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SHORT COMMUNICATION

Location Tracking of Moving Crew Members for Effective Damage Control in an Emergency

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ABSTRACT

In an emergency, the commanding officer may have limited information, and crew members may behave differently compared to how they behaved during training. In an emergency situation, if the commanding officer is aware of each crew member's location and role in that situation, one can disseminate orders expeditiously and precisely. To realise a faster and more precise dissemination of orders through better awareness of each crew member's location and role, real-time crew member tracking is needed. The technical feasibility of a real time crew-tracking system based on a wireless sensor network has been studied, with the intent to improve effective commanding in an emergency. Location tracking was achieved using instrumentation consisting of ZigBee tags, routers, and gateways, which were used to record the location and role data of moving crew members on a full-scale ship.

Keywords: Wireless sensor network, ZigBee tags, location recognition, moving crew, communications, emergency situation handling, damage control

1. INTRODUCTION

Since any damage to a ship can adversely affect impact critical systems and mission capabilities, all crew members must work in close cooperation. Effective communication among the crew members engaged in a task is extremely important. With this in mind, primary or secondary means of onboard a ship communication do not guarantee effective communication in emergency situations.

From a commanding officer's point of view, the ability to recognise an emergency situation and make expeditious and appropriate decisions is very important; however, to make such decisions, commanding officers need to be immediately aware himself about each of the crew member on duty, that is crew member's location and role, as well as the overall condition of the emergency situation. If a commander knows the location and role of each crew member and is able to communicate orders to them in real time, the situation can more easily be controlled. Such a scenario can be most conveniently and cost-effectively achieved by tracking crew members with a sensor network based on wireless communication systems; however, most wireless communication devices use the GHz frequency range, and therein, face several challenges when deployed in steel-structured naval vessels.

2. CREW MEMBERS' LOCATION AND ROLE RECOGNITION IN AN EMERGENCY

Crew members are repeatedly trained to react and follow specific damage control scenarios. However, most accidents occur suddenly and do not provide crew member an opportunity to use their training. Moreover, the judgment of the commanding officer is often inhibited by limited information about the state of the situation[1].

In emergency training tests, effective ship-wide communication is critical to establishing an integrated damage-control effort. By knowing each crew member's location and role, ship recoverability can be enhanced, as shown in Fig. 1, which depicts a simple flow chart that outlines actions for damage control using crew member location information.

To recognise each crew member's location and to control emergency, US Navy uses specific equipment such as wireless fire fighting ensemble which equipped with low-light infrared imaging, video and high quality voice communications[2]. However this kind of equipment is big, heavy, and expensive. When one considers wireless sensor network for location recognition on land based system, he finds that various studies have been performed. However, warships are commonly constructed from steel, making the application of wireless communication in the GHz frequency range difficult. Furthermore, this specific environment limits the usability of other types of wireless sensor networks.

ZigBee tags were considered in this experiment to track each crew member's location and role due to their small size and durability. ZigBee tags communicate less data compared to Bluetooth or Wi-Fi, but enough to transmit role code of each crew member. In addition, ZigBee tags require less power compared to other technologies, making

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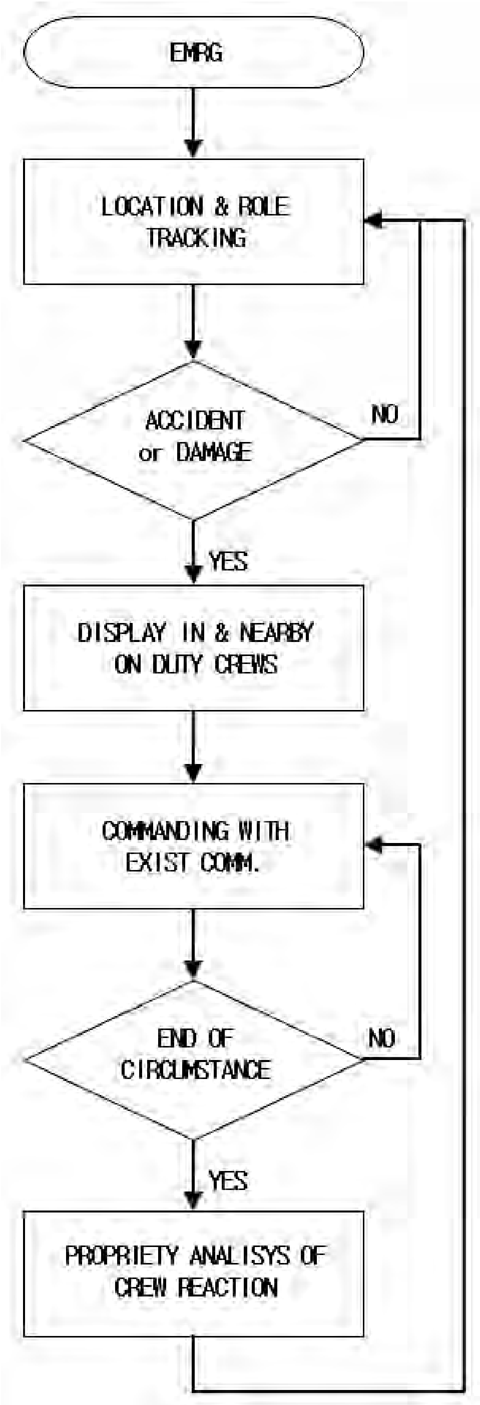


Figure 1. Flow chart of a damage control concept using crew member location tracking.

them feasible to deploy without the need for battery change over the course of a single few-week duration voyage. In addition, ZigBee tags exhibit better communication performance compared to RFID. Table 1 compares several wireless technologies.

To recognise each crew member's role, specific codes are required. In the previous study, HnCP (Home network Control Protocol) 1.0 was used to build role recognition codes of crew members[4], as shown in Table 2. HnCP is a standardised protocol for low-speed PLC (Power Line Communication) and it can reduce load of data transmission, not only for PLC but also for ZigBee-based data transmission.

Table 1. Performance comparison of various wireless technologies[3]

	ZigBee	Bluetooth	Wi-Fi
Standard	802.15.4	802.15.1	802.11
Speed	250 kbps	1 Mbps	~54 Mbps
TX	35 mA	40 mA	400+mA
Standby	3 uA	200 uA	20 mA
Memory	32-60 KB	100 + KB	100 + KB
Network	MESH	P to Multi P	P to Multi P

Table 2. Codes for each crew member's role recognition

Crew member Code (Product Code)	0x0000 ~ 0x7F00
Role Code (Logical Code)	0xXX01 ~ 0xXXFE
Zone Code (Location Code)	0x8100 ~ 0xFE00
Crew member Category Code (Product Category Code)	0x00

3. TEST LOCATION AND EQUIPMENT

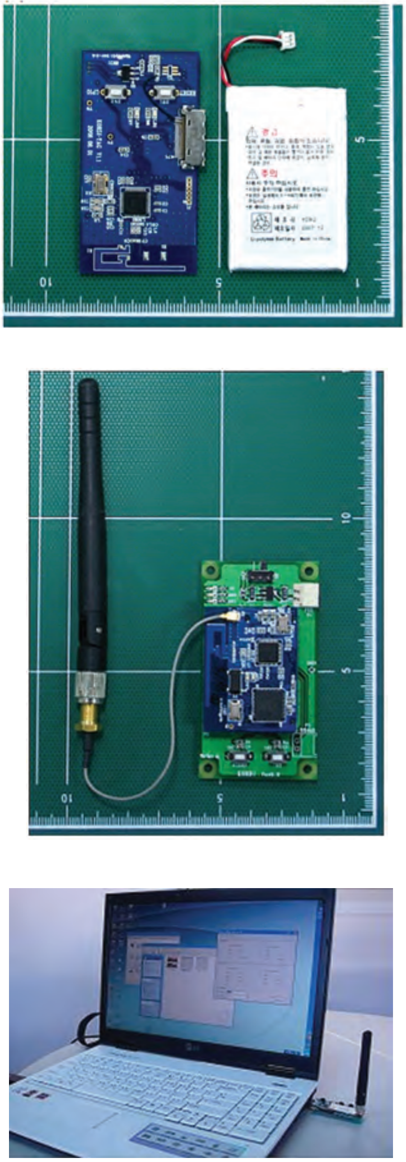
Wireless communication using the ZigBee communication protocol was tested inside a 3500 ton training ship to characterise the performance of this protocol in tracking crew member's movements inside a steel-structured ship. Table 3 summarises the training ship specifications.

For the tests performed in a real ship, a lithium polymer battery was embedded into a 2.4 GHz 250 kbps ZigBee tag that had been programmed to pulse power emissions at 1 Hz to minimise electricity consumption, as shown in Fig. 2(a). The size of the ZigBee tag was designed such that it could be incorporated into a crew member's name tag. Also, designed was a wireless router, as shown in Fig. 2(b), and a gateway with control software, as shown in Fig. 2(c).

Each ZigBee Tag is a reduced function device (RFD) and routers take the role of PAN coordinator as a full function device (FFD). To consider that a naval ship is divided into many zones which divides still structure, each router take a role of cluster coordinator within bulkheads or a zone. Gateway gathers crew members' location and role of each crew member information from router, and send it to the bridge via local area network (LAN) or ship

Table 3 Training ship specifications

Parameter	Value
Length (m)	102.7
Width (m)	14.5
Height (m)	7
Tonnage (m)	3640
Speed (knot)	15 (17 max.)



(a)

(b)

(c)

Figure 2. (a) ZigBee tag, (b) router, and (c) personal computer with gateway.

wide area network (SWAN). Within bulkhead (BHD), star network is considerable. Point-to-point network is good for outside of the BHD and within main vertical zone (MVZ).

4. EXPERIMENTAL DETAILS

Prior to testing moving ZigBee tag communication performance, stationary ZigBee tags were subjected to performance tests in the steel-structured ship environment. This experiment was carried out in a real ship and it used a ZigBee tag and router system. In this experiment, signal strength was measured by a link quality indicator (LQI), which is a metric of the current quality of the received signal defined by the relationship given in Eqn. (1). The LQI estimates how easily a received signal can be demodulated by accumulating the magnitude of the error between ideal constellations and the received signal[5].

$$LQI = 255 \times \frac{RSSI - dBm_{\min}}{dBm_{\max} - dBm_{\min}} \tag{1}$$

where,

$RSSI$ is the received signal strength indication,

$dBm_{\max}$ is the maximum power of dBm, and

$dBm_{\min}$ is the minimum power of dBm.

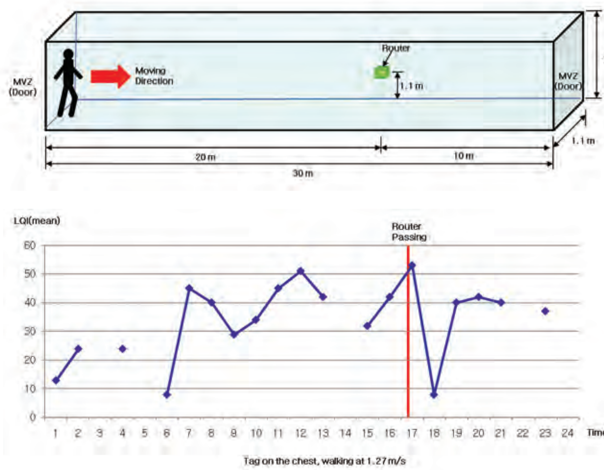
Stationary ZigBee tags's location recognition in a room of steel-structure is favourable. However, in a real emergency, crew members move fast and their movement is unpredictable. Therefore, the technical feasibility of locating highly mobile crew members should be verified.

In this study, several experiments were conducted using ZigBee tags to assess the technical feasibility of tracking the real-time location of mobile crew members in a real ship.

Figure 3(a) depicts the test environment. Tracked subjects moved from one end of a corridor to the other end, wherein the two corridor ends meet with main vertical zones (MVZ), which prevent the spread of fires. The length of the test corridor was 30 m, wherein the router was placed 20 m away from the starting point in the corridor to evaluate signal strength as a function of distance.

First, a router was placed at a height of 1.1 m above the floor and a ZigBee tag (akin to a name tag) was attached to the chest of a test subject. The subject was instructed to walk at a rate of approximately 1.27 m/s. As shown in Fig. 3(b), the moving subject's ZigBee tag signal was not recognised by router and gateway.

This poor result of signal being not recognized by the router and the gateway was due to the obstruction put up by the steel structure of naval vessel. For this reason, we mediate the ZigBee tag's signal emit power was mediated several times and finally was set on minimum level to avoid dependence of structural difference. Time interval of signal emission was also mediated to 0.1 s and the LQI was



(a)

(b)

Figure 3. Test environment and initial experiment result: (a) test environment of location tracking, (b) an example of walking speed ZigBee tag experiment results without mediation.

averaged after ten identical signal emissions and so, the crew location data was checked at 1 s interval.

After the mediation, as shown in Fig. 4(a), the moving subject's ZigBee tag signal was well recognised. ZigBee tag signal strength was observed to change as the relative distance between the subject and the router changed. This changing signal strength makes it possible to locate a subject's location in the corridor.

To measure the influence of the human body on signal strength, a subject carried a ZigBee tag in his left hand and again walked at the same aforementioned speed. The presence of body mass resulted in a 50 per cent signal strength reduction; however, the router was still able to identify the mobile tag's signal, and therefore location [Fig. 4(b)]. By moving the location of the router to the ceiling, LQI values were improved to the same levels as those depicted in Fig. 4(a), as depicted in Fig. 4(c).

All naval vessels are built according to regulations. These regulations set the minimum width of the main corridor, which allows enough space for two fully-equipped moving crew members. Therefore, in this experiment, a maximum of two subjects are considered to be able to move together.

When two persons are transversely arranged in the test space, their bodies can reduce the signal strength of ZigBee tags. Tests were performed to assess the ability of tags to distinguish two moving crew members' transverse and longitudinal locations in real time. As shown in Fig. 4(d), when a router was positioned at a height of 1.1 m and ZigBee tags were attached to the two subjects' chests, their moving locations and relative positions (ex. who is on the left side) were well-recognised. When subjects carried the ZigBee tags in their hands, the signal strength was weakened, as before, but still distinguishable, as demonstrated in Fig. 4(e). Similarly as before, signal strength was improved by changing the location of the router to the ceiling, as shown in Fig. 4(f).

In case of an emergency, location tracking is also needed when crew members rapidly move between decks via stairways. In these experiments performed during the study, the location of moving tags between decks was well recognised, as shown in Fig. 5.

5. CONCLUSIONS

In this study, a new method of crew member location and role tracking has been introduced. Though there are many rooms to full fill, technical feasibility was experimentally validated under certain restrictions. Crew members locations and role tracking using moving ZigBee tag signal strength were tested and proved viable for use in steel-structured ships. However, this experimental result do not guarantee the same performance in all

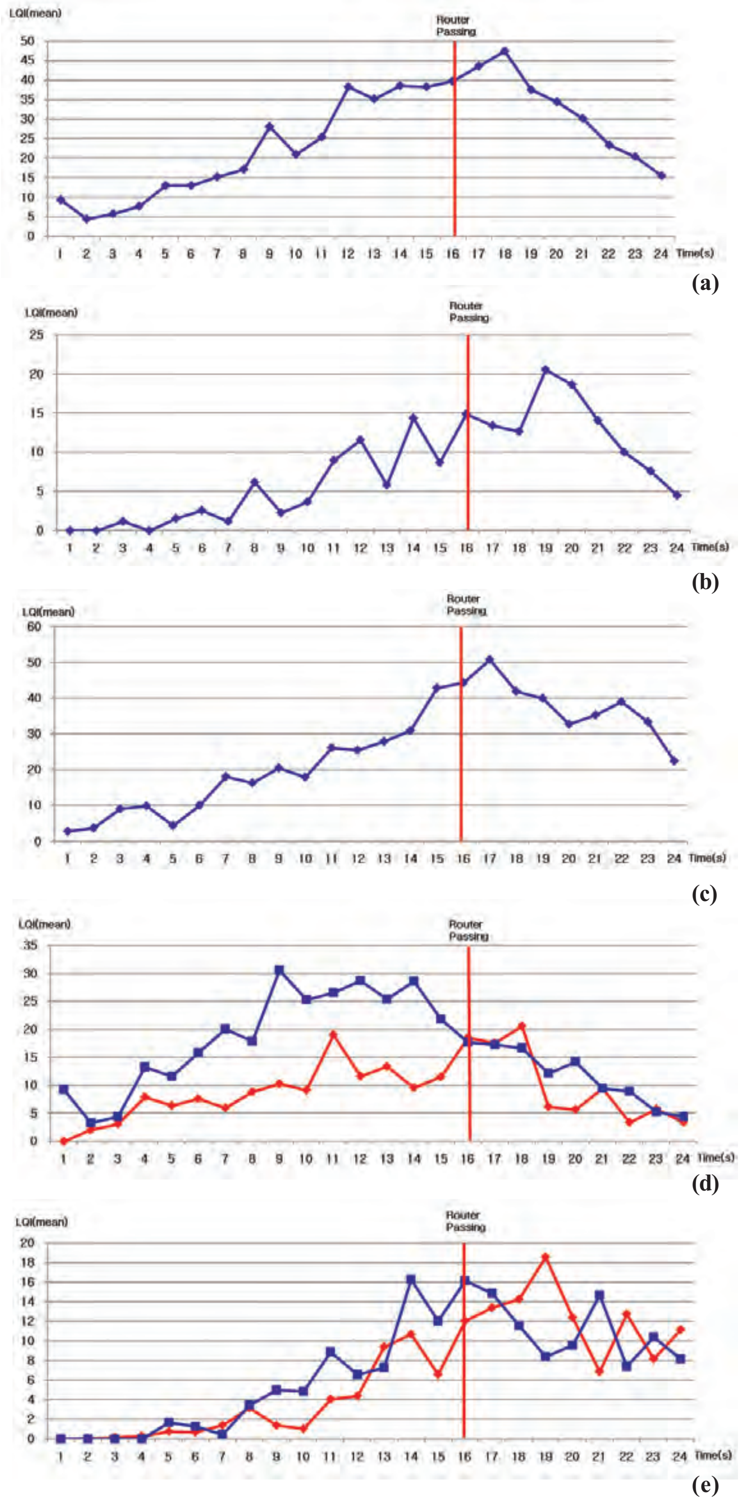


Figure 4. Examples of ZigBee tag experiment results: (a) A router was positioned at a height of 1.1 m, ZigBee tags were attached to the subject' chests, (b) A router was positioned at a height of 1.1 m, ZigBee tags in the two subjects' hands, (c) A router was positioned at the ceiling, ZigBee tags in the two subjects' hands, (d) A router was positioned at a height of 1.1 m, ZigBee tags were attached to the two subjects' chests, (e) A router was positioned at a height of 1.1 m, ZigBee tags in the two subjects' hands, (f) A router was positioned at the ceiling, ZigBee tags in the two subjects' hands.

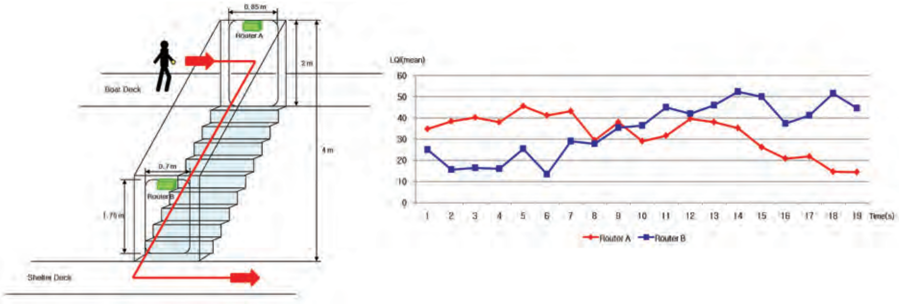


Figure 5. Experimental results of moving ZigBee tags traversing between decks.

types of ships and maximum supportable nodes should be experimentally proved in the near future.

The monitoring of real-time crew members' locations during training and in real emergencies will help damage control. Crew members' location and roles will assist the onboard training organiser and commanding officer by providing complete information to base his decisions. Furthermore, the quality of many onboard training programme will be enhanced by monitoring of crew members' locations during exercises.

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