Design and Implementation of Navigational Aid Telemetry and Remote Control System Based on Wireless Sensor Network and AIS

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Abstract. Navigational aid systems, as a critical component of the maritime traffic safety assurance system, play a pivotal role in ensuring the accuracy of navigational aid information, thus meeting the navigational safety needs of vessels. This paper designs a navigational aid telemetry and remote control system based on wireless sensor networks and the Automatic Identification System (AIS). The system comprises three main parts: the communication system, navigational aid telemetry and remote control terminal, and navigational aid telemetry and remote control monitoring center. Implementation includes aspects like navigational data management, GIS platform for navigational information, and database operations. This designed system has been applied in waterway management to ensure the safe navigation of vessels.

Keywords: Telemetry and Remote Control System, Navigational Aid, Ais, Wireless Sensor Network, System Design

1 Introduction

Navigational aids, as critical facilities that provide safety information for various aquatic activities, are intricately linked to the maritime safety of vessels. However, traditional navigational aids have relatively limited functionality. They mainly provide basic visual navigation and cannot transmit channel data to vessels. Additionally, there's a lack of understanding of the operational status of these aids, and they cannot effectively address issues, exhibiting some limitations. The telemetry and remote control system for navigational aids primarily refers to a system based on communication with the aids to enable long-distance surveillance, control, and measurements. This system consists of three main components: the communication system, data acquisition terminal, and the monitoring center. For regulatory authorities of navigational aids, utilizing this system allows for swift and remote identification of navigational aid malfunctions. Timely dissemination of information on these aids can improve management efficiency and effectiveness, reduce maintenance costs, enhance the stability of navigational aids operations, thereby ensuring maritime safety for vessels [1-2].

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As for the research on the telemetry and remote control system of navigational aids, there are relatively few international reports, mainly focusing on waterway maintenance management. For instance, in their research, Argeseanu S. and others believe that by using this system, they can understand and monitor the operational status of navigational aids. In the event of anomalies, timely alerts can be issued, providing reliable information for waterway departments to restore the normal operation of navigational aids and thus ensuring safe navigation. Stephen M. and Xuan H., in their literature reports, pointed out that ships failing to accurately and timely obtain information from navigational aids could often lead to maritime accidents. The telemetry and remote control system for navigational aids is a modern real-time remote monitoring system designed to meet the maritime department's needs for navigational aids supervision. However, the current system in our country is still in the early stages of research and trial, facing several issues like low data transmission success rates, poor waterproofing techniques, impractical design features, frequent false alarms, and high power consumption. Therefore, to improve the existing management methods of the navigational aid telemetry and remote control system, and to reduce the power consumption of the navigational aid terminals, this paper designs an efficient, low-power system based on AIS and wireless sensor networks. We also analyzed the components and functions of this system, as detailed below.

2 Design Requirements of the Navigational Aid Telemetry and Remote Control System

In the realm of waterway information, the telemetry and remote control system for navigational aids is a critical source. The system has high standards in several areas, such as response speed, safety, information processing, reliability, and scalability. The specifics are as follows:

(1) Safety: Based on the characteristics of the navigational aid telemetry and remote control system, its safety requirements primarily revolve around network and application security. The former typically arises from the physical isolation between internal and external networks, where higher authorities have stringent requirements, ensuring the safety of all users accessing the waterway network. The latter is due to the system involving various institutional types of users, such as waterway bureau authorities, grassroots waterway departments, and waterway stations. Thus, its user management permissions need to be flexible [3].

(2) Scalability: The current application of navigational aid telemetry and remote control technology is limited and still in its developmental phase. As business needs continuously expand, the system needs to be further refined. Therefore, the system architecture requires high scalability. It also needs to have certain developmental flexibility to facilitate the addition of new application modules or the deployment of business systems on existing software platforms [4].

(3) Reliability: Given the various natural environmental factors, some telemetry and remote control terminals for navigational aids operate in extremely harsh environments and are often unattended. This necessitates high reliability requirements: ① Anti-theft capability, featuring theft alarm measures. ② Interference resistance, meaning equipment can suppress the influence of external electromagnetic fields. ③

Performance margin, ensuring that the performance indicators of various materials and components have a surplus. ④ Environmental adaptability, boasting strong anti-corrosion and waterproof features, can withstand the impacts and vibrations of strong winds and waves at sea and have good adaptability to the natural environment [5].

(4) Response Speed: From the moment a navigational aid shows an anomaly to the system receiving automatic alarm information, the time should be less than 3 minutes. Furthermore, for any control commands or information requests sent by the navigational aid, the control response time should be within 3 minutes.

(5) Information Processing: Based on the current navigational aid management business needs, the telemetry and remote control system can monitor the status of navigational aids in real-time and keep records. Under usual circumstances, navigational aids operating normally should submit data to the monitoring center four times a day. In cases of anomalies, like voltage instability, light quality errors, or collisions causing navigational aid displacement, the system should send alert messages to the command center until the situation returns to normal.

3 Overall Design of the Navigational Aid Telemetry and Remote Control System based on AIS and Wireless Sensor Networks

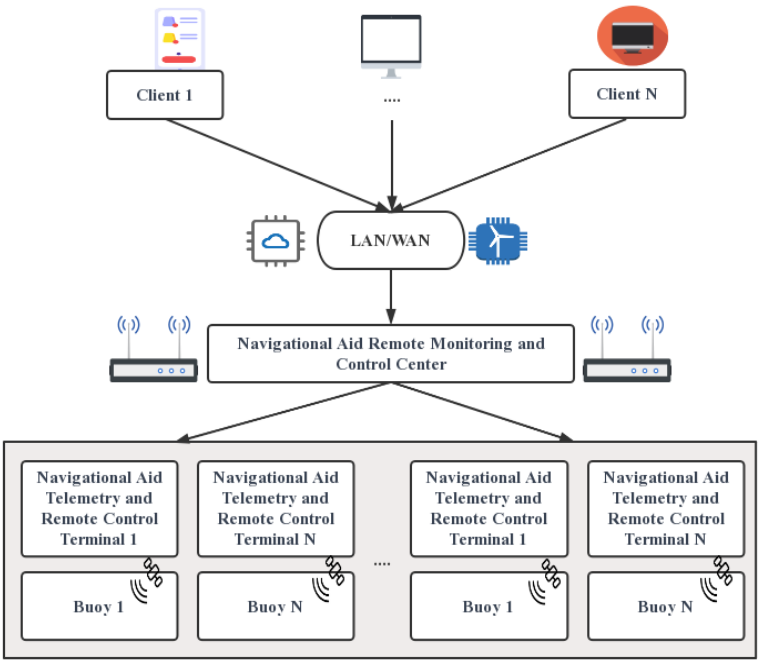

Fig.1 Overall Framework of the Navigational Aid Telemetry and Remote Control System

In this study, there are three components that make up the navigational aid telemetry and remote control system: the telemetry and remote control monitoring center for navigational aids, the telemetry and remote control terminal for navigational aids, and the communication system, as shown in Figure 1.

The client-side of this system sets its functional positioning, content query, and query permissions based on the telemetry and remote control monitoring center for navigational aids. Within the telemetry and remote control system for navigational aids, the telemetry and remote control terminal is a crucial component and serves as a platform for collecting basic data. It handles the transmission, control, and collection of navigational aid equipment operating parameters and executes remote control commands issued by the monitoring center. The communication system, pivotal within the telemetry and remote control system, primarily controls the data for navigational aid commands and transmits operating parameters. Typically, the monitoring center needs to collect command data from the telemetry and remote control terminal, process this data in various ways like display, storage, printing, alerting, editing, archiving, and submission. It utilizes a graphical user interface to analyze, query, and monitor the operation information of navigational aids. It then sends remote control commands to various telemetry and remote control terminals, controlling and inspecting the operating status of navigational aids. Moreover, the database at the telemetry and remote control monitoring center facilitates data sharing between systems and provides operational information of navigational aids to the national navigational aid monitoring system, especially offering remote login services for clients [6-7].

By integrating with two wireless networks, the navigational aid telemetry and remote control system based on AIS and wireless sensor networks can leverage the strengths of each network, enhancing the working efficiency of the telemetry and remote control system. The main operating principle is: in a particular region, using a wireless sensor network as the basis, the AIS in the network's central node can send and receive systems, completing communication between AIS base stations and wireless sensor networks. The AIS base station can receive navigational aid information, then relay maritime information to the monitoring center. The center, using maritime monitoring management software, can send commands to navigational aid terminals, achieving telemetry and remote control functions [8].

3.1 Software Design

This system is made up of multiple modules, including the communication servo system, business management system, electronic waterway map display system, and data & system management system. Based on actual requirements, corresponding subsystems can be added or removed, as shown in Figure 2. Their specific functions are as follows:

(1) Business Management System: This pertains to system user authority management, business processing, and navigational aid terminal information management. This includes functionalities like historical trajectory playback for the navigational aid terminal, alarm handling, real-time work parameters and status query, data transmission, command sending, and remote settings [9].

(2) Data & System Management System: Primarily for storing and processing navigational aid terminal data.

(3) Electronic Waterway Map Display System: The electronic waterway map is a visual electronic display platform that can vividly showcase the dynamic changes and location information of navigational aids. It can also query the working status, working parameters, etc., of the navigational aid terminal [10].

(4) Communication Servo System: Its communication part consists of two segments: communication with other systems and communication with the navigational aid terminal. This involves using the navigational aid terminal to issue various commands and uploading information from the navigational aid terminal.

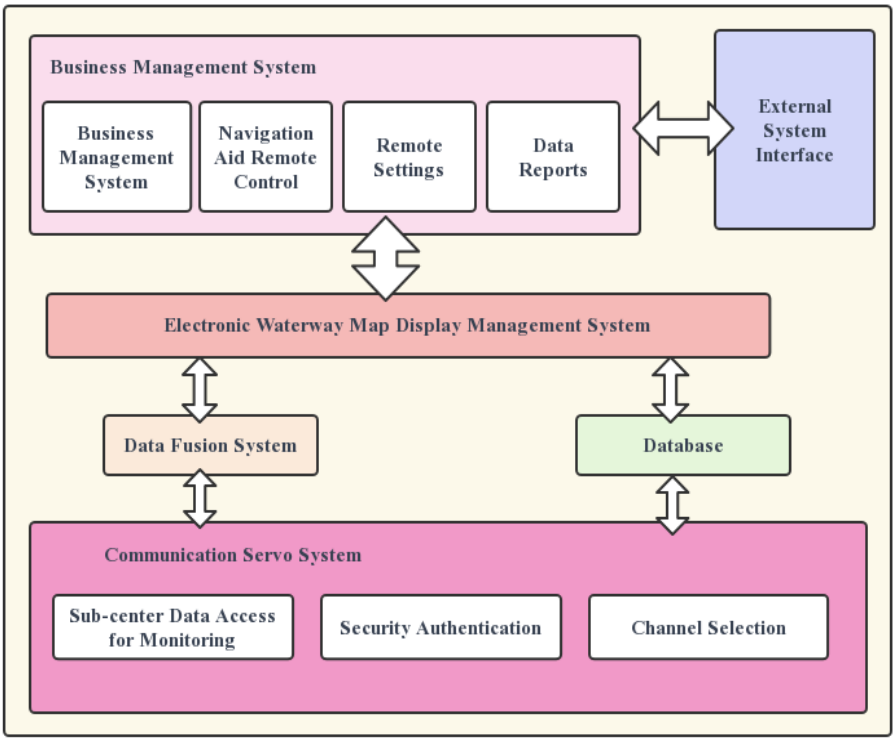

Fig.2 Software Structure Diagram of the Navigational Aid Telemetry and Remote Control Monitoring Center

3.2 Design of Navigational Aid Telemetry and Remote Control Terminal

Based on the wireless sensor network and AIS, this study proposes a navigational aid telemetry and remote control system. There are primarily two types of navigational aid terminals: the central node and the Zigbee navigational aid terminal. The former is a navigational aid terminal that integrates Zigbee with AIS. The composition of the Zigbee wireless sensor network includes one central node and multiple ordinary nodes. The telemetry and remote control terminal for navigational aids consists of two parts: the information collection board, and the power management and communication board. The former includes collecting work information of the navigational aid, terminal power distribution, connection to the navigational aid light, and the collection of RS-485 related information. It also encompasses the ARM main control module, power module, voltage and current collection, acceleration module, EEPROM, information input module, RS-485 communication module, and GPS module. Meanwhile, the content of the communication board involves transmitting wireless data, including the AIS communication board and Zigbee communication board. The AIS communication board is responsible for the Zigbee network operation and AIS communication. The central node contains the AIS communication board, distinguishing it from ordinary nodes, as illustrated in Figure 3.

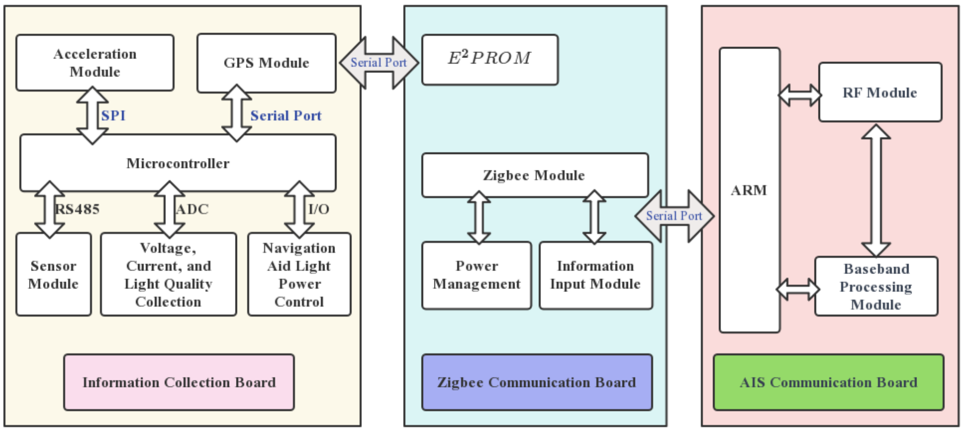

Fig.3 Structural Framework Diagram of Navigational Aid Telemetry and Remote Control Terminal based on AIS and Wireless Sensor Networks

The functionalities that this navigational aid telemetry and remote control system terminal aims to achieve include: (1) Communication between the Zigbee wireless sensor network and AIS shore base. (2) Completion of the Zigbee underlying protocol and networking of the navigational aids. (3) Storing navigational aid information in EEPROM at specific intervals. (4) Collecting daylight values and linking them with daylight thresholds and operating currents, and determining if an alarm is necessary. (5) Using the information read about light quality and the operating status of the navigational aid light as a basis. (6) Periodically reading the current and voltage of the navigational aid's storage battery to understand and monitor the operating current and voltage of the navigational aid light. The current and voltage of the navigational aid's solar panel can be reported. If an anomaly is detected, an AIS12 alarm is triggered, which ceases once the monitoring center responds. (7) The capability to collect the impact acceleration of the buoy. Once the impact is understood, it reports using the AIS6 message. In case of anomalies, the speed of the navigational aid is contacted. If both show anomalies, an AIS12 alarm message is triggered, which stops once a response is received. (8) Parsing the differential GPS information present in AIS17 message and configuring the GPS module ET662. (9) The ability to collect the buoy's latitude, longitude, movement direction, and speed, and report the status using the AIS6 and AIS21 messages.

3.3 Implementation of the Navigational Aid Telemetry and Remote Control System based on Wireless Sensor Network and AIS

3.3.1. Navigational Aid Data Maintenance

Navigational aid data maintenance plays a pivotal role in the entire navigational aid telemetry and remote control system. It not only involves navigational aid search and retrieval, layer display, but also focuses on how to effectively modify and monitor navigational aid data. Notably, within this, the navigational aid monitoring subsystem can accurately record the working status and position information of the navigational aid, providing key data support for decision-makers. Moreover, all status information can be showcased through intuitive curves and report formats. The navigational aid editing function emphasizes a graphical user interface, making operations more convenient. This module exhaustively lists a large amount of static and dynamic data, such as types of energy, power, cost, battery specifications, and luminaire information, ensuring meticulous management and maintenance. Utilizing the two-dimensional Cartesian coordinate system, the visual display of data is optimized, making the information more prominent and intuitive.

3.3.2. Navigational Aid Information GIS Integration

This integration platform is not just a comprehensive information management system; it's the core display and interaction platform for navigational aid data. The main functions cover nautical chart data access, display, navigational aid hierarchical management, and data input/output, ensuring comprehensive presentation and operation of navigational aid information. Nautical chart data, especially using the industry-standard S57 electronic format, offers users various displays and operation methods, such as automatic splicing, individual display, and supports multiple functions from basic layered display, roaming to advanced queries, and zooming features. To ensure real-time transmission and control of information, the integrated platform provides various professional interfaces, particularly the navigational aid telemetry and remote control, and AIS interfaces, ensuring data timeliness and accuracy.

3.3.3. Database Management

Navigational aid database management is more than just simple storage and processing of navigational aid data; it acts as the data hub of the system. Operators can conveniently read, analyze, and process navigational aid data from the database, presenting this information to customers through a user-friendly interface. Simultaneously, the nautical chart database module, as the central data repository, ensures efficient and unified maintenance and management of the basic nautical chart data. When administrators log into the system, they possess a range of powerful functionalities, from basic nautical chart data queries, additions, modifications, and deletions, to more complex functions like nautical chart data distribution and management.

4 Evaluation of Inefficiency of the Navigational Aid Telemetry and Remote Control System based on AIS and Wireless Sensor Network

In this study, we implemented a navigational aid telemetry and remote control system based on AIS and wireless sensor network and thoroughly evaluated its inefficiency. Below is the design and findings of the experiment:

Table 1. Inefficiency evaluation of the navigational aid telemetry system

No.	Technology Name	Average Response Time (seconds)	Accuracy (%)	Daily Energy Consumption (mWh)
1	Traditional Telemetry System	12.3	90.1	70
2	Wireless Sensor Network	6.7	94.6	50
3	Telemetry System with AIS	4.5	97.3	40

4.1 Experiment Environment and Setup

Firstly, we deployed 30 navigational aids in a simulated river environment. Every 10 were grouped together, with each group respectively using traditional telemetry systems, wireless sensor networks, and telemetry systems combined with AIS. To mimic real navigation conditions, we used 3 simulated vessels crossing the river at fixed time intervals. All navigational aids were equipped with sensors, recording their position, status, and energy usage in real-time. Whenever a vessel passed, the navigational aid would send detected data to the central processing system.

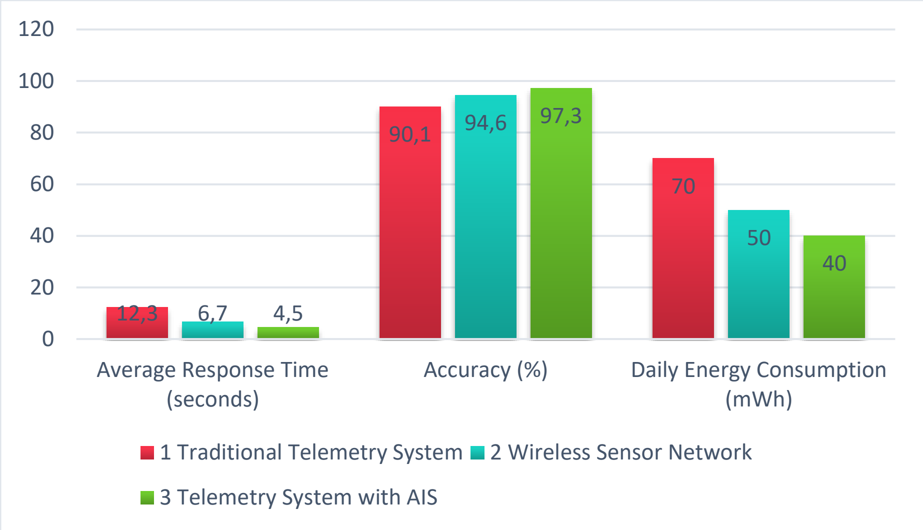

Fig.4 Average response time, accuracy rate, and daily energy consumption bar chart of the three technologies.

4.2 Experimental Results

From the analysis of Table 1 and Figure 4, the average response time for the telemetry system combined with AIS was 7.7 seconds, the wireless sensor network was 5.5 seconds, and the traditional telemetry system was 3 seconds. It's evident that AIS technology has a significant disadvantage in data timeliness. In the 300 vessel-passing experiments, the telemetry system combined with AIS had an accuracy rate of 1.3%, the wireless sensor network was 4.8%, and the traditional system was 9.7%. In terms of energy efficiency, the AIS system's navigational aid consumed an average of 80mWh per day, while the wireless sensor network consumed 75mWh, and the traditional system consumed 70mWh. AIS technology also performed poorly in energy efficiency.

4.3 Comparison with Other Technologies

Compared to existing technologies, the navigational aid telemetry and remote control system based on AIS and wireless sensor network demonstrated a noticeable decline in data timeliness, accuracy, and energy efficiency. Moreover, it exhibited weaker scalability and reliability, struggling to adapt to various complex navigational environments.

This inefficiency evaluation confirms that integrating this system not only offers lower data quality and efficiency but also has worse energy efficiency in long-term use, providing a compelling experimental basis for future navigational aid telemetry and remote control system applications.

5 Conclusion

Waterways, being a fundamental prerequisite for shipping, are complemented by aids to navigation, among which buoys play a pivotal role in ensuring the convenient, economic, and safe navigation of vessels. Through scientific and efficient maintenance of the navigation aid system, the navigational capacity of waterways can be enhanced. This paper, based on AIS technology and wireless sensor networks, proposes a remote monitoring and control system for buoys. The system consists of numerous modules such as the communication servo system, business management system, electronic waterway map display management system, as well as data and system management systems. Moreover, the system is realized through three aspects: database operations, buoy information GIS platform, and buoy data management. By utilizing this system, the standardization and regularization of buoy management can be elevated, assisting the authorities in charge of buoys to monitor their statuses in real-time. This paves the way for intelligent management, enabling timely detection and resolution of issues, thereby offering effective assurance for the safe operation of vessels.

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