XBee Positioning System with Embedded Haptic Feedback for Dangerous Offshore Operations: a Preliminary Study

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***Abstract*— The problem of identification and isolation of dangerous zones in offshore installations is investigated in this preliminary work. A node positioning algorithm is implemented in order to track and identify the operational movements on board the vessel. This implementation is realised with an XBee network that uses a trilateration method, making it possible to actively monitor and dynamically identify several on board zones in different operational scenarios. The crew members can be given varying degrees of access permissions in accordance with their job duties. In this way, access to dangerous areas can be easily controlled in a modular fashion.**

Subsequently, the user's risk perception is considered. Traditionally, the responsibility of proper hazard identification is placed on the operators. For this reason, more attention is being given to the way that people think, feel and behave in response to risk. Risk is perceived differently by different people, and in this sense, the user's experience and therefore ability to perceive risk can be greatly improved with the use of *haptics*. Haptic feedback, also known as *haptics*, is the use of the sense of touch in a user interface designed in such a way as to provide the user (operator) with additional information. In this work, a vibration motor is embedded in the operator's helmet, thus providing intuitive haptic feedback. The operator perceives different types of risks according to the surrounding areas due to the integration of this technology with the XBee-based positioning algorithm and by using distinctive feedback patterns.

Related experiments are carried out to validate the efficiency of the proposed technology. In particular, the presented approach demonstrates a great potential for an effective risk reduction from both an individual as well as an overall evaluation of the potential harm.

***Index Terms*— Risk Reduction, Haptic Feedback, Positioning, XBee.**

I. INTRODUCTION

In the maritime industry, the last few decades have seen a growing interest in developing new technologies for controlling modern vessels and related maritime equipment [1], [2]. Increasingly demanding marine operations are at the heart of the maritime industrial cluster. These advanced operations are associated with a high level of uncertainty on board of an offshore installation because such an installation usually operates in a dynamic environment in which technical, human and organisational malfunctions may cause accidents.

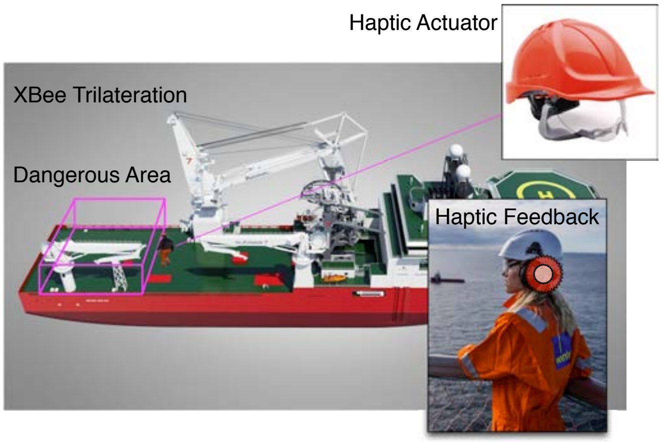


Fig. 1: The idea of realising an XBee-based positioning system with embedded haptic feedback for dangerous offshore operations.

In order to improve safety of offshore installations the classic methodology for risk estimation is usually applied. A generally accepted definition of risk among experts is: the danger unwanted events may have on human, environmental, and economic values [3]. The Offshore Safety Case regulations holds operators responsible for identifying the major hazards and to reduce risks to As Low As is Reasonably Practicable (ALARP) [4]. The regulations specifically state that Quantitative Risk Assessments (QRA) must be used when preparing the Safety Case. However, this formal risk estimation does not necessarily correspond with an individual's perception of risk. Taking this into consideration, improving the user's risk perception plays a crucial role in effective risk reduction. There is an urgent need to develop faster methods and tools that enhance an individual's perception and assessment of dangerous situations on board a vessel so that accidents can be avoided.

In this preliminary work, the question of how to identify and isolate dangerous areas is initially investigated. The underlying idea is shown in Fig. 1. When performing offshore operations, several areas on the ship can be identified as dangerous zones according to different operational scenarios. When considering efficiency and safety, it is very important to prevent or limit access to dangerous spaces so that accidents can be avoided. In order to identify and track the operator's movements on board the vessel, a node positioning algorithm is implemented in an XBee network [5] using a trilateration method. Several on board areas and zones that need to be actively monitored can be dynamically identified according to different operational scenarios. Different access permissions can be set individually for all the crew members in accordance with their specific duties so that a more modular access to the dangerous areas can be achieved.

Following this, the user's risk perception is considered. Currently, offshore installations put the onus on the operators to identify the major hazards. For this reason, the way in which people think, feel and behave in response to risk is receiving increasing attention, both among academics and those who are involved in promoting and regulating safety. Risk is perceived differently by different people. In this optic, the use of *haptics* can significantly improve the user experience when considering risk perception. Haptic feedback, also known as *haptics*, is the use of the sense of touch in a user interface designed to provide additional information to the operator. Touch is one of the most reliable and robust senses: it is fundamental to our memory and for discerning. In this work, a vibration motor is embedded in the operator's helmet to provide the user with an intuitive haptic feedback. By integrating this technology with the proposed XBee-based positioning algorithm and by using distinctive feedback patterns, the user perceives different kinds of risks according to the surrounding areas.

In order to validate the efficiency of the proposed technology, related experiments are carried out. In particular, significant and effective risk reduction is seen both from individual and overall evaluations of the potential harm.

The paper is organised as follows. A review of the related research work is given in Section II. In Section III, we focus on the description of the proposed system architecture, analysing the communication protocol, the adopted network configuration and the selected trilateration method. Related experiments and results are shown in Section IV. In Section V, conclusions and future works are outlined.

II. RELATED RESEARCH WORK

In order to limit access to potentially dangerous areas on board of the vessel, a positioning and tracking technology for the crew members is needed. The localisation problem has been widely investigated in literature. The Global Positioning System (GPS) is the most common location service. However, the accuracy of the GPS system makes it unsuitable for tracking people in a limited and complex environment such as an offshore installation. In addition, the GPS system is severely limited when considering indoor settings. Given this, some other technologies including infrared, ultrasonic, vision systems and electro-magnetic field strength are possible solutions with their own respective limitation and constraints [6]. Radio frequency (RF) is another promising technology, which utilises Received Signal Strength Indicator (RSSI) to track moving objects if both moving objects and some reference objects are using RF signals to communicate [7]. Theoretically, the revived RSSI is a function of the distance between the transmitter and the receiver as indicated in many propagation models. However, in practice, there are many problems including the layout structure of the areas to be monitored, reflections problems that my arise by moving objects, refraction, diffraction, dead-spots and absorption of radio signals. Nevertheless, since RSSI is a relatively economical solution, RF-based localisation has become a hot research issue [8]. Different radio modules can be used to implement this technology. For instance, Xbee modules [5] are used to create a small-scale network in order to verify different positioning algorithms in [9]. The adopted localisation method is RSSI-based. Xbee modules feature low-cost, high-flexibility and low-power characteristics. For this reasons, this technology looks promising when considering possible applications in dangerous areas on board of a vessel. In this preliminary work, the possibility of implementing an XBee-based positioning algorithm for tracking the crew members movements on board of an offshore installation is investigated.

Concerning the use of *haptics* to improve the user's risk perception, several studies have been presented by different authors. When a human is subjected to touch or tactile feedback, the associated sensory motor information is conveyed to the brain, leading to perception. For instance, various applications whose function is the prevention of accidents are present in the automotive industry. In [10], the potential use of vibrotactile warning signals to present spatial information to car drivers is investigated. In [11], the impact of tilting the driver's seat according to the relative distance and velocity to objects outside the car using a haptic feedback chair is investigated. In the maritime field, the use of haptic joysticks is becoming widespread for manoeuvring cranes and on-board devices that require precise control. As an example, a flexible modelling and simulation architecture for haptic control of maritime cranes and robotic arms is presented by our research group in [12].

However, to the best of our knowledge, no integrated systems for localising and intuitively alerting the operator with haptic feedback about potentially dangerous areas on board the vessel exist in the marine field to date.

III. SYSTEM ARCHITECTURE

In this section, the system architecture is presented. We first illustrate the adopted design choices, the chosen trilateration method and the modular organisation of the framework. We then describe the proposed system architecture, analyse the adopted network configuration, the communication protocol and the selected trilateration method.

A. Design choices

The design of the proposed architecture is based on the following principles:

- Low-cost: the system is built with low-cost off-the-shelf components.
- Modularity and flexibility: several on board areas and zones to be actively monitored can be dynamically identified according to different operational scenarios. Different permissions can be set individually for the crew members in accordance with their specific duties, allowing for more controlled, modular access to dangerous areas.
- Reliability: the system is easy to maintain, modify and expand by adding new features.
- Non-invasive approach: the system requires minimal changes to the environment to be monitored.

In order to follow these principles, XBee radio communications modules [5] are adopted to build the system network. The XBee modules are based on the IEEE 802.15.4/Zigbee Wireless Personal Area Network (WPAN) standards. These modules allow for building a low-power, low-maintenance, and self-organising network. When compared with other radio modules, the XBee modules offer considerable advantages:

- the primary advantage is that the XBee modules are bi-directional. Most budget systems only transmit in one direction, so the transmitter has no idea whether the receiver is actually getting the data. The XBee modules transmit and receive in both directions, so that it is possible to test whether the system is working correctly.
- The second advantage is that of unique addressing. Each XBee unit has a unique serial number. This means that two (or more) units can be set up to communicate exclusively with each other, ignoring all signals from other modules.
- The third advantage is that the XBee module has a built-in data-packet building and error-checking to ensure reliable data transmission.
- Finally the XBee protocol allows for a number of radio channels. By setting different units on different radio channels, additional interference can be avoided.

For the adopted Xbee network, the Application Programming Interface (API) mode has been selected and preferred to the default transparent mode [5]. API mode is a frame-based method for sending and receiving data to and from a radio's serial Universal Asynchronous Receiver/Transmitter (UART). The API gives the programmer the ability to:

- change parameters without entering command mode;
- view the RSSI and source address on a packet by packet basis;
- receive packet delivery confirmation on every transmitted packet.

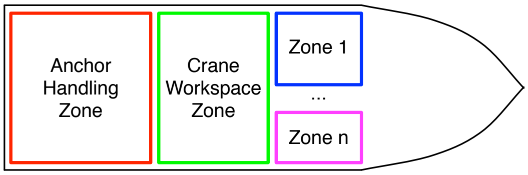


Fig. 2: The modular organisation of the proposed framework.

B. Trilateration method

The ZigBee network infrastructure, which operates at 2.4 GHz radio frequency, provides radio signal properties as part of the Quality of Service such as the Time of Arrival (ToA), Time Difference of Arrival (TDoA), Angle of Arrival (AoA) and the RSSI [13]. Using the RSSI value, the distance to a node can be estimated and a trilateration calculation can be performed against other nodes with known positions. Trilateration is a method of determining the relative position of objects using the geometry of triangles in a similar fashion as triangulation. The adopted method was introduced in [14] and it is based on the calculation of the intersection of three spheres of which the radius is obtained from the distance estimated from the RSSI value; in order to work this model requires that the *blind* node must be inside the intersection of three reference nodes. For further details, the reader is referred to [14].

C. Modular organisation

The proposed architecture features a modular organisation. The area to be monitored on the considered offshore installation is divided in elementary modular areas or zones as shown in Fig. 2. It should be noted that each zone can be further divided into sub-zones in order to ensure an adequate sensor density. In this way, different areas can be monitored with different access permissions and priorities. These zones can be easily configured and dimensioned according to different operational scenarios. For instance, one zone can be used to monitor the workspace of a crane, while another zone can be dedicated to the monitoring of the anchor handling area on the deck. Each elementary zone of the system can be implemented as shown in Fig. 3. In detail, a client-server pattern is adopted. Three nodes are used as clients and are fixed on the considered area to be used as reference points, while a *blind* node is embedded in the operator's helmet. The clients communicate with a server. In the following, the key elements of the system architecture are presented.

D. Hardware

On the hardware side, all the adopted controllers are implemented on *Arduino*-based boards [15]. Using *Arduino*-

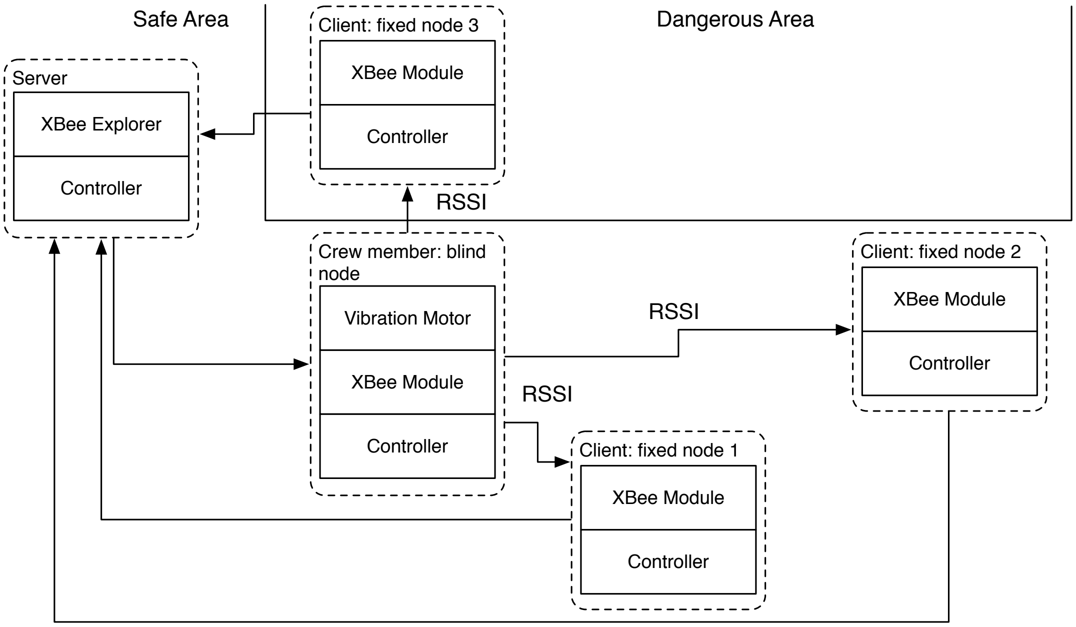
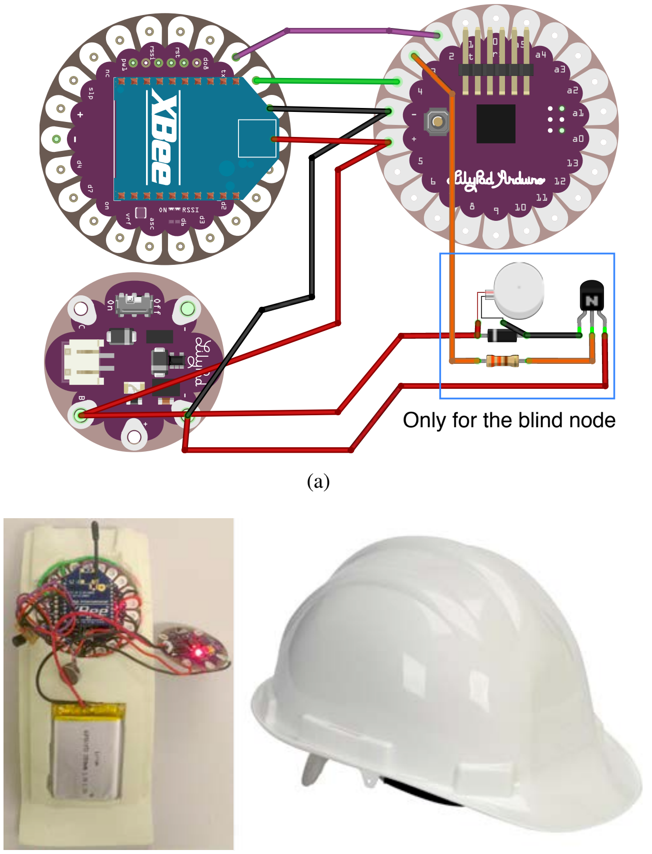


Fig. 3: The system architecture for each basic zone of the system.

based boards simplifies the amount of hardware and software development needed to get a system running. On the software side, *Arduino* provides a number of libraries to make programming the micro-controller easier. The choice of using *Arduino* boards makes the framework easy to maintain and makes it possible to add new features in the future. In particular, to speed up the developing process and to improve the reliability of the system, the *xbee-arduino* library [16] is adopted for communicating with XBee nodes in API mode.

1) Blind node: one *LilyPad Arduino* board [15] based on the *ATmega328* micro-controller is used for the *blind* node. The choice of the *LilyPad Arduino* board is motivated by the fact that this controller is especially designed for wearables and e-textiles. It can be sewn to fabric and similarly mounted power supplies, sensors and actuators with conductive thread. These features make the *LilyPad Arduino* board ideal for the integration of the *blind* node in the operator's helmet. The *LilyPad XBee* breakout board [15] is adopted to host one *XBee 1mW Wire Antenna - Series 1* radio communications module [15]. One vibration motor is used to provide the user with distinctive feedback patterns according to the surrounding areas. Finally, one *LilyPad LiPower* [15] board is used as power supply, which permits the use of rechargable Lithium Polymer batteries. The wiring schematic for the *blind* node hardware is shown in Fig. 4-a, while the real circuit which is embedded in the operator's helmet is shown in Fig. 4-b.

2) Clients: the electrical configuration of the clients is nearly identical to the *blind* node configuration except for the fact that the vibration motor and all the related electronic components are not present.



(a)

(b)

Fig. 4: (a) the wiring schematics for the *blind* node and for the clients, (b) the real circuit which is embedded in the operator's helmet.

```
//create an XBee object
XBee xbee = XBee();
void setup() {
  //initialise the serial channel
  Serial.begin(9600);
  //initialise the XBee network
  xbee.begin(9600);
  //configure one output pin for the motor
  pinMode(motor, OUTPUT);
}
//start the main loop
void loop() {
  //read any available data from the server
  xbee.readPacket();
  //check location and actuate motor for vibration
      with different patterns in dangerous zone
  checkLocationAndVibrate();
  //retrieves RSSI values and broadcasts them to
      the clients
  retrieveAndForward();
}
```

Algorithm 1: The logic of the *blind node*.

3) Server: an *Arduino Uno* board [15] equipped with an *XBee Explorer* module [15] is used for the server applications.

E. Logic of the framework

In the following, the logic of the framework is presented for the *blind* node, the clients and the server, respectively.

1) Blind node: The *blind* node runs a program that iteratively retrieves the RSSI values and broadcasts these parameters to the fixed nodes through the network. The *blind* node also has the ability to receive different flags from the server. According to the received flag, the vibration motor is actuated with a different frequency, providing the operator with a particular haptic feedback. The vibration frequency increases as long as the operator penetrates a dangerous area. The pseudo code for the program running on the *blind* node is shown in Algorithm 1.

2) Clients: Each client works as a fixed node and runs the same program. This program receives the broadcasted messages from the *blind* node and forwards them to the server. The pseudo code of the client program is shown in Algorithm 2.

3) Server: The server program implements the positioning method. In particular, the data containing the RSSI parameters are iteratively received. After filtering these data, the corresponding distances are calculated. Then the trilateration algorithm is applied in order to estimate the *blind* node location. The server pseudo code is shown in Algorithm 3.

IV. EXPERIMENTAL RESULTS

As given in [17], in order to acquire a distance, the server uses the following equation:

$$RSSI = -(10n\log_{10} d + A), \tag{1}$$

```
//create an XBee object
XBee xbee = XBee();
void setup() {
  //initialise the serial channel
  Serial.begin(9600);
  //initialise the XBee network
  xbee.begin(9600);
}
//start the main loop
void loop() {
  //read any available data from the blind node
  xbee.readPacket();
  //read RSSI and corresponding node address
  getPacketContent();
  //forward data to the server
  sendToServer();
}
```

Algorithm 2: The logic of the clients.

```
//create an XBee object
XBee xbee = XBee();
void setup() {
  //initialise the serial channel
  Serial.begin(9600);
  //initialise the XBee network
  xbee.begin(9600);
}
//start the main loop
void loop() {
  //read any available data from the clients
  xbee.readPacket();
  //read RSSI and corresponding client address
  getPacketContent();
  //filter RSSI values
  filterRSSIvalues();
  //localise node
  calculateDistances();
  localiseBlindNode();
  //send position to the corresponding blind node
  sendPositionToBlindNode();
}
```

Algorithm 3: The logic of the server.

where n is a signal propagation constant or exponent, d is the distance from the *blind* node to the reference node and A is the received signal strength at 1 meter distance. In particular, the distance d is calculated as follows:

$$d = 10^{\left(\frac{RSSI-A}{10n}\right)}. \tag{2}$$

Related experiments are carried out in order to compare the real data to the ideal expected values. The results of this comparison are shown in Fig. 5. The fit is quite promising for small distances, and this shows that the RSSI based distance estimation of the target node can be used. However, for larger distances, the RSSI based distance estimation is not so good, and therefore should be used with caution.

In addition, there are several factors that degrade and impact the RSSI values in a real application scenario includ-

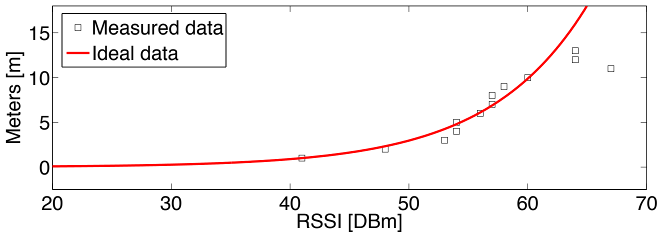


Fig. 5: Comparison between real data and ideal values.

ing reflections on metallic objects, superposition of electromagnetic fields, diffraction at edges, refraction by media with different propagation velocity, polarisation of electromagnetic fields and unadapted MAC protocols. Consequently, the results are often affected by measuring errors.

V. CONCLUSION AND FUTURE WORK

A preliminary study of an XBee-based positioning system for offshore operations was presented in this paper. The system allows for dynamically monitoring several on board zones according to different operational scenarios. A modular admission to the dangerous areas can be achieved by individually setting different access permissions for all the crew members in accordance with their specific duties. The user's risk perception is significantly improved by using a vibration motor embedded in the operator's helmet, which provides the user with an intuitive haptic feedback.

This work highlights the potential of an RSSI-based positioning system for an effective risk reduction from both an individual as well as an overall evaluation of the potential harm. The obtained experimental data are quite promising for small distance estimations. However, for larger distances, the RSSI based distance estimation method does not provide very stable results, and therefore should be used with caution. The use of distance estimation to provide localisation can generate results that are not very accurate but can be viewed as an acceptable solution for this preliminary study.

In the future, different localisation algorithms can be implemented and tested for an extensive comparison like the ones described in [9]. To improve the proposed system, a multi-sensor fusion approach with the integration of different sensors may be adopted. One more possibility that we are considering as future work is the integration of the proposed framework with a wearable integrated health sensor monitoring system for offshore operations that we recently developed [18]. This integration will make it possible to localise each operator on board the vessel and immediately provide first aid when accidents occur. Finally, some effort should be put in the standardisation process of the proposed system to meet the standards required by the maritime regulation.

VI. ACKNOWLEDGMENTS

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