Information and Computer (ICFTIC), Qingdao, China, 2–4 December 2022; IEEE: Piscataway, NJ, USA, 2022; pp. 286–289. [CrossRef]
172. Zuo, Z.; Huang, H.; Sun, B.; Wu, P. Research on underwater target location based on side-scan sonar carried by unmanned surface vehicle. *Yi Qi Yi Biao Xue Bao/Chin. J. Sci. Instrum.* **2023**, *44*, 310–319. [CrossRef]
173. Wang, L.; Xiang, J.; Wang, H. Local Path Planning Algorithm for Unmanned Surface Vehicle Based on Improved Bi-RRT. *Ship Build. China* **2020**, *61*, 21–30.
174. Wang, J. Research on Local Collision Avoidance Algorithm for Unmanned Ship Based on Behavioral Constraints. In *Bio-Inspired Computing: Theories and Applications; Proceedings of the BIC-TA 2023, Changsha, China, 15–17 December 2023*; Communications in Computer and Information Science; Springer: Singapore, 2024; Volume 2062, pp. 396–408. [CrossRef]
175. Liu, C.; Liu, K. Global Path Planning for Unmanned Ships Based on Improved Particle Swarm Algorithm. In *Bio-Inspired Computing: Theories and Applications; Proceedings of the BIC-TA 2022, Wuhan, China, 16–18 December 2022*; Communications in Computer and Information Science; Springer: Singapore, 2023; Volume 1801, pp. 106–116. [CrossRef]
176. Nunia, V.; Poonia, R.C. A Review and Comparative Study on Surface Vehicle Path Planning Algorithm. In Proceedings of the International Conference on Data Science, Machine Learning and Artificial Intelligence, Windhoek, Namibia, 9–12 August 2021; ACM: Times Square, NY, USA, 2021; pp. 106–109. [CrossRef]

177. Wang, Y.; Liang, X.; Li, B.; Yu, X. Research and Implementation of Global Path Planning for Unmanned Surface Vehicle Based on Electronic Chart. *Adv. Intell. Syst. Comput.* **2018**, *690*, 534–539. [CrossRef]
178. Peng, W. A Global Path Planning Method for USV Based on Improved A_Star Algorithm. In Proceedings of the 2023 IEEE 7th Information Technology and Mechatronics Engineering Conference (ITOEC), Chongqing, China, 15–17 September 2023; IEEE: Piscataway, NJ, USA, 2023; Volume 7; pp. 669–673.
179. Rong, Y.; He, Z.; Wang, S. A Local Path Planning Method for Unmanned Surface Vehicles in Dynamic Environment. *Wuhan Ligong Daxue Xuebao (Jiaotong Kexue Yu Gongcheng Ban)/J. Wuhan Univ. Technol. (Transp. Sci. Eng.)* **2023**, *47*, 275–280. [CrossRef]
180. Long, Y.; Su, Y.; Lian, C.; Zhang, D. Hybrid bacterial foraging algorithm for unmanned surface vehicle path planning. *Huazhong Keji Daxue Xuebao (Ziran Kexue Ban)/J. Huazhong Univ. Sci. Technol. (Nat. Sci. Ed.)* **2022**, *50*, 68–73. [CrossRef]
181. Tong, J.; Wu, N.; Qi, J.; Wang, J. Double-layer hybrid path planning method for asv obstacle avoidance. In Proceedings of the 30th International Ocean and Polar Engineering Conference, Shanghai, China, 11–16 October 2020; pp. 3897–3902.
182. Wang, J.Y.; Xu, L.X.; Wang, Y.L. Enhanced Hybrid A* Path Planning for Unmanned Surface vessels Using Integrated Kalman Filtering. In Proceedings of the IEEE 2nd Industrial Electronics Society Annual On-Line Conference (ONCON), SC, USA, 8–10 December 2023; IEEE: Piscataway, NJ, USA, 2023. [CrossRef]
183. Yang, Q.; Yin, Y.; Chen, S.; Liu, Y. Autonomous exploration and navigation of mine countermeasures USV in complex unknown environment. In Proceedings of the the 33rd Chinese Control and Decision Conference (CCDC), Kunming, China, 22–24 May 2021; IEEE: Piscataway, NJ, USA, 2021; pp. 4373–4377. [CrossRef]
184. da Silva Junior, A.G.; Dos Santos, D.H.; de Negreiros, A.P.F.; Silva, J.M.V.B.d.S.; Gonçalves, L.M.G. High-level path planning for an autonomous sailboat robot using q-learning. *Sensors* **2020**, *20*, 1550. [CrossRef] [PubMed]
185. Jialin, L.; Jianqiang, Z. Global path planning of unmanned boat based on improved ant colony algorithm. In Proceedings of the 4th International Conference on Electron Device and Mechanical Engineering (ICEDME), Guangzhou, China, 19–21 March 2021; IEEE: Piscataway, NJ, USA, 2021; pp. 176–179. [CrossRef]
186. Yu, L.; Qian, T.; Ye, X.; Zhou, F.; Luo, Z.; Zou, A. Research on obstacle avoidance strategy of USV based on improved grid method. In Proceedings of the 4th International Symposium on Power Electronics and Control Engineering, Nanchang, China, 10–13 September 2021; SPIE: Bellingham, Washington, USA, 2021; Volume 12080. [CrossRef]
187. Zhang, B.; Xiong, Y.; Mou, J.; Zhang, J.; Yu, J.; Liu, H. Design of Route Planning Wireless Network Control System for Unmanned Surface Vehicle. In Proceedings of the 11th International Symposium on Computational Intelligence and Design (ISCID), Hangzhou, China, 8–9 December 2018; IEEE: Piscataway, NJ, USA, 2018; Volume 1, pp. 75–79. [CrossRef]
188. Zhang, L.; Han, Y.; Jiang, B. Research on Path Planning Method of Unmanned Boat Based on Improved Artificial Potential Field Method. In Proceedings of the 6th Asian Conference on Artificial Intelligence Technology (ACAIT), Changzhou, China, 9–11 December 2022; IEEE: Piscataway, NJ, USA, 2022. [CrossRef]
189. Selfridge, J.M.; Tran, L.D.; Hou, G. Autonomous vehicle path planning and tracking: A vision based approach. In Proceedings of the AUVSI Unmanned Systems North America Conference, Washington, DC, USA, 16–19 August 2011; Volume 3, pp. 1674–1684.
190. Song, L.; Chen, Z.; Dong, Z.; Xiang, Z.; Mao, Y.; Su, Y.; Hu, K. Collision avoidance planning for unmanned surface vehicle based on eccentric expansion. *Int. J. Adv. Robot. Syst.* **2019**, *16*, 1–9. [CrossRef]
191. Hu, X. Research on autonomous obstacle avoidance assistance system for surface unmanned vehicle based on intelligent vision. In Proceedings of the IEEE International Conference on Control, Electronics and Computer Technology (ICCECT), Jilin, China, 28–30 April 2023; IEEE: Piscataway, NJ, USA, 2023; pp. 663–667. [CrossRef]
192. Tang, P.P.; Zhang, R.B.; Shi, C.T.; Yang, G.; Liu, D.L. Local obstacle avoidance for unmanned surface vehicle using a hierarchical strategy. *Yingyong Kexue Xuebao/J. Appl. Sci.* **2013**, *31*, 418–426. [CrossRef]
193. Lee, C.; Chung, D.; Kim, J.; Kim, J. Nonlinear model predictive control with obstacle avoidance constraints for autonomous navigation in a canal environment. *IEEE/ASME Trans. Mechatronics* **2024**, *29*, 1985–1996. [CrossRef]
194. Chen, D.; Li, W.; Bao, X.; Zhu, K. Velocity obstacle collision avoidance approach for USV with towed array. *Huazhong Keji Daxue Xuebao (Ziran Kexue Ban)/J. Huazhong Univ. Sci. Technol. (Nat. Sci. Ed.)* **2020**, *48*, 72–77. [CrossRef]
195. Deepakkumar, P.; Kavipriya, P. Autonomous navigation of marine vehicles using video camera and range sensor. *Int. J. Appl. Eng. Res.* **2015**, *10*, 18303–18308.
196. Praczyk, T. Neural anti-collision system for Autonomous Surface Vehicle. *Neurocomputing* **2015**, *149*, 559–572. [CrossRef]
197. Xu, X.; Lu, Y.; Liu, X.; Zhang, W. Intelligent collision avoidance algorithms for USVs via deep reinforcement learning under COLREGs. *Ocean Eng.* **2020**, *217*, 107704. [CrossRef]
198. Mu, D.; Li, T.; Han, X.; Fan, Y.; Sun, X.; Liu, Y. Geometric Collision Avoidance Algorithm for Unmanned Surface Vehicle Based on Multi-objective. In Proceedings of the 5th International Conference on Intelligent Autonomous Systems (ICoIAS), Dalian, China, 23–25 September 2022; IEEE: Piscataway, NJ, USA, 2022; p. 159–165. [CrossRef]
199. Jeong, M.; Li, A.Q. Risk vector-based near miss obstacle avoidance for autonomous surface vehicles. In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Las Vegas, NV, USA, 24 October 2020–24 January 2021; IEEE: Piscataway, NJ, USA, 2020; pp. 1805–1812. [CrossRef]
200. Matveev, K.I. Modeling of Autonomous Hydrofoil Craft Avoiding Moving Obstacles. In SNAME Maritime Convention, Houston, TX, USA, 27–29 September 2022. [CrossRef]
201. Gonzalez-Garcia, A.; Collado-Gonzalez, I.; Cuan-Urquizo, R.; Sotelo, C.; Sotelo, D.; Castañeda, H. Path-following and LiDAR-based obstacle avoidance via NMPC for an autonomous surface vehicle. *Ocean Eng.* **2022**, *266*, 112900. [CrossRef]

202. Thakur, A.; Svec, P.; Gupta, S.K. GPU based generation of state transition models using simulations for unmanned surface vehicle trajectory planning. *Robot. Auton. Syst.* **2012**, *60*, 1457–1471. [CrossRef]
203. Gadre, A.S.; Sonnenburg, C.; Du, S.; Stilwell, D.J.; Woolsey, C. Guidance and control of an unmanned surface vehicle exhibiting sternward motion. In Proceedings of the 2012 Oceans, Hampton Roads, VA, USA, 14–19 October 2012; IEEE: Piscataway, NJ, USA, 2012. [CrossRef]
204. Zhai, Y.; Huang, J.; Liu, C.; Liu, Y. Research on Motion Management and Control System of USV. In Proceedings of the Seventh International Conference on Electromechanical Control Technology and Transportation (ICECTT), Guangzhou, China, 26–28 May 2022; SPIE: Bellingham, Washington, USA, 2022; Volume 12302. [CrossRef]
205. Sonnenburg, C.R.; Woolsey, C.A. Modeling, identification, and control of an unmanned surface vehicle. *J. Field Robot.* **2013**, *30*, 371–398. [CrossRef]
206. Chen, J.; Zhang, Q.; Qi, Y.; Leng, Z.; Zhang, D.; Xie, J. Trajectory Tracking Based on Backstepping Sliding Mode Control for Underactuated USV. In 36th Youth Academic Annual Conference of Chinese Association of Automation (YAC), Nanchang, China, 28–30 May 2021; IEEE: Piscataway, NJ, USA, 2021; pp. 294–299. [CrossRef]
207. Deng, H.; Wang, R.; Miao, K.; Zhao, Y.; Sun, J.; Du, J. Design of unmanned ship motion control system based on DSP and GPRS. In Proceedings of the International Conference on Information Technology and Electrical Engineering, Xiamen Fujian, China, 7–8 December 2018; ACM: Times Square, NY, USA, 2018. [CrossRef]
208. Dewi, R.P.; Asfihani, T.; Nurhadi, H. Design Control of Autonomous Surface Vehicle Position Using Proportional Integral Derivative Method. In International Conference on Advanced Mechatronics, Intelligent Manufacture and Industrial Automation (ICAMIMIA), Surabaya, Indonesia, 8–9 December 2021; IEEE: Piscataway, NJ, USA, 2021; pp. 131–136. [CrossRef]
209. Fahimi, F.; Van Kleeck, C. Alternative trajectory-tracking control approach for marine surface vessels with experimental verification. *Robotica* **2013**, *31*, 25–33. [CrossRef]
210. Karnani, C.; Raza, S.A.; Asif, M.; Ilyas, M. Adaptive Control Algorithm for Trajectory Tracking of Underactuated Unmanned Surface Vehicle (UUSV). *J. Robot.* **2023**, *2023*, 4820479. [CrossRef]
211. Huang, Y.; Bucchi, A. Froude-Krylov force estimation and waypoint tracking control of an underactuated model boat. In Proceedings of the OCEANS 2023, Limerick, Ireland, 5–8 June 2023; IEEE: Piscataway, NJ, USA, 2023. [CrossRef]
212. Li, B. Research on control of unmanned surface vehicle based on deep reinforcement learning. *Shipbuild. China* **2020**, *61*, 14–20. [CrossRef]
213. Chen, C.H.; Chen, G.Y.; Chen, J.J. Design and implementation for USV based on fuzzy control. In Proceedings of the International Automatic Control Conference (CACS), Nantou, Taiwan, 2–4 December 2013; IEEE: Piscataway, NJ, USA, 2013; pp. 345–349. [CrossRef]
214. Mattos, D.I.; Soares Dos Santos, D.; Nascimento, C.L. Development of a low-cost autonomous surface vehicle using MOOS-IvP. In Proceedings of the Annual IEEE Systems Conference (SysCon), Orlando, FL, USA, 18–21 April 2016; IEEE: Piscataway, NJ, USA, 2016. [CrossRef]
215. Shin, J.; Kwak, D.J.; Lee, Y.I. Adaptive path-following control for an unmanned surface vessel using an identified dynamic model. *IEEE/ASME Trans. Mechatronics* **2017**, *22*, 1143–1153. [CrossRef]
216. Valenciaga, F. A second order sliding mode path following control for autonomous surface vessels. *Asian J. Control.* **2014**, *16*, 1515–1521. [CrossRef]
217. Xu, X.; Sheng, L. Design and Implementation of USV Tracking Controller Based on STM32. *Wuhan Ligong Daxue Xuebao (Jiaotong Kexue Yu Gongcheng Ban)/J. Wuhan Univ. Technol. (Transp. Sci. Eng.)* **2018**, *42*, 626–630. [CrossRef]
218. Papelis, Y.; Weate, M. Operations architecture and vector field guidance for the Riverscout subscale unmanned surface vehicle. In Proceedings of the International Defense and Homeland Security Simulation Workshop, Athens, Greece, 25–27 September 2013; pp. 55–60.
219. Priandana, K.; Kusumoputro, B. Development of Self-Organizing Maps neural networks based control system for a boat model. *J. Telecommun. Electron. Comput. Eng.* **2017**, *9*, 47–52.
220. Zhu, Q. Design of control system of USV based on double propellers. In Proceedings of the IEEE International Conference of IEEE Region 10 (TENCON), Xi'an, China, 22–25 October 2013; IEEE: Piscataway, NJ, USA, 2013. [CrossRef]
221. Xia, L.; Shao, C.; Li, H.; Cui, Y. Robust Model-based Reinforcement Learning USV System Guided by Lyapunov Neural Networks. In Proceedings of the 2022 IEEE International Conference on Robotics and Biomimetics (ROBIO), Jinghong, China, 5–9 December 2022; IEEE: Piscataway, NJ, USA, 2022; pp. 1976–1981. [CrossRef]
222. Huang, Y.; Ji, Z. Autonomous boat dynamics: How far away is simulation from the high sea? In Proceedings of the OCEANS 2017, Aberdeen, Scotland, 19–22 June 2017; IEEE: Piscataway, NJ, USA, 2017; pp. 1–8. [CrossRef]
223. Ma, Y.; Zhao, Y.; Diao, J.; Gan, L.; Bi, H.; Zhao, J. Design of Sail-Assisted Unmanned Surface Vehicle Intelligent Control System. *Math. Probl. Eng.* **2016**, *2016*. p. 2958240. [CrossRef]
224. Zheng, M.; Yang, S.; Li, L. Stability analysis and TS fuzzy dynamic positioning controller design for autonomous surface Vehicles based on sampled-data control. *IEEE Access* **2020**, *8*, 148193–148202. [CrossRef]
225. Yoo, N. A Study of Trim Tab Management System for an USV and a Small Boat. In *Advanced Multimedia and Ubiquitous Engineering; Proceedings of the International Conference on Multimedia and Ubiquitous Engineering, Xian, China, 24–26 April 2019*; Lecture Notes in Electrical Engineering; Spirnger: Singapore, 2020; Volume 590, 370–376. [CrossRef]

226. Pereira, A.; Das, J.; Sukhatme, G.S. An experimental study of station keeping on an underactuated ASV. In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, Nice, France, 22–26 September 2008; IEEE: Piscataway, NJ, USA, 2008; pp. 3164–3171. [CrossRef]
227. Felix, F.; Rosa, M.R.; Rodiana, I.M. Heading Direction Control for Omnidirectional Unmanned Surface Vessels Using PID Anti-windup. In Proceedings of the 3rd International Conference on Information Technology, Advanced Mechanical and Electrical Engineering (ICITAMEE), Yogyakarta, Indonesia, 20–21 July 2022; AIP: Melville, NY, USA, 2023; Volume 2865. [CrossRef]
228. Ge, Y.; Zhong, L.; Qiang, Z.J. Research on USV Heading Control Method Based on Kalman Filter Sliding Mode Control. In Proceedings of the Chinese Control And Decision Conference (CCDC), Hefei, China, 22–24 August 2020; IEEE: Piscataway, NJ, USA, 2020; pp. 1547–1551. [CrossRef]
229. Abrougui, H.; Nejim, S.; Dallagi, H. A Combined Heading Controller with Line Following Approach for Self-Steering an Autonomous Surface Vehicle. In Proceedings of the IEEE International Conference on Advanced Systems and Emergent Technologies (IC_ASET), Hammamet, Tunisia, 29 April–1 May 2023; IEEE: Piscataway, NJ, USA, 2023. [CrossRef]
230. Su, Y.; Chen, Y.; Pan, X.; Wang, H.; Zhao, Z.; Liu, H. Design and Simulation of Heading Controller for Unmanned Boat Based on Fuzzy Neural PID. In *Bio-Inspired Computing: Theories and Applications; Proceedings of the International Conference on Bio-Inspired Computing: Theories and Applications, Wuhan, China, 16–18 December 2022*; Communications in Computer and Information Science; Springer: Singapore, 2023; Volume 1801 CCIS, pp. 554–566. [CrossRef]
231. Zhong, W.; Yang, Z.; Wen, J.; Feng, Y.; Huang, X.; Lu, D. A Motion Control System Based on Auto Disturbances Rejection Controller for Unmanned Surface Vessel with Double Propellers and Single Rudder. *Ship Build. China* **2020**, *61*, 167–176.
232. Kawamura, Y.; Tahara, J.; Kato, T.; Baba, S.; Koike, M. Control of μ-autonomous surface vehicle using sliding mode control. *Sens. Mater.* **2019**, *31*, 4231–4245. [CrossRef]
233. Bao, T.; Zhang, B.; Chen, Z.; Zhou, Z. USV Motion Control Systems Based on i.MX RT1052 Module. *Ship Build. China* **2020**, *61*, 97–104.
234. Wang, L.; Wu, Q.; Liu, C.; Xie, S.; Chu, X. Design method of USV course-tracker based on simulation and real vessel experiment. In Proceedings of the 4th International Conference on Transportation Information and Safety (ICTIS), Banff, AB, Canada, 8–10 August 2017; IEEE: Piscataway, NJ, USA, 2017; pp. 236–245. [CrossRef]
235. Chen, Z.; Jin, J.H.; Zhang, B.; Bao, T.; Zhou, Z.X. Adaptive control method of unmanned surface vehicle course based on MSFIGA algorithm. *Chuan Bo Li Xue/J. Ship Mech.* **2023**, *27*, 1273–1282. [CrossRef]
236. Baek, S.; Woo, J. Model reference adaptive control-based autonomous berthing of an unmanned surface vehicle under environmental disturbance. *Machines* **2022**, *10*, 244. [CrossRef]
237. Fernández-Gutiérrez, D.; Hagemann, N.; Wang, W.; Doornbusch, R.; Jordan, J.; Schiphorst, J.; Leoni, P.; Duarte, F.; Ratti, C.; Rus, D. Design of an autonomous latching system for surface vessels. In Proceedings of the 2022 International Conference on Robotics and Automation (ICRA), Philadelphia, PA, USA, 23–27 May 2022; IEEE: Piscataway, NJ, USA, 2022; pp. 1099–1105. [CrossRef]
238. Kim, S.R.; Jo, H.J.; Kim, J.H.; Park, J.Y. Development of an autonomous docking system for autonomous surface vehicles based on symbol recognition. *Ocean. Eng.* **2023**, *283*, 114753. [CrossRef]
239. Molberg, J.; Bandzul, T. Inverting the ratio: One operator to many vehicles. In Proceedings of the Unmanned Systems North America Conference, Orlando, FL, USA, 29–31 August 2006; Volume 2, pp. 735–750.
240. Thein, M.W.L.; Renken, M. Comparative Study of Heading and Speed Control Techniques for Small Autonomous Surface Vehicles. In Proceedings of the OCEANS 2018 MTS/IEEE Charleston, Charleston, SC, USA, 22–25 October 2018. [CrossRef]