Sensor Modules for Enhancement of Safety Performance in Construction Safety Management

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Abstract. Safety management is very important for construction sector as it is the most hazardous working environments when it comes to occupational fatalities. The high cases such as injuries at the workplace, illnesses, and fatalities often caused harm to the workers and create the delay on the work progress. Therefore, this paper reviewed the whole operation process of the sensor modules that enhanced safety performance to prevent accidents occurred on construction site. By providing lab scale location-based safety management services to the workers, this technology able to allow a speedy response in the event of accident. From the benchmark conducted, there are three study that had been conducted previously using vibrational alert signal which identified as an accurate transmitted especially inside a danger zone, as the vibrational function of the sensor module able to function within the designated range. The second benchmark shows that previous study able to identify errors in the location information of the workers arising from obstacles, even though so the technology able to conveyed within the designated range as well. Thirdly, the previous study able to shows the information of a fall was conveyed quickly upon occurrence, and the previous study showed that fall able to identified using the context-aware information from the sensor module. The findings showed that the real-time location and context-aware information collected from the sensor module can be used to prevent accidents and respond quickly in the event of a fall. However, the vibration signal which generated by sensor module was insufficient to alert the workers when approaching the danger zone at construction site. Therefore to improve the whole development of prototype sensor module a further study is needed to incorporate the vibrational and alarm signal for recognising accidents upon occurred for enhancement safety management at construction sites.

1. Introduction

Construction risks at construction sites could be arisen from many sources. Due to the construction is tight scheduled, project-based, and decentralized occupation [1]. Second, construction risks also could generate by trait of trades of on-site workers that might affect construction safety [2]. The implementation of safety management on construction site is either based on management-driven or technology-driven [3]. In general, the construction safety management could be enhanced by improve safety performance and minimise the rate of accidents on-site. From the study, it indicates that the management perspective which includes safety management processes such as safety education and training, and alter the individual/organizational characteristics such as workers’ trade traits that could
affect safety at site. However, these human safety errors could not be completely eliminated through safety education and training; thus, it leads to the implementation of innovative technologies that could assist and improve on existing management-driven safety management practices. These technical approaches that could enhance the management efforts [4]. The construction organisations are reluctant to implement innovative Information and Communication Technologies (ICT) mainly due to the project-based and fast-paced working environment [5]. The advanced development of ICT that made researchers gradually realised the vital of new technologies to many management practices, this including safety management [6]. Hence, by study the application of the beacon technology, which is gaining attention as a real-time location-tracking technology for the purpose of developing a location sensor module with integrated of vibrational and alarm signals that is appropriate for safety management of workers at sites.

2. Overview of construction industry

In comparing with other sectors, the amount of workers involved in construction site accidents has been accelerated yearly. Figure 1 shows the trends of construction accidents report based on the Korea ministry of employment and labour, and the annual statistics report between 2011 and 2016 [7]. One could say that the rise in construction site accidents are due to the increased in the volume of construction projects that made possible by advancement in construction plants and know-how that resulted in recruiting of a larger amount of construction workers at a construction project site, this issue could not be compensated by safety training and deployment of safety officers alone. The construction accidents are the most common types of accidents, and these accidents occur at a similar rate every year, because most of these safety-related accidents happen suddenly, there are certainly limits in safety management. Therefore, in order to minimise the accidents on construction sites, it is vital to implement more aggressive safety management at sites. However, the IoT is applied in a simplistic manner, and capable of gathering of various types of data extensively the actual utilization of such data has been minimal, although the radio-frequency identification (RFID) technology is deployed to construction sites, but it is not recognized as a technology for construction safety management from the aspect of construction site workers due to the presence of technical limitations pertaining to the RFID tag recognition rate, scope of recognition and mutual communication [8].

![Figure 1. Trends in occupational accident victims in construction industry (Source: [7]).](image)

3. Real-time location system

From the research, it indicates that through management based perspective which includes the safety management processes such as providing safety training and education, and also changing the workers’ attitude and organisational characteristics towards construction safety. However, the workers’ bad practices are difficult to change thoroughly through safety training and education. Hence, it is necessary
for the construction industry to introduce various technologies that could help and upgrade the existing management driven safety management practices. These innovative technologies are for the enhancement rather to replace the management effort [4], however, the implementation in the construction site is slow due to the temporary project-based and fast-paced changing working site condition of the industry [5]. It is a matter of fact, with the gradually advances in the ICT, the researcher realised the significant of the new technology towards the construction and safety management practices [6]. Among the innovative technologies, the rear-time location using sensing devices have able to solve much of the construction safety related problems due to its ability to track and locate of workers, materials, and plants in real-time at site [7,9].

The aim of this study is to apply beacon technology for construction safety management, which has garner attention as a real-time location-tracking technology, and for the objective of developing an integrated sensor module which is appropriate for construction safety management of workers at construction sites. The research are expected to improve the construction safety of workers with the application of new ICT, and also lead to formation of ICT-applied system for labour and materials management. The application of FRID and RTLS will be proposed as a method for solving the construction safety at site. Table 1 showed some journals published on the impact of rear-time location towards construction safety at sites.

**Table 1. Journals on the impact of rear-time location towards construction safety at sites.**

| Author | Journal Title                                                                 | Technologies applied to RTLS                                                                 | Performance of RTLS                          | Significant to site safety management                      |
|--------|-------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|---------------------------------------------|----------------------------------------------------------|
| [10]   | Control and application of accuracy positioning estimation based on real-time location system | The used of UWB antennas and IoT technologies in RTLS                                     | UWB sensor module for RTLS                  | Development of ultra-wide band antennas for construction safety. |
| [11]   | Applying Sensor-Based Technology to Improve Construction Safety Management     | The various sensor-based technologies used in construction safety.                         | An effective way to collect, identify and process information | It provides real-time construction safety management      |
| [12]   | Accuracy Improvement of Real-Time Location Tracking for Construction Workers  | To prevent work accidents and accuracy RTLS at construction sites,                         | Established a location tracking algorithm and concept of using assistant tags.              | RTLS system for precision real-time positioning at sites. |
| [13]   | Incorporating workers Awareness in the Generation of hazard proximity warnings. | Gather feedback from workers for creating an effective hazard proximity warning system for sites. | An improved hazard proximity warning system for field applications that utilize sensors | Implementation of advanced sensors by integrating the awareness of workers into the creation of hazard alarms. |
| [14]   | An embedded Sensory System for Worker Safety: Prototype Development and Evaluation. | Using an embedded sensory system which enable workers to better perceive their surroundings. | Transmission of sensing signal is fast and long range.                                 | Sensor is an effective device for data transmission.         |
| [15]   | A Framework of On-Site Construction Safety Management Using Computer Vision and Real-Time Location System. | Construction safety management system using Fast R-Convolution Neural Network (CNN)--based computer vision and Bluetooth Low Energy (BLE)- RTLS | Enable moving objects to be tracked, and the next location can be predicted.                | To warn workers approaching hazardous zone through a smartphones, via loud sounds and vibrations. |
Tracking System using LoRaWan Technology

- Long Range transmitter enabled tracking device to perform as data accumulation server
- LoRaWAN platform replace the use of IoT infrastructure on the existing Wireless Standard.
- LoRa is a low power, wide area network, and with long-range communication link.

Implementation of Safety Management System for Improving Construction safety Performance.

- Risk identifying and monitoring safety at construction projects.
- To minimise risk at construction site.
- To enhance safety at construction site.

Building information modelling in combination with real-time location systems and sensors for safety performance enhancement.

- BIM could analyse whether the PPEs are worn through integrating pressure sensors and positioning technologies.
- A wireless network architecture consisted of end nodes, repeaters/checkpoints and coordinators is considered.
- RTLS and virtual construction are created to judge whether the worker needs to wear a helmet and give a warning.

Design and Implementation of Location and Activity Monitoring System Based on LoRa

- Sensor for real-time data gathering and transmitting it to server
- It could gather data precisely and with long distant reception
- User could trace the activity and location data via smartphone

Automatic Fall Detection Using Smartphone Acceleration Sensor

- Using smartphone and a detection algorithm to improve fall detection
- Using smartphone for locating fall.
- To improve fall detection and minimise false alarm rate.

Technology’s Role in Safety Management

- Virtual reality and Augmented reality
- Safety context and real-time data of workplace condition
- It can send location details to managers in field office for monitoring

3.1. The advantages of technology in construction safety management

Some of these technologies could be applied jointly to generate safety benefits on the workplace. For instance, the laser scanners or UAVs are often used to scanning at site and to capture a detailed set of data before creating a point cloud for the deployment of a BIM model. Table 2 showed some of the potential safety benefits of technology in construction sector.

Table 2. Potential Safety Benefits of Technology in Construction (Source: [21]).

| Technology                                      | Potential safety benefit                                      | Example                                                                 |
|------------------------------------------------|-------------------------------------------------------------|------------------------------------------------------------------------|
| Building Information Modelling (BIM)           | • Enable risks elimination or substitution (design for safety). | • Automated safety-rule checking platform to identify potential risks before commencing work and suggest risk prevention measures [13] |
|                                                | • Improve risks recognition and identification.             | • Enable site personnel report near-hits to managers and supervisors to detect and mitigate potential workplace risks [22]. |
|                                                | • Improve safety inspections.                               |                                                                        |
|                                                | • Enhance safety planning, awareness or communication.      |                                                                        |
| Laser Scanning                                 | • Benefit for risks recognition and identification.         | • Identify blind spots of a heavy construction equipment in the job site using a 3-D laser scanner [23]. |
|                                                | • Improve safety planning, awareness or communication.      | • Take accurate measurements of heavy equipment and the surrounding environment prior to start of work [10]. |
|                                                | • Enhance safety conditions of construction site.           |                                                                        |
3.2. Utilised of sensing technology in construction safety

Sensing technologies are used for construction safety, for instance, in accident forewarning system, safety route prediction and planning, integrated safety management, structural health monitoring, safety training, and education and highly dangerous operations management. Some of applications of sensing technology are showed in table 3.

| Adoption in Construction safety  | Sensing Technology                                      | Significance of usage                                                      |
|---------------------------------|---------------------------------------------------------|---------------------------------------------------------------------------|
| Risk Avoidance                  | Radio frequency identification, ultra-wide band, Zigbee, sensing devices and wireless sensor network | For plants and workers tracking and locating                               |
| Safety Design                    | 1. For construction site plants and workers planning.   | Radio frequency identification, ultra-wide band, Vision sensing           | For planning & scheduling of plants and manpower                           |
| Hazard Identification           | 1. To identify & categorise of hazardous areas.         | Radio frequency identification, ultra-wide band, Ultrasound, Vision sensing, sensors and wireless sensor network | Barring workers from entering hazardous area, and find out workers’ risk behaviour. |
| Integrated safety management    | 1. QA & QC management of building materials and resources. 2. Health and safety management of workers. | Global positioning system, radio frequency identification, ultra-wide band, ultrasound, Vision sensing, sensing devices and wireless sensor network | Checking building materials and resources’ quality. Introduce new ideas for workers’ safety at site. |
| QA & QC for Structural & building health | Sensing devices and wireless sensor network | Monitor structural & building health                                         |
3.3. Sensor module
This sensor module consisted of a device which could collect beacon signals for RTLS, a 2nd device for collecting data on acceleration and angular velocity that caused by falls, and a 3rd wireless networking device that provides the information collected earlier.

The beacon signals are able for real-time locating, this sensor module system with a built-in communication device of Bluetooth 4.0 or higher. Similarly, to be able to measure the context-aware data of workers at sites, the MPU-6050 (Inven Sense Inc.) is used as a chip to measure the acceleration and angular velocity of falls. The MPU-6050 is built-in with a 3-axis gyro sensor and a 3-axis acceleration sensor. It also uses nRF52832 which manufactured by Nordic for micro controller unit (MCU) and SPI and GPIO interfaces. Thus, enable the sensor chip and LoRa transmission and reception chip control, and equipped the Bluetooth function, that is characterised by low power consumption when sending and receiving wireless beacon signals. The sensor module is shown in figure 2.

| Sensor Module (MPU-6050) | Battery | micro controller unit MCU(nRF52832) | SWITCH | Bluetooth Low Energy (BLE) Module | Semtech SX1276 (LoRa) Long Range communication link |
|--------------------------|---------|-------------------------------------|--------|----------------------------------|---------------------------------------------------|

Figure 2. Sensor module architecture [28].

3.4. The long range communication and Gateway wireless network
The sensor module’s Long Range communication and Gateway are using wireless network technology. The collected data of indoor location, tilt, and acceleration are sent through Long Range communication. The Long Range communication used chip for sending and receiving of data. The chip required frequency and bandwidth’s range is set at between 137MHz and 1020MHz for communication (https://www.lora-alliance.org/). The benefits of Long Range communication are suitable for low power sensor device and no need to install many gateway due to it has long-distance transmission ability. However, the disadvantages of LoRa communication is low transmission speed if the volume of data transmitted is large, to compensate this weakness, it is required to reduce the amount of transmission data.

3.5 The server device
The deployment of Server device for filtering and processes the data received by the sensor module. The server device also perform the real-time processing of position data, and context data of workers that received by the sensor device, and also providing the information to the site manager for action. Similarly, it also transmits alert signals to the workers that approaching the hazardous area for avoiding accidents to occur.

3.6. The creation of advanced sensor for construction safety
The development of new sensor that incorporating vibration and siren signal into the sensor module. This new sensor with enhanced safety feature will alert the worker who wearing it when approaching danger zone. The sensing signal received by sensor receiver which worn by the worker who approaching
the danger zone will calculate the distance and sends the data to the server and to the manager, and at the same time, it will triggered the vibration signal and siren signal of sensor module. Figure 3 shown the safety management system architecture of RTLS.

![Safety management system architecture](image)

**Figure 3.** Safety management system architecture of worker Monitoring System for Activity Recognition and construction site RTLS [12].

3.7. **Potential targeted experiment using the integrated sensor with vibration and siren signal feature.**

First experiment was performed at the Chow Kit Trade Centre construction project site, and at the Lower roof level with potential high risk of accident. When the worker who worn a prototype integrated sensor module receiver with vibration and alarm signal approaching the danger zone that with three sensing transmitters installed at appropriate location of the danger zone with a designated radius of between 5m and 10m, the sensing receiver device will produced vibration and siren signal to alert the worker. The vibration intensity and interval of the sensor module was programmed to the requirements and adjusting accordingly to the circumstances of the construction site. For instance, a strong vibration intensity is required initially when a worker is entered a danger zone, and then weak vibration intensity could be set at certain intervals thereafter. The result of the experiment showed the outcome performance of prototype was effective to prevent potential accidents at construction sites.

Second experiment was performed at the similar area as first experiment to find out the effect of the signals weakened with obstacles positioned between the signal transmitters and receiver, for instance, the presence of a concrete wall of certain thickness and to find out for errors in the location information. At most of the construction site, there are usually have many construction plants and materials placed at different location. In the previous studies have shown that a limitation to indoor locating has been described as the numerous errors in location positioning measurements due to the present of concrete walls of certain thickness on site. To verify whether this problem could be resolved by using the prototype integrated sensor module, a worker who warn a prototype integrated sensing receiver was approaching a 200mm thick concrete wall on site as an obstacles, and establishing an danger zone with a radius of 10m. The experiment results indicated that accuracy of distance measurement was accurate, the alert signals were properly generated and transmitted within the 10m radius of the designated danger zone.

Third experiment was performed at same location as above to see the aware of context of fall. This experiment was to find out whether in the event of a fall accident, the context-aware system could become aware of the context of fall worker, and provide the related information to the field manager quickly in order to take necessary emergency measure to assist the victim. The study result shown that worker who worn the prototype integrated sensor module with acceleration and gyro sensor could receive help due to the data of fall detection could be inform by the system to the field manager during the fall event through using the real-time location-tracking technology and response swiftly to the situation.
3.8. Summary of the research gap
The current construction safety management could be improved with further enhance on the information technology, with a wide range of systems and technologies, for instance, the improvement on the current modules, however, it need to tab the technical limitation that might prevents the substantial improvements. For further improvement in safety management of workers at construction sites, it is necessary to apply IoT-based information technology, there has recently vital for persons and things to manage their own safety. Hence, in order to limit the accidents at construction sites, it is necessary to develop a prototype with the application of real-time location-tracking technology that based on beacon signal technology and a context-aware technology incorporated into sensor technology to form an enhanced sensor module with vibration and siren feature for speedy, effective and efficient response was fabricated in this study. From the outcomes of the experiments, it has shown that it would be possible to implementing the enhanced sensor module system to the construction sites.

4. Conclusion
Currently, the construction safety management that using the sensor modules with the integration of a vibration motor could give an alert signal to the worker that wearing the device, however, it could further improve by incorporating an alarm system within the sensor module. Thus, in order to enhance the safety management system at site, a prototype sensor module with real-time location tracking technology that based on beacon technology and context-aware technology incorporated with vibration and alarm system in sensor technology was fabricated for experiments, and the results showed it is possible to apply to the construction site. This chapter has presented the methodology to study sensor modules with beacon-based location tracking technology and context-aware technology. The experiments were carried out for fall of context-aware, wireless indoor positioning technique of real-time location tracking, and the degree of signal strength weakened with the present of obstacles at site that caused errors in the location measurements. The designed experiments and its procedure were for compliment to the objectives of this study.

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