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The Analysis of Intelligent Functions Required for Inland Ships

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Abstract: Sorting out the requirements for intelligent functions is the prerequisite and foundation of the top-level design for the development of intelligent ships. In light of the development of inland intelligent ships for 2030, 2035, and 2050, based on the analysis of the division of intelligent ship functional modules by international representative classification societies and relevant research institutions, eight necessary functional modules have been proposed: intelligent navigation, intelligent hull, intelligent engine room, intelligent energy efficiency management, intelligent cargo management, intelligent integration platform, remote control, and autonomous operation. Taking the technical realization of each functional module as the goal, this paper analyzes the status quo and development trend of related intelligent technologies and their feasibility and applicability when applied to each functional module. At the same time, it clarifies the composition of specific functional elements of each functional module, puts forward the stage goals of China's inland intelligent ship development and the specific functional requirements of different modules under each stage, and provides reference for the Chinese government to subsequently formulate the top-level design development planning and implementation path of inland waterway intelligent ships.

Keywords: inland intelligent ships; functional module; intelligent technologies; functional requirements

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1. Introduction

Compared with traditional ships, intelligent ships possess numerous advantages, such as safety, reliability, energy conservation, environmental friendliness, and economic efficiency. With the rapid development and widespread application of technologies such as artificial intelligence, the Internet of Things, cloud computing, and big data, intelligent ships based on digitization and aiming for autonomy have become a new focus in the shipbuilding industry, international shipping, and maritime circles [1]. In recent years, the development of intelligent ships has achieved remarkable results. In January 2022, the Japanese container ship Mikage completed a fully autonomous navigation test from Tsuruga Port in Fukui Prefecture to Sakaiminato Port in Tottori Prefecture over a total distance of about 270 km. In addition to the Automatic Identification System (AIS) of the ship and the radar, the ship was equipped with visual cameras, infrared cameras for nighttime, and an artificial intelligence (AI) learning system for detecting other ships. In April 2022, China's first self-developed autonomous 300 TEU container ship, "Zhi Fei," made its maiden navigation at Qingdao Port, which has three driving modes: manual, remote control, and unmanned autonomous navigation. It is capable of realizing intelligent perception and cognition of the navigation environment, autonomous route planning, intelligent collision avoidance, automatic berthing and unberthing, and remote control navigation. By the end of 2023, the ship had sailed over 20,000 nautical miles, with its intelligent navigation system consistently operating safely. In April 2022, the Norwegian ship "Yara Birkeland" entered commercial operation as the world's first fully electric, unmanned container ship equipped with remote control and autonomous navigation systems. In June 2022, the South Korean super-large natural gas (LNG) carrier "Prism Courage" completed an oceanic intelligent navigation experiment. The same month, the unmanned electric ship "The May Flower" conducted intelligent perception and decision-making with its AI captain and edge computing system during its first fully autonomous transatlantic navigation. In January 2023, the world's first scientific research ship with remote control and autonomous navigation in open waters, "Zhuhai Yun," was delivered for use in Guangzhou, China. It is expected that the International Maritime Organization (IMO) will issue the "Maritime Autonomous Surface Ship Code (MASS Code)" by the end of 2024 and implement it on 1 January 2025. This code is a comprehensive set of regulations tailored for MASS to address issues that existing maritime organization documents cannot adequately address or have not yet addressed for MASS. Reviewing the current research status of major international research institutions in the field of intelligent ships, the development of intelligent ships primarily focuses on ocean-going ships, with relatively few applications in inland ships. There are several reasons for this. Firstly, at the international level, intelligent ship development is still in the early stages of system development and testing, and further refinement, integration, and reliability verification of intelligent ship technology are needed. Secondly, compared to sea navigation environments, inland waterway navigation environments are more complex. From a safety perspective, current inland ship operations still heavily rely on subjective judgments, decisions, and responses based on human experience. Thirdly, compared with the scale of sea ships and marine transportation, the scale of manufacturing and operating bodies of inland ships is small, and there is still a lack of economic capacity and development consciousness in the introduction of intelligent technology.

At present, there are relatively few international studies on intelligent inland ships. This article summarizes the functional classification or grading of intelligent ships by international representatives of classification societies and shipbuilding companies, systematically organizes the technology, and takes into account the specific aspects of inland waterway navigation. It extracts functional modules that meet the development needs of inland intelligent ships and combines them with the current development status and technological forecasts of ship intelligence technology. It proposes functional requirements for the development of China's inland intelligent ships by 2030, 2035, and 2050.

The remaining part of this paper is organized as follows. Section 2 briefly outlines the international classification of smart ship functional modules and analyzes the necessity of functional modules. Section 3 describes in detail the technologies related to smart ships, including intelligent perception technology, intelligent communication technology, intelligent evaluation technology, intelligent decision-making technology, and intelligent control technology. Section 4 gives a prediction of the functional demand for inland waterway smart ships under different stages. Section 5 summarizes the conclusion and describes the future research direction of inland intelligent ships.

2. Analysis of Functional Modules for Inland Intelligent Ships

2.1. Current Classification Status of Functional Modules for Intelligent Ships

Currently, there is no universal consensus among international research institutions regarding the classification of intelligent ship functions or standards for intelligent grades. In December 2015, the China Classification Society (CCS), taking into account both domestic and international experiences in intelligent ship applications and the future direction of ship intelligence, developed and issued the world's first "Rules for Intelligent Ships". Subsequently, it underwent multiple iterations, was updated, and reissued as the "Rules for Intelligent Ships (2024)" in December 2023, which takes safety, economy, high efficiency, and environmental protection as the starting points and introduces the new concept of artificial intelligence. It divides intelligent ship functional modules into eight categories: intelligent navigation, intelligent hull, intelligent engine room, intelligent energy efficiency management, intelligent cargo management, intelligent integration platform, remote control, and autonomous operation [2]. In February 2017, Lloyd's Register issued the "Code for Unmanned Marine Systems," which adopts a system similar to traditional ship regulations. Its chapters are highly consistent with traditional ship regulations and are divided into sections such as structure, stability, control, electrical, navigation, propulsion systems, and firefighting. From the perspective of unmanned operation, the regulation provides corresponding discussions on the scope, purpose, functional objectives, and performance requirements of unmanned systems [3]. In October 2018, Det Norske Veritas (DNV) proposed in its "Class Guideline Smartship" that intelligent ships should possess a total of five intelligent features: enhanced foundation, operational enhancement, performance enhancement, safety and reliability enhancement, and enhanced condition monitoring [4]. In June 2022, the American Bureau of Shipping (ABS) introduced the "Smart Functions for Marine Vessels and Offshore Units," proposing that intelligent ships should include five aspects of intelligent functions: structural health monitoring, machinery health monitoring, asset efficiency monitoring, operational performance management, crew assistance, and functional enhancement [5]. In January 2020, the Japan Ship Classification Society (JSCS) outlined two functional goals for intelligent ships from the perspective of supporting crew operations in its "Guidelines for Automated/Autonomous Operation of ships." These goals include designing and developing unmanned ships and short-distance small ships with the aim of reducing the number of crew members and designing and developing partial automation or remote support for onboard tasks. This guideline does not directly classify the autonomous level of ships but categorizes automation operation systems and remote operation systems from the perspectives of system design, development, installation, and operation [6]. In 2019, the European Union launched the Autonomous Ship Research and Development Program. In this program, the functions of smart ships are typically categorized as autonomous navigation systems, intelligent energy management, intelligent ship operations, communication and remote monitoring, and autonomous safety systems to meet the needs and challenges of autonomous ship navigation [7]. In November 2021, the Netherlands Forum Smart Shipping (SMASH) published the Smart Shipping Roadmap, which sets out a vision for the development of smart shipping in the Netherlands towards 2030. Its short-term goal is to reduce the number of ship drivers through ship automation and intelligent technology and to realize "autonomous human assistance" on ships on a small scale [8]. Furthermore, relevant international shipbuilding enterprises and research institutions have also put forward their respective research focuses in the development of intelligent ships, as shown in Table 1.

Table 1. Summary of intelligent ship specifications of internationally relevant agencies.

Organization	Date	Related Documents	Primary Content
China Classification Society (CCS)	December 2015 (Updated as of December 2023)	Rules for Intelligent Ships 2024	Intelligent Navigation, Intelligent Hull, Intelligent Engine Room, Intelligent Energy Efficiency Management, Intelligent Cargo Management, Intelligent Integration Platform, Remote Control, Autonomous Operation
Lloyd's Register of Shipping (LR)	February 2017	Code for Unmanned Marine Systems	Structure, Stability, Control, Electrical, Navigation, Propulsion System, Firefighting
Det Norske Veritas (DNV GL)	October 2018	Class Guideline Smartship	Enhanced Foundation, Operational Enhancement, Performance Enhancement, Safety and Reliability Enhancement, Enhanced Condition Monitoring

Table 1. *Cont.*

Organization	Date	Related Documents	Primary Content
American Bureau of Shipping (ABS)	June 2022	Smart Functions for Marine Vessels and Offshore Units	Structural Health Monitoring, Machinery Health Monitoring, Asset Efficiency Monitoring, Operational Performance Management, Crew Assistance and Functional Enhancement
Nippon Kaiji Kyokai (NK)	January 2020	Guidelines for Automated/Autonomous Operation of ships	Streamlining and unmanned crewing of small, short-distance ships; automation or remote operation of part of the ship's operations, mainly in support of the crew
European Union (EU)	2019	Autonomous Ship Research and Development Program	Autonomous Navigation Systems, Intelligent Energy Management, Intelli-gent Ship Operations, Communication and Remote Monitoring, Autonomous Safety Systems
Netherlands Forum Smart Shipping (SMASH)	November 2021	Smart Shipping Roadmap	In the short term, focus on reducing the number of ship drivers through ship automation and intelligent technology, and realize "autonomous human assistance" for ships on a small scale
Rolls-Royce	2014	Advanced Autonomous Waterborne Applications (AAWA)	Focusing the functional research and development of intelligent ships on two aspects: firstly, intelligent subsystems, and secondly, realizing the intelligence of the whole ship's platform [9]
Hai Lanxin	2016	Intelligent Ship 1.0 Specialization	Focusing on the development of ship intelligent assisted autopilot system, completed the ship assisted autopilot system with sensing, decision-making and execution functions [10]
Hyundai Heavy Industries Group	2017	Intelligent Ship Program	Focusing on the research and development of intelligent navigation, intelligent berthing and other auxiliary systems for ships [11]

By sorting out the functional module division of intelligent ships of the above eight institutions or organizations, it can be seen that the current mainstream classification of ship autonomy level mainly targets specific functions or operations and elaborates in detail what functions or operations can be realized by the system when it is at different levels of autonomy, covering from manual operation to full autonomy.

2.2. Necessity Analysis of Functional Modules

CCS "Rules for Intelligent Ships (2024)" has a fairly complete framework of intelligent ship specifications and corresponding functional and technical requirements, which is more suitable for guiding the development of intelligent ships on inland waterways in China. As illustrated in Figure 1, the regulations propose eight intelligent modules from a technical perspective, forming a complete system of functional and technical requirements for intelligent ships. However, in the context of inland ship development towards 2030, 2035, and 2050, the actual development status of inland ships needs to be taken into account. For the intelligent hull module, the ship structure serves as the most fundamental system unit and one of the most stable and reliable components of a ship. The current level of modern manufacturing is sufficient to ensure the stable and reliable operation of the hull throughout its lifecycle. There is scarce evidence of inland maritime accidents caused by excessive damage to the ship's hull structure. Therefore, investing excessive research and development costs in the already stable and reliable hull structure in the short term may not be economically justified. As for the remote control and autonomous operation module, the realization of remote control and autonomous operation of the ship not only requires the ship itself to have a high level of intelligence but also must rely on reliable, stable, low-latency means of communication and an intelligent remote control platform, which is the integrated embodiment of the ship end-ship and shore communication-shore control center. The integration of the ship's intelligence and external intelligent technology, not only by the intelligent ship itself, can be realized independently. Moreover, the inland navigation environment has the characteristics of narrow and long water bodies, which are more limited and complex compared to the marine environment. The safety risk of remote control of inland ships is greater when other intelligent functions are not yet mature. At the same time, there are still many problems with the large number of inland ships, complex ship types, generally low level of advanced system equipment, and the overall quality of crew that still needs to be further improved. In addition, compared to ocean-going vessels, inland ships can always maintain short-distance contact with onshore bases during navigation, and the demand for remote control is weaker than that of ocean-going vessels. Therefore, remote control of ships does not have significant economic advantages in the short term [12].

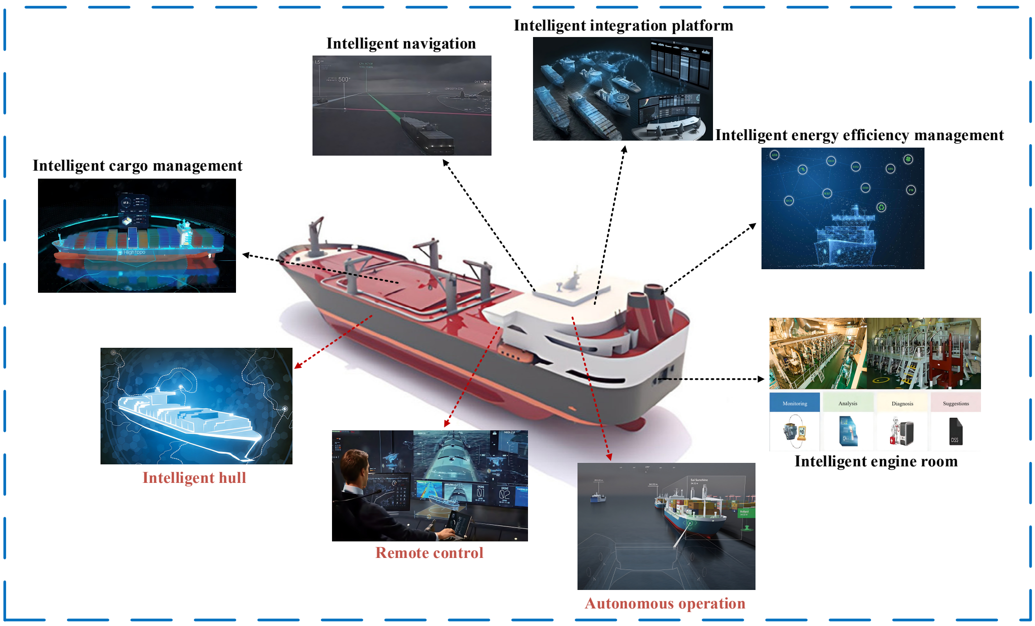

Figure 1. Analysis of functional modules for inland intelligent ships.

3. Intelligent Ship Technology

From the dimension of science and technology, an intelligent ship requires a high degree of integration of information and control, which needs to be supported by a complete technical system. Taking the equivalent replacement of manpower with intelligent functions as the criterion and analyzing it from the perspective of the technical realization path of functional modules, the intelligent ship technology system specifically includes the complete technology chain composed of intelligent perception technology, intelligent communication technology, intelligent evaluation technology, intelligent decision-making technology and intelligent control technology. The details are as follows:

3.1. Ship Intelligent Perception Technology

Perception technology is the basis for realizing ship intelligence, which mainly includes navigation environment information perception, ship state monitoring, information analysis and processing, as shown in Figure 2. Intelligent perception technology utilizes various onboard sensor devices to perceive and monitor information regarding the ship's own state (including dynamic information, hull structural condition, energy efficiency and energy consumption, mechanical equipment and system operation conditions), external environment, cargo and cargo hold condition, etc., and realize the intelligent collection and processing of ship state information data.

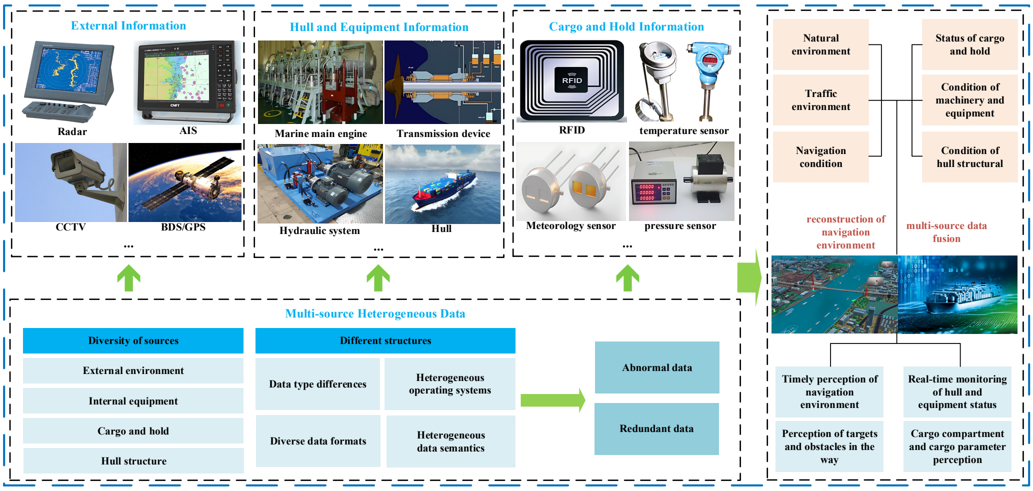

Figure 2. Ship intelligent perception technology diagram.

3.1.1. Navigation Environment Information Perception

Navigation environment information sensing technology mainly utilizes GPS, AIS, radar, depth sounder, motion sensor, wind speed, direction meter, and other sensing devices to obtain various environmental information outside the ship, which provides more reliable data support for subsequent key technologies such as intelligent assessment and intelligent decision-making.

Thompson et al. [13] proposed an efficient LiDAR-based target segmentation method for the marine environment that utilizes 3D occupancy grid segmentation to effectively map large areas. Xu et al. [14] proposed a novel network architecture for small SAR ship target feature extraction and multi-field feature fusion combined with dual-feature mobile processing based on bridge node and feature assumptions, which solved the problem of misdetections and false detections in the detection of small SAR ship targets. Ye et al. [15] proposed an EA-YOLOv4 algorithm with an augmented attention mechanism, which utilizes a convolutional block attention module (CBAM) to search for features in the channel dimension and spatial dimension, respectively, to improve the feature perception ability of the model for ship targets. Hu et al. [16] propose to add the natural image quality evaluation (NIQE) index in the generative adversarial network (GAN) to make the generated image have a better effect than the real image set in the existing dataset, which effectively solves the problems of underwater image distortion, low visibility, low contrast, and other problems.

3.1.2. Ship State Monitoring

Ship condition monitoring involves monitoring the condition of the ship's structure, equipment, and loaded cargo, which can be achieved by collecting parameters related to the ship's hull, engine room, cargo, and energy consumption systems.

Wang et al. [17] introduced machine learning algorithms and proposed a ship's machinery room equipment's condition monitoring method that combines manifold learning and Isolation Forest. By reducing the complexity of the data through dimensionality reduction in raw data, intelligent monitoring of ship machinery room equipment's condition is achieved. Zhuang et al. [18] designed a ship's electromechanical equipment's vibration signal data acquisition system based on wireless sensor networks. This system can collect multi-channel monitoring data in real-time and accurately, improving the accuracy of ship electromechanical equipment's vibration signal detection and analysis capabilities. Hover et al. [19] developed and applied a hull monitoring planning algorithm, dividing the hull into an open hull and complex regions. The open hull part is mapped using integrated acoustic and visual methods, while the complex part achieves high-resolution full imaging coverage of all structures through large-scale planning programs. Zhan [20] developed a ship energy consumption data acquisition and transmission system based on the virtual instrument Labview platform by optimizing the traditional ship energy consumption data acquisition system, which improved the integration degree of the system as well as the accuracy of the energy consumption data. Tong et al. [21] realized the automatic acquisition of parameters such as humidity and gas content of the cabin by installing explosion-proof automatic acquisition and analysis equipment on the dome of the forward part of the cargo hold and achieved the automatic acquisition of parameters such as moisture and gas content of the cabin to reduce the danger of cargo management for LNG carriers. Jiang [22] designed a ship's dangerous goods detection system based on IoT technology, RFID imaging, and other technologies. This system has excellent cargo information acquisition capabilities and can accurately read label information for different categories of dangerous goods for detection. Hu et al. [23] proposed a ship's cargo hold environmental monitoring and control system based on the SSM framework. By integrating Socket monitoring interfaces into the SSM framework, communication between local clients and cloud servers is established, enabling effective monitoring of cargo hold environmental parameters.

3.1.3. Information Analysis and Processing

Information analysis and processing technology involves collecting, organizing, analyzing, and mining data collected through perception using information technologies such as machine learning. This technology helps improve the operational efficiency and safety of ships.

Liu [24] designed and implemented a data conversion algorithm that transforms relational models into XML Schema. Based on this algorithm, a multi-source heterogeneous data integration platform was designed to address the challenges of integrating multiple heterogeneous data sources and dynamic information service patterns in shipping. Chen et al. [25] analyzed the IoT data mining technology of the ship big data platform, reasonably set the content of different functional layers, formed an efficient operation and management chain, and solved the problems of wide data sources and an unstable network of the ship monitoring platform. Liu et al. [26] developed a fuzzy logic-based multi-sensor data fusion algorithm and proposed a two-stage fuzzy logic association method. By integrating it with the Kalman filter, the system's data calculation performance was effectively optimized.

Currently, the application of relevant perception technologies on ships is already widespread. However, in the development process of inland intelligent ships towards 2030, 2035, and even 2050, challenges persist in their application. These challenges include overcoming adverse weather conditions, numerous obstacles in inland waterways, limited detection range, and insufficient accuracy in perception, all of which affect the ability to obtain reliable data. With the enhancement of the ship's sensing ability, the amount of data collected by the ship's sensors will also increase [27], so communication technology needs to be continuously improved with the development of sensing technology.

3.2. Ship Intelligent Communication Technology

Communication technology can further integrate and share the information collected and processed by perception technology, open the channel of information between various systems of the ship, and exchange and communicate the corresponding state information of its own ship with the outside world to realize reliable, stable. and low-latency intelligent data exchange, as shown in Figure 3.

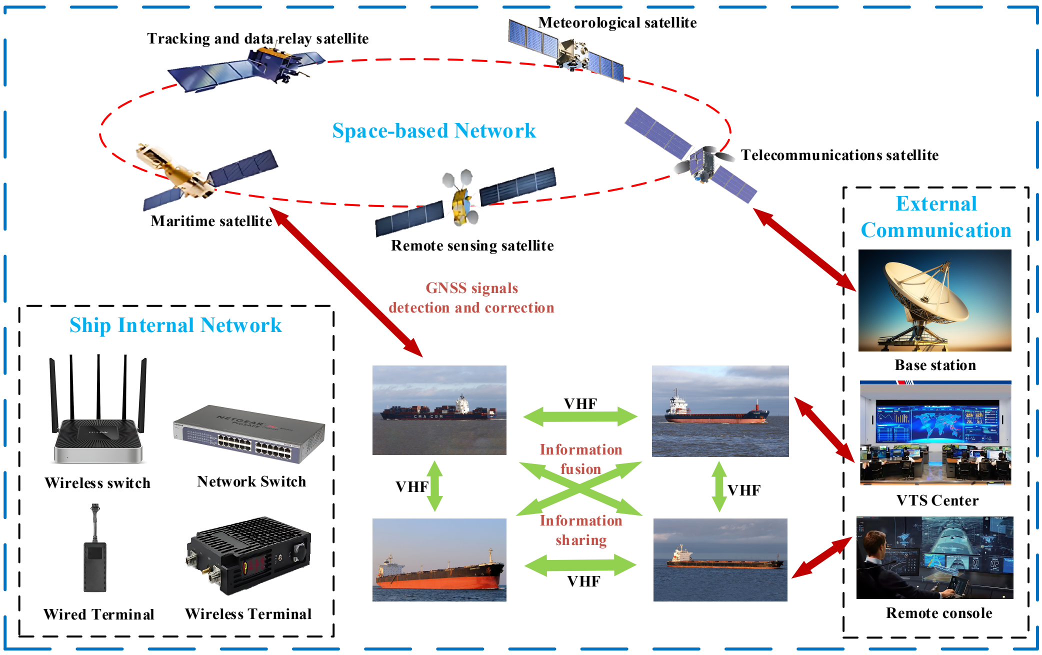

Figure 3. Ship intelligent communication technology diagram.

Zhang [28] proposed an intelligent power allocation algorithm based on deep reinforcement learning (DNN) within the framework of the ship's Internet of Things short packet communication network structure, under the constraint of data transmission security capacity. This algorithm demonstrates good stability in data transmission. Yang et al. [29] introduced a ship communication information transmission channel control algorithm based on an improved bandwidth estimation algorithm. By calculating bandwidth sample values and updating the filtering bandwidth sample value thresholds, intelligent control of the large data transmission channel was achieved. Yoo et al. [30] proposed a distributed state quantization formation design method under a directed network for a low-complexity designated performance control scheme, realizing quantization communication. Cai et al. [31] proposed a marine IoRT system based on deep reinforcement learning and a GEO/LEO heterogeneous network for IoRT data collection and transmission. Data are forwarded to the ground data center through satellite links, achieving seamless coverage and capacity expansion.

Based on the various information data collected by perception technology, communication technology needs to break through the barrier of mutual independence of the data of various systems and equipment and centralize and integrate the information on the external environment, the ship, and the condition of the cargo in order to comprehensively improve the operating efficiency of the ship. In addition, on the inland ships, the fusion of information data and other ships or shore facilities for data exchange, can be more effective coordination between ships in a variety of navigational environments, collision avoidance operations, and ship route planning, berthing and unberthing, loading and unloading of goods and other operations. However, considering the high dynamic changes in the navigation environment of intelligent ships and the large amount of sensor data, etc., the performance of the 5G mobile communication system, which is being vigorously deployed by various countries, is still difficult to satisfy the requirements of intelligent communication for ships; therefore, the research on intelligent communication technology should also focus on new methods and new technologies [32].

3.3. Ship Intelligent Evaluation Technology

Evaluation technology can realize the use of computers to simulate human perception, analysis, thinking, decision-making, and other processes to cognitively calculate the relevant data of each system and the uncertainty, imprecision, and partially real problems, and then make evaluations and give relevant suggestions. It mainly includes navigational posture assessment, hull structure condition assessment, energy consumption and energy efficiency condition assessment, cargo and cargo hold condition assessment, fault diagnosis, etc., as shown in Figure 4.

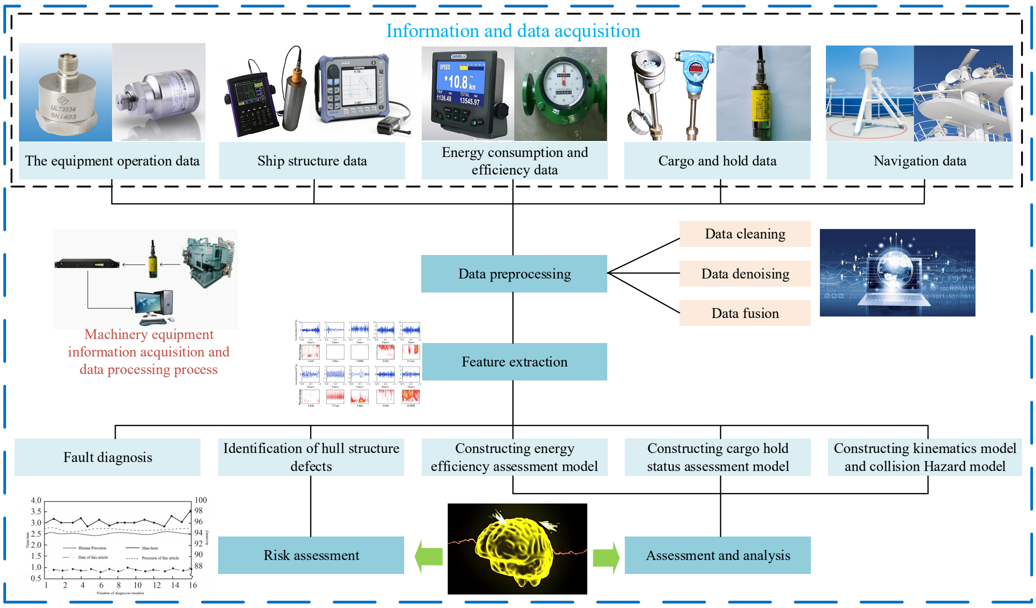

Figure 4. Ship intelligent assessment technology diagram.

3.3.1. Navigational Posture Assessment

Realizing real-time assessment of ship navigation posture is one of the keys to enhancing the navigation safety of intelligent inland ships. Through the equipment information collected by perception technology or the system data obtained by communication technology fusion, using deep learning and other intelligent assessment technology to carry out cognitive computation on the navigation environment in the waters and the attitude of the ship, to make judgments on the real-time encounter situation of the ship, and to make predictions and assessments of the encounter situation in a short period of time in the future through the training of adopting different collision avoidance measures in the current situation and to give appropriate maneuvering suggestions.

Cheng et al. [33] proposed a fuzzy logic model to estimate the adaptability risk of crossing gaps and conducted a collision risk assessment of conflict points in the scenario. The model takes into account the relationship between the adaptive risk of the selected crossing gap and the collision risk of the conflict point, which can reduce the ship operation risk from the source of risk development. Bi et al. [34], using the alpha-shape algorithm and Voronoi diagram, categorized safety assessment indicators for coastal waters into five risk levels: very low, low, moderate, high, and very high. They then applied entropy weight theory to calculate the weights of evaluation indicators, establishing a model for assessing safety risks in coastal waters that fully considers the impact of objective factors and the uncertainty of safety assessment indicators. Chen et al. [35] introduced fuzzy theory into the ship risk assessment model, which can adapt well to changes in heading, speed, and position, to some extent addressing the problem of poor comprehensive evaluation and collision avoidance effectiveness of ships. Xu et al. [36] proposed an intelligent hybrid collision avoidance algorithm based on deep reinforcement learning that can accurately judge the collision situation, give reasonable collision avoidance actions, and realize effective collision avoidance in the complex environment of dynamic and static obstacles. Xin et al. [37] expanded the application of complex network theory and node deletion methods, quantifying the interactions and dependencies between multiple ships in collision scenarios and enabling collision risk assessment at any spatial scale.

3.3.2. Hull Structure Condition Assessment

Ship structural condition assessment involves real-time monitoring of dynamic parameters of the ship's structure to identify key information, such as stress distribution and fatigue damage, and to perform condition assessment and prediction. This technology can effectively enhance ship safety, navigation efficiency, and operational efficiency.

Akpan et al. [38] modeled the corrosion growth as a time-varying stochastic function of the hull structural component thickness reduction over time, used the second-order reliability method (SORM) to calculate the instantaneous reliability of the main hull structure, and put forward a time-varying reliability calculation method for the corrosive structure of the ship based on the hazardous rate function. Wang [39] took the structural condition monitoring system of a new type of polar ship as the research object and gave a set of reasonable measurement point arrangements, load inversion, and strength assessment scheme through theoretical research and computational analysis. Liu [40] based on the design technical indexes of ultra-large ships and the operational characteristics of the actual ship, and combined with all kinds of norms and standards, established an assessment system of the impact of the effects of torsion, thumping vibration, and other effects on the structural safety of the ship's hull, which fills in the blanks of the monitoring norms and assessment standards of the ultra-large ships. Lang et al. [41] established a fatigue assessment model for 2800 TEU container ship based on measured data using machine learning technology, which can accurately capture the nonlinear increase in fatigue. Compared with the traditional spectral method, this method can realize more accurate monitoring of ship fatigue damage.

3.3.3. Energy Consumption and Energy Efficiency Condition Assessment

Ship Energy Consumption and Energy Efficiency Condition Assessment is to realize real-time analysis and assessment of ship energy consumption and energy efficiency by integrating sensors, data acquisition, processing, and intelligent analysis technologies to provide decision-making support for ship management. This technology is of great significance for reducing operation cost, saving energy, and reducing emissions.

Wang [42] adopted the fuzzy set analysis method to form a set pair for ship energy consumption and ideal operating conditions. Comprehensive evaluation results were obtained from the analysis of proximity, uncertainty, and trend levels, addressing the fuzziness and uncertainty issues of factors affecting ship energy consumption evaluation. Fan et al. [43] considered the stochastic nature of environmental parameters and established a new ship energy efficiency model based on the Monte Carlo simulation method, which was applied to ship performance simulation. This facilitated ship managers in evaluating maritime ship energy efficiency, thereby promoting energy conservation and emission reduction in the shipping industry. Wang et al. [44] used Long Short-Term Memory (LSTM) neural network with better prediction performance for a sequential dataset to establish a ship energy consumption prediction model and used a genetic algorithm to optimize the network structure and hyper-parameters, which greatly improved the prediction accuracy of the energy consumption model, which is of great significance for the optimization and improvement of the energy efficiency of ships.

3.3.4. Cargo and Cargo Hold Condition Evaluation

The assessment of cargo and cargo hold conditions primarily relies on the coordinated operation of various sensors and sensing systems. Through real-time monitoring, data processing, predictive assessment, and other means, it achieves a comprehensive understanding and effective management of the condition of cargo and cargo holds.

Gao et al. [45], based on embedded development, collect real-time data on humidity, temperature, oxygen concentration, smoke concentration, and cold well liquid level inside the cargo hold, detect the condition of hatch closure, and capture real-time video information inside the cargo hold, designing a comprehensive cargo hold monitoring system. Lan et al. [46], based on the risk transmission model of the cargo transportation process chain, constructed a model system for risk analysis and quantitative assessment of cargo transportation based on real-time dynamic big data fusion technology, thereby achieving informatization and modern intelligent supervision of the entire process and all aspects of cargo. He [47] proposed a weighted average combined assessment method for the security of critical information in ship cargo hold surveillance video, which uses BP neural network, support vector machine, and extreme learning machine to assess the security of critical information in ship cargo hold surveillance video and improves the results of the assessment of the security of critical information in ship cargo hold surveillance video.

3.3.5. Fault Diagnosis

Fault diagnosis involves analyzing relevant data from various systems to determine if they are in a stable condition. If the equipment is found to be in poor condition, corresponding evaluations are made based on the type and severity of the fault, and alerts or warnings are issued accordingly.

Jiang et al. [48] divided the intelligent fault diagnosis of ship power units into three key stages: data signal acquisition, data feature extraction, and fault identification and prediction. They proposed that the goal should be to achieve condition-based maintenance and health management of ship power units and advocated for establishing a cloud-based data monitoring system. Cheng [49] applied the artificial neural network algorithm from the artificial immune algorithm to diagnose faults in ship electronic equipment, addressing the inefficiency of manual fault diagnosis methods. Ozturk et al. [50] proposed an intelligent fault diagnosis system for ship mechanical systems using a classification tool based on support vector machine principles. Liu et al. [51] designed a convolutional neural network intelligent fault detection optimization algorithm based on frequency domain information features. The algorithm detects a small number of false alarms, but the detection effect is significantly improved compared with the previous one, which can provide a valuable reference for robust fusion of sensors on surface ships. Tang et al. [52] developed a ship engine room remote fault diagnosis system based on a hybrid B/S and C/S architecture for ship power unit fault diagnosis. This system is stable, reliable, and accurate in fault diagnosis, providing a promising solution for the development of intelligent ships.

In the actual operation of inland ships, the ships are less manned, and the assessment of ship intelligence will be beneficial to improve the operational efficiency of the equipment and the navigation safety of the ship, discover the negligence that the manpower fails to discover in time, reduce the maintenance cost, and guarantee the safe operation of the ship. In the subsequent development of ship intelligence, the comprehensive use of intelligent databases and intelligent machine computing, fully expanding the application of artificial intelligence technology in intelligent ships, integrating the advantages of more advanced computer technology [53], more sophisticated instruments, and more efficient expert systems [54], thus enhancing the intelligence level of ship assessment technology.

3.4. Ship Intelligent Decision-Making Technology

Decision-making technology can combine the recommendations made by the assessment technology, comprehensively apply artificial intelligence technologies such as expert databases, neural networks [55], genetic algorithms, machine learning [56], etc., and retrieve databases from the ship or the shore at the same time, intelligently correlate the reasoning and analysis of the ship's historical data, automatically calculate the optimal solution of each solution, and provide the function of visualization and human–machine interaction so as to assist the decision making of the crew or autonomous decision making. It also provides visualization and human–computer interaction functions to assist the crew in decision-making or autonomous decision-making, and realizes the goal of keeping the related systems and equipment in efficient operation. Ship intelligent decision-making technology includes navigation assistance decision-making, hull and equipment maintenance assistance decision-making, energy efficiency management assistance decision-making and intelligent loading assistance decision-making. Among them, the hull structure and equipment are more stable and reliable, so the current research on intelligent decision-making technology mainly focuses on navigation-related decision-making, i.e., route planning and intelligent collision avoidance, as shown in Figure 5.

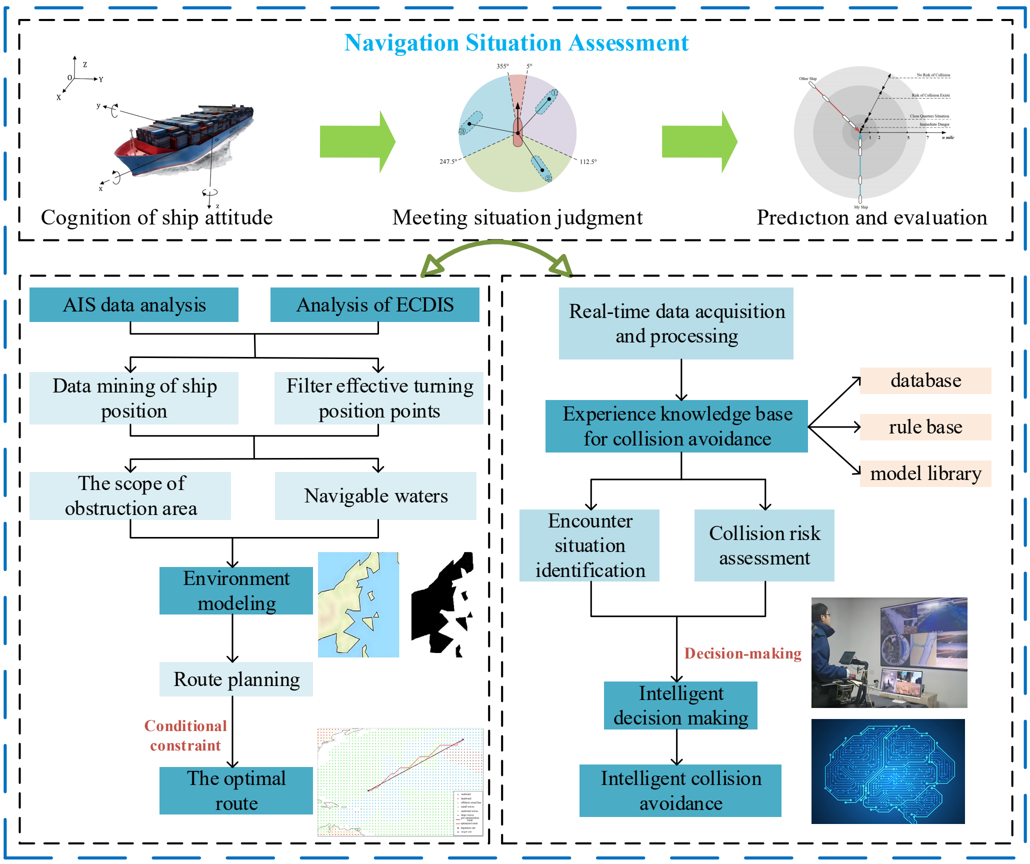

Figure 5. Ship intelligent decision-making technology diagram.

3.4.1. Route Planning

Route Intelligent Planning is a navigation method that obtains real-time traffic and environmental information about the water ahead through various sensors, such as AIS and radar, during navigation and then intelligently selects the ship's position and course within the waterway to optimize the route for safe, efficient, and environmentally friendly navigation.

Liu et al. [57] proposed a hybrid heuristic approach integrating genetic algorithms and particle swarm optimization algorithms to enhance the accuracy and robustness of route planning in constrained waterways. Pan et al. [58] utilized the Delaunay triangulation algorithm to devise a method for adjusting the weights of navigable networks under environmental disturbances, enabling the planning of suitable routes for ships of different scales in various environments. Liang et al. [59] introduced an efficient, robust, adaptive, and implementable route planning algorithm based on leader-node ant colony optimization and a trajectory maintenance control algorithm using nonlinear feedback, enhancing both the efficiency and safety of ship navigation. Ma et al. [60] employed a hierarchical mapping method to separate the decision layer from the weather information layer, directly obtaining route and speed decision schemes conforming to ship maneuverability and crew habits. They proposed a new strategy that simultaneously optimizes ship routes and speeds, significantly reducing the cost of route generation. Zhou et al. [61] proposed a ship path planning method based on historical trajectory data and the SARIMA model, effectively addressing ship collision issues caused by buoy displacement in the navigation of large, slow autonomous ships.

3.4.2. Intelligent Collision Avoidance

Intelligent collision avoidance is the core issue of intelligent ship navigation. Based on the historical trajectory and position, the ship predicts the future course of the ship, evaluates the risk of collision according to the actual situation, and chooses the best time to carry out the automatic collision avoidance operation in order to complete the safe avoidance.

Zhang et al. [62–64] proposed an autonomous decision-making model for complex encounter situations of multi-ship based on the deduction of ship maneuvering process, model predictive control (MPC), modified velocity obstacle (VO) algorithm, and grey cloud model. Wang et al. [65] employed the Twin Delayed Deep Deterministic Policy Gradient (TD3) reinforcement learning algorithm to address the coordinated control problem of unmanned surface ships (USVs) regarding speed and heading. The TD3-IC controller exhibits outstanding robustness and adaptability even in the presence of disturbances and variations in USV parameters. Li [66] combined deep reinforcement learning algorithms with autonomous navigation decision-making technology, proposing an autonomous navigation decision-making algorithm based on an improved Deep Q-Network (DQN) model. By establishing a reasonable state space, a discrete action space, and a comprehensive reward function, this algorithm enhances autonomous navigation decision-making. Xu et al. [67] tackled the intelligent collision avoidance decision-making problem in multi-ship encounters, presenting an improved Sparrow Search Optimization algorithm based on Gaussian mutation and Tent chaotic mapping. This algorithm efficiently finds collision avoidance paths that are safe and economical, providing collision avoidance decision-making references for ship navigators. Zhao et al. [68] devised an autonomous collision avoidance algorithm suitable for intelligent ships based on navigation experience. By constructing a dynamic collision avoidance knowledge base, this algorithm automatically acquires dynamic collision avoidance knowledge, estimates real-time danger assessment thresholds, generates, verifies, and optimizes collision avoidance decision implementation schemes, thus achieving autonomous collision avoidance in intelligent ship navigation. Wang et al. [69] introduced an unmanned ship collision avoidance method based on deep reinforcement learning, incorporating the MMG model to account for ship maneuvering characteristics. This method ensures autonomous collision avoidance in complex environments while complying with COLREG regulations. Wang et al. [70] proposed an autonomous collision avoidance sequential decision-making chain construction method based on humanoid thinking. The construction process involves situational awareness, collision risk identification, collision avoidance rule library and strategy set construction, humanoid thinking sequence collision avoidance strategy generation, collision avoidance process monitoring and strategy adjustment, and restoration of navigational conditions, thereby enhancing the collision avoidance decision-making capability of unmanned ships in multi-ship encounter scenarios.

In the process of intelligent development of inland ships, intelligent decision-making technology can effectively reduce the labor intensity of crew members, mitigate various risks caused by human operational errors, and enable crew members to make the most accurate judgments and achieve the most reliable decisions in the shortest possible time. In order to realize the change in decision-making mode from driver to human–machine integration, the main body of ship control should fully understand and master the information from various sources and make efforts to improve the reliability of the navigational environment situation and the assessment of the operation condition of the system and equipment. Through in-depth research on quantitative techniques of collision avoidance rules and good seamanship, the safety and reliability of intelligent decision-making on ships can be improved.

3.5. Ship Intelligent Control Technology

The control technology can realize intelligent control such as route speed optimization, system and equipment maintenance, energy efficiency control, and automatic loading/unloading based on the optimized loading/unloading scheme under different navigation scenarios and complex environmental conditions through the corresponding decision-making scheme, as shown in Figure 6.

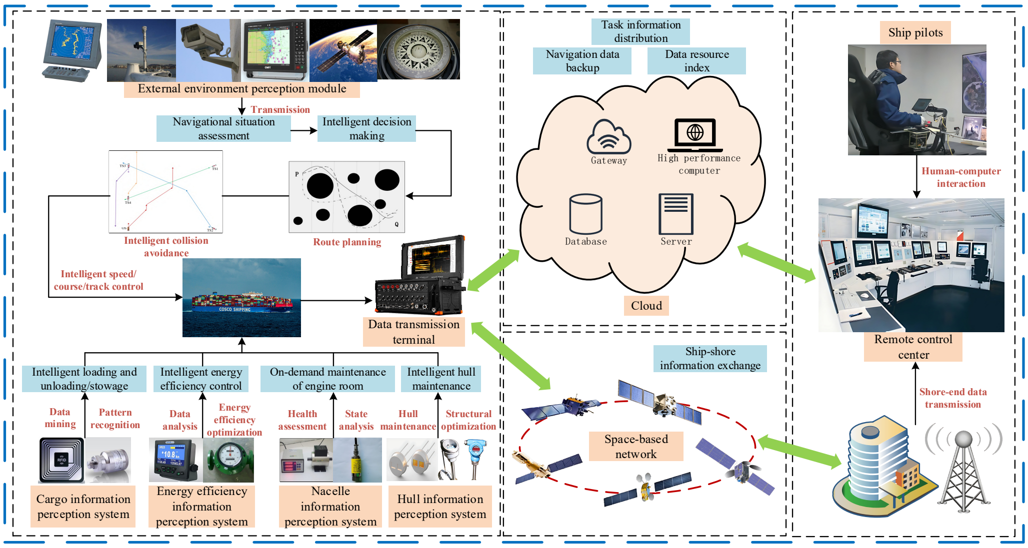

Figure 6. Ship intelligent control technology diagram.

3.5.1. Motion Control

Intelligent ship motion control refers to the use of intelligent technology and electronic technology to control the ship's motion, including heading, speed, attitude angle, and other parameters, in order to improve the ship's automation and intelligence level.

Wu et al. [71] employed the MMG separation model to establish a mathematical model for twin rudder twin propeller interference ships under marine navigation conditions. They proposed an improved practical tool for nonlinear control systems called CMAC-VPID, achieving trajectory control for twin-rudder twin-propeller ships. Teng et al. [72] proposed a hierarchical model predictive control (H-MPC) tracking method combining model predictive control (MPC) and hierarchical control, which effectively achieves intelligent ship tracking of target ships. Considering wind and wave disturbances, Liu et al. [73] transformed them into equivalent rudder angles generated by the ship and proposed an ITCA algorithm combining the Nomoto model and sliding mode control, capable of automatically stabilizing berthing according to the ideal heading angle in undisturbed conditions. Li [74] addressed the design problem of the guidance subsystem under time-varying environmental disturbances and proposed an integral parameter adaptive ILOS guidance law, providing a rational and effective theoretical optimization method for the practical application of intelligent ships in engineering. Pham et al. [75] combined neural networks with fuzzy logic control to design an autonomous ship steering system operating in disturbed environments. They selected an ANFIS controller, significantly enhancing system stability and trajectory accuracy.

3.5.2. Remote Control

Remote control refers to the use of technologies such as positioning navigation, auxiliary control, and beyond visual line of sight operation to manipulate ships from an onshore control center or other remote locations.

Yoshida et al. [76] improved the methodology for developing a regulatory framework for RO capability by applying a typical case to a remote control system based on the previous work. It identifies the trend of ship-perceived failures and provides the required information and additional requirements. Basnet et al. [77] integrated models such as Noisy-OR gates, Parent-divorcing, etc., and proposed a new risk analysis method by combining the improved STPA with BN, which can provide reliable support for real-time decision-making by remote pilotage. Chen et al. [78] proposed a delay-compensated state estimation method for remotely controlled ships with uncertain delay navigation measurements. This method effectively improves the stability and effectiveness of remote control.

3.5.3. Energy Efficiency Control

Energy efficiency control refers to the optimal management of energy consumption and emissions of ships through intelligent technical means, which is an important means to realize energy savings and emission reduction in ships and improve operational efficiency.

Perera et al. [79] identified potential energy-saving scenarios during ship operation based on proposed energy flow pathways. They also discussed the use of appropriate navigation strategies within designated ECAs to reduce exhaust emissions. Wang et al. [80] established dynamic optimization models for ship energy efficiency, considering time-varying environmental factors and non-linear ship energy efficiency systems, and designing control algorithms and controllers for dynamic optimization of ship energy efficiency. This method effectively enhances ship energy efficiency and reduces CO_2 emissions. Guo [81] aimed to reduce the energy efficiency ratio of ship energy efficiency control systems effectively. He established a distributed ship energy efficiency data collector using distributed data collection technology to optimize the distribution of energy efficiency data collection resources. Chen et al. [82] developed a hybrid optimization algorithm combining the chaos algorithm with GWO to design a nonlinear model predictive control energy management strategy. This strategy maximizes optimality to achieve rational energy distribution.

3.5.4. Automatic Loading and Unloading and Intelligent Stowage

Automatic loading and unloading along with intelligent cargo stowage refer to the idea and method of simulating the dock dispatcher through artificial intelligence algorithms, etc., and realizing the automation and intelligence of ship loading, unloading, and dispensing by taking into account the situation of the equipment, the state of the stacks, etc.

Qin et al. [83] proposed a pseudo-gradient estimation algorithm based on the multi-innovation theory and a model-free control law based on multi-innovation. They developed specifications for open-loop control system based on the characteristics of liquid cargo loading and unloading systems and constructed the software and hardware framework OCSSLA for liquid cargo loading and unloading systems, which partially addressed key issues in intelligent control systems for liquid cargo loading and unloading. Liu [84] considering both ship safety and economy, established a multi-objective constrained optimization mathematical model for bulk carriers with ship trim control as a constraint. The intelligent loading of bulk carriers fully utilizes the computational power of computers, compensating for the deficiencies of traditional manual loading. The loading plans provided effectively improve the longitudinal force situation of the ship. Wang [85] based on practical work experience, proposed a method to inspect ship loading conditions using NAPAMANAGER, achieving automatic inspection of ship loading conditions.

3.5.5. Hull and Equipment Maintenance as Needed

Maintenance according to the condition of the hull and equipment, that is, based on the assessment results, to develop a reasonable safety management maintenance plan and optimization program, and through the maintenance management system to achieve effective maintenance of the hull and equipment. It is of great significance in reducing maintenance costs, improving navigation safety, and extending the life of equipment.

Hou et al. [86] utilized graph theory to establish a mathematical model of diesel engine systems. Building upon intelligent damage assessment and reconstruction algorithms, they designed an intelligent damage assessment and reconstruction system for damaged diesel engine systems based on UML and implemented it in the VB programming environment. This significantly enhances the usability, survivability, and safety of ships. Yan [87], through the analysis of vibration signals from diesel generators, constructed a probabilistic neural network model for identifying faults in diesel generators. Based on the health assessment and fault identification of ship diesel generators, intelligent operational maintenance management strategies were formulated, establishing a modern ship health management and intelligent operation and maintenance system. Hong et al. [88], leveraging digital twin technology and big data analytics, implemented a remote operation and maintenance system for ship intelligence. They established a comprehensive analysis of real-time operating condition, fault prediction, and situational maintenance virtual interaction models for key ship equipment, forming an effective equipment health management system.

For the action program after decision-making, the control technology will be able to execute specific operations to practice. The research on inland intelligent ships is by no means an overnight success but requires long-term R&D investment and experience accumulation, and the degree of intelligence of the ship will be gradually and progressively enhanced. In the recent development process, the crew in the ship to support decision-making and control will still be the main way, intelligent control technology or will rely on robots, drones, and other advanced technology [89], by being able to replace some of the manpower as the goal and then realize autonomous decision-making and control.

Currently, with the continuous development of artificial intelligence, big data, the Internet of Things, and other high-tech scientific and technological fields, the application of intelligent ship technology needs to follow the trend of modern science and technology development, combined with the existing advanced technology to carry out a wider range of in-depth use and integration, and continue to create a more practical and efficient new technologies to achieve the full coverage of the intelligent ship functional requirements of the technology chain, this can be specified by the illustration shown in Figure 7.

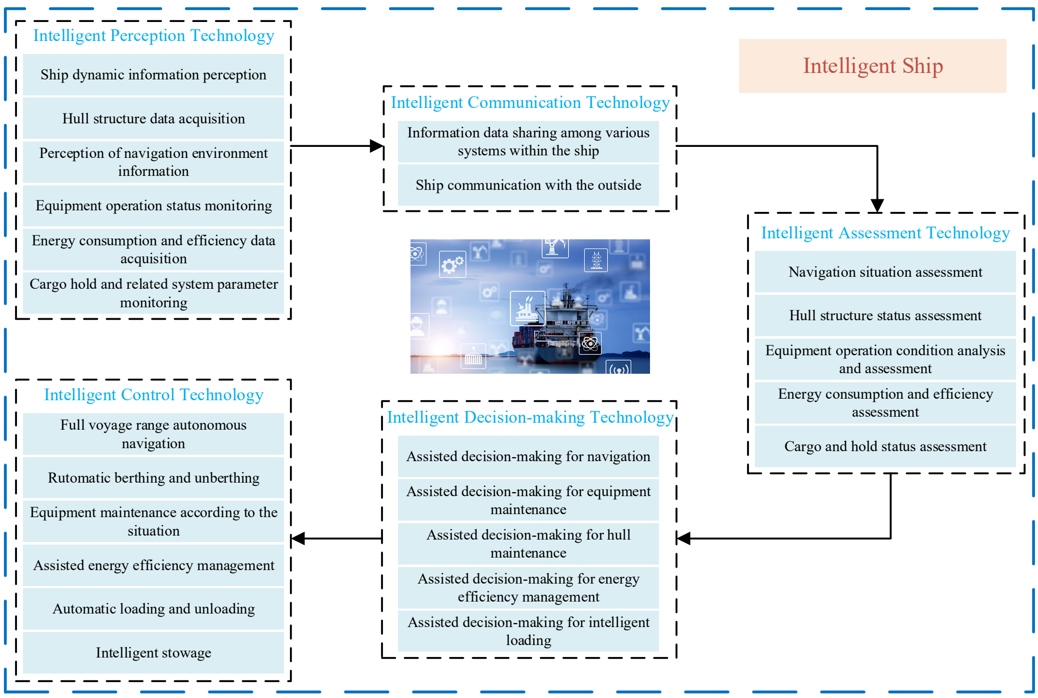

Figure 7. Intelligent ship technology chain.

4. Inland Intelligent Ship Functional Requirements Forecast

4.1. Association between Inland Intelligent Ship Functions and Intelligent Technologies

The intelligent function of inland ships is the application of intelligent ship technology. The development of intelligent technology requires the accumulation of time, and the development of intelligent ships must also follow the objective law of gradual and phased development. The development of inland intelligent ships must be based on the objective development law of intelligent technology: the degree of intelligence from assisted decision-making gradually transitions to full autonomy, and the scope of intelligence follows the direction of development from individual systems to parts of the system and then to the whole ship.

4.2. Overall Development Goals of Inland Intelligent Ships

China generally formulates a development strategy for a period of five years. Currently, China is in the final stage of the 14th Five-Year Plan (2020–2025), so we chose the next Five-Year Plan (2026–2030) as the first stage of the development of inland intelligent ships. At the same time, the Chinese government has issued development planning documents such as the "Outline for the Development of Inland Transportation [90]" and the "Implementing Opinions on Accelerating the Green and Intelligent Development of Inland Ships [91]", which sets strategic development goals related to inland shipping and intelligent inland ships for 2030, 2035, and 2050. Therefore, we chose 2030 as the short-term development planning node for inland intelligent ships and 2035 and 2050 as the mid-term and long-term planning nodes, respectively.

Based on the current situation of China's inland ships, the development plan for inland shipping and intelligent ships formulated by the Chinese government, as well as domestic and international trends in intelligent technology. Based on normative technical documents such as the "MASS Code "and the "Rules for Intelligent Ships (2024)", we make functional predictions for intelligent inland ships in China at different stages of development.

The development of inland intelligent ships in the near future (to 2030) will still be dominated by modularized intelligent aids and focus on the five key functional modules, namely, intelligent navigation, intelligent engine room, intelligent energy-efficiency management, intelligent cargo management, and intelligent integration platform, in order to ensure efficient utilization of scientific and technological resources. In the medium term (towards 2035), the functions of each module should be more perfect, stable, and reliable, and progress has been made in the intelligent hull module, which can realize the linkage of multiple intelligent modules of the ship and the formation of a new shipping industry characterized by full intelligence. In the long-term development plan facing 2050, remote control and fully autonomous control functions will be realized, and the eight functional modules mentioned in the "Rules for Intelligent Ships (2024)" will be comprehensively covered so as to form the global intelligence and high degree of intelligence of inland ships, as shown in Table 2.

Table 2. Overall prediction of functions for inland intelligent ships.

Development Stage	Planning Year	Overall Prediction of Intelligent Functional Goals	Functional Module
Near Term	2030	Modular intelligence, primarily at an initial level with assistance	Intelligent Navigation, Intelligent Engine Room, Intelligent Energy Efficiency Management, Intelligent Cargo Management, Intelligent Integration Platform
Mid Term	2035	Multi-intelligent module linkage, intelligent level advancement	Addition of intelligent hull module
Long Term	2050	Global intelligence, highly intelligent	Addition of remote control and autonomous operation modules

4.3. Specific Development Goals and Predictions for Inland Intelligent Ships at Different Stages

In the near-term development of inland intelligent ships towards 2030, inland intelligent ships should be able to realize local modularized intelligence, and the required functional modules mainly focus on navigational safety and green and efficient operation, which specifically include five functional modules: intelligent navigation, intelligent engine room, intelligent energy efficiency management, intelligent cargo management, and intelligent integration platform, as shown in Table 3.

Table 3. Forecast of inland intelligent ship functionality requirements for 2030.

Functional Module	Goal of Intelligence	Division of Intelligent Functional Stages
Intelligent Navigation	Achieving reliable ship situational awareness and environmental information perception, equipped with route planning functionality	(1) Intelligent perception function (2) Monitoring function for ship's floating state and dynamic motion (3) Design optimization function for route and speed
Intelligent Engine Room	Achieving monitoring, diagnosis, and evaluation of ship engine room condition and equipment operation, and providing intelligent decision support and maintenance plans based on problem types	(1) Engine room condition monitoring function (2) Engine room equipment health assessment function (3) Engine room auxiliary decision-making function (4) Engine room condition-based maintenance function (5) Remote control of the main propulsion device from the wheelhouse and periodic unmanned watchkeeping capability
Intelligent Energy Efficiency Management	Assessing the ship's energy efficiency, navigation, and loading condition to provide evaluation results and solutions such as speed optimization and optimal loading based on longitudinal trim optimization	(1) Ship energy efficiency online intelligent monitoring function (2) Ship speed intelligent optimization function (3) Optimal loading function based on trim optimization
Intelligent Cargo Management	Monitoring of cargo condition onboard and related systems, combined with the ship's cargo condition and port terminal condition, to achieve formulation and optimization of loading/unloading plans, as well as process risk alerting and decision-making	(1) Function of sensing the condition of cargo, cargo holds, and related systems (2) Function of formulating and optimizing cargo loading/unloading plans (3) Function of alarm for abnormal states, analysis of causes, and formulation of assisted decision-making
Intelligent Integration Platform	Complete the standardization of interface types for various intelligent modules within inland ships, enabling the integration of existing module information of intelligent ships, with the integration platform being open-ended	(1) Integration of local area network systems within the ship (2) Formation of a unified digital twin system by various intelligent modules (3) Preliminary data processing function (4) Integration of information and data between existing modules

In the mid-term development phase of inland intelligent ships towards 2035, it is predicted that it will mainly realize the perfection of single-module intelligent function and multi-modular intelligent function linkage. The functional modules at this stage mainly include intelligent navigation, intelligent hull, intelligent engine room, intelligent energy efficiency management, intelligent cargo management, and intelligent integration platform, as shown in Table 4.

Table 4. Forecast of inland intelligent ship functionality requirements for 2035.

Functional Module	Goal of Intelligence	Division of Intelligent Functional Stages
Intelligent Navigation	Achieve the intelligent motion requirements of various ships for safe and efficient navigation, anchoring, and berthing/departing in various navigation scenarios	(1) Integration of multiple functions of the 2030 intelligent navigation module (2) Autonomous navigation function for regular routes (3) Fully autonomous navigation function for the entire navigation (4) Automatic berthing and unberthing
Intelligent Hull	Achieve three-dimensional modeling and maintenance of the hull, providing auxiliary decision-making for the maintenance and replacement of hull and deck machinery during the operational phase of the ship	(1) Hull structure and deck machinery monitoring function (2) Formulation of hull structure and deck machinery maintenance plans (3) Record and evaluation of hull structure condition (4) Formulation of structure replacement plans
Intelligent Engine Room	Achieve fully autonomous operation and realize the goal of a fully intelligent engine room system	(1) Integration of multiple functions of the 2030 intelligent engine room module, adapting to the development of engine rooms in new energy-powered ships (LNG, electric, etc.) (2) Continuous normal operation of engine room equipment within unmanned duty cycles
Intelligent Energy Efficiency Management	Achieve real-time monitoring, evaluation, and optimization of ship energy efficiency, realizing the goal of complete intelligence	(1) Integration of multiple functions of the 2030 intelligent energy efficiency management module (2) Fully automated energy efficiency management
Intelligent Cargo Management	Implement fully intelligent cargo management, including automatic generation and optimization of cargo stowage plans, as well as autonomous loading and unloading	(1) Integration of multiple functions of the 2030 intelligent cargo module (2) Automatic generation and optimization of cargo loading plans (3) Automatic loading and unloading functions (4) Intelligent ballast water management functions
Intelligent Integration Platform	Integrate the newly added information management system with the capability of data exchange among multiple modules	(1) Integration of multiple functions of the 2030 intelligent integration platform module (2) Ship-shore information data communication (3) Information data communication among multiple modules

In the long-term development phase of inland intelligent ships towards 2050, according to the current pace of development in artificial intelligence, the Internet of Things, big data, and other technologies, it is expected that significant progress will have been made in inland intelligent ships. It is anticipated that the ultimate functions of remote control and autonomous operation will be achieved. Remote control of ships refers to the ability of a ship to be controlled by a remote control station or position outside the ship, enabling the ship's operation. Autonomous operation of ships refers to the ability to achieve fully autonomous operation in open waters or throughout the entire navigation without the need for onboard crew operation. Both functionalities require the foundation of the aforementioned intelligent modules to fulfill their roles effectively. The functional modules at this stage mainly include the intelligent hull, intelligent integration platform, remote control, and autonomous operation of ships, as shown in Table 5. In this stage, the intelligent navigation, intelligent engine room, intelligent energy efficiency management, and intelligent cargo management modules should have already been fully implemented and integrated into the intelligent integration platform, thus no longer requiring separate discussion.

Table 5. Forecast of inland intelligent ship functionality requirements for 2050.

Functional Module	Goal of Intelligence	Division of Intelligent Functional Stages
Intelligent Hull	Achieve the goal of fully intelligent ship hull, including self-diagnosis, and autonomous handling capabilities	(1) Integration of multiple functions of the 2035 intelligent hull module (2) Local strength monitoring of the hull, real-time monitoring of overall longitudinal strength, and stability calculation (3) Intelligent adjustment of ballast water, heading, and speed to ensure the ship is always in a safe state (4) Fully autonomous hull maintenance and upkeep
Intelligent Integration Platform	Realize comprehensive monitoring and intelligent management of various ships, including engineering and research ships, and achieve real-time two-way data exchange with shore-based systems	(1) Integration of multiple functions of the 2035 intelligent integration platform module (2) Information sharing and presentation function (3) Providing support for other intelligent applications on the basis of meeting its own information display and data diagnosis functions
Remote Control	Capable of being controlled by a remote control station or control position outside the ship, enabling unmanned operation of the ship	(1) Stable and applicable wireless communication equipment for ships with sufficient bandwidth (2) Beyond-line-of-sight control, scene perception, and real-time sharing of video information (3) Intelligent detection, alarm, and control processing functions
Autonomous Operation	Fully autonomous operation throughout the entire navigation	(1) Achieve fully autonomous navigation and comprehensive analysis decision-making from berth to berth (2) Real-time monitoring, evaluation, decision-making, and intelligent control of all ship systems

5. Conclusions

This paper systematically examines the current status of the division of intelligent ship function modules by international major classification societies, shipbuilding companies, and organizations such as the European Union and analyzes the required function modules for intelligent inland ships. From the perspective of the technological implementation of intelligent functions, a complete intelligent ship technology system is constructed, including intelligent perception technology, intelligent communication technology, intelligent evaluation technology, intelligent decision-making technology, and intelligent control technology. Through in-depth analysis of the technological connotation, it can be concluded that these five modules are all necessary key technologies and critical for realizing the intelligence of inland ships and are of great significance for the development of intelligent inland vessels and inland navigation. Taking into account the current situation of China's inland ships, the development plans on inland shipping and intelligent ships issued by government departments, and the development trend of intelligent technology, the functional requirements of intelligent inland ships in the near, medium, and long term are predicted. This article can provide suggestions for the development of intelligent inland ship implementation strategies in China and other regions of the world.

Ship intelligence is an inevitable trend in the development of the shipping industry. At present, the application of inland navigation is uncommon, and the intelligent development of inland ships based on intelligent technology is still in the primary stage. Sorting out the demand for intelligent functions and the many bottlenecks faced in the process of future intelligent development is conducive to clarifying the development direction of inland intelligent ships and promoting the development of inland intelligent ships in an orderly manner.

Realizing the ultimate goal of fully autonomous navigation of intelligent ships not only requires the ships themselves to have a high level of intelligence but also requires the joint progress of multiple supporting technologies such as shore-based platforms, network communications, intelligent waterways, and intelligent ports. Therefore, multiple technologies should integrate and promote each other, and then jointly promote the formation of high-quality shipping systems.

In addition, in terms of the development of intelligent ships on inland waterways in terms of laws and regulations, management mechanisms, production benefits, and other aspects of the same, there are many problems to be further standardized and breakthroughs. The next step also needs to be coordinated by some parties to coordinate the conflict of interest between the application of technology and market demand and steadily promote the development of ship intelligence.

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