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Research Article

Design of a Smart Cabin Lighting System Based on Internet of Things

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Abstract: With the rapid advancements in mobile devices and wireless network technologies, the Internet of Things (IoT) has become more powerful and popular than ever. The aim of IoT is to efficiently control various types of objects through wireless communications. This paper aims to design an IoT-based smart lighting system that reduces development costs and saves power consumption. Unlike public open spaces, the focus of this paper is on ship cabin spaces. As ship cabins have unique properties, such as requiring gas-based power generation and preferring a wireless environment, designing a smart cabin lighting system is crucial and has significant commercial value. The smart cabin lighting system is designed with four features. Firstly, it can automatically control the lighting devices around people using position-sensitive devices. Secondly, it enables setting on/off and adjusting the luminance for lighting devices through Touch Keypads. Thirdly, the system can be controlled using an app to turn on/off and adjust the luminance of lighting devices. Lastly, the lighting devices equipped with sensors collect specific data on cloud servers for analysis. The underlying communication protocol used to interconnect the smart lighting devices, sensors, and Touch Keypads is Zigbee. The smart cabin lighting system can be applied to marine lighting, thus improving the commercial value of enterprises related to marine lighting.

***Keywords*:** Internet of Things, smart lighting system, ship cabin spaces, sensors, Zigbee

1. Introduction

The Internet of Things (or IoT for short) [1-5], which is currently one of the most popular emerging fields, is a network composed of ordinary objects (e.g., machines, devices, and personnel) interconnected with each other. As the name suggests, IoT generally uses wireless networks as the underlying infrastructure, and each object is equipped with an electronic tag to connect to the Internet and to allow for tracking of its specific location. Through IoT technology, server computers can centrally manage and control each object, and further collect the data generated by each object to aggregate into big data for analysis. In real life, there are many applications that are closely related to IoT. Several common IoT applications are listed in the following.

(1) *Smart home environment*: with IoT technology, a central computer can monitor the operating status of the refrigerator (such as temperature and humidity), as well as the storage status of food inside the refrigerator (e.g., expiration dates or inventory status). It can also remotely control the operation of the television and collect information about

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favorite programs, monitor the door lock, and upload information about comings and goings. (2) *Smart transportation*: through IoT technology, a central computer can collect various vehicle driving information for transportation route analysis to achieve time and cost savings. It can remotely control the vehicle and search for its location to prevent theft, and use satellite navigation and driving recorder information to analyze driving behavior patterns, etc. (3) *Smart healthcare*: with IoT technology, a central computer can use sensors to detect a baby's body temperature, breathing, and heart activity to understand their health status. It can use security cameras to monitor the daily behavior of the elderly and provide body index feedback on a health judgment basis. Additionally, it can be used for medication management to remind patients to take their medicine or help locate medication, etc.

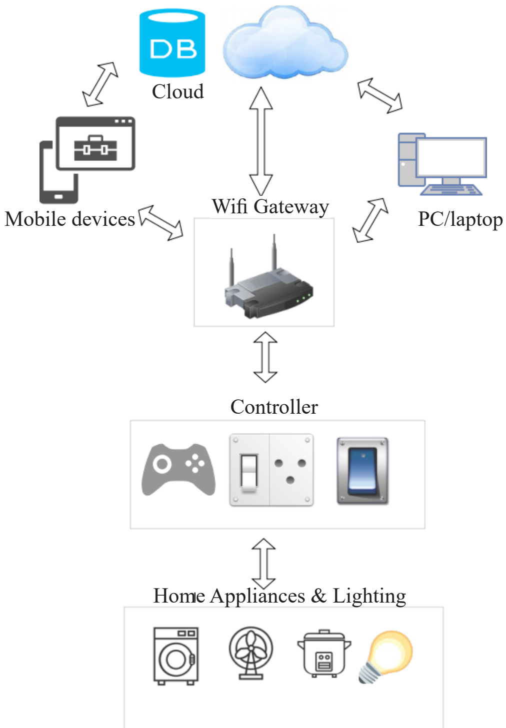


Figure 1. An operation flowchart of smart home appliance

Figure 1 is an operation flowchart of smart home appliances based on an IoT architecture. The bottom layer consists of household appliances such as washing machines, rice cookers, and lamps, each of which can communicate and transmit data with the upper layer controller (which can be a remote control, a fixed switch, or a smart plug) through wireless networks. In addition to controlling the on/off switch of the appliances, the controller can also receive data from sensors installed on the appliances (such as temperature, humidity, or brightness). After collecting sensor data, various controllers can transmit the data back to the upper-layer Wi-Fi gateway through wireless networks. Finally, the Wi-Fi gateway can integrate various types of data and transmit them through wireless networks to terminal devices such as mobile devices, desktop computers, and cloud servers for further data analysis to obtain useful information.

The main goal of this paper is to design an IoT-based smart lighting system. Unlike public open spaces such as parking lots and commercial public areas [6-9], the focus of this paper is on ship cabin space which is a confined and enclosed area. The structure of a ship cabin is illustrated in Figure 2. Due to the unique characteristics of a ship's enclosed cabin, it is of considerable importance to tailor a smart lighting system specifically for this environment. Below, we list the characteristics of the ship's cabin and discuss them one by one.

The more energy-saving the cabin lighting, the better. When ships are sailing, they mostly rely on burning gasoline or diesel to generate electricity or use solar energy for power generation. For long-distance ships, it is particularly important to save power consumption as much as possible because it is difficult to predict whether unforeseen circumstances during sailing will cause insufficient fuel inventory. Using a smart cabin lighting system can avoid power consumption. Smart bulbs are connected wirelessly and can communicate with each other. By using specific sensors such as PIR motion sensors to detect the position of personnel, the surrounding smart bulbs can be turned on or adjusted in brightness through wireless networks. Automated control will greatly save the power consumption of the cabin lighting system compared to the manual operation of the bulbs.

The fewer wires used inside the cabin, the better. Traditional cabin lighting fixtures are connected by electrical wires, which require a large amount of additional cost. The operation of smart cabin lighting systems relies on wireless network communication technology, so connecting the wires between the lamps is not necessary. In other words, the cost of purchasing these wires can be effectively reduced. On the other hand, the safety of the sailing vessel and personnel is also an important consideration. When a sailing vessel is on the sea, the worst thing that may happen is a fire, because there is no escape. If a large number of wires are used as the underlying foundation of the cabin lighting system, it will increase the possibility of wiring fires. The use of smart cabin lighting systems can effectively reduce the risk of wiring fires.

The hard hull makes wiring and troubleshooting difficult. For traditional ship cabin lighting systems, the hard hull noticeably increases the difficulty of lighting fixture installation and wiring. Modifying the hull for lighting system installation can also affect the aesthetics of the ship. On the other hand, the hard hull also increases the difficulty of troubleshooting the lighting systems (e.g., replacing the entire light fixture or the wires due to damage). In a smart ship cabin lighting system, the light fixtures are noticeably smaller in size than traditional light fixtures and sockets, making them easier to install, configure and troubleshoot.

The cabin items or layout are frequently changed. For large container ships, the capacity or size of the items carried may vary according to different types of voyages. As for leisure and tourism ships, changes in the cabin layout may be required due to local cultural considerations or promotional events. In situations where different goods are placed or the layout is changed, the arrangement of lighting fixtures and the connections between them may need to be adjusted accordingly. However, this is difficult to achieve or requires a significant cost in traditional lighting environments. Therefore, developing a smart cabin lighting system can provide greater flexibility in the arrangement of lighting fixtures. This is because mobile devices can remotely control smart lighting fixtures without fixed switches, and the positioning of the fixtures is not limited by the wiring connections between them.

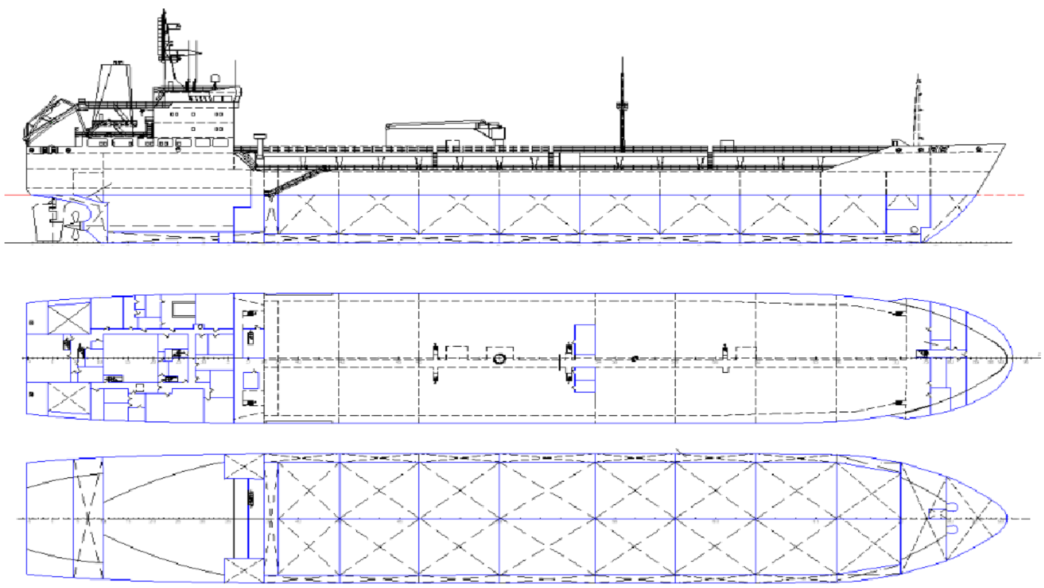


Figure 2. Structure of ship cabin

Through the discussion of the characteristics of the cabin mentioned above, it is necessary and important to develop a smart cabin lighting system based on IoT technology. In the following, we first describe the IoT architecture in Section 2, and then present the selection of necessary components for the smart cabin lighting system in Section 3. Next, the system framework is shown in Section 4 and how to query and analyze the sensor data is presented in Section 5. Finally, Section 6 concludes this paper.

2. Architecture of IoT

As shown in Figure 3, the architecture of IoT [10-14] refers to the structural framework that enables the communication and interaction between IoT devices, sensors, gateways, cloud platforms, and applications. The typical IoT architecture is presented using a five-layer model as follows.

The Perception Layer: this layer includes all the physical devices and sensors that are used to collect data from the physical world. These devices can be anything from simple temperature sensors to complex cameras and drones. The data collected from these devices is typically in the form of raw sensor data, which needs to be processed and analyzed before it can be used.

The Network Layer: this layer is responsible for the communication between IoT devices and the cloud platform. It includes various networking technologies such as Wi-Fi, Bluetooth, Zigbee, and cellular networks. It also includes gateways that are used to connect legacy devices to the cloud platform.

The Middleware Layer: this layer is responsible for managing the flow of data between IoT devices and the cloud platform. It includes various components such as data brokers, message queues, and data analytics engines. The middleware layer is also responsible for managing security and access control to IoT devices and data.

The Application Layer: this layer is where the actual applications and services are developed that use the data collected from IoT devices. These applications can be anything from simple monitoring and control systems to complex predictive analytics and machine learning algorithms. The application layer can be further divided into three sub-layers: (1) data processing layer is responsible for processing and filtering raw data collected from the perception layer. (2) service layer provides various services such as data visualization, data aggregation, and data analytics. (3) business logic layer is responsible for implementing business logic based on the data collected from IoT devices.

The Business Layer: this layer includes various business models and services that are developed based on the data collected from IoT devices. These models can be anything from subscription-based services to pay-per-use models. The business layer is also responsible for developing new revenue streams and creating new business opportunities based on the data.

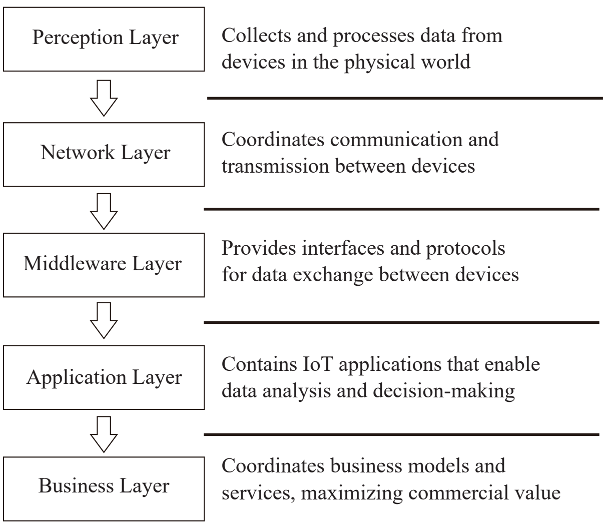


Figure 3. Illustration of IoT architecture

3. Design of system components

The main objective of this paper is to design a smart ship cabin lighting system based on the IoT architecture, which is expected to have the following functions: (1) location sensors automatically detect the position of personnel within the ship cabin to control the lighting device switch, (2) control lighting device switch and adjust the brightness through smart touch keypad, (3) develop an Application (App) to control lighting device switch and adjust the brightness, and (4) smart lighting devices sense data and send it back to the server for storage. To accomplish the mentioned functions, certain essential components for the smart cabin lighting system must be selected, which are described separately as follows.

3.1 *Selection of communication protocol*

To enable communication between each component of the smart cabin lighting system, it is necessary to first select the communication protocol used. Currently, the communication protocols used in smart lighting systems can be divided into two types: wired (e.g., telephone line and Ethernet IEEE802.3) and wireless (e.g., Wi-Fi, Bluetooth, and Zigbee). For the smart cabin lighting system, it is desirable that the overall lighting operation is based on a wireless network, which can adjust lighting and save energy. It should have a large transmission range and good scalability. Based on these considerations, the Zigbee communication protocol with low power consumption is selected as the underlying wireless network communication method.

3.2 *Selection of ZigBee chip*

To enable smart lighting devices to operate through the Zigbee network protocol, a Zigbee chip must be installed in each lighting device. In addition, some Zigbee chips must be deployed in the IoT for routing and coordinating functions. The Zigbee chip responsible for the routing function is called a *Zigbee Router*, which is an intermediate node that is always active and mainly used to assist in data transmission and forwarding between lighting devices. The Zigbee chip responsible for coordinating function is called a *Zigbee Coordinator*, whose main function is to store network information and define the best transmission path between two nodes in the network. The CC2530 Zigbee chip (structured as shown in Figure 4) produced by Texas Instruments is used to build the IoT so that the lighting devices can communicate with each other through Zigbee signals. The CC2530 chip can be widely used in 2.4-GHz IEEE 802.15.4 systems, RF4CE control systems, ZigBee systems, and various applications such as smart building automation, industrial control measurement and monitoring, and low-power wireless sensor networks.

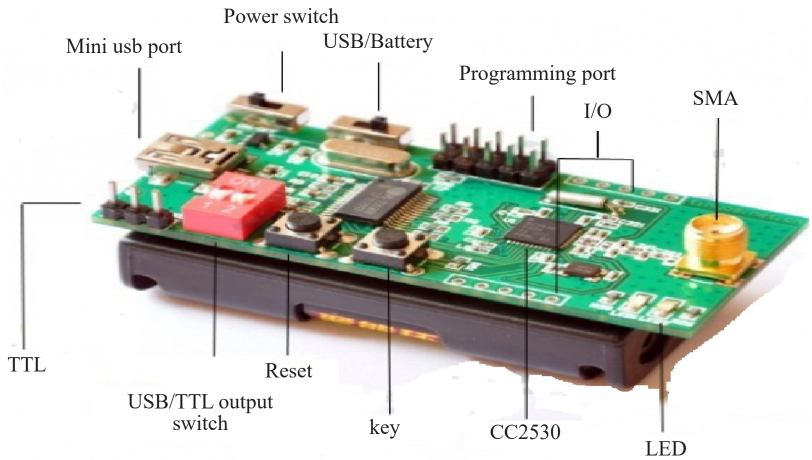
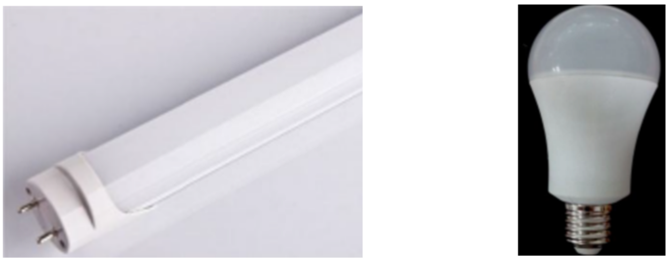


Figure 4. Zigbee chip

3.3 *Selection of smart light tube and bulb*

There are many types of lighting fixtures available in the market. Two types of lighting fixtures, namely, dimmable LED T8 tubes and dimmable LED bulbs, are used for implementing smart lighting. The specifications for these two types of lighting fixtures are provided in Figure 5(a) and Figure 5(b), respectively.



Model Name	LT-2T8-10 UN	LT-4T8-18 UN
Input Volt.	AC100V~AC277V	
Power Consume	10 W/0.1 A	18 W/0.16 A
Length	590 mm	1,198 mm
Dimming Range	0%~100%	
Operating Temperature	-10 °C~+50 °C	
Transceiver Type	IEEE 802.15.4 ZigBee 2.4 Ghz	
Transmission Range	Up to 70 m	
Transmission Frequency	2,405 Mhz~2,480 Mhz	

Model Name	GP1 502-D07
Input Volt.	AC100V~AC240V
Power Consume	7W
Size	120 mm × 60 mm
Dimming Range	0%~100%
Operating Temperature	-10 °C~+40 °C
Transceiver Type	IEEE 802.15.4 ZigBee 2.4 Ghz
Transmission Range	Up to 70 m
Transmission Frequency	2,405 Mhz~2,480 Mhz

Figure 5. (a) Dimmable LED T8 tube and (b) Dimmable LED bulb

3.4 *Selection of touch keypad*

The smart cabin lighting system is expected to have the function of controlling the on/off switch and brightness adjustment of the lighting devices through a fixed smart touch keypad. Therefore, it is necessary to select the *power controller* and the *touch keypad* and integrate them to create a smart touch keypad. Specifications for the power controller and touch keypad used in the smart cabin lighting system are shown in Figure 6.

3.5 *Selection of motion detector*

One of the functions of the smart cabin lighting system is to automatically detect the position of personnel inside the cabin to control the lighting device switch. Therefore, a position sensor needs to be selected as the instrument for detecting personnel positions. In this paper, a *PIR motion detector* is used as the position sensor, and its specifications are shown in Figure 7.

3.6 *Selection of sensor*

In the smart cabin lighting system, since the smart lighting fixtures are installed in various locations in the cabin, specific sensors can be added to the fixtures to sense environmental data (such as temperature and humidity) in the surroundings. Data can be collected through the Zigbee wireless network and transmitted to the server for further data analysis. For example, collecting temperature and humidity data can be used to determine whether there is a fire in the cabin. Therefore, some sensor components would be used to develop value-added functions for the smart cabin lighting system (a more detailed explanation will be provided in Section 5).

Product Name	GP1506-300
Power Supply	DC+9 V~DC+12 V
Product Size	84.5 mm × 44.5 mm × 22.5 mm
Dimming Range	0%~100% (3 channels)
Operating Temperature	0 °C~+40 °C
Transceiver Type	IEEE 802.15.4 ZigBee 2.4 Ghz
Transmission Range	Up to 70 m
Transmission Frequency	2,405 Mhz~2,480 Mhz

Product Name	TH-101Z
Product Type	Capacitive
Power Supply	AC85 V~AC265 V/50 Hz~60 Hz
Product Size	112 mm × 72 mm × 30.5 mm
Operating Temperature	-10 °C~+45 °C
Transceiver Type	IEEE 802.15.4 ZigBee 2.4 Ghz
Transmission Range	Up to 80 m
Transmission Frequency	2,405 Mhz~2,480 Mhz

Figure 6. (a) Power controller and (b) Touch keypad

4. The framework of smart cabin lighting system

In the previous section, we have described the components required for the smart cabin lighting system. Next, we use Figure 8 to illustrate the system framework and provide detailed explanations for each component.

(1) All the lighting devices (including the LED T8 tubes and the LED bulbs) in the cabin are equipped with Zigbee chips and sensors for data detection.

(2) Several Zigbee chips are deployed in the cabin as Zigbee Routers (shown as yellow boxes in the figure) to assist in data transmission and forwarding between lighting devices.

(3) A Zigbee Coordinator (shown as a red box in the figure) is used to store network information, define the optimal transmission path between two nodes in the network, and serve as a bridge for communication with the Wi-Fi protocol.

(4) PIR motion detectors are installed in the cabin to detect personnel positions, and the lighting devices around personnel are controlled through the Zigbee communication protocol.

(5) Several fixed smart touch keypads are installed in the cabin (each of which has its own control range) to control the lighting devices within that range via the Zigbee communication protocol.

(6) The Application (App) is developed to communicate with the Wi-Fi Gateway (composed of Wi-Fi AP and Zigbee Coordinator) through the Wi-Fi protocol and then controls the operation of smart lighting devices through the Zigbee protocol via the Wi-Fi Gateway.

(7) The sensors equipped on the smart lighting devices regularly detect data, and then the data is returned to the Wi-Fi Gateway via the Zigbee protocol. The data is then uploaded to a cloud server for further analysis via the Wi-Fi protocol by the Wi-Fi Gateway.

Product Name	GP1601-z8-xxx
Power Supply	DC+5 V~DC+12 V
Coverage	120 °
Detect Distance	Up to 7 m
Product Size	70 mm × 54 mm × 45 mm
Dimming Range	0%~100% (3 channels)
Operating Temperature	-10 °C~+50 °C
Transceiver Type	IEEE 802.15.4 ZigBee 2.4 Ghz
Transmission Range	Up to 80 m
Transmission Frequency	2,405 Mhz~2,480 Mhz

Figure 7. PIR motion detector

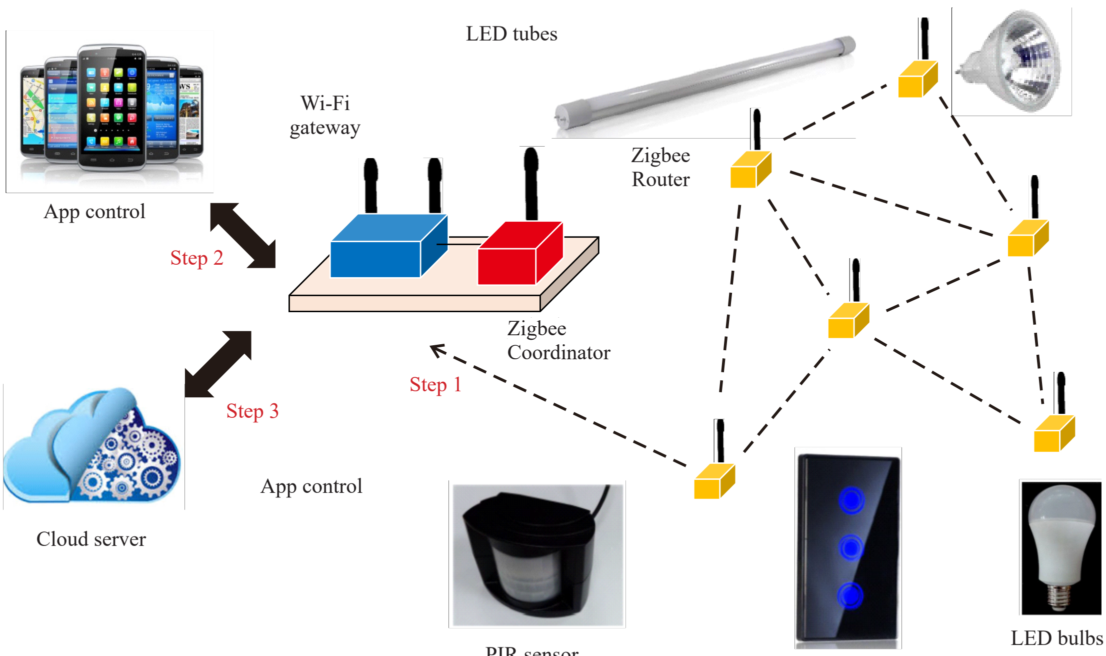


Figure 8. Framework of smart cabin lighting system

5. Query and analysis of sensor data stored in the cloud server

As mentioned in the previous section, a group of sensors is installed in the smart lighting devices (e.g., the LED tubes and bulbs in Figure 8) to detect temperature and humidity. The collected data will be transmitted through the Zigbee communication protocol and then stored in a cloud server. As a result, for each sensor, the data is kept in the form of (Z_i, B_i, T_i, H_i, t_i), where Z_i represents the Zigbee chip number installed on the LED T8 tubes or the LED bulbs, B_i corresponds to the number of each block in the cabin, and T_i and H_i are the temperature and humidity values, respectively, detected by the sensors at time t_i. That is, in Figure 8, Step 1 involves the transmission of data to the cloud server, which is accomplished using the Zigbee Routers and the Zigbee Coordinator. By using the cloud server built in the cabin environment, users (such as captain and crew members) can use the designed app to check temperature and humidity values at different times. In addition, the sensor data can be analyzed to determine and monitor the cabin environment.

Querying the sensor data (refer to Step 2 in Figure 8): the smart cabin lighting system offers three types of queries to process the cloud data: temporal query, spatial query, and spatiotemporal query. (1) The *temporal* query [15, 16] returns the temperature and humidity values of all sensors inside the ship's cabin for a specific time instant or a time interval. Additionally, it also returns the sensor data that exceeds a certain threshold for temperature and humidity within the specified time range. (2) The *spatial* query [17, 18] retrieves the temperature and humidity of a specific sensor or a block of sensors within the ship's cabin. Similarly, it also returns the sensor data with abnormal temperature and humidity by setting a threshold. (3) The *spatiotemporal* query [19, 20] combines the above two types of queries to determine the temperature and humidity values of sensors in a certain area during a specific time period.

Analyzing the sensor data (refer to Step 3 in Figure 8): the smart cabin lighting system can automatically trigger events by analyzing the sensor data returned from the above three types of queries. For example, when the temperature and humidity of sensors in a certain area remain abnormal for three minutes, it indicates the possibility of a fire. At this point, the system can send an alarm to various areas of the ship's cabin. Another scenario is when the sensor in a certain area has not returned data for a period of time, the system can send a notification to maintenance personnel to inspect the area for possible sensor damage or communication problems with the IoT. By analyzing the sensor data, the system can effectively monitor the ship's cabin environment to ensure safe navigation.

6. Conclusions

The main objective of IoT is to efficiently control various types of objects using wireless communications. In this paper, we present the design of an IoT-based smart cabin lighting system aimed at reducing development costs and saving power consumption. The smart lighting devices in the system are interconnected using the Zigbee communication protocol. The smart cabin lighting system is designed with four key features. Firstly, it can automatically control the lighting devices around people using position-sensitive devices. Secondly, it enables setting on/off and adjusting the luminance for lighting devices through Touch Keypads. Thirdly, the system can be controlled using an app to turn on/off and adjust the luminance of lighting devices. Lastly, the lighting devices equipped with sensors collect specific data on cloud servers for analysis. The developed smart cabin lighting system can be applied to marine lighting, thus enhancing the commercial value of marine lighting-related enterprises.

There are several promising opportunities for extending this work in the future. One such avenue involves monitoring and tracking cabin crew using the IoT-based smart cabin lighting system. Additionally, exploring the applicability of this lighting system in other real-world settings could be another avenue worth pursuing.

Acknowledgments

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Conflict of interest

The author declares that he has no conflicts of interest regarding the content of this article. The study was conducted independently and the author received no funding from any organization or entity with a financial interest in the subject matter. The author has no financial relationships with any organizations or entities that could be perceived to influence the research presented in this article.

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