Intelligent Fire Early Warning and Monitoring System for Ship Bridge Based on WSN

Shubo Wu[1], Xinqiang Chen[2], Huixing Chen[1] and Jinquan Lu[1]

[1]Merchant marine college, Shanghai Maritime University, Shanghai, 201306 China;

[2]Institute of Logistics Science and Engineering, Shanghai Maritime University, Shanghai, 201306 China.

Abstract

To ensure navigation safety, it is essential to detect ship bridge's early fire warning indices effectively in real-time, while corresponding measurements will be implemented to rule out potential fire hazards. Hence, an intelligent ship bridge fire early warning system is designed based on wireless sensor network (WSN). Such system can intelligent monitor bridge's temperature, smoke and other gases generated by bridge's facilities' burning. The proposed fire early warning system can intelligent detect abnormal values of temperature, smoke etc. and send the fire-warning information to all the available monitoring platforms. Thus, the crew is able to obtain the concrete fire information and extinguish fire-hazard as early as possible, which guarantees the ships and lives safeties.

Keywords

Wireless sensor network (WSN), Intelligent detection, Ship bridge, Fire early warning, Smart ship.

1. Introduction

The vigorous development of the shipping industry has promoted a surge in the number of ships, and the number of ship accidents caused by fires has also increased. Ship engine room and bridge are the key areas of ship fire warning and monitoring [1-4]. The ship bridge is an important on-site command center during the ship's navigation and the safety of the bridge directly determines the safety of people, ships, and cargo during the ship's transportation. The fire hazards caused by electrical device is increasing with the raising of various ship electrical device (especially those related to ship bridge) when ships are developing towards electrification, automation and large-scale development. Moreover, the ship's bridge stores various device (e.g., VHF and mid-high frequency combined radio, radar, log, automatic car clock recorder, etc.), which are required for the ship's navigation and worked in the environment with constant pressure, stable, and dry. However, the fire hazard of electrical device in ship bridge increased due to the device work in harsh power environment with humid, vibrating space for a long time [5].

Additionally, it is difficult for the crew to quickly reach the bridge fire scene through the narrow cabin passages and stairs when the fire broke out due to ship bridge on the upper floors and the narrow of internal space, cabin passage and staircase, which only accommodate one person through [6]. Many scholars focused on fire warning in ship engine room and other enclosed compartments [7-9], but few researches on fire early warning of ship bridge and the disaster caused by the ship bridge fire is devastating [10]. In recent years, the emerging wireless sensor network (WSN) and intelligent network technology have the advantages of low cost, wide-area and intelligent monitoring, real-time, accurate positioning and less manual intervention, which make it the first choice for monitoring fire hazards on the ship bridge [11]. Therefore, this paper proposes a ship bridge fire intelligent monitoring and early warning system based on WSN to effectively monitor and discover potential fire dangers in the ship bridge area, and notify the ship's crew in time to better protect the ship's property and safety.

2. New Technology of Ship Fire Monitoring Based on WSN

The existing ship fire detectors are generally single-type fire detectors, that is, they can only detect a single fire alarm indicator within the monitoring area. For example, ship-borne smoke detectors can only detect the smoke signals produced by combustion when fire breaks out, while temperature-sensitive detectors can only detect changes in temperature per unit time within the monitoring area. However, since the narrow of each cabin, the passages and stairs connecting the cabins, the upper computer monitoring system only can determine the fire alarm in monitoring area rather the specific location in a short time when receiving the fire alarm information transmitted by the shipboard fire detector, which extends the ship's fire-fighting time to a certain extent.

Wireless sensor network technology can effectively solve the weakness of traditional ship fire detectors. First, each monitoring node of the WSN is a composite sensor node and can simultaneously monitor information such as smoke, light intensity, and temperature in the target area. Moreover, each node automatically forms a wireless sensor monitoring network through an ad hoc network. When a monitoring node loses its working capacity, other nodes in the network can immediately re-organize the network, ensuring the robustness of the fire wireless sensor monitoring network. Secondly, the sensor nodes are all assigned a unique and different 64-bit network address and internal network ID within the network. The host computer can quickly determine the specific location of the fire alarm through the node ID when receiving the fire alarm information from the sensor node, and save fire to the greatest extent time. Based on the above advantages, WSN is used to construct a new type of ship bridge fire prevention and monitoring system to improve the safe navigation coefficient of ships.

3. System Structure

The fire prevention and monitoring system (FPMS) of ship bridge based on WSN is mainly composed of wireless sensor network on-site monitoring module, information processing and forwarding module, host computer monitoring and user interface module, etc. The basic prerequisite for the successful operation of the system is that it has a relatively complete network structure. Therefore, the network architecture of the system is introduced before introducing the various functional modules of the system.

3.1 System Network Structure

One of the prerequisites for the normal operation of the intelligent fire early warning system is that the entire system network is unobstructed. More specifically, the data monitored by the sensor nodes can be sent to the host computer monitoring system through the wireless network in real time. The host computer monitoring system will timely display relevant fire alarm information in fire warning terminal in the engine room and the crew room (e.g., captain, chief mate, chief engineer, general crew) to remind ship staff that there is a fire hazard on the bridge and need to be eliminated in time.

The area or device that the entire system needs to monitor includes navigation device, communication device, meteorological device, other device and chart room of the ship bridge. Therefore, the underlying network system of the system network is mainly composed of the communication clusters of navigation device, meteorological device, communication device, other device and chart room. The host computer monitoring and display terminal of the system network is the core of the entire system network. The host computer monitoring display terminal processes various monitoring information transmitted by the site node in real time. Once there is a fire hazard, the terminal will automatically and real-time transmit the fire alarm information to the fire alarm information display terminal in the crew room through WSN. The system network structure diagram is shown in Fig. 1.

3.2 On-Site Monitoring Module

The on-site monitoring module is mainly composed of wireless sensor nodes. The sensor nodes are arranged in the key area of the ship bridge and near various navigation aids (e.g., radar, electronic chart, car clock, automatic car clock recorder, autopilot , ship combined weather instrument, search and rescue radar transponder, etc.), which are important device to ensure the safety of ship navigation.

Moreover, the electrical device of these navigation aids is easy to accumulate heat during operation and likely to cause a fire due to the high temperature of the circuit when heat dissipation system of the device fails. Hence, the navigation aids of the ship bridge are the key place to prevent fire hazards and the important monitoring area of the fire monitoring sensor network.

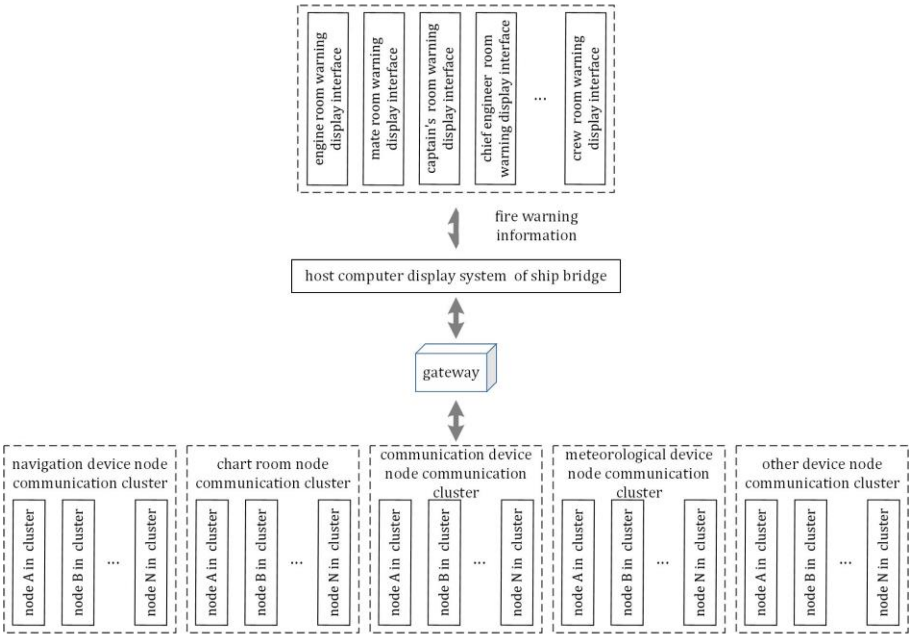

Fig. 1. Network structure of monitoring system

The wireless sensor nodes of this system can simultaneously monitor various fire early warning index (FEWI) information of the ship bridge including temperature, smoke, carbon monoxide (or gas produced by the combustion of other objects), etc. The node's radio frequency module sends data monitored by the sensor nodes to the sink node after the A/D analog-to-digital conversion, and then the sink node sends it to the host computer monitoring system through the gateway. If the temperature of the monitoring area of the node is greater than 50 degrees Celsius (or other preset warning temperature value), or the CO and other gas content, smoke or other indicators in the monitoring area exceed the warning value, the host computer system will receive the alarm message sent by the node. Meanwhile, the watchman on the bridge can also notify the captain or other senior crew of real-time fire warning information in time through the ship's command phone, and the ship's on-site senior commander will designate a person to conduct inspections and eliminate fire hazards.

In the designed wireless sensor network intelligent monitoring system, the ship bridge is divided into different monitoring areas according to the type of device. For example, communication device monitoring area (CDMA), navigation device monitoring area (NDMA), weather device monitoring area (WDMA), emergency alarm device monitoring area (EADMA), chart monitoring area (CMA), other devices monitoring area (ODMA), etc. Different device monitoring areas obtain different network cluster numbers assigned by the host computer and each monitoring area forms a communication cluster by self-organizing networks. The head of each cluster is assumed by the node closest to the host computer monitoring system and the node can communicate with each other of communicate with other cluster node through the cluster head. Since the cluster head node is responsible for transmitting the information collected by all nodes in the cluster to the host computer, forwarding the command of the host computer to the nodes in the cluster, and the communication and information relay between the clusters. This is a huge energy consumption for the cluster head node. Hence, the cluster head node of the on-site monitoring module does not actively perform the monitoring task under normal circumstances. If the cluster head node is required to perform the monitoring task, the monitoring command can be sent to the cluster head through the host computer.

3.3 Information Processing and Forwarding Module

The information processing and forwarding module of the FPMS system mainly includes the convergence node, the gateway and the host computer system. The workflows can conclude as follow: (1) the on-site monitoring node packs the monitoring information and sends it to the sink node. (2) the sink node performs preliminary screening of the information (i.e., removes some glitch data and redundant information), and then sent organized data to gateway of the wireless sensor network in the preset period of time. (3) the gateway relays the information to the host computer. The gateway node is arranged near the upper computer to facilitate the data exchange between it and the host computer system in the designed FPMS system. On the one hand, the FPMS system gateway formats the information transmitted by the sink node and forwards it to the host computer monitoring system. On the other hand, it repackages the commands sent by the host computer to the on-site sensor nodes and converts them into commands and data format, which can be recognized by the sensor nodes. FPMS system information processing and forwarding module structure block diagram is shown in Fig. 2.

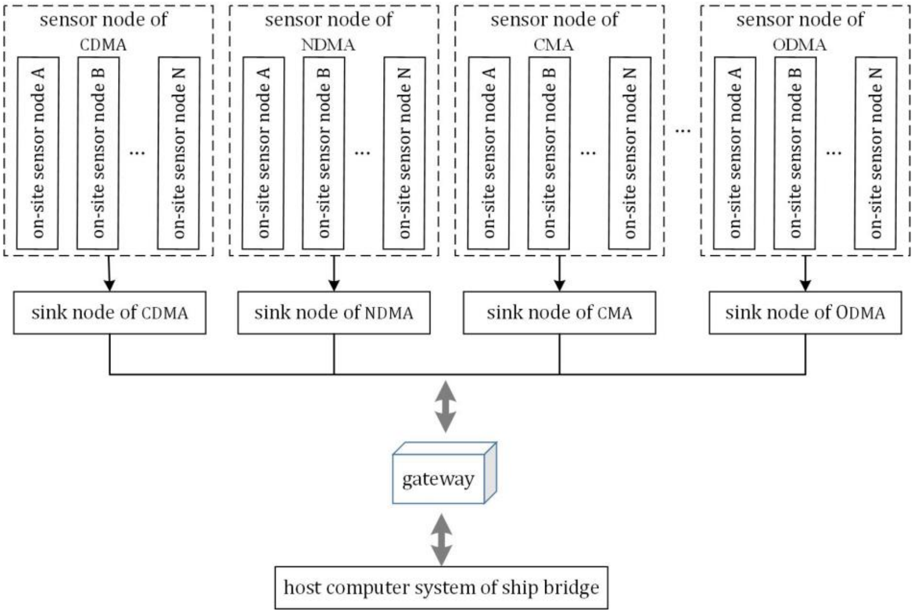

Fig. 2. Monitoring information acquisition and relay module

The host computer system needs to perform the following tasks in this module: (1) it deeply processes the data after receiving the on-site data collected by the wireless sensor node transmitted by the gateway, and further de-redundancy, deburring, and removal of fake data, etc. for the purpose of obtaining the real data of the entire ship bridge monitoring scene. (2) if the temperature or smoke in a monitoring area (e.g., the chart room) exceeds the normal numerical fluctuation range, the host computer will issue monitoring commands in real time to obtain the data information of the fire alarm indicators in the area at regular intervals. After the relevant staff eliminates the fire hazard, the host computer will remotely control the sensor nodes in the area, cancel the fire alarm, and continue to monitor the information (e.g., temperature, humidity and smoke).

4. System Monitoring Experiment

The simulation site of system monitoring display experiment is the combined liquid cargo simulation ship newly built by Shanghai Maritime University (see Fig. 3). The monitoring area of the ship bridge mainly includes the distress alarm device area, the meteorological device area, and the communication device area, etc. The monitoring experiment is mainly divided into system networking test, system monitoring display effect test and fire alarm information forecast display. The experiment targets are three areas prone to fire hazards including the communication device of the bridge, the distress alarm device and the chart room, which are represent a communication cluster.

The communication device of the bridge, the distress alarm device has four sensor nodes (one of which is the cluster head node), and the cluster head is assumed by the node closest to the host computer system in the cluster. Considering the monitoring range and energy of sensor nodes, the distance between cluster heads of adjacent communication clusters is about 10 m. The chart room area is setting five sensor monitoring nodes because it belongs to the key fire prevention area, which stored paper and electronic charts.

Fig. 3. Fire warning experiment platform

The chart room is separated from the ship bridge by a door, which causes interference and obstruction in communication between the sensor nodes in the chart room and the host computer. Hence, an information relay node is arranged between the chart room and the host computer system. The relay node is arranged at the junction of the chart room and the ship bridge and it is responsible for collecting the data information transmitted from the chart room cluster head node and transmitting it to the display terminal of the host computer monitoring system. Fig. 4 shows the network topology structure diagram displayed on the monitoring display terminal after the sensor node is self-organized. The CORD node represents the gateway, and the ship attendant (experimenter) sends the relevant control commands of the sensor node through the gateway. **FFFFFFFFFFFFFF format represents the 64-bit network address obtained by the node. The 03FFFFFFFFFFFFFF node represents the cluster head node of the communication device communication cluster and the signal strength between the cluster head and the gateway is 5 decibel milliwatts, indicating that the signal strength in the monitoring area is poor, but this signal strength can still complete the task of transmitting sensor node monitoring data.

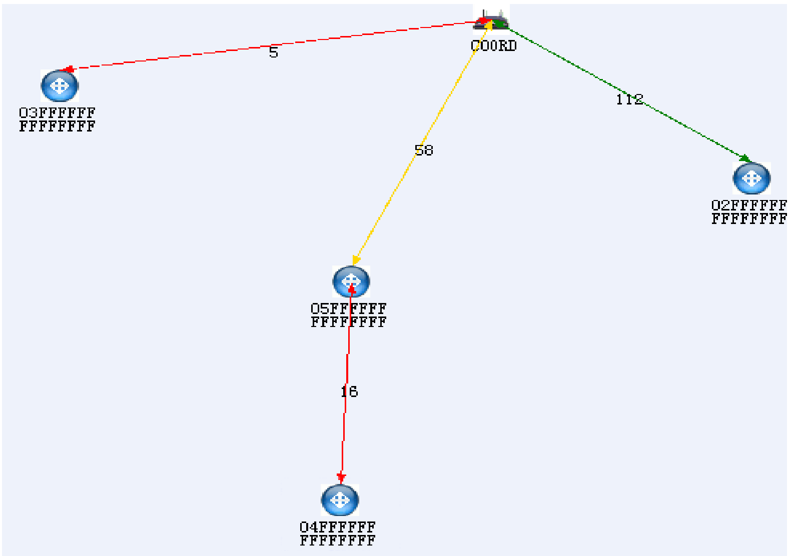

Fig. 4. Monitoring network topology diagram

Where 05FFFFFFFFFFFFFF represents the network address of the cluster head node responsible for the communication between the chart room cluster head node and the host computer, and 04FFFFFFFFFFFFFF represents the cluster head node in chart room. From Fig. 4, we find the wireless signal between the relay node and the host computer monitoring system is very good (the signal strength is 58 decibels milliwatts), and the wireless signal strength of the relay node and the chart indoor cluster head node is average (signal strength value is 16 decibel milliwatts). The wireless signal between the cluster head node of the distress alarm communication cluster with the network address of 02FFFFFFFFFFFFFF and the host computer monitoring system is in a super strong state. Additionally, Fig.4 illustrates that WSN has successfully realized the self-organizing network between nodes, and the nodes in each monitoring area automatically form their own communication clusters.

Fig. 5 shows the monitoring data sent back from the scene by the sensor node in the chart room responsible for monitoring the storage area of the paper chart after the watchman (experimenter) sent a command to view the data information of the chart room through the host computer. The temperature, light intensity, and wireless signal intensity values monitored by the node within 60 seconds (the units are degrees Celsius, lux, and decibel milliwatts, which are also the default units in this paper).The red curve represents the temperature monitoring data sequence of the sensor node and shows that the temperature value of the area stored paper chart in the chart room is about 20 degrees Celsius, which belongs to the normal temperature range. The black curve represents the light intensity curve of the monitoring area of the node, and its value is about 30 lux. This indicates that the light in the area is good. Since the temperature data and light data collected by the sensors did not fluctuate significantly and basically in a steady state of change. It can be seen that there is no fire hazard in the chart room. Moreover, the wireless signal strength between the node and the relay node is 120 decibel milliwatts, which indicates that the communication between the nodes is smooth, and the host computer system can effectively obtain the data information of the on-site monitoring node.

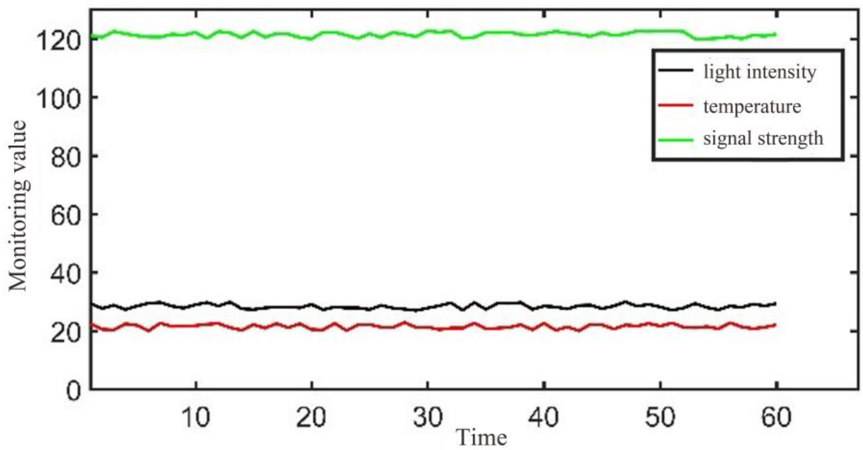

Fig. 5. Monitoring data graph displayed by the host computer

In order to simulate the fire alarm situation of the ship bridge monitoring network, the temperature source of the ship bridge is artificially added to increase the indoor temperature of the ship bridge chart room. Fig. 6 shows that the sensor monitoring node of the chart room can sensitively collect abnormal changes in indoor temperature. The temperature data collected by the node quickly jumped from 20 degrees Celsius to 100 degrees Celsius, and abnormal temperature fluctuations are also transmitted to the host computer system in time. When the host computer system receives the information that the temperature is higher than the normal temperature threshold, it immediately pops up the fire warning information, and transmits the relevant fire alarm information (including the location of the network node, the fire area, the alarm time, etc.) to monitoring platform for shipborne fire alarm information through the ship fire monitoring sensor network. Then The monitoring platform sends out fire alarms and informs all crew members on board to take measures to extinguish the fire source to ensure the safety of the crew's lives and property.

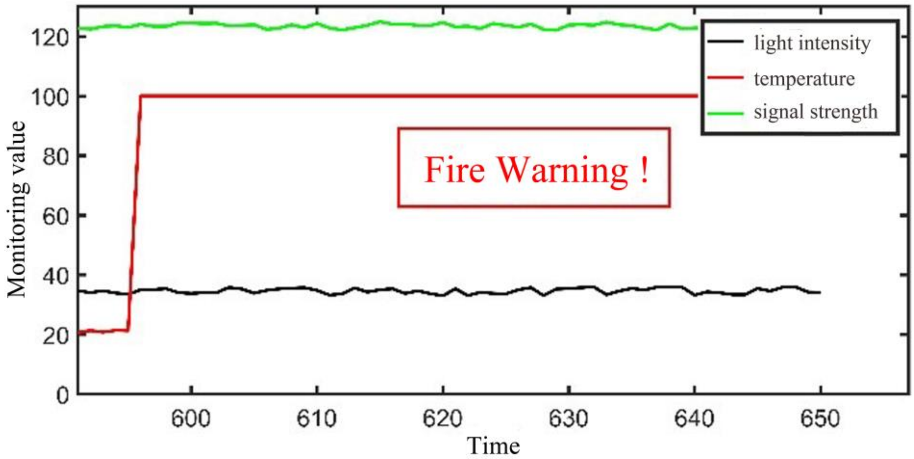

Fig. 6. Display interface of ship bridge fire warning

5. Conclusions

This paper describes a ship bridge intelligent fire early warning and monitoring system based on WSN, which uses WSN to intelligent monitor the ship bridge and obtains real-time fire warning index values in the monitoring area. Once the FEWIs reach or exceed warning threshold, the personnel on duty on the bridge of the ship can quickly find and deal with the potential fire hazards based on the relevant information sent by the sensor nodes. Related fire alarm monitoring experiments show that the system can better complete the monitoring task, and it plays a positive role in the fire prevention and monitoring of the ship bridge. But the robustness of the system network is not good and susceptible to external interference (e.g., electromagnetic wave signals, vibration, etc.). That is our future research work.

Acknowledgements

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