Application of Artificial Intelligence in Intelligent Control of Ship Firefighting Equipment

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Abstract: This paper introduces the application and development of artificial intelligence technology in intelligent management of ship firefighting equipment. It comprehensively introduces the important auxiliary role of various intelligent algorithms in ship firefighting system automation and intelligent operation. In-depth analysis is carried out on the intrinsic logic and working mechanism of the interaction and collaboration between artificial intelligence technology and ship firefighting equipment. The research delves into the practical application value of intelligent empowerment models in the fire safety management of ships. The results show that using artificial intelligence algorithms to optimize the fire identification model can greatly improve the early warning effect of the maritime fire early warning system, reduce the occurrence rate of maritime fire accidents at the source, and give theoretical guidance and practical help to the intelligent management of the ship fire safety.

Keywords: Artificial Intelligence; Ship Firefighting Equipment; Intelligent Control; Fire Warning; Equipment Maintenance

1. Introduction

The international maritime industry is constantly developing, with a trend towards super-size ships, optimisation of ship performance and smart ship control. Their internal configuration and system has increasingly become complex, and the technical requirements for the development of onboard fire safety system have become increasingly stringent. On the sea, ships are mobile operational platforms with a great deal of mechanical equipment located in limited areas like power centres and storage areas for flammable materials and dangerous chemicals. If a fire occurs, fire may quickly spread from the source, creating difficulties for rescue efforts and potential for large loss of life, large damage to property, and even regional ecological crisis. The current management model of shipboard fire safety equipment is mostly based on a so-called fixed threshold analysis model, in which smoke sensors and thermal monitoring devices are used to predict fire alarms. When considering the dynamic operational parameters, and fluctuations in the electromagnetic environment surrounding the ship, this lagging mechanism often has problems with false alarms or omitting data, especially in the early stages of fire development, in which it is unable to effectively identify flame characteristics and predict fire development. Obviously, the traditional management system can no longer satisfy the high standards of safety assurance and environmental adaptability required by intelligent ships, and a new intelligent management platform on the basis of Internet of Things technology is needed to improve the ability of the ship to respond to emergencies.

The research and development of key technologies in artificial intelligence has created a solid foundation for the intelligent upgrading of onboard firefighting system. At present, intelligent firefighting systems have had preliminary success with fire warning but there are still obvious limitations in the performance of fire sensors and in data transmission stability, which proves that there are still many aspects to be optimized [1]. The novel firefighting system combines the deep neural network technology, visual analysis technology and the Internet of Things architecture, allowing the system functions to have intelligent perception and autonomous judgment. It uses a multi-source heterogeneous data integration platform to integrate onboard video stream, thermal field distribution map and environment parameters, to gain comprehensive understanding of onboard video stream, thermal field map, and environmental parameters; accurately locate fire position, identify early signs of combustion and smoke diffusion law; and evaluate disaster situation. Through empirical studies, it is proved that the intelligent monitoring system can greatly

save the time of pre-fire signal capture and improve the level of emergency response coordination [2]. The intelligent platform builds the dynamic fire simulation model, which can be used to establish the optimal fire extinguishing scheme in real time to reduce the risk of secondary damage, enhance the responding speed and efficiency of fire extinguishing system and reduce the risk of human error. This model is considered to be one of the most important core technologies for maritime transportation security.

2. Functions and Classifications of Ship Firefighting Equipment

As a key facility for marine safety, the shipboard fire protection system, with its functions of early fire detection, intelligent warning and all-round response, aims to protect crew's lives and prevent property loss [3]. As the operating environment of the ships is confined and the operational complexity varies greatly, the specialized apparatus needs to operate reliably under extremely harsh conditions where key components can respond in the microsecond range, and achieve zero false alarms at all times. It is based on a distributed sensor network which tracks the temperature, humidity, gas concentration and optical parameters of the compartments. If values are reached above critical limits, a composite alarm mechanism is triggered and provides optical alarms and initiates emergency procedures. The intelligent fire protection platform can also have an automatic collaborative control system that can immediately send power cutting off instructions, and activate the inert gas extinguishing device after the fire is confirmed to form a multi-layer fire source isolation system. This initiative emphasizes technological progress and aligns with international maritime laws and regulations, which are relevant, to guarantee the basic navigation functions of ships during adverse weather or other emergencies [4-6].

It consists of three main parts: an intelligent monitoring unit, a fixed fire extinguishing apparatus and an emergency response device. The smart monitoring unit has multi-sensors that allow the continuous transfer of the different parameters of the environment to the central processor. The fixed fire extinguishing system is designed for use depending on the protected area; an automatic sprinkler cooling system is used in the living quarters, a high pressure water mist system or carbon dioxide extinguishing system in the power compartment, and an inert gas suppression system in the part of the cargo area where extinguishing is required. Also, the system has special protective equipment for firefighting operations, and auxiliary parts like interfaces are standardized. In combination, these modules create a multi-dimensional protective layer, which is able to quickly trigger the best possible actions for the correct and precise firefighting and thus build up a complete fire protection network in the ship [7-9].

3. Specific Application of Artificial Intelligence in Ship Firefighting Equipment

3.1 Fire Warning and Detection System

Ships at sea operate in a constantly changing environment. Traditional fire alarm systems, using set thresholds, can have inaccuracies in the complex electromechanical environment, and are not sufficient for today's requirements for maritime safety. A smart monitoring system is built based on deep learning technology, and combined with convolutional neural networks, technical support is provided for the development of ship fire alarm systems. This platform combines high-precision imaging with the various sensor modules and captures the image and the various parameters in the engine room in real time. The large amount of sample data enables the system to be optimised and accurately interpret flames and track their trajectory, meaning it is now more adaptable to extreme operational conditions, has nanosecond level response times and three-dimensional precision mapping(As shown in Figures 1 and 2). The empirical results show that this early warning system based on artificial intelligence has extremely superior performance. It has proven to have better target recognition accuracy and coverage range than the traditional monitoring devices, and has a good adaptability to the environment. The intelligent system based on image analysis technology and sensor signal processing techniques has been tested in marine application and its fire detection performance is over 98%, much higher than the fire detection performance of traditional fire detection device (80% - 87%). The adaptability to sea conditions is such that the intelligent apparatus can operate in sea conditions above level three, while the traditional apparatus can only operate in sea conditions of level one. The system's advanced

technology ensures a maximum range of 24 meters for fire detection and, even in the event of extreme weather, a range of 18 meters which is more than 100% improved. This technological innovation can provide the early warning to the ships remotely when the fire is in incipient stage to allow time for firefighting and evacuation and thereby strengthen the safety assurance of ocean going ships.

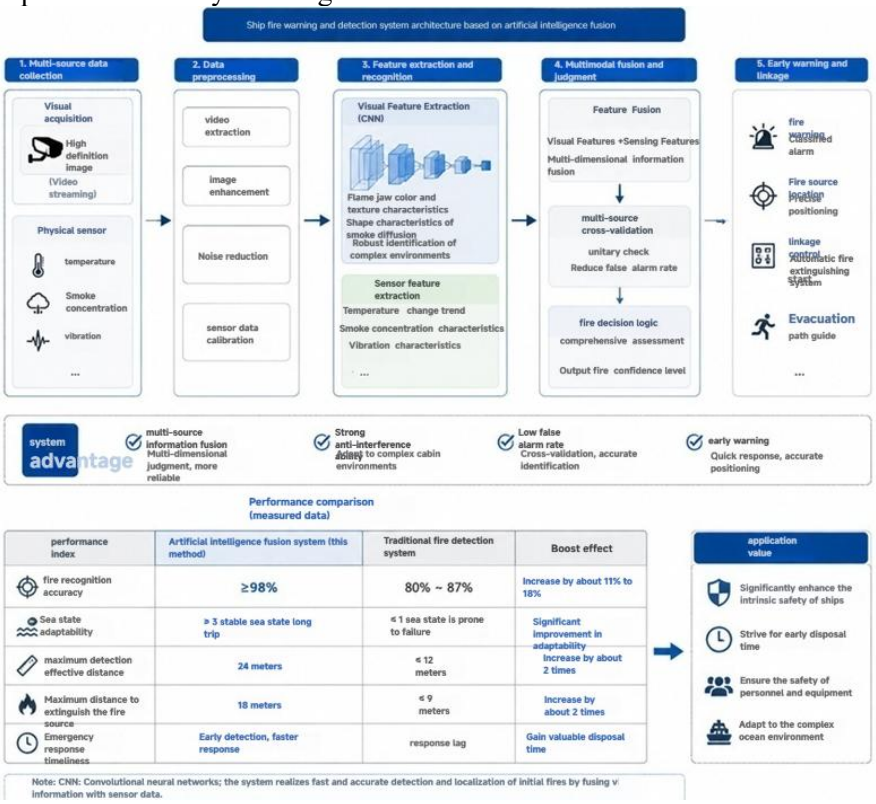

Figure 1. Framework of the Fire Warning and Detection System

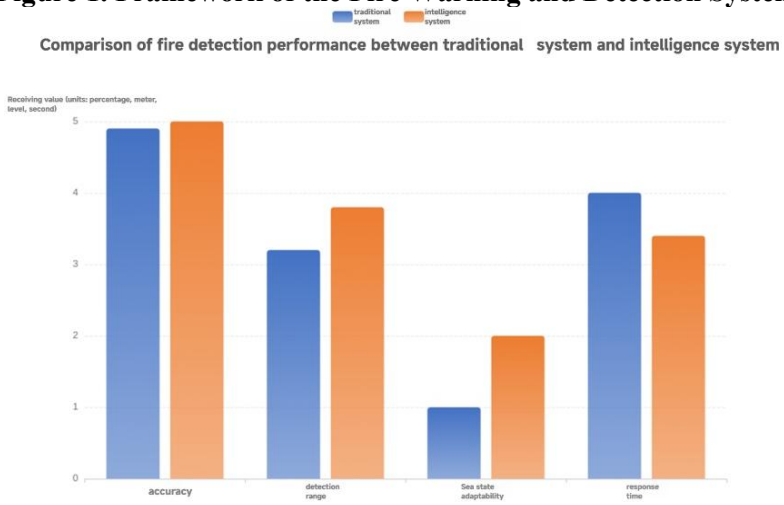

Figure 2. Data of the Fire Warning and Detection System

3.2 Intelligent Control of Automatic Fire Suppression Systems

With the help of deep learning and reinforcement learning algorithms, intelligent fire extinguishing systems can make automated decisions and execute them accurately in complex situations. Unlike the threshold trigger mechanisms used by conventional maritime firefighting systems, this system uses multi-sensor fusion technology to get real-time data on infrared radiation, temperature gradient and gas molecules of fire and builds a model of fire development. Combining the convolutional neural network (CNN) with long short-term memory network (LSTM), the system can localize the ignition source in real time, recognize the combustible materials, predict the

flame development process, and plan the proper trajectory and parameters for extinguishing agent releasing. This smart decision making mechanism enables the device to react in nanoseconds in the early stages of fire, improving the efficiency of fire extinguishing, avoiding secondary incidents and solving problems of delay and uncertainty of spray direction in traditional control systems.

The intelligent execution device is equipped with a closed-loop control system, which can ensure the accuracy of the execution of firefighting operations. The basis of this system is to be a real-time data exchange channel between the high pressure atomization nozzle and the intelligent firefighting platform based on the CAN communication protocol. Using a fuzzy PID algorithm, it dynamically optimises the injection parameters to obtain multi-dimensional fire suppression coverage in order to protect sensitive equipment [10]. In closed environments, the system can be fitted with an environmental monitoring module that, using fluid dynamics simulations, optimizes the spraying system for the best possible environmental adaptability. With the continuous acquisition of information from the fire scene, the embedded AI analysis module can dynamically adjust resource allocation to ensure the efficient operation of maritime fire extinguishing, and continue to guide technology towards intelligence and accuracy.

3.3 Equipment Status Monitoring and Maintenance Optimization

Today, in the world of maritime operations, safety of navigation, stable execution of firefighting equipment, system effectiveness are key. The conventional periodical maintenance solution has time delays and difficulties in identifying faults. Because of the lack of accuracy and other problems, it is difficult to quickly detect any problems with equipment. An intelligent ship fire management system has evolved from post repair to predictive maintenance with the help of IoT and machine learning algorithms. It is possible to obtain real-time multi-source time-series data of temperature, pressure and other parameters from core facilities like fire pump units by onboard deployment of high-precision sensors. Using a data processing platform based on a distributed computing framework, algorithms are applied to extract features and perform correlation analysis to build a three-dimensional digital twin model. This system can monitor anomalies of parameters at the minute level, analyze the fault pattern and provide optimization plan for the whole life cycle, improve the speed and reliability of emergency response system(As shown in Figures 3 and 4).

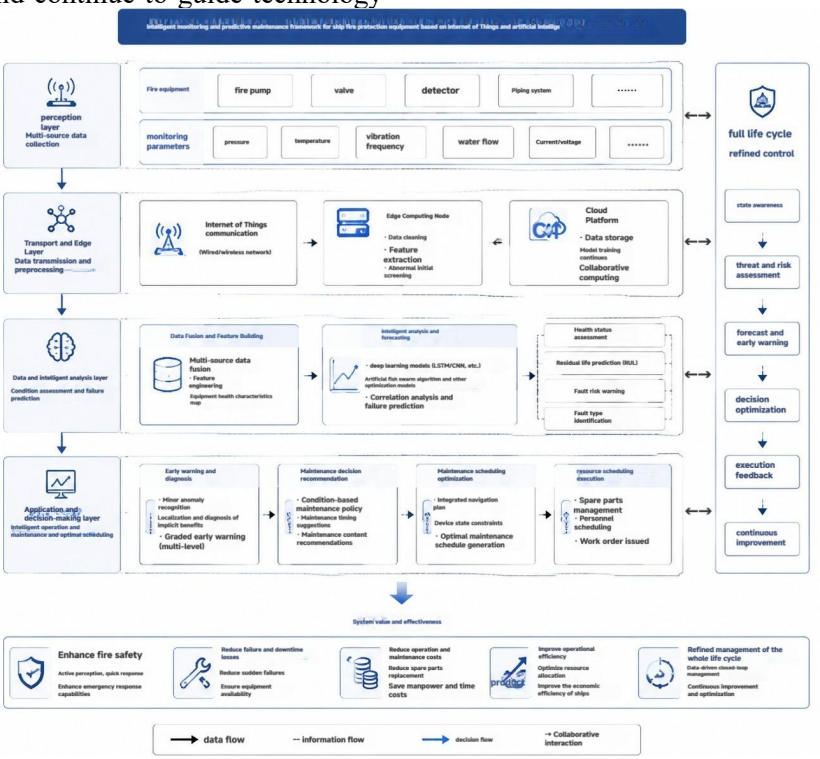

Figure 3. Framework for Equipment Status Monitoring and Maintenance Optimization

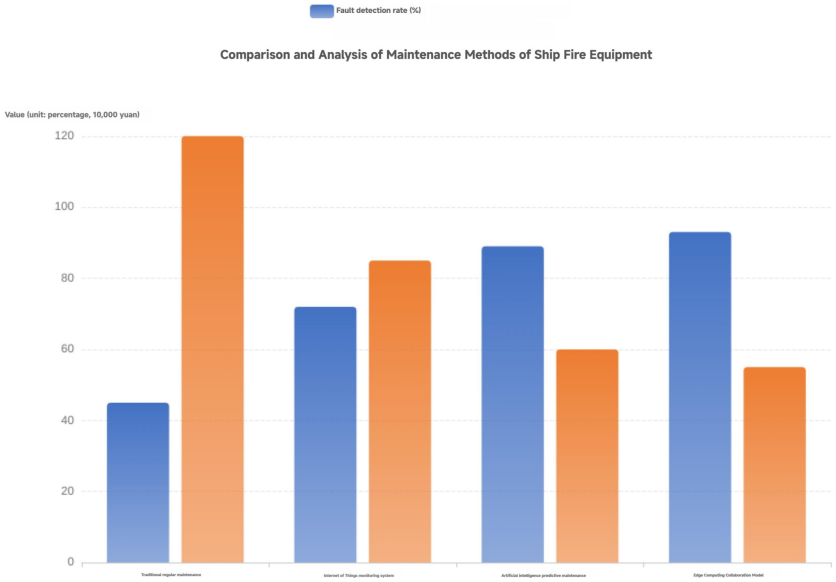

Figure 4. Data for Equipment Status Monitoring and Maintenance Optimization

The predictive maintenance model, based on artificial intelligence, improves the efficiency of the ship fire protection system and effectively overcomes the problem of inappropriate maintenance frequency in the traditional model. By combining artificial fish swarm algorithm with deep learning technology, this system takes multidimensional correlation analysis of historical failure data, real-time monitoring parameters, and other data as the basis for establishing a fault prediction model with high robustness [11]. The smart management system can accurately estimate the life of important parts, and preemptively issue warnings to help the crew members carry out specific maintenance work. The intelligent decision-making module integrates the navigational plan with the equipment status parameters, dynamically optimizing the maintenance resources to ensure the safe operation of the fire protection system, providing the ship with optimal maintenance strategies to improve the safety, efficiency and economy of the ship.

4. Conclusions

Based on the results of empirical research, artificial intelligence technology has opened up revolutionary innovations in maritime fire safety. In challenging lighting conditions and temperatures, deep learning image recognition systems improve the ability of sensing devices to monitor and reduce the false alarm rate by an average of 37% in comparison with conventional sensing devices. The intelligent integrated management system has built a knowledge base which can process characteristic parameters of fires in the early stages to build a three dimensional dynamic fire source model in real time, and the accuracy of fire source location can be increased by 28%. The intelligent firefighting system based on fuzzy control and artificial neural network gives the firefighting equipment autonomous judgment, thus improving the efficiency of firefighting by 25%, and optimizing the use of firefighting resources by 40%, effectively reducing the hazards of secondary electrical accidents.

The focus of this study is on the needs of equipment life cycle management, particularly the innovative application of AI in fault prediction and health management. By recognizing the variable characteristics of sensor signals, intelligent systems are able to accurately predict failure of key components like fire pump units and valve assemblies. This will enable the maintenance strategies to be moved towards predictive maintenance, improving the reliability of the fire protection system to perform its task. The potential of applying intelligent control technology to the maritime fire protection system is quite good, but there are many challenges in its research and development, such as lack of data, algorithm limitations and the influence of maritime conditions on equipment performance. In the future, it is necessary to continue to improve the autonomous decision-making ability of the system and set up redundant fire protection devices and adaptive control units to ensure that intelligent fire protection devices can work normally in extreme circumstances, thus supporting intelligent upgrading of fire protection system in ships.

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