Review of the Key Technology Research on Intelligent Locks

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Abstract. Owing to the high capacity, low costs, and environment-friendly characteristics, shipping has an important role in the sustainable development of the economy, society, and environment. However, with the development of the water transportation economy, the capacity of many navigation locks, such as the Three Gorges ship lock and the Beijing-Hangzhou Canal ship lock, has been hard to meet the increasing demand for passing through the locks. Thus, they have become the "bottleneck" limiting the navigation of the waterways. In the background of the vigorous development of intelligent transportation, the Intelligent Locks has been promoted through extensive research of the Intelligent Locks model, exclusive technology, and intelligent equipment, which is of great significance to improve the efficiency of vessels passing through the locks and enhance the function of waterways. This review starts from the current situation of the research on Intelligent Locks. We summarize the focus of the research on Intelligent Locks and the main tasks of Intelligent Locks. Moreover, the contents of Intelligent Locks are also introduced, such as the network communication platform, intelligent ship identification, positioning system, safety detection system, an intelligent guidance system for shipping, etc. Finally, we conclude that it is the informatization and intelligence that can improve the navigation ability and the management level of ship locks. At the same time, compared with the huge capital demand and the long-period construction of new ship locks, it will have obvious advantages of capital and time by attaching great importance to the automation, informatization, intelligent constructions, and applications of new technologies of existing ship locks.

Keywords: Intelligent locks · Safety and efficiency · Network communications

1 Introduction

According to the requirements of the "Outline of building China into a country with strong transportation network" issued by the Communist Party of China Central Committee and the State Council, China will be basically building the strength in transportation. As a water transportation hub, the inland navigation structure is also an important part of a country with a strong transportation network. By promoting the development of navigation structures, it can improve the efficiency of the locks and

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enhance the navigability of waterways, which is of great significance to promote the development of the water transport economy and even the national economy. However, the existing large-scale navigation structures in China still have many prominent contradictions such as the mismatch between demand and supply, the mismatch between quantity, efficiency, and the lack of multi-node linkage. The intelligent operation management of navigation structures is still in its infancy, and the theoretical research has lagged behind the production practice. With the increasingly tight resource and environmental constraints faced by the construction of water transport infrastructure, as well as the Internet of Things and intelligentization of transportation infrastructure, it is urgent to re-engineer and optimize the process, and make use of emerging cross-border technologies such as 5G and artificial intelligence. The construction of Intelligent Locks is an important development trend and direction for navigation structures to improve the traffic supply capacity, safety guarantee capacity, and operation efficiency.

With the low social attention, the research on Intelligent Locks started relatively late. In the context of the vigorous construction of smart transportation, the concept of Intelligent Locks has gradually received attention in the process of theoretical research and practical development, attracting scholars to discuss it from different perspectives, but there is no unified standard definition for it yet. Chen (2015) demonstrated that the Intelligent Locks is a combination of sensor lock, digital lock, and palm lock. At the same time, it is also a scientific lock, a human lock, and an innovative lock. Intelligent Locks = interconnection of infrastructure and information + coordination of ship lock organization management and operation mechanism + smart thinking (Zhang and Qian 2018). Feng and Zou (2014) showed that through the means of the mobile terminal, video monitoring, programmable logic controller, and other means, the perception layer can be built to provide perception capabilities for Intelligent Locks. Wu (2011) believed that by improving the service level of supporting smart applications, more refined services can be provided for managers, crew members, and salesmen.

Under the requirements of safety, efficiency, and intelligence, the Intelligent Locks is based on lock informationization and intelligent transportation, relying on a more mature high-end technology system, a more coordinated system, and a more matching security system to achieve convenient and scientific management of ship locks. Ship lock informatization is the necessary premise and necessary stage of Intelligent Locks. And the Intelligent Locks is the advanced form and inevitable result of ship lock informatization.

2 Current Status and Focus of Intelligent Locks

At present, there are nearly 1,000 locks in China, and the proportion of medium and large locks is more than 30%. In terms of the lock control system, the Three Gorges Lock and the Gezhouba Lock have realized information-based operation and management, and are also the locks with the highest level of automation in China, realizing unmanned and centralized monitoring operation. In addition, the Three Gorges Lock control system is at the leading international level in terms of safety reliability. As the operation and management of the locks tend to be “unmanned or less manned”, the

computer monitoring system is more and more widely used in the daily operation of the locks to achieve monitoring and control of the locks, providing a strong guarantee for the safety and reliable operation of the locks. The computer monitoring system is more and more widely used in the daily operation of the locks to achieve monitoring and control of the locks, providing a strong guarantee for safe and reliable operation of the locks (Li and Kong 2013). It is worth noting that there are still a large number of ship locks in China with relatively primitive operation control methods and a low degree of informatization. They are still mainly based on manual experience management, and there is a huge gap between the intelligent operation and management of ship locks (Li 2001).

At the same time, many of the current intelligent concepts remain at the level of comprehensive information systems. They are only based on information systems, such as AI technology, big data technology, 5G, and other technologies. In addition, there is a lack of in-depth research on the concept and model of Intelligent Locks.

The study of Intelligent Locks must form a complete system from data collection to intelligent application, i.e., to establish an Intelligent Locks application model, using Intelligent Locks equipment, Intelligent Locks operation, and management technology to support the realization of the Intelligent Locks model. The criteria for judging the Intelligent Locks need to pay attention to the following four points:

(1) The efficiency of the locks;
(2) The level of security of the locks' operation;
(3) The level of maintenance, management, and joint scheduling of locks;
(4) The level of service to passing ships.

3 Research Objectives and Key Issues

The key to Intelligent Locks is to build an Intelligent Locks application model and innovative smart technology. Its research objects include the three main bodies of locks: "Lock", "Management" and "Ship". The "Lock" refers to the lock control system, monitoring system, sensing equipment, security inspection equipment, and fast crossing intelligent guidance equipment, including the lock entity. The "Management" refers to the comprehensive information system, the scheduling and charging system of the locks, etc., and the "Ship" refers to the ship's behavior of crossing the locks.

As shown in Fig. 1, the goal of Intelligent Locks is to build a trinity application model of "lock", "management" and "ship". The interconnection and data sharing among the three subjects can improve the navigation efficiency of locks, the security level of lock operation, the management level of locks, and the service level of passing ships.

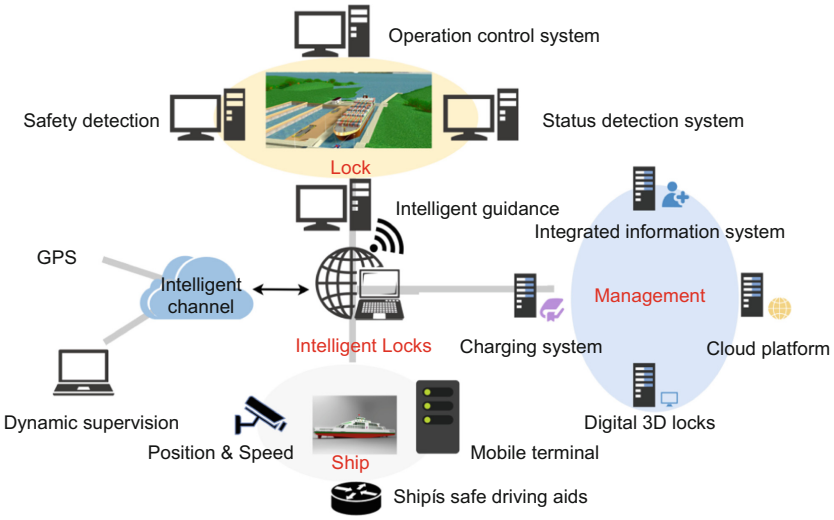

Fig. 1. Trinity application model of "lock", "management" and "ship"

The key issues to be realized in the Intelligent Locks are.

(1) Network communication platform: relying on the Internet, the trinity application model of "lock", "management" and "ship" is built to realize data interconnection and interoperability;
(2) Ship identification and positioning technology: to meet the functions of intelligent identification, precise positioning, and detecting the whole process of entering and leaving the lock;
(3) Ship safety detection technology: to complete the detection of dangerous goods, the load and draught of the ship, the superelevation of the ship, the prohibited parking area in the lock chamber, and the speed of the ship;
(4) Intelligent guidance equipment: to guide ships to quickly enter and leave the lock;
(5) Automatic ship berthing system equipment: to achieve automatic identification and mooring;
(6) Automatic monitoring system: to realize the automatic control of the gate;
(7) Intelligent dispatching system: to ensure the safe, fast, and orderly entry and exit of the lock.

4 Key Technology Research of Intelligent Locks

The research of Intelligent Locks can introduce cross-border technologies such as cloud services, big data analysis, AI (Artificial Intelligence), and Industry 4.0 (Chen 2018). The main research contents are as follows.

4.1 Network Communication Platform

The comprehensive information management system of the locks should be able to fully integrate the information of the systems such as scheduling plan, toll management, safety supervision, operation monitoring, status monitoring, and auxiliary navigation of the locks. To realize the integration of the whole information system of the lock, the platform shall meet the following requirements.

4.1.1 Information Interaction Between Lock and Ship

The ship's basic information, safety information (draft, pre-gear position, approach speed), berthing position and deviation, out-of-bounds status, and planned (remaining) lock-through time can be displayed at the lock control room end (see Fig. 2).

With the development of mobile business, to realize the intelligent guidance, the interactive system can show the information including approach position, navigation speed, actual speed, berthing position, planned crossing time, and the current status of the ship, to the ship through APP and cell phone client.

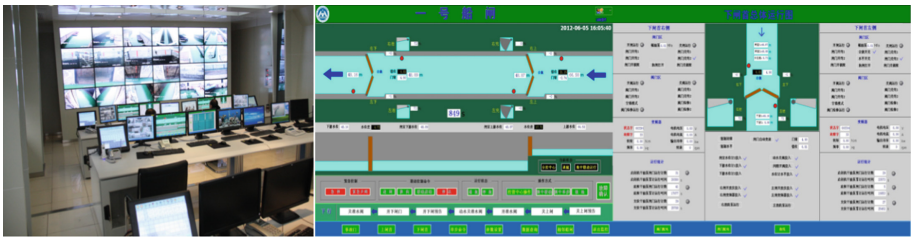

Fig. 2. The control room side of the lock

4.1.2 Active Optimization of Self-learning

The integrated information management system of locks can record and store the data of passing ships' size and gate times, perform unsupervised feature extraction on the pre-processed data, actively learn the optimal passing control parameters under various types of water level coordination relationships, establish a model under the real working parameters of locks and conduct training. The real-time data of the gate crossing are imported into the model and calculated to obtain the optimal fleet combination, as shown in Fig. 3.

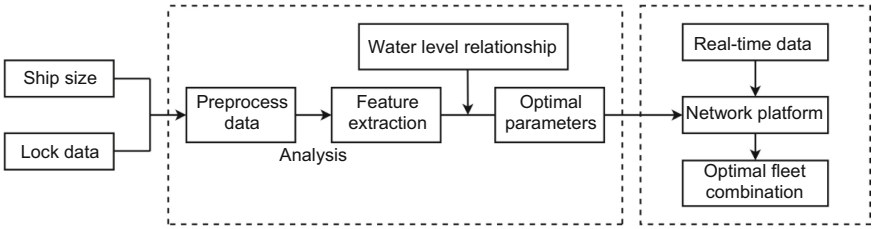

Fig. 3. Active optimization of self-learning model flow chart

4.2 Identification and Positioning System

As shown in Fig. 4, during the process of entering and leaving the lock, the identification and positioning system can obtain information about the ship and its precise position, which is essential to realize the intelligent operation of the lock.

- By locating and measuring the speed of ships, the efficiency and safety of passing the gates and moving berths can be improved.
- Through accurate localization of the ship's position in the lock chamber, it can be judged whether the ship's parking position meets the requirements and can give feedback on the real-time position information to the ships so that they can quickly complete the ship's parking and mooring in the lock chamber.
- Through the detection of the height limit and no-stopping area, it can ensure the safety of ships passing through the lock and the safety of the lock's hydraulic and metal structures (Lv 2020).
- By detecting the presence of ships or no ships in the lock, the automatic control system is realized in cooperation with the process of passing through the lock.

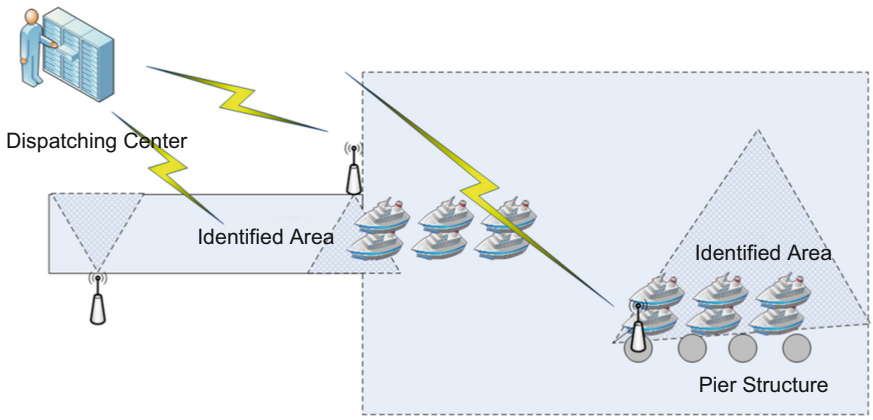

Fig. 4. Intelligent ship identification and positioning system

Ships can use GPS (Global Positioning System) for positioning and identification. However, when they enter the lock, it is impossible to use GPS for accurate positioning because of the water level drop, surrounding buildings blocking, and other factors. Combined with the current development of intelligent identification and positioning technology, the following technical research directions are mainly available:

- RFID (Radio Frequency Identification), as shown in Fig. 5, can be used for ship identification in the area of the pier structure, gate, and lock chamber. The error of identification can also be controlled within the acceptable limits according to the actual demand, and the accuracy of high-frequency recognition can reach more than 99.9% (Yang 2011).

- Within the detection distance of more than 500 m, millimeter-wave radar can reach the positioning accuracy of ±0.15 m and the speed measuring accuracy of ±0.15 m/s.
- With the detection of 2D and 3D, LiDAR (Light Detection and Ranging) has higher detection accuracy than millimeter-wave radar. However, the effective range of the LiDAR is currently between 50 and 100 m, which is shorter than millimeter-wave radar.
- The research of video recognition in ship locks started earlier than other technologies described above. Affected by light, environmental conditions, and other factors, the misjudgment rate of video recognition is also higher than other methods (Wang 2008).

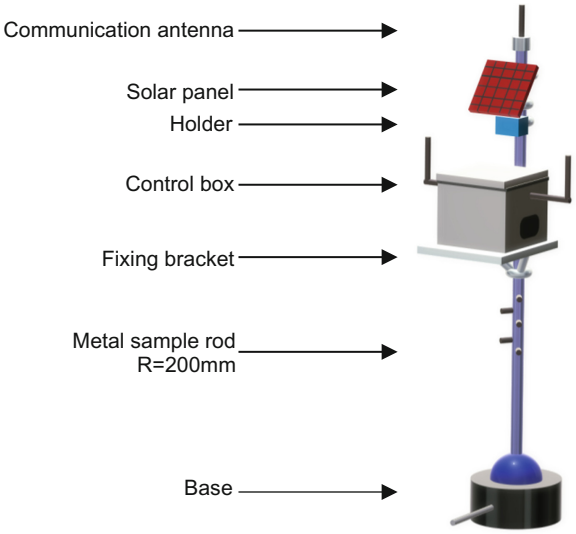

Fig. 5. The RFID equipment

Identification and positioning system is a comprehensive technology. In other words, the use of a single method often fails to meet the requirements of full regional coverage and detection accuracy. The methods, including image processing, pattern recognition, neuronal networks, and deep learning, need to be further explored. At the same time, the reliability of recognition still needs time to verify and continuously optimize.

4.3 Security Detection System

As an important part of intelligent services in the Intelligent Locks, security detection system, including the inspection of speed, dangerous goods, load, and draught of ships (see Figs. 6 and 7), can ensure the safety of ships when passing through the locks (Zhao 2020).

Fig. 6. Security check equipment for gates

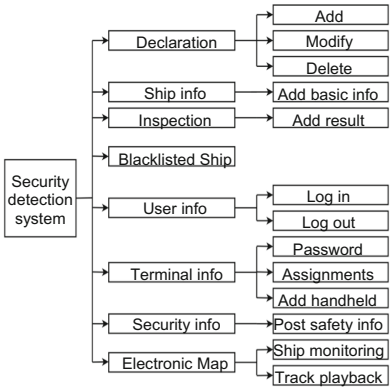

Fig. 7. Gate-passing security check platform

Due to the large sizes of the ships and the variation in water level, the development and implementation of safety detection equipment have more technical and construction difficulties. For example, speed detection on the highway is a very simple technical application, but in the locks, the speed limit is only 0.8 m/s. Accompanied by a large variety of water levels, the different types of ships, and other factors, it requires a security detection system that has not only high accuracy but also intelligent identification capabilities.

4.4 Intelligent Guidance System

Based on ship identification and accurate positioning, an intelligent guidance system is to guide vessels to pass through the gate quickly using an intelligent ship navigation APP, fixed or mobile information board, lock chamber berth delineation guidance, and so on. There are the goals of an intelligent guidance system:

- Managing the order of ships entering the locks.
- Giving reasonable speed, and safe spacing to sailors.
- Notifying the berthing information for vessels and deviation alerts for parking.
- Offering feedback on the vessel's driving information to the guidance system.

As the bond between "ship", "gate" and "management", the intelligent guidance system reduces the manual work of ship dispatching and improves the efficiency and security of the management. Figure 8 shows that the 3D laser cloud point technology applied to car navigation will become the new direction of ship detection (Guo et al. 2020).

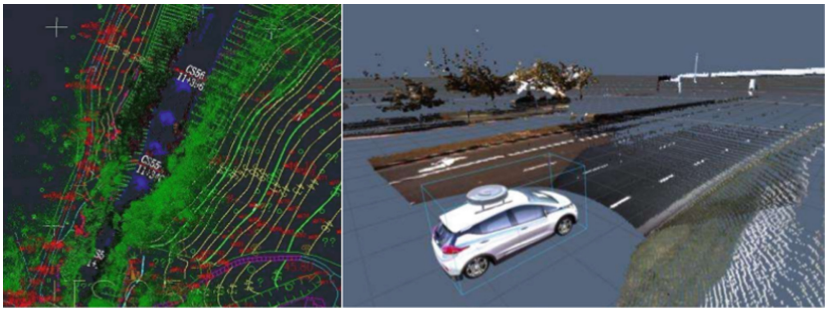

Fig. 8. 3D laser cloud point technology

4.5 Automatic Mooring and Parking System

In traditional locks, it takes a lot of time to enter, moor and exit the locks, which limits the operational efficiency of the locks. An automatic mooring and parking system will be a disruptive technology for the new locks.

4.5.1 Parking System

Automatic berthing includes two ways: self-propelled entry and exit of the lock and external force to pull in and out of the lock. To realize the automatic navigation of the ship, it is necessary to develop a self-propulsion system of the ship. However, due to the large differences between ships passing through the lock, the applicability is poor. Figure 9 shows an external force pulling in and out lock system suitable for large water heads, which can be implemented in the new construction or overall renovation of the ship lock. Alternatively, a six-degree-of-freedom intelligent robotic arm can be used, as shown in Fig. 10, to sample the target object with acquisition equipment such as a camera, and then combine pattern recognition, image processing, and other methods to analyze and process the acquired image data to obtain the spatial position of the ship. Finally, the obtained information is used to enable the robotic arm to automatically identify and grab the ship's bollard, and to quickly move the ship to the specified berthing position (Du et al. 2017).

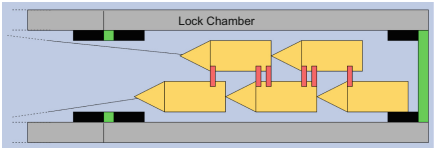

Fig. 9. The external traction

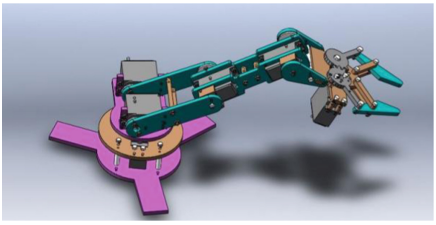

Fig. 10. The six-degree-of-freedom robotic arm

4.5.2 Mooring System

After the ship enters the lock, the ship needs to be moored reliably to resist the external impact caused by the water filling and draining. The vacuum-type automatic floating mooring system can also lift automatically with the change of water level in the lock chamber, as shown in Fig. 11. After the ship enters the lock, it should be able to identify with the berthing bollard system, and after the ship is accurately parked, the system should automatically connect to the bollard on the ship, and after the water filling and draining is completed, the bollard connection is automatically released.

Fig. 11. The vacuum-type automatic floating mooring system

4.6 Intelligent Monitoring System

The intelligent monitoring system can integrate the on-site sensor collection equipment, control equipment, centralized monitoring equipment, video monitoring equipment, broadcasting equipment, and navigation command guidance equipment of the locks into one whole (see Fig. 12). Compared with the common lock control system, it has the following features:

- Key sensors and components are redundantly configured and have self-diagnostic functions. On-site equipment should meet the standards for unattended operation, and be able to accurately locate, alarm, and automatically remove faulty equipment or emergency treatment when the system fails.
- The control system is interlinked with the video, broadcasting, and navigation command guidance equipment to achieve automatic monitoring.
- The system can fully guarantee the centralized monitoring operation's security, reliability, and stability.

Fig. 12. The intelligent monitoring system

4.7 Intelligent Scheduling System

Scheduling is an important link to ensure the safe, fast, and orderly entry and exit of the ship lock. Through scientific and reasonable planning, the economic and social benefits of the ship lock can be fully utilized, and the transport conditions in a certain area can even be improved. In the existing ship lock scheduling methods, the shipping management department still mainly adopts the manual method, i.e., experience management and qualitative analysis (Wang 2021). Therefore, the efficiency of the ship lock will be limited to a certain extent by the technical level, work experience, working status, etc.

At present, an intelligent dispatching system can be developed, and advanced scheduling algorithms can be used to optimize the dispatching of ships passing through the locks and reduce the waiting time of the fleets passing through the locks. The development of shipping in foreign countries is more developed, and the standardization of ship locks and ships is higher than that in China (Shang et al. 2011). Bugarski et al. (2013) proposed a decision support system for ship lock management based on fuzzy theory, which can be used for decision support in the ship lock scheduling process and training of ship lock managers; Verstichel et al. (2014) believed that the ship lock scheduling problem can be divided into three interrelated sub-problems: ship layout, lock chamber allocation, and lock operation scheduling. Ji et al. (2017) established a multi-objective optimization model for the ship lock scheduling problem. Liu and Qi (2002) proposed a heuristic algorithm, which effectively solved the contradiction between the lock chamber area utilization and the priority of ships passing through the lock. Finally, the experimental data showed that the algorithm can improve the efficiency of the actual scheduling and scheduling of the Three Gorges Ship Lock.

The intelligent scheduling system should grasp the status of vessels passing through the gate in time, such as vessel tonnage, vessel size, personnel information, loading situation and arrival time, etc., and use advanced scheduling algorithms to

automatically schedule the vessels to the gate according to the principle of maximizing the utilization rate of the gate space and minimizing the cost of time passing through the gate, with the following main functions and features:

- An intelligent scheduling model that meets the requirements of safety and efficiency.
- Supporting automatic visualization of scheduling information management.
- Supporting two-way information interaction management between ships and locks, such as APP to realize intelligent registration of ships waiting for locks and pushing of service information, etc., as shown in Fig. 13.
- Supporting the deepening application of AIS (Automatic Identification System).

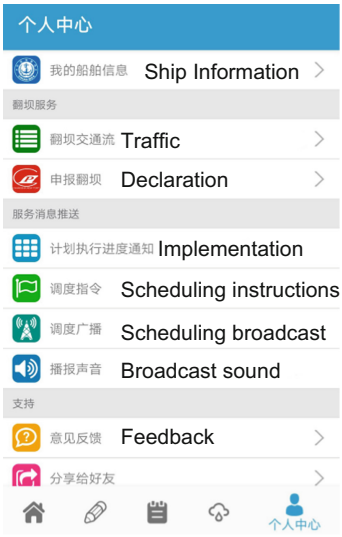

Fig. 13. "Intelligent dispatching" APP declaration interface (from Hunan General Aviation Dispatching APP)

5 Conclusions

Compared with the huge capital demand for new ship locks and their long construction period, the operation and management level of locks can be improved by fully tapping the existing lock resources, strengthening the team construction, improving the maintenance level of locks, attaching importance to the automation, informatization and intelligent construction of locks and the application of new technology, which has obvious financial and time efficiency advantages and should be the primary means to improve the navigation capacity of locks.

Under the guidance of informatization and intelligence, researching "Intelligent Locks" is an effective way to improve the navigation ability and the management level of ship lock operation. In the future, it is necessary to combine the basic data of the ship lock and the shipping information, use the big data platform to strengthen the top-level design and planning of "Intelligent Locks", promote the comprehensive integration of modern information technology with ship navigation management and services, and establish comprehensive management and maintenance.

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References

Bugarski V, Backalic T, Kuzmanov U (2013) Fuzzy decision support system for ship lock control. Expert Syst Appl 40(10):3953–3960

Ji B, Yuan X, Yuan Y (2017) Orthogonal design-based Nsga-Iii for the optimal lockage co-scheduling problem. IEEE Trans Intell Transp Syst 18(8):2085–2095

Verstichel J, De Causmaecker P, Spieksma F, Berghe GV (2014) The generalized lock scheduling problem: an exact approach. Transp Res Part E-Logist Transp Rev 65(SI):16–34

Chen C (2015) Intelligent transportation, 2nd edn. Tsinghua University Press. (in Chinese)

Chen C (2018) Liner operation optimization of the Yangtze River based on shipping big data. Wuhan University of Technology, p. 144. (in Chinese)

Du X, Cai Y, Lu T, Wang S, Yan Z (2017) A robotic grasping method based on deep learning. ROBOT 39(06):820–828 (in Chinese)

Feng F, Zou Y (2014) Study and implementation of IOT-based trinity ship supervision system for customs. Mod Electron Tech 37(06):83–87 (in Chinese)

Guo J, Liu C, Yu Z, Zheng M, He Z, Chu X (2020) Application and outlook of ship perception based on LiDAR. In: The 15th china intelligent transportation annual conference, Shenzhen. (in Chinese)

Li Z, Kong B (2013) Application of monitoring and control system for ship lock. Appl Traffic Eng Ind 10:33–36 (in Chinese)

Li Z (2001) A lock optimized scheduling and decision system based on the Internet. Nanjing Hydraulic Research Institute. (in Chinese)

Liu Y, Qi H (2002) The two-dimension optimization arranging heuristic algorithm and its application in the Yangtse Gorges Permanent Ship Lock decision system. Comput Modern. 01:1–3 (in Chinese)

Lv Y (2020) Research on intelligent integration of security inspection for ship passing through lock. Dalian Maritime University, p. 84. (in Chinese)

Shang J, Wu P, Tang Y (2011) On multiple-lane lock's joint scheduling plan based on computer simulation. Port Waterw Eng 09:199–204 (in Chinese)

Wang J (2008) The application of video tracking and identification technology in sea route video surveillance. Xiamen University, p. 58. (in Chinese)

Wang Y (2021) Multi-step ship locks chain scheduling of the Xijiang River shipping line based on dynamic binary tree. Port Waterw Eng 03:159–163 (in Chinese)

Wu X (2011) Research on solution for design and management to data layer of shipbuilding informatization service platform. Harbin Engineering University. (in Chinese)

Yang G (2011) Research on RFID localization algorithm. Henan University of Science and Technology, p. 75. (in Chinese)

Zhang J, Qian J (2018) Intelligent ship lock. Southeast University Press (in Chinese)
Zhao C (2020) Research on remote safety inspection system for navigable ships of Xiangjiaba ship lift. Dalian Maritime University, p 81. (in Chinese)

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