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Real-time Alarm, Dynamic GPS Tracking, and Monitoring System for Man Overboard

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Ships are the most important means of transportation for maintaining the marine economy in most countries. Coastal patrol is an important task of the state to prevent smuggling and other dangerous coastal activities. However, unfortunate accidents involving people on board ships and coast guards drowning in the sea occur from time to time. To save the lives of those who have fallen into the sea, most international searches are carried out by satellite searches, helicopter rescue, and the dispatch of boats. They are not only time-consuming but also inefficient. For this reason, we propose in this paper a real-time alarm, dynamic global positioning system (GPS) tracking, and monitoring system for man overboard (MOB). The system consists of four parts: wearable sensing aids, modular long-range access points (LoRa APs), physical electric fences, and a central control system, as well as three methods of detecting and protecting against MOB. These methods include real-time notification of MOB with wearable sensing aids, virtual electric fence monitoring based on the size of the ship, and instant notification triggered by a physical electric fence around the ship. As shown in a laboratory test and an actual sea test, the three MOB sensing methods developed in this research can perform instant detection and notification actions. We have thus demonstrated a method for the real-time detection of MOB by a shipwrecked ship itself that also promptly proposes a rescue action.

1. Introduction

The marine economy has always been an important economic source of foreign trade in most countries, and it also is an important basis for maintaining people's quality of life. Examples are offshore and pelagic fisheries, mariculture, offshore oil fields, tourism, ferries, cargo ships,

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cruise ships, warships, and other types of marine transportation. Among them, the agricultural products required by the public, and the fuel, mining products, chemicals, machinery, and equipment required by factories are all transported by freighters. Thus, their traffic volume is increasing. In the global marine economy, various commercial and cargo ships play a very important role. With the ever-increasing demand for various human technology products and daily necessities, the number of merchant ships at sea is increasing. Under such circumstances, many cargo ships must sail at sea, which has led to many sea accidents. These include man overboard (MOB) accidents, resulting from human negligence, poor seaworthiness of vessels, poor weather, collisions between ships, and other factors. Even during warship duties, military exercises, or on the way to search and rescue, there have been accidents involving MOB. The rescue of MOB should be within a 72 h period; otherwise, precious life will be lost owing to factors such as loss of physical strength or body temperature. However, in the vast sea area, it is difficult to find drowning people.

To resolve this issue, as early as 1984, some scholars proposed rescue methods through satellite information transmission using satellite systems to carry out air and sea rescue.(1) In the Cospas-Sarsat development program of the international organization of low-orbit satellites, small battery-powered transmitters have been installed on ships or aircraft, which will start manually or automatically when an accident occurs. Once the system is triggered, its transmitter will send an SOS signal, which is a low-power omnidirectional signal that a satellite can receive. The satellite receives this distress signal and immediately forwards it to an Earth station, and then sends the information to a rescue center via a traditional communication line. In a marine rescue conference in 1994, an image processing technique applied to the detection of rescue targets in marine rescue was proposed.(2) To detect small targets such as drowning people in the wide sea area, image processing techniques based on color information and composite image sensors using machine vision were used to improve the measurement accuracy and image processing speed. In 2010, an automatic identification system (AIS) was applied to a marine search and rescue radar.(3) By using the constant false alarm rate (CFAR) algorithm, the authors improved the recognition of targets at sea. In this study, a learning mechanism was used to establish AIS information of samples, and maximum likelihood estimation (MLE) was used to estimate the threshold (t) of targets, allowing all ships to be distinguished and searched for. Therefore, the efficiency and accuracy were improved when using a marine search and rescue radar to search for targets. However, owing to poor visibility at sea level and serious interference, the effectiveness of search and rescue is poor.

In 2011, a wireless ad hoc network based on the global positioning system (GPS) for marine monitoring, searching, and rescuing (MSnR) was proposed.(4) The authors used a wireless ad hoc network consisting of small fishing boats to provide positioning services to improve sea-to-land wireless radio links from the small fishing boats to central inland stations. GPS can provide positioning services, while in an ad hoc network consisting of small fishing boats, short-distance communication considerably enhances the sea-to-land link. The method is used to continuously report and monitor all boats and their locations in an emergency requiring the search and rescue process. In 2013, an autonomous air-sea rescue system using particle swarm optimization was proposed.(5) This heuristic technique is used to search for survivors of a sinking ship in an area of the sea, which was compared with a random search as a benchmark. The search in the study was carried out by four small unmanned helicopters on a fixed platform. In the case of a single surface ship, the assigned helicopter determines the survivors in the area by measuring the temperature of each point in the search space using an infrared camera. On average, the particle swarm optimization algorithm searches a smaller area than the random method, and the former detects more targets, demonstrating the effectiveness of heuristic techniques.

In 2013, Schulz *et al.* proposed system considerations and VCO design for a local positioning system at 2.4 GHz for the rescue of people on ships and in the sea.(6) In this article, a positioning system for passengers on board and in the sea (MOB) was described. System considerations such as oscillation and modulation frequency were evaluated. The baseband structure was considered for necessary design tradeoffs, which are for positioning a large number of different passengers in a rational update time. A cross-coupled oscillator was used in 0.18 μm BiCMOS technology, which was optimized as a reflector tag. After measurements, the above-mentioned circuit had an output power of 5 mW at 36 mW DC power, which resulted in a high efficiency of 14% in continuous mode.

In 2014, Mao *et al.* proposed a communication protocol using the BeiDou satellite for a MOB monitoring system.(7) ITU proposed a concept of the MOB system and published a draft proposal for MOB to facilitate research and development in this area. The MOB system is a portable, low-power electric device that can be easily attached to clothes or wrists. In the case of danger, the wearer can send a distress signal to base stations or rescue stations manually or automatically. In the polling mode used in the protocol, there is a fail-safe function in the MOB system, because it is activated when no signal is detected. The protocol reduces the false alarm rate and improves the reliability of the communication process through the mechanism of retransmission and error checking. Moreover, by introducing repeaters, the protocol also solves the problem of expanding the coverage of base stations.

In 2017, Agroudy *et al.* built a received signal strength indicator (RSSI) MOB localization system for the safe evacuation of large passenger ships.(8) In this paper, the authors proposed a MOB positioning system that is based on measuring the RSSI between intelligent life vest tags and one interrogator station inside an unmanned aerial vehicle (UAV). This system uses a parallel track search path with better positioning results than those of other search methods. The measurement was performed in a search area of 500 m × 350 m and had a mean error of 37.5 m. In the same year, Jian *et al.* proposed a design of a smart search and rescue device composed of sonar detection and other components.(9) Owing to the increasing number of marine accidents, marine search and rescue missions are becoming increasingly difficult. In this paper, the authors describe a fast and accurate intelligent search and rescue device to accurately locate drowning people. GPS, sonar technology, marine battery technology, database synchronization, and wireless transmission technology are combined, and the system includes three sets of equipment: an active rescue terminal, a receiving terminal, and search and rescue display equipment. With this device, vital signs of victims can be quickly searched for. When the sonar device searches for feedback, GPS provides accurate positioning for accurate rescue. The search and rescue equipment is powered by marine batteries which can be used for a long time. This marine intelligent search and rescue equipment has the characteristics of high speed, strong wind and wave resistance, long working time, rapid access to the marine danger area, and efficient unmanned search and rescue. Xiao *et al*. used drones to assist the US Navy in visual navigation to respond to marine accidents with a large number of casualties.[10] Unmanned surface vehicles (USVs) and UAVs are integrated to compensate for the shortage of rescue manpower and automate search and rescue operations in order to reduce the number of casualties during an emergency rescue phase.

In 2018, Li *et al*. of the School of Information and Control Engineering, Qingdao University of Technology, China, proposed an improved design of an AIS for MOB.[11] AIS transponders and receivers use two VHF radio frequencies, 161.975 and 162.025 MHz, to communicate, identify ships, and track targets, and for simple message exchange. In this study, they used AIS, which is required by the International Maritime Organization and should be installed in international waters, to make small devices part of the infrastructure. The system uses Gaussian minimum shift keying (GMSK)-modulated direct digital synthesizer (DDS) to stabilize the frequency band and special antennas to improve GPS and VHF reception. When a person is involved in an accident, an alarm can be triggered to transmit a distress signal and the GPS position to a nearby ship with an AIS system. It then asks boats nearby to assist in the search and rescue work of MOB.

Advances in technology have led to the gradual improvement of life-saving equipment, and many companies in various countries have also created smart alarm systems for this purpose, but no new technology and equipment have been introduced. It seems that the formal process cannot keep up with the progress of science and technology so that the speed of search and rescue cannot be considerably improved. Rescue is difficult if the search and rescue misses the prime period. In this study, we propose a monitoring system with multiple protective lines that provides a 24 h safety monitoring system for operators on the deck of ships through the use of sensing aids, physical infrared fence sensing, satellite positioning virtual warning lines, and the monitoring system.

2. Research Methods

In this paper, we propose a real-time alarm, dynamic GPS tracking, and monitoring system for MOB, and its R&D target includes four units: wearable sensing aids, modular long-range access points (LoRa APs), physical electric fences, and a central control system. There are three sensing procedures that can issue an alarm for MOB, which are wearable sensing aids with instant notification, a virtual electric fence monitoring system customized on the basis of the size of the ship, and physical electric fences around the ship that trigger an instant notification.

The system architecture is shown in Fig. 1. The scenario of the system is as follows. The deck crew are equipped with a waterproof sensing aid, including GPS and "G-sensors" and LoRa wireless transmitters. The sensing aid can record the movement position and attitude displacement of the wearer on the deck at any time and is connected with the central control host to transmit information at any time. Around the ship, multiple sets of infrared electric fences are used to form a protective net. When the wearer falls into the sea, an electric fence around

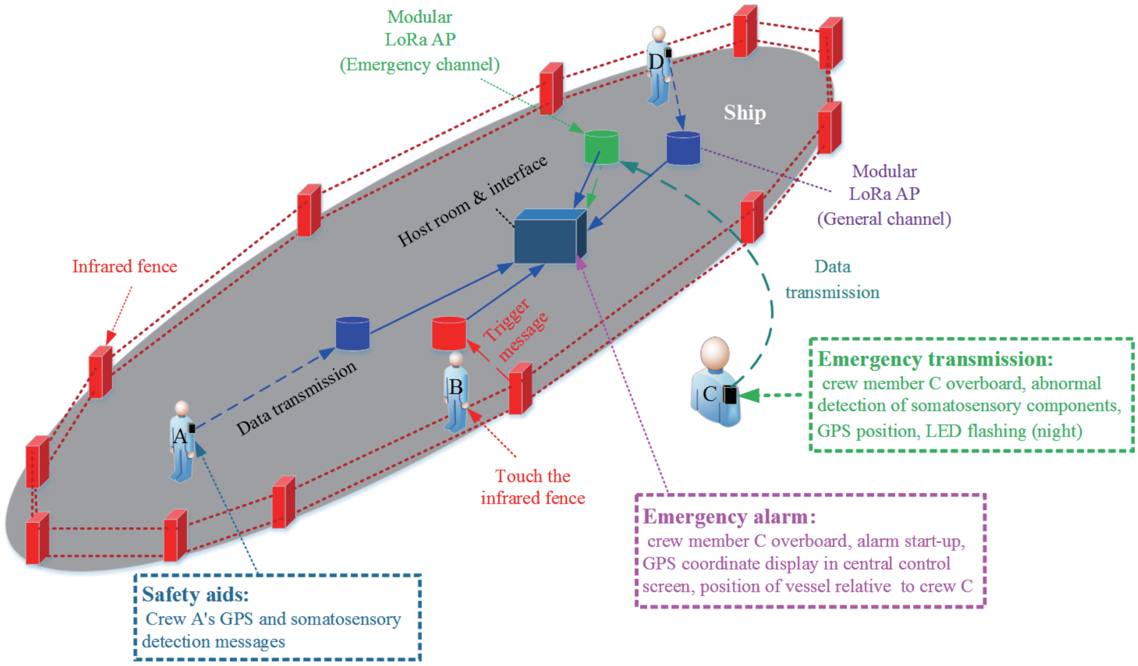


Fig. 1. (Color online) System diagram.

the ship will be triggered first. When the electric fence is blocked, the fence will send signals back to the gateway through the LoRa transmitter of the infrared fence, and then the address will be converted and transmitted by Modbus to the host room through the data conversion box. The waterproof sensing aid on the human body also triggers the G-sensor in the box owing to the acceleration generated by the free fall of the person caused by MOB. The distress signal is sent to the LoRa AP via LoRa communication and sent back to the central computer of the host room for notification. The control center inside the ship displays the synchronization message on the monitor screen and immediately issues an alarm. After detecting the crew overboard, the waterproof sensing aid will continue to transmit the position of the drowning person to the LoRa AP and then return it to the central control system. From the monitoring screen of the central control system, the GPS relative positions of the ship and the crew overboard will be immediately presented to facilitate the follow-up rescue operations. Figure 1 shows a detailed functional description of each unit of the system.

2.1 Wearable sensing aids

The wearable sensing aids are the core technology of the system and are mainly used to monitor the movement of crew members on the deck. The internal core structure is shown in Fig. 2, which can be divided into six units: central processing, communication, sensing, flash, power management, and virtual fence units. They are also IP68 waterproof grade.

The design description of each unit is as follows.

1. Central processing unit (CPU): The CPU is a combination of a microcontroller unit (MCU) with related circuits, and it was developed with a Microchip PIC 8-bit MCU. This MCU

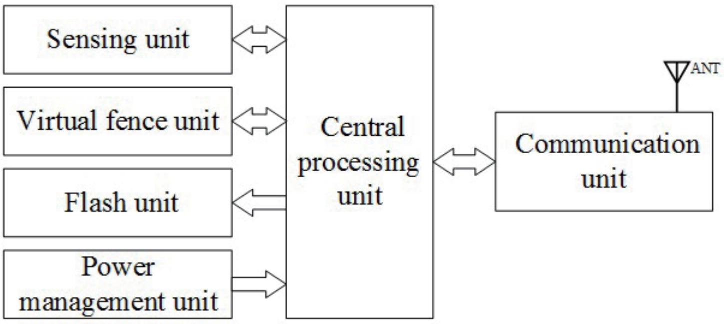


Fig. 2. Diagram of the core structure of the wearable sensing aid.

features nanowatt XLP technology for very low sleep current. It includes a core-independent peripheral, which can effectively reduce the burden on the CPU when performing this function and improve the CPU execution efficiency. The main task of this unit is to manage the operations of the communication unit, sensing unit, flash unit, and power management unit. The operation of the relevant program is carried out according to the received signal command.

2. Sensing unit: This unit has two functions: global navigation satellite system (GNSS) reception and G-sensor free-fall detection. The details are as follows:

a. GNSS reception: In this study, we used u-blox M8N as the main component of the GNSS receiver. It provides –167 dBm high sensitivity and minimal acquisition time while maintaining low system power. Different GNSSs can be acquired and tracked at the same time. They can receive the GPS of the USA, the Quasi-Zenith Satellite System (QZSS) of Japan, the Global Navigation Satellite System (GLONASSG) of Russia, or the BeiDou Navigation Satellite System (BDS) of China. GNSSs can be used in marine environments around the world.

b. Free-fall detection: The function of this part is to detect that the wearer has fallen into the sea. We use a three-axis accelerometer and a gyro sensor to detect the triaxial acceleration of the wearer moving on the deck of a ship. Firstly, the MCU is used to perform fusion computing,[12] and then a digital filter is used to filter out noise to obtain a stable output value. As shown in Fig. 3, when the CPU detects that the Z-axis acceleration changes from 9.8 to zero, then Z-axis acceleration increases to 9.8, and then the value oscillates (the phenomenon of falling into the sea and then surfacing, and the behavior of floating up and down), it can be judged that the person is overboard. The built-in LoRa transmitter of the waterproof sensing aid immediately transmits a distress signal to the LoRa AP. Continuous transmission of its GPS position allows the central control system to monitor position changes after MOB; the flow chart of free-fall detection is shown in Fig. 4.

c. The time basis for deciding when a person falls into the sea is as follows. When a person wearing a wearable sensing aid falls from a ship, the free-fall behavior is detected by the sensing aid after x seconds, and in the next y seconds after falling, the gravitational acceleration begins to decrease. This can be judged as MOB, where the detection of the

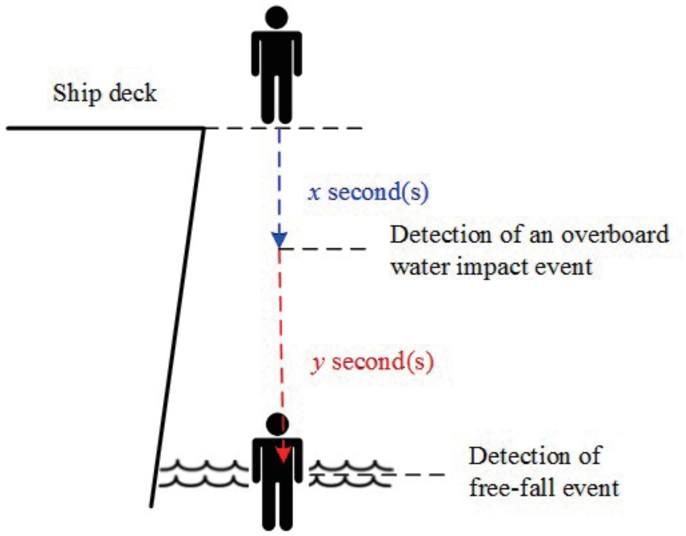


Fig. 3. (Color online) Example of free-fall judgment.

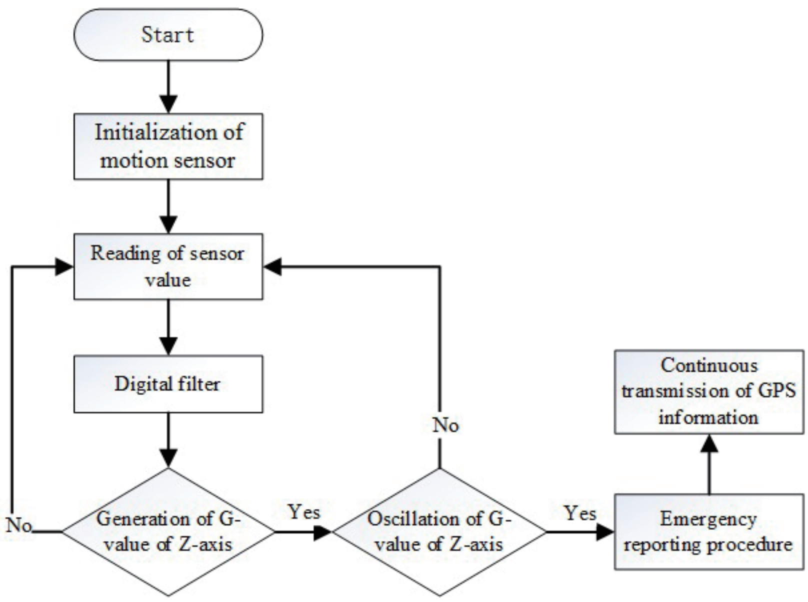


Fig. 4. Flow chart of free-fall detection.

free-fall time of x seconds is taken into account when a person jumps on the deck or jumps from a height to the floor.

3. Communication unit: The communication unit includes LoRa communication and the communication protocol, which is described in detail as follows.

a. LoRa wireless communication: LoRa is an ultralong-range low-power data transmission technology released by Semtech in 2013,[13] which is a low-power wide-area network (LPWAN) communication technology.[14–16] Before LPWAN appeared, we could only choose between long-distance transmission and low-power consumption. The emergence of LoRa wireless technology has changed the trade-off between transmission distance and power consumption. The data transmission rate of LoRa is between 20 and 100 kbps, and the communication distance can reach 5 km.(17) There is no redundant land in the vast ocean where relay stations can be set up to relay data. Therefore, in this project, we used spread-spectrum technology to enable LoRa to achieve its long-distance, noise-resistant characteristics for transmission. The LoRa transmission rate can be adjusted freely. The lower the transmission rate, the farther the transmission distance.

b. Communication protocol: This system uses a customized communication format (as shown in Tables 1 and 2). Each command has a fixed header file "A5". Then, the device ID, function type, data length, and data content are provided in order. When the command is in the process of transmission, it may be disturbed by the environment and result in abnormal errors in data transmission. Therefore, a cyclic redundancy check (CRC) is used at the end to confirm that the command is correct.

A device ID is called a device identification code. It is mainly used when users configure multiple devices in the same communication channel. Even if the host receives the correct information, it still uses the ID to determine which crew member sent it. The device ID is a set of two-byte codes that can accommodate up to 65536 sets of devices. GNSS data provide the coordinates of the drowning person, which are represented by GPS longitude and latitude coordinates in this paper. The coordinates are expressed as two sets of numbers containing six digits after the decimal point, such as (22.626893, 120.315646). To reduce the amount of transmission, the IEEE 754 code is used for transmission instead of the commonly used ASCII format. IEEE 754, also known as the IEEE binary floating-point arithmetic standard,(18) has been the most widely used floating-point arithmetic standard since the 1980s. According to the single-precision data format, the data can be reassembled into useful data using Eq. (1). In this way, the amount of transmission can be considerably reduced from 20 to 8 bytes, which can not only shorten the transmission time but also reduce power consumption.

$$Data = (-1)^{Sign} \times (1.Mantissa) \times 2^{e-127} \quad (1)$$

Table 1
Communication protocol format.

Header	Device ID	Function type + data length		Information content	Check code	
0 × A5	2 bytes	4 bits	4 bits	*N* bytes	CRC Low	CRC Hi

Table 2
Descriptions of the communication protocol function type.

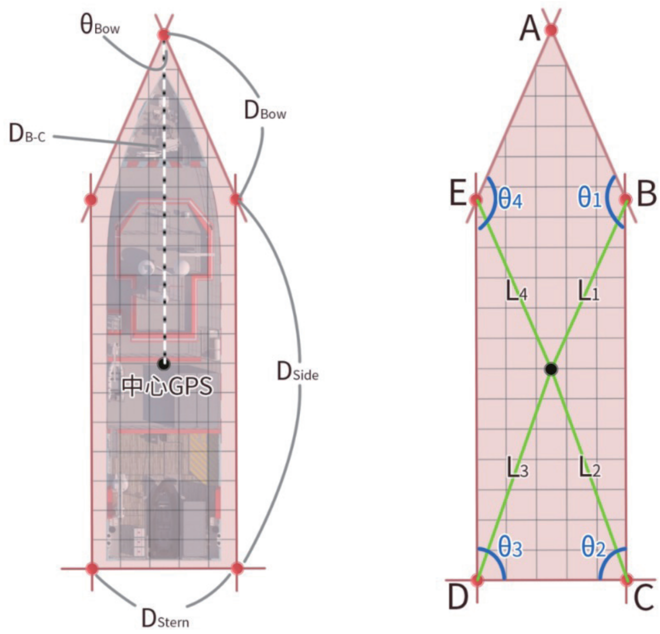
Function type code	Function description
0 × 02	Return GNSS data
0 × 13	Transmit low-power alarm
0 × 24	Transmit fall alarm
0 × 35	Pass rest of error message
0 × 46	Updating GPS position information of ship

4. Virtual fence unit: Virtual fencing is the second line of defense for MOB detection. If the victim is beyond the fencing area, alarms will also be issued. The virtual fence is a five-sided fence. The center of the hull is used as a reference point. The coordinates of each point of the virtual fence can be calculated instantly through various known parameters. The known parameters include both the predefined hull size and real-time measurement parameters. The real-time measurement parameters include the GPS coordinates of the hull center point and the ship's course angle, where the hull size is defined as in Fig. 5(a), the length of the bottom of the ship (D_{Stern}), the length of the side of the ship (D_{Side}), the length of the bow side (D_{Bow}), the bow angle (θ_{Bow}), and the bow-to-center length (D_{B-C}).

 To find the coordinates of each point of the virtual fence (A–E) [Fig. 5(b)], first we need to determine the lengths L_1–L_4 from the center point to each point and the angles θ_1–θ_4 in Fig. 5(b). These parameters can be calculated using Eqs. (2)–(10). Then, the longitude and latitude can be calculated using the coordinates of points A–E (P_x, P_y) of the virtual fence using Eqs. (11) and (12) of GPS (P_{0x}, P_{0y}), L_1–L_4, and θ_1–θ_4 of the hull center. Finally, combined with the GPS coordinates returned by the MOB aids, it can be judged whether the MOB is beyond the fence.

$$L_1 = \sqrt{D_{B-C}^2 + D_{Bow}^2 - 2 \times D_{B-C} \times D_{Bow} \times \cos\left(\frac{\theta_{Bow}}{2}\right)} \tag{2}$$

$$\theta_1 = 90 - \sin^{-1}\left(\sin\left(\frac{\theta_{Bow}}{2}\right) \times \frac{D_{Bow}}{L_1}\right) \tag{3}$$



(a) (b)

Fig. 5. (Color online) (a) Definition of hull size and (b) calculation points.

$$\theta_x = \sin^{-1}\left(\frac{D_{Stern} - D_{Bow} \times \dfrac{\sin\left(\dfrac{\theta_{Bow}}{2}\right)}{\sin\left(90 - \dfrac{\theta_{Bow}}{2}\right)}}{2 \times D_{Side}}\right) + 90 - \theta_1 \tag{4}$$

$$L_2 = \sqrt{L_1^2 + D_{Side}^2 - 2 \times L_1 \times D_{Side} \times \cos(\theta_x)} \tag{5}$$

$$\theta_2 = -180 + \sin^{-1}\left(\sin(\theta_x) \times \frac{L_1}{L_2}\right) + \theta_1 + \theta_x \tag{6}$$

$$L_3 = L_2 \tag{7}$$

$$\theta_3 = -180 - \theta_2 \tag{8}$$

$$L_4 = L_1 \tag{9}$$

$$\theta_4 = -\theta_1 + \theta_2 + \theta_3 \tag{10}$$

$$P_x = P_{0x} + L_x \times \sin(\theta_x - \theta_{AZ}) \tag{11}$$

$$P_y = P_{0y} + L_y \times \cos(\theta_y - \theta_{AZ}) \tag{12}$$

5. Flash unit: The flash unit is originally in the dormant state. When the sensing aid is in the emergency alarm state, the flash unit is activated, wakes up, and flashes with high-brightness LED lights to help the rescuers search for the drowning person at night.
6. Power management unit: Power management is carried out through the combination of an electric meter and the MCU (as shown in Fig. 6) in order to control the turn-on and turn-off sequence of each power supply, the voltage detection of each power supply, and temperature detection. Good power management can increase the service life of batteries, prevent unnecessary power consumption of the system, and greatly enhance battery endurance. This can also increase the time available to assist in the rescue and improve the chance of survival

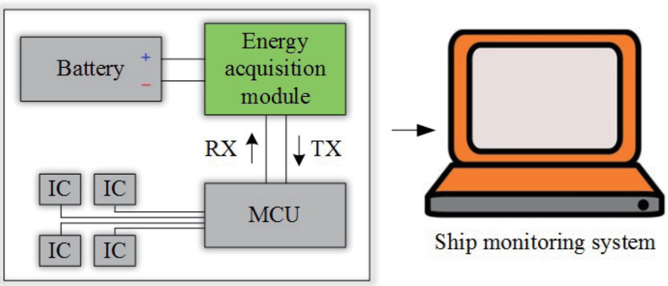


Fig. 6. (Color online) Architecture of power management.

of the MOB. When the energy detection module detects that the power of the aid is less than 40%, it will immediately issue an alarm and send the information back to the host station of the ship to remind the relevant personnel of the need to charge and replace the aid.

2.2 Modular LoRa AP

In this study,[17,19] channels are cut into one channel per MHz in the 410–441 MHz radio frequency band, so there are 32 channels available, as shown in Fig. 7. The LoRa AP is

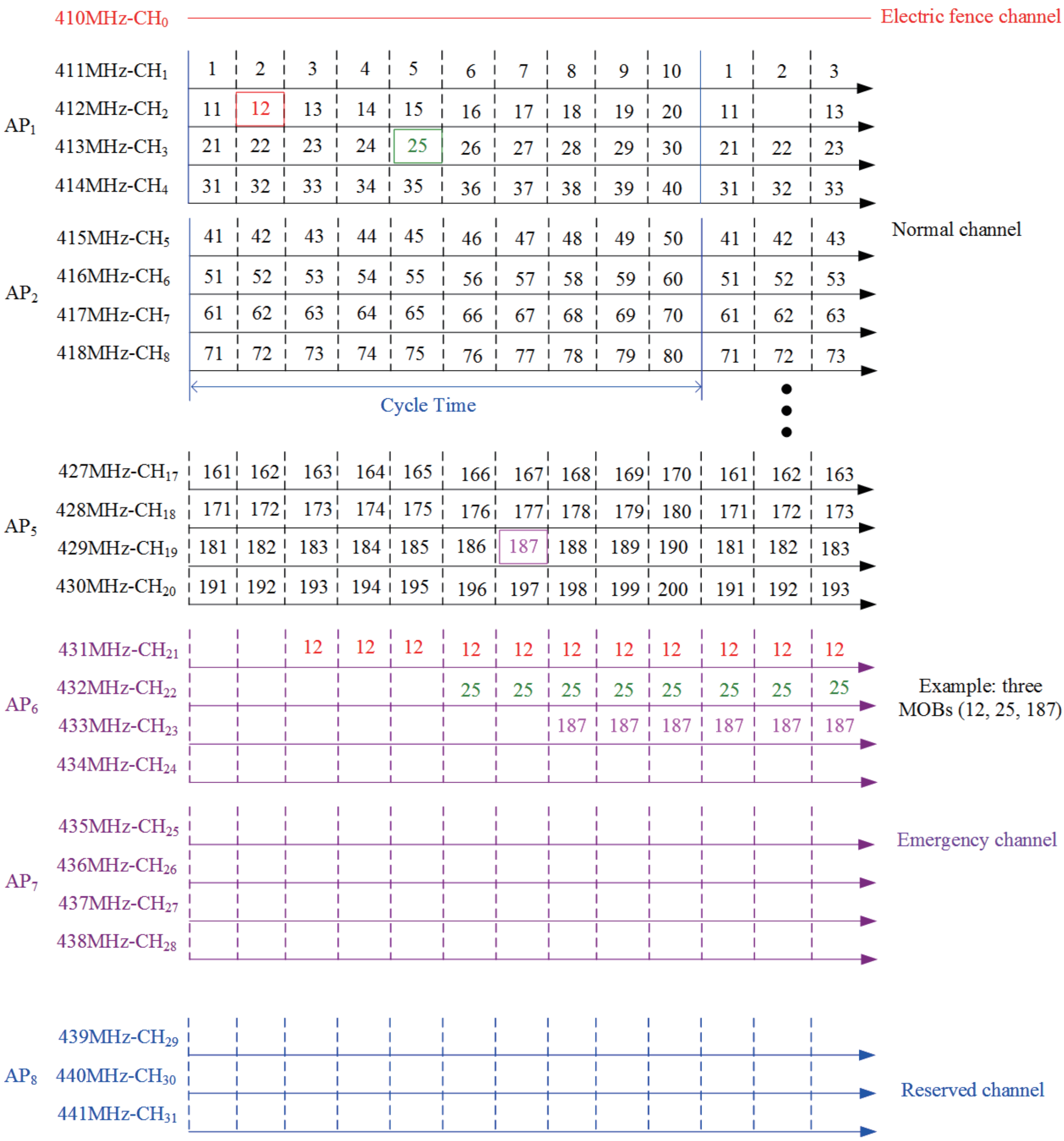


Fig. 7. (Color online) Channel setting table for 410–441 MHz.

modularized into general, emergency, and special channels. All channels are planned as follows.

1. General-channel LoRa AP: This is used to receive data from GPS coordinates and accelerometers transmitted by the aids on deck. Every four channels, Ch_0–Ch_4, Ch_5–Ch_8, Ch_9–Ch_{12}, Ch_{13}–Ch_{16}, and Ch_{17}–Ch_{20}, were classified into a group, i.e., five groups and 20 channels in total. Every four channels are designed as a set of LoRa APs, and each channel is designed to upload LoRa data in a time slot.[20,21] The time slot uses GPS time as the synchronization time, and the cycle time of each channel is designed for ten time slots to provide for ten sets of aids. Each aid uploads data to the preplanned time slot according to its ID number. Therefore, each group of general channel LoRa APs can provide 40 aids to receive the displacement information of the aid wearers transmitted by the aid.
2. Emergency-channel LoRa AP: This is used to receive real-time GPS coordinate information transmitted by people wearing aids when overboard. Every four channels, Ch_{21}–Ch_{24} and Ch_{25}–Ch_{28}, were classified into one group, i.e., two groups and eight channels in total. Every four channels were designed as a set of LoRa APs, and each channel uses a time slot to provide aids for drowning people to transmit the real-time GPS coordinate information. The time slot belongs to a dedicated channel. To clearly determine the GPS location information of the drowning person, each channel is for one person only, the LoRa transmission is transmitted with a high-power chip, and the distance is about 5–10 km.
3. Special-channel LoRa AP: Since the numbers of infrared emitters and receivers of the electric fence on the ship are not large and the distance is small, Ch_0 uses this LoRa AP for the communication of each electric fence TX–RX pair. Polling[22] is used for data transmission of the communication protocol. We plan to use Ch_{29} to identify ship IDs (which are recorded in the ship's central control system). Ch_{30}–Ch_{31} will be reserved for the future expansion of other functions of the MOB system.

Taking Fig. 7 as an example, when the aid wearer with Ch_2 ID number 12 is overboard at a cycle time, the sensing aid immediately requests exclusive access to the LoRa AP of the emergency channel. Then, it switches to an emergency dedicated channel (Ch_{21}) immediately at the next slot. Sensing aids will use redundant power to transmit the GPS position as well as an LED strong light display (night mode). At the same cycle time, when the aid wearer with ID number 25 is also overboard, the sensing aid will immediately make an exclusive access request with the LoRa AP of the emergency channel. Then, it switches to an emergency dedicated channel (Ch_{22}) immediately at the next slot. The system can be used by 200 people wearing sensing aids at the same time and can monitor the position of real-time dynamic GPS coordinates of eight drowning people at the same time. (If there are too many people overboard, the incident is a shipwreck level and needs emergency international aid.)

The architecture of the core controller development of the LoRa AP is shown in Fig. 8. The LoRa AP core control board is designed to use an ARM embedded system and communicate with the LoRa chipset through the UART interface, and then wirelessly communicate with electric fences and accessories to transmit various data. In the data transmission part of the MOB host, the core controller has built-in Wi-Fi and Ethernet communication interfaces, so it can adopt a Wi-Fi or Ethernet communication mode to actively push data to the MOB

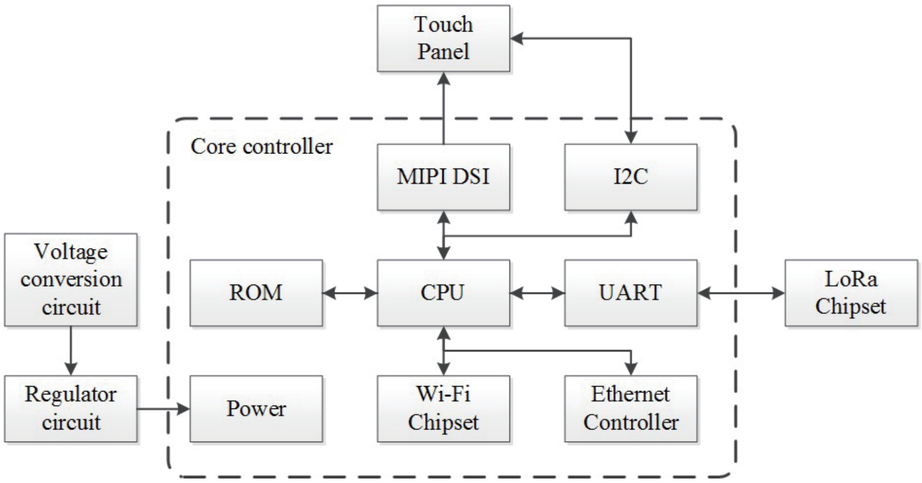


Fig. 8. Architecture of core controller development of LoRa AP.

system host. Also, a touch panel design is added to the program. The core controller displays the screen through the MIPI DSI interface and handles the panel touch control through the I2C interface. The touch panel is designed to allow people to easily set the LoRa wireless communication band. A general transmission monitoring LoRa AP or emergency transmission monitoring LoRa AP can be set. The general transmission monitoring LoRa AP is responsible for collecting data from 40 sets of aids (device identification code, status, battery power, GPS coordinates, etc.). The emergency transmission monitoring LoRa AP is responsible for collecting data from four sets of aids (device identification code, GPS coordinate position, etc.) after MOB. Therefore, the aid data can be collected quickly after MOB, and the GPS coordinates of a person's position can be updated continuously and rapidly. Moreover, parameters such as ID number can be set through the touch panel and can be associated with the MOB system, and the MOB system can display various data of the people.

2.3 Electric fence

The early traditional fences used high-voltage power grids or fences as fence protection. However, with the advancement of technology, electric fencing without an entity and with an alarm function has been developed. At present, various electric fences on the market are listed as follows.

1. Pulse electric fence: After the pulse host is energized, the emitter generates a high-voltage pulse or a low-voltage pulse, which is transmitted to the front fence to form a loop, and then the pulse is transmitted back to the receiving end of the pulse host. If someone invades and destroys the front fence or cuts off the power supply, the pulse host will issue an alarm and transmit the alarm signal to other security equipment. However, because the physical pulse electric fence needs to be energized, it may cause electric shock when the crew members are at work. Moreover, it is extremely expensive to supply power for a long time.

2. Video surveillance electric fence: Image recognition technology is used to judge whether an intrusion alarm is needed. It is more accurate and not easy to misreport. A camera is required, the hardware cost is high, and the equipment consumes a large amount of power.
3. Motion detection electric fence: A line is drawn within a camera's shooting range, and if the line is crossed, the alarm will be activated. This type is designed to trigger an alarm when a pixel of the image from the camera changes. It is easy to misreport and requires a camera. The hardware cost is high and the equipment consumes a large amount of power.
4. Infrared electric fence: A twin infrared emitter and an infrared receiver are used to install an emitter aligned face-to-face with a receiver. When an object passes through the infrared irradiation area, it sends a signal to the host to send an alarm. The equipment is low-cost, easy to install, and has low power consumption. Its structure is shown in Fig. 9.

From the above description, the characteristics of different types of electric fences are summarized in Table 3. The pulse electric fence can easily interfere with the crew operation because of the installation of physical lines, the video surveillance electric fence requires large computing resources whose hardware cost is high and maintenance is not easy, and the motion detection electric fence is not suitable for the ship operation environment. For various reasons, the above three types are not suitable for the marine environment and may even hinder the operation at sea. Therefore, the architecture of the infrared electric fence was chosen for the implementation of the electric fence for the MOB system.

Infrared electric fences have been improved to make them more suitable for use in marine environments. To apply the electric fence to ships of different sizes, in this study, we combine LoRa wireless transmission technology with the electric fence, so that the electric fence can match the size and shape of the hull to configure its device position and operate in the optimal monitoring state. The wireless electric fence system is built in a circular loop to surround the

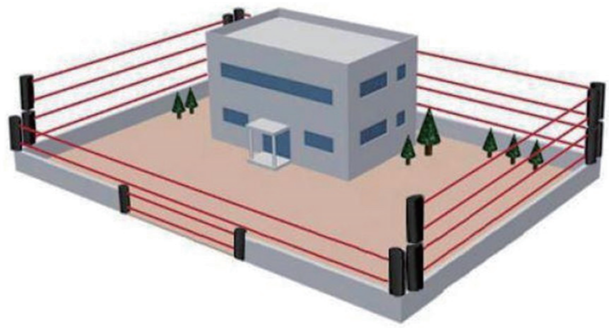


Fig. 9. (Color online) Infrared electric fence.

Table 3
Comparison of various types of electric fences.

Type	Pulse type	Video surveillance	Motion detection	Infrared type
Price	Medium	High	Medium	Medium
Convenience	Low	High	Low	High
Maintenance cost	Medium	High	Low	Low
Expansion cost	Medium	High	Medium	Low

periphery of the ship. When the electric fence is interrupted, the trigger status is recorded immediately, and the data are transmitted back to the central computer through the LoRa Gateway for recording and interpretation. The system architecture of the electric fence is shown in Fig. 10. The hardware structure of the infrared electric fence is shown in Fig. 11. The core uses the MCU PIC24F16KA101. The sensing signals of an infrared photoelectric sensor and the LoRa communication control circuit are connected to the MCU for control and state reading. Since the infrared photoelectric sensor has a 24 V output, electrical isolation must be used to prevent damage to the MCU.

2.4 Central control system

The monitoring and alarm structure of the MOB system is shown in Fig. 12. There are two service programs in the LoRa AP. One is the central control monitoring service program, which receives all LoRa AP information from ships (receiving all data transmitted from sensing aids on the deck) and electric fence monitoring data. In the process of receiving, the information is updated to the database in real time, and it is determined whether the obtained values are reasonable. If the electric fence monitoring system and the free-fall sensing system

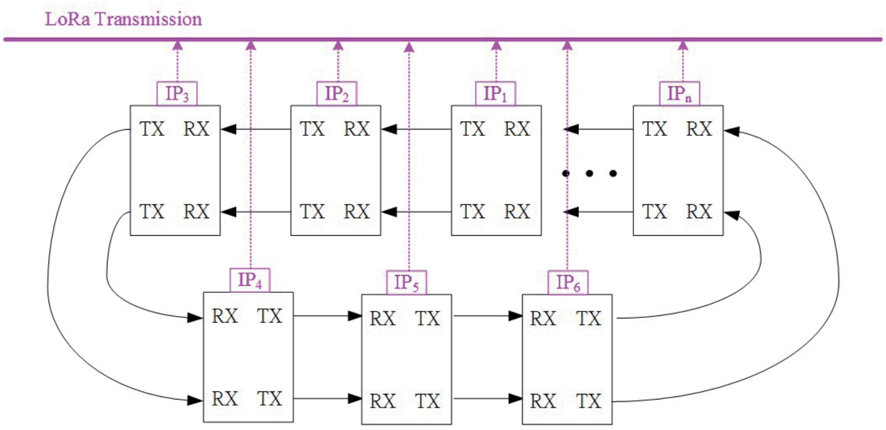


Fig. 10. (Color online) Diagram of the electric fence monitoring system.

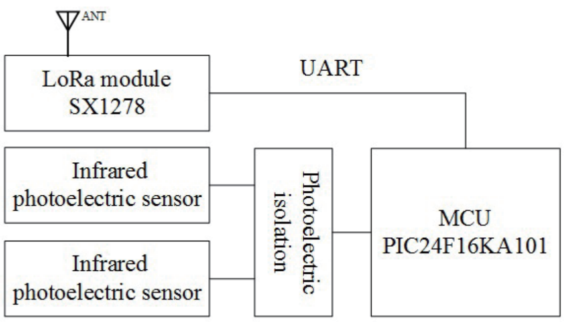


Fig. 11. Architecture of infrared electric fence hardware.

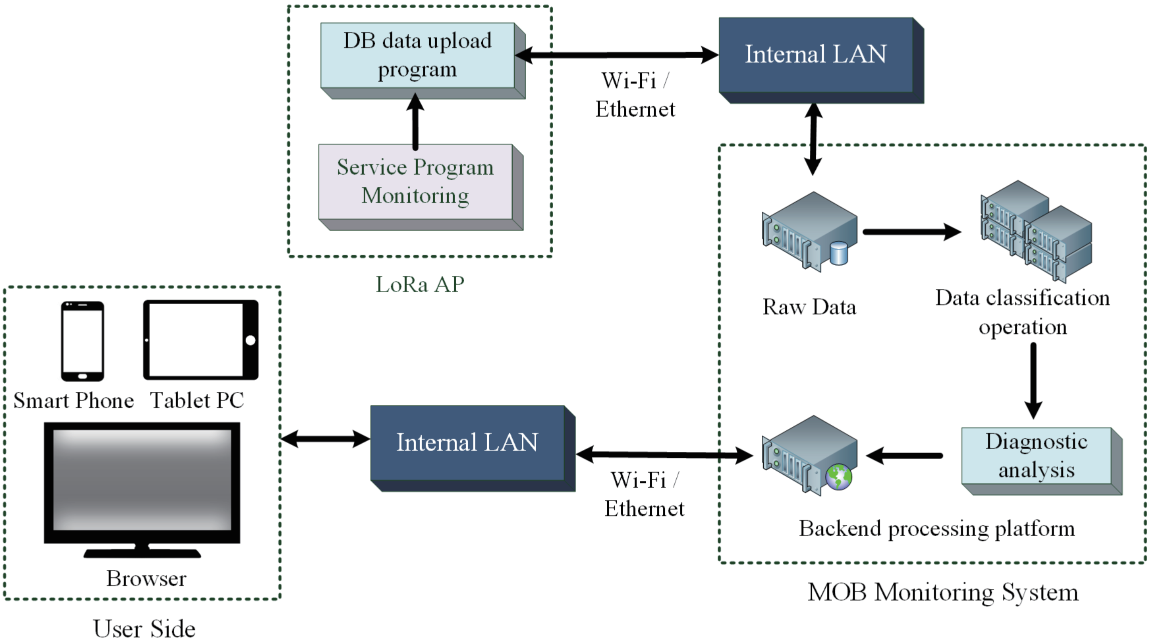


Fig. 12. (Color online) Architecture of monitoring and alarm for the central control system.

simultaneously trigger an event, it means that a person has fallen overboard. The system will immediately issue an alert and notify the rescuer at the same time. When the central control computer receives the information transmitted from the electric fence, the sensing aids, and the detecting of free-fall, the trigger event data are entered into the database and judged. When there are at least two types of triggering behavior, it means that there are already people overboard.

The other service program is the data upload service program, which is responsible for transmitting valid data to the monitoring and alarm system for MOB (with an information display panel) through Wi-Fi/Ethernet. The raw data program is responsible for collecting raw data and storing it in the SQL server database. The data classification operation program is responsible for the batch calculation of raw data and the data screening and classification. The diagnostic analysis program is used to analyze the data of an abnormal situation and to compare the data after batch calculation, such as by data analysis and comparison of information transmitted from GPS coordinates, aids, and other sensing devices. It also presents information such as the position of people wearing aids, virtual electric fence status, and physical electric fence status with a graphical user interface. In addition, the information display panel will immediately display the location of the drowning person on the screen. The coverage of the display screen is centered around the ship and extended to 1000 m to ensure adequate coverage. The screen will also immediately display the current number of connected people on the deck of the ship. It will also display the warning screen that shows the alarm. The system screen is shown in Fig. 13.

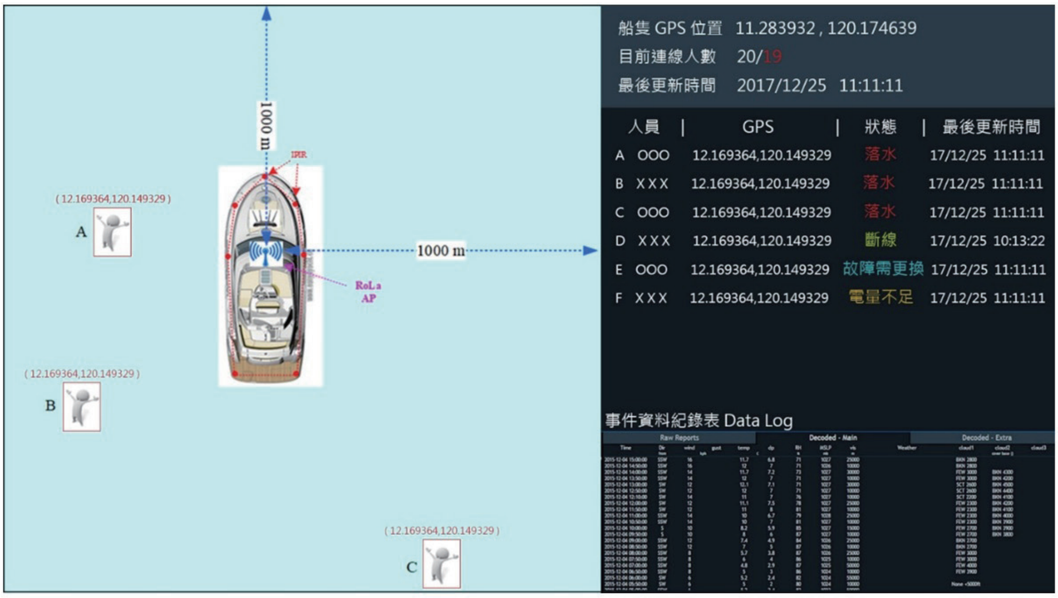


Fig. 13. (Color online) Diagram of monitoring and alarm system for MOB.

3. Experimental Tests and Discussion

The research results and system tests of the wearable sensing aids, modular LoRa AP, and physical electric fencing units for the MOB system are described as follows.

1. Wearable sensing aids: The hardware circuit and PCB design of the aids are drawn using Altium software. The circuit board shell is shown in Fig. 14. To achieve waterproof IP68 grade, a thermally conductive pouring sealant is used for the PCB. The thermally conductive sealant is a low-viscosity flame-retardant two-component silicone thermally conductive pouring compound that can be cured at room temperature or by heating. The higher the temperature, the faster the curing. The main application areas are the pouring for electronic and electrical components and pouring for similar temperature sensors.

   Figure 15 shows the change in *Z*-axis acceleration detected by wearable sensing aids when a person falls into the water. In the figure the blue area is a free-fall event, which is followed by the red area, which is a shock event after falling into the sea. The sequence and occurrence time of the two events can be used to determine whether a MOB event has occurred.
2. Infrared electric fence: The physical entity and shell of the infrared electric fence are integrated as shown in Fig. 16. Its shell material is aluminum 6061 and it is waterproof up to IP68, and the infrared transmission distance of each group is 60 m.
3. Modular LoRa AP: The modular LoRa AP physical entity assembly is shown in Fig. 17. An active broadcast protocol is used for the LoRa transmission to send messages, and the synchronous transmission technology can reduce the occurrence of signal collision. Its synchronization mechanism uses PPS precise second output provided by GPS and UTC world coordination time to synchronize all the aids, so that the sensing aids can actively

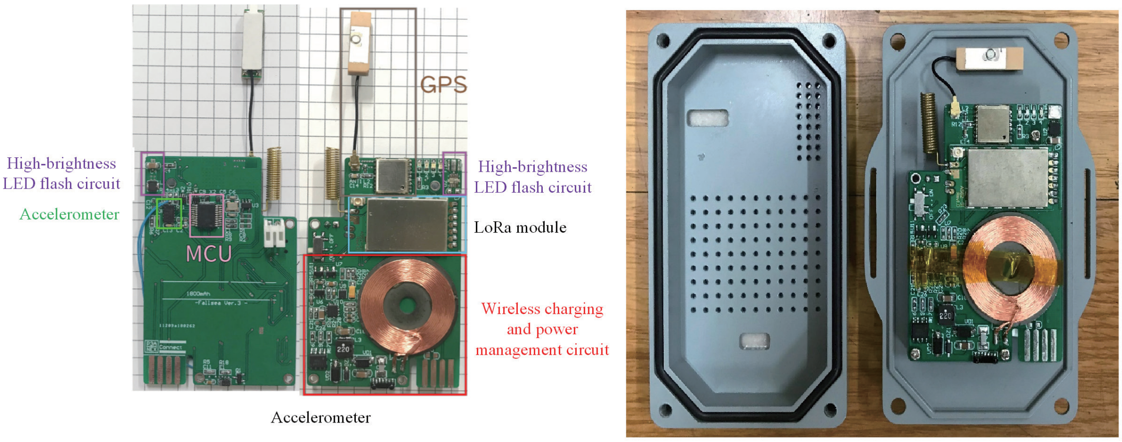


Fig. 14. (Color online) Physical circuit board of aids for the MOB system.

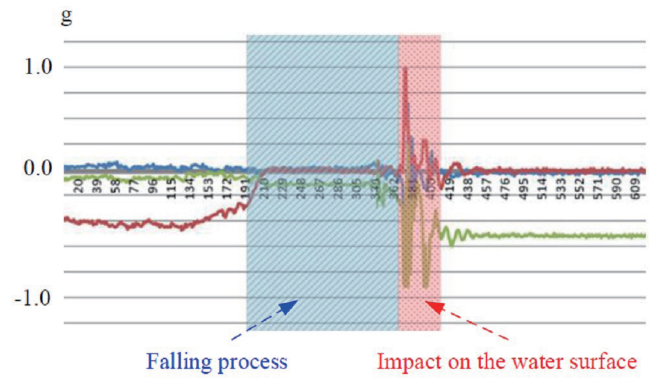
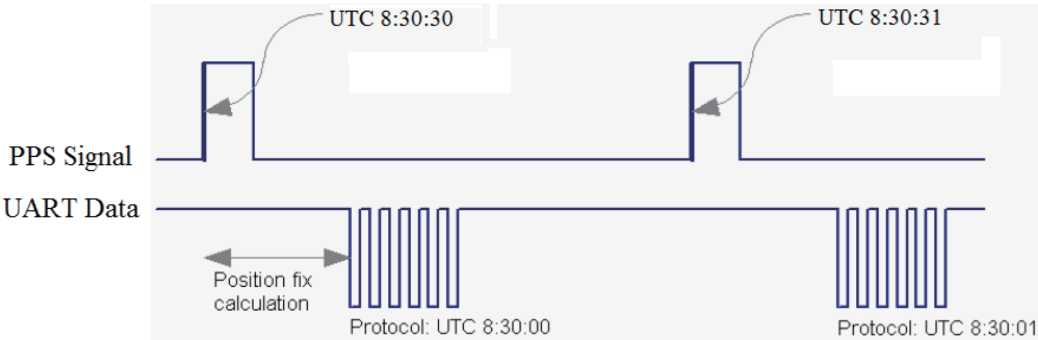


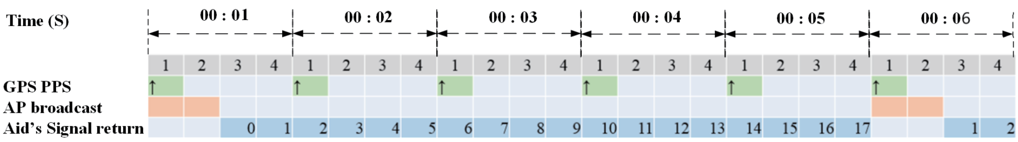
Fig. 15. (Color online) Change in *Z*-axis acceleration detected by the sensing aid during MOB event.

Fig. 16. (Color online) Infrared electric fence circuit combined with aluminum 6061 housing.

Fig. 17. (Color online) Diagram of modular LoRa AP assembly.



(a)



(b)

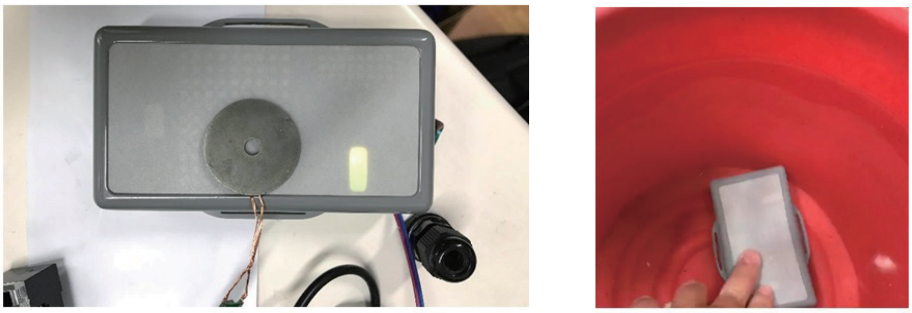
Fig. 18. (Color online) Diagram of modular LoRa AP communication protocol. (a) Synchronization mechanism and (b) time slot (assuming $N = 5$).

return data at a specific time, as shown in Fig. 18(a). Normally, a fixed time slot is adopted for data returns, which are divided into four time slots (250 ms) per second, and one communication cycle is N seconds. The first 0.5 s is fixed for AP broadcasting, so each band will serve $4N - 2$ aids, as shown in Fig. 18(b).

4. Laboratory Function Tests of MOB System

4.1 Laboratory function tests of wearable sensing aids

The charge and discharge test of wearable sensing aids is shown in Fig. 19(a). There is no problem with the wireless charging process, and the charging time is about 2 h. The waterproof test is shown in Fig. 19(b). There is no evidence of water leakage after a water immersion test



(a) (b)

Fig. 19. (Color online) Wearable sensing aids: (a) wireless charging test and (b) waterproof test.

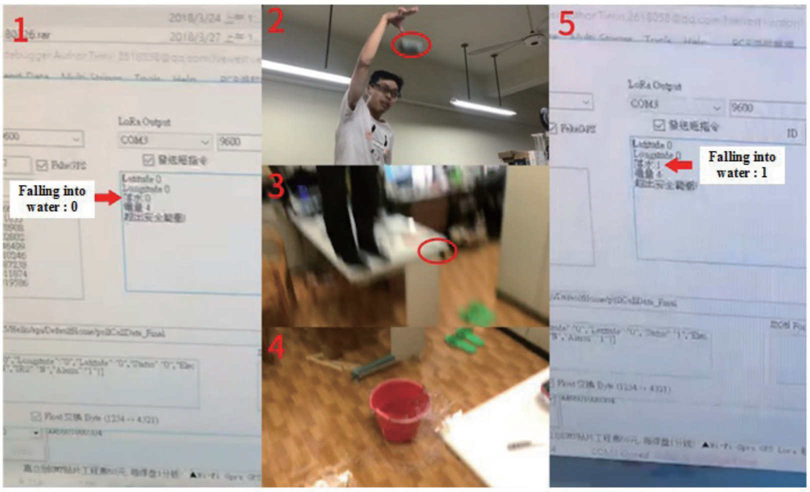


Fig. 20. (Color online) Falling into water notification test for wearable sensing aids.

for a full day. As shown in Fig. 20, the function of judging and issuing an alarm when an aid falls into the water is also correct.

4.2 Modular LoRa AP test screen

Figure 21 shows the modular LoRa AP test screen designed in this paper. Its content includes the status values returned by the receiving ship's GPS signal, the ID of the person falling into the sea, and the infrared electric fence. Extracted data are assembled into JSON format and then sent back to the database of the server of the central control center system to provide the required information for the monitoring screen.

4.3 Interface of central control system of ship

As shown in Fig. 22, the interface screen of the ship central control center system designed in this study includes the status information of the wearable sensing aids of the drowning person and the infrared electric fence, which can be interpreted by the personnel of the ship control center.

Fig. 21. (Color online) Test of modular LoRa AP.

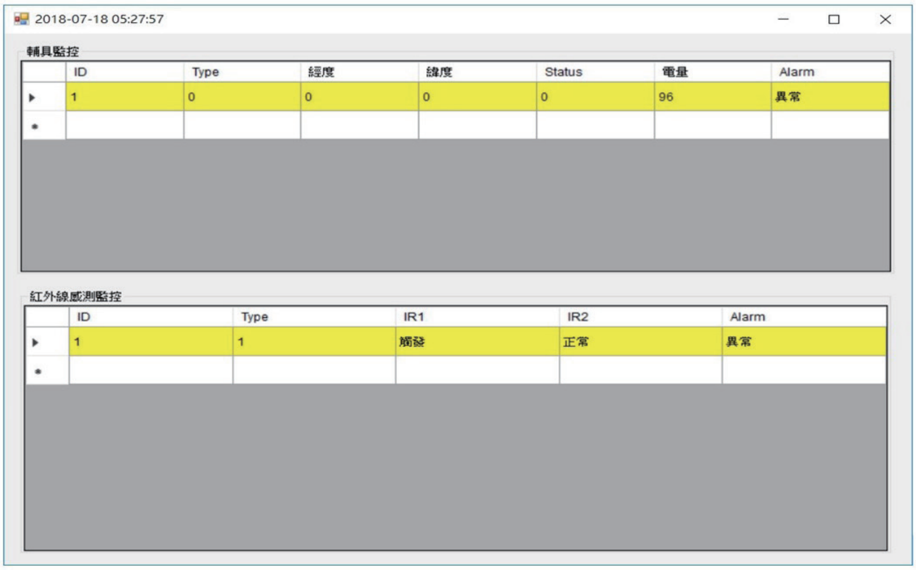
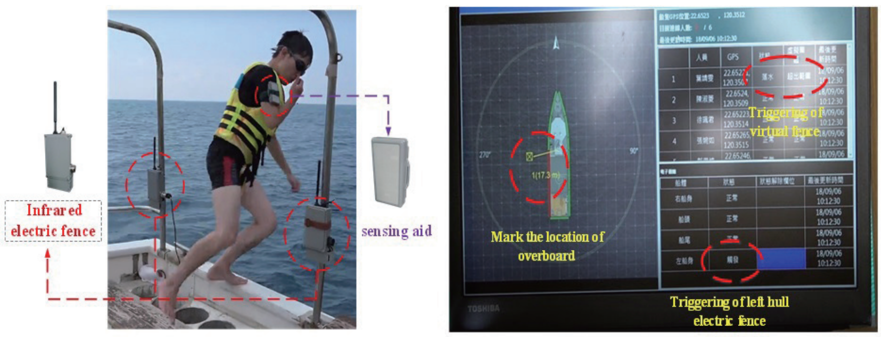


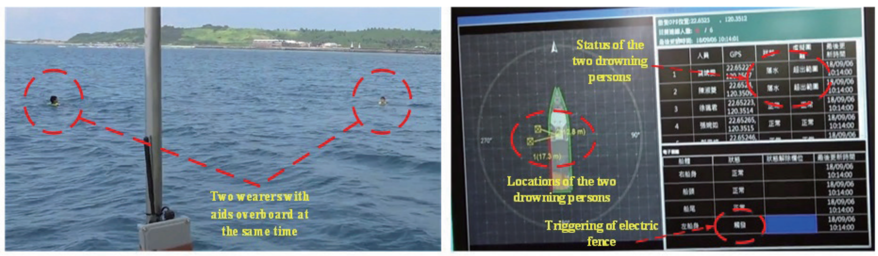
Fig. 22. (Color online) Display interface of central control center system of ship.

5. Actual Sea Test of MOB System

The R&D team conducted a system function sea test on September 21, 2018. A boat was chartered for testers to dive into the sea in Dapeng Bay, Pingtung County, Taiwan. In the process of the actual testing of the sensing and notification system for MOB, the deck crew should firstly wear the above-mentioned wearable sensing aids developed with G-sensors, LoRa wireless transmission, and GPS positioning. Physical electric fences were also set around the boat. Tests were carried out on the above system for ship A's emergency notification when the crew members of ship A were overboard. The test contents include the detection notification of sensing aids falling into the sea, the notification test of the physical electric fence, the notification test of the virtual electric fence, and the LoRa communication distance test. The testers on board all wore life jackets and their arms also had the smart sensing aids developed by the team for the sea test. The tests of triggering the physical electric fence and the detections of MOB with smart sensing aids, the GPS virtual electric fence, and other entities were carried out in sequence and observed on the display screens of a notebook computer simulating the central control system in each test. As shown in Fig. 23(a), the tester performed MOB to test the physical electric fence. The central monitoring system showed that the electric fence was successfully triggered and indicated the distance and relative position of the drowning person and the hull. To simulate multiple MOB at the same time, two testers wearing the aids simultaneously jumped into the sea and gradually drifted away from the boat. Figure 23(b) shows the system test in the case of two people overboard at the same time. The figure shows that the system successfully recognizes the accidents of two people overboard, and the relative GPS coordinate positions of the two people drowning at the same time are displayed in the central monitoring system. To test the effective transmission distance of LoRa wireless communication of the safety aids, we maneuvered the boat to gradually increase the distance between the boat and the testers who were stationary on the shore. The communication was maintained up to a distance of 3000 m on the sea surface.



(a)



(b)

Fig. 23. (Color online) System tests of real-time alarm and monitoring system for MOB. (a) Real-time display of the central monitoring system and (b) test of two people overboard at the same time.

6. Conclusions

The marine economy is an important source of foreign trade in most countries, but casualties caused by MOB have not been effectively addressed. In this research, we used sensing technology, communication technology, and the integration of many mature practical products to develop a real-time alarm and monitoring system for MOB. This system provides a method for the real-time detection of MOB by the ship itself and promptly proposes a rescue action. The results of various MOB system functions were obtained by laboratory and actual sea testing. The waterproofing of the wearable sensing aids and the real-time notification of MOB were successfully achieved. The electric fence can distinguish between the sprinkling of seawater or the touching of personnel, so as not to cause malfunction. In the function test of the virtual electric fence, the system also successfully notified the ship's central control center when the tester was away from the boat in an actual sea area. Finally, in the distance test of LoRa communication, the system also successfully completed the communication transmission up to a distance of 3 km.

Compared with the traditional way of rescue, the monitoring system developed in this study can quickly learn about the occurrence of MOB events, so that ships can quickly send rescue teams. It can track the locations of drowning people continuously through wireless transmission so that it is not easy for the rescue team to lose the target. It is thus possible to rescue drowning people and improve their chances of survival.

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References

1 W. C. Scales and R. Swanson: IEEE Spectr. **21** (1984) 48. https://doi.org/10.1109/MSPEC.1984.6370206
2 T. Sumimoto, K. Kuramoto, S. Okada, H. Miyauchi, M. Imade, H. Yamamoto, and T. Kunishi: Proc. IECON'94 - 20th Annual Conf. (IEEE, 1994) 723. https://doi.org/10.1109/IECON.1994.397874
3 Y. Shijun, L. Ying, and X. Peng: 2010 2nd WRI Global Congr. Intelligent Systems (2010) 65. https://doi.org/10.1109/GCIS.2010.46
4 D. D. Do, H. V. Nguyen, N. X. Tran, T. D. Tran, and Y. V. Vu: Asia-Pacific Microwave Conf. (2011) 1510.
5 K. J. Rafferty and E. W. McGookin: 2013 Int. Conf. Connected Vehicles and Expo (ICCVE) (2013) 459. https://doi.org/10.1109/ICCVE.2013.6799836
6 M. Schulz, A. Strobel, and F. Ellinger: 2013 10th Workshop on Positioning, Navigation and Communication (WPNC) (2013) 1. https://doi.org/10.1109/WPNC.2013.6533275
7 X. Mao, X. Liu, T. Feng, and K. Chen: 17th Int. IEEE Conf. Intell. Transp. Syst. (ITSC) (2014) 1910. https://doi.org/10.1109/ITSC.2014.6957981
8 N. E. Agroudy, G. Georgiades, N. Joram, and F. Ellinger: 2017 13th Conf. Ph.D. Research in Microelectronics and Electronics (PRIME) (2017) 177. https://doi.org/10.1109/PRIME.2017.7974136
9 Z. Jian, Z. Liang, Z. Li-nan, and L. Nan: 2017 Int. Conf. Computer Network, Electronic and Automation (ICCNEA) (2017) 383. https://doi.org/10.1109/ICCNEA.2017.73
10 X. Xiao, J. Dufek, T. Woodbury, and R. Murphy: 2017 IEEE/RSJ Int. Conf. Intelligent Robots and Systems (IROS) (2017) 6105. https://doi.org/10.1109/IROS.2017.8206510

11 Y. Li, K. L. Chung, S. Xie, Y. Yang, M. Wang, and X. Geng: IEEE Access **6** (2018) 25220. https://doi.org/10.1109/ACCESS.2018.2828399
12 Y. Nam and J. W. Park: IEEE J. Biomed. Health. Inf. **17** (2013) 420. https://doi.org/10.1109/JBHI.2012.2235075
13 M. Aref and A. Sikora: 2014 2nd Int. Symp. Wireless Systems within the Conf. Intelligent Data Acquisition and Advanced Computing Systems (2014) 19. https://doi.org/10.1109/IDAACS-SWS.2014.6954616
14 X. Zhang, M. Zhang, F. Meng, Y. Qiao, S. Xu, and S. Hour: IEEE IoT J. **6** (2019) 590. https://doi.org/10.1109/JIOT.2018.2847702
15 W. Ayoub, A. E. Samhat, F. Nouvel, M. Mroue, and J. Prévotet: IEEE Commun. Surv. Tutorials **21** (2019) 1561. https://doi.org/10.1109/COMST.2018.2877382
16 U. Raza, P. Kulkarni, and M. Sooriyabandara: IEEE Commun. Surv. Tutorials **19** (2017) 855. https://doi.org/10.1109/COMST.2017.2652320
17 W. San-Um, P. Lekbunyasin, M. Kodyoo, W. Wongsuwan, J. Makfak, and J. Kerdsri: 2017 3rd Asian Conf. Defence Technology (ACDT) (2017) 32. https://doi.org/10.1109/ACDT.2017.7886152
18 IEEE Standard for Floating-Point Arithmetic: IEEE Std 754-2019 (Revision of IEEE 754-2008) (2019) 1. https://doi.org/10.1109/IEEESTD.2019.8766229
19 S. Benaissa, D. Plets, D. Nikolayev, M. Deruyck, L. Verloock, G. Vermeeren, L. Martens, E. De Poorter, F. A. M. Tuyttens, B. Sonck, and W. Joseph: Electron. Lett. **55** (2019) 422. https://doi.org/10.1049/el.2018.8150
20 W. P. Chen, W. F. Wang, and W. S. Hwang: J. High Speed Networks **17** (2008) 59. https://doi.org/10.3233/JHS-2008-0328
21 J. Du and W. Shi: IEEE Trans. Veh. Technol. **57** (2008) 3723. https://doi.org/10.1109/TVT.2008.920476
22 J. R. Lai, H. Y. Huang, W. P. Chen, L. K. Wang, and M. Y. Cho: Math. Prob. Eng. **2015** (2014) 1. https://doi.org/10.1155/2015/919278

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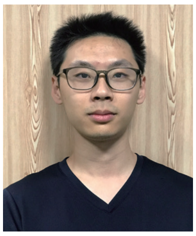

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