Applying beacon sensor alarm system for construction worker safety in workplace

Ying Huang1, Kong Fansheng1*, He Yifei1

1 School of Civil Engineering, Xi’an University of Architecture and Technology, Xi’an, Shaanxi, 710055, China

Kong Fansheng*: kongfansheng@xauat.edu.cn

Abstract. The construction site is one of the most dangerous workplaces among all the industries, workers are exposed to various hazards sources. Ubiquitous accidents occur even with detailed regulations and laws. Situation awareness theory revealed that there are three processes when people are dealing with the changing environment: perception of environmental situation, comprehension of what people are dealing with and decision-making. The likelihood of risky behaviours increases a lot when any of these processes go wrong. In this paper, the author proposed an alarm system to help workers get a better perception of construction site and improve the efficiency and quality of safety management. In this system, a beacon sensor will be deployed on the hazard source and it will keep send Bluetooth package to receiver equipment. Workers will carry the receiver, a BLE sensor, to calculate the distance between people and the hazard point. If the distance is less than the setting number, the sensor will trigger the alarm to broadcast siren and send the unsafety behaviour event to manager backend to archive the entire process.

1. Introduction

The construction site has always been identified as one of the most dangerous workplaces. A scissor lift operator named Jorge Castillo-Riffo in Royal Adelaide Capital construction site in November, 2014. Investigators found he died because of the collision of the machine and a slab[1]. In 2016, an electronic engineer Stephen Wyatt was crashed between a mobile machine and a doorway[2]. These fatal accidents drew people’s attention in making workers in construction site to be aware of the environment when they are working.

Even though many governments issue different administrative directives and industry guidelines to standardize construction safety management, injuries and fatalities still happen. Departments like Occupational Safety and Health Administration, Safety Work Australia, and Ministry of House and Urban-Rural Development of P.R.C. keep updating the accident data in construction site, a report revealed that the most common workers’ injuries are cut and open wounds which is accounting for 30% among all injuries; and the reason for injuries includes being hit by object(31%), lifting, pushing or pulling(30%) and falling(15%)[3]. Researchers found that workers and safety supervisors cannot identify all the hazards in workplace so that over-reliance on personnel management is not a proper way[4].

1.1. Situation awareness

There are three inherent topics when talking about Situation Awareness (SA): “a constrained time and space, the comprehension of the meaning and the projection of their status in the near future”. The
three topics are defined in a limited environment, whereas the details will change if the environmental conditions change. Initially, SA started to be an important concept in aircraft industry in the last years of 20th century, which has been a vital metrics for pilot and need to be considered in aircraft design[5]. In a dynamic situation, part of personal state of knowledge which related to the similar condition will be a resource to make decisions in comprehensive system, that is SA procedure. In order to make a wise decision on environment, people need to combine perception of situation elements, personal comprehension and goal together according to SA system. In the SA model, the three steps to achieve SA and a proper decision-making are affected by individual and external factors, in other words, both individual’s ability and the complexity of the environment will contribute to SA.

Wickens[6] reviewed that SA theory has been applied into various fields such as human training, human error analysis, selection analysis, teamwork efficiency and industry automation. As the automation is a tendency in both manufacture and construction industries, lots of experts and scholars take SA as a central point in related research. Baumann and Krems[7] analyzed the first process of SA procedure, argued that cognitive basis was necessary to be used in drive task as a basic knowledge. Ghimire et al.[8] designed a computing system to assess the SA statement in complex project in order to improve the efficiency in project management level since the challenges and problems in complex project are incline to transformation. On the other hand, in traffic management areas, SA also has a far-reaching impact, Salmon et al.[9] extent SA theory to traffic safety fields and found the relationship between road external condition, the frequency of usage and the conflict for various users like drivers, motorcyclists and cyclists when these users are in the same situation. Regarding construction site, workers need to perceive the hazards in time as a premise to define the risks and prevent them from injuries, some research designed a few equipment to help workers perceive the hazard surround the workplace like Differential Global Positioning System (DGPS), wireless and web-based technologies. Their research revealed that various technologies can help to improve the safety management furthermore. A typical example to combine SA theory and advanced equipment is the use of 3D eye-tracing equipment to record the track of eye ball to find the subject’s sight line to evaluate the SA of subject who is into a designed environment.

1.2. The usage of Beacon sensor system in safety management

The prototype of beacon sensor system for safety management appeared in approximately 1995, Jurgen[10] designed a collision alarm system which could detect distance and warn collision, but there existed a defect that the system will be triggered by any objects at any time. OSHA modified the prototype to integrate identification ability in the system which means it can identify different signals when deployed[11]. Later on, the system was used in mining fields to prevent accidents since the lighting conditions in the mine are very poor and collisions are prone to occur.

Sensing technics have developed rapidly in decades, video camera, ultrasonic, radar, RFID and GPS have been used in safety management area. Vehicle industry applies video camera system to help drivers perceive blind points clearly and record driving activities. Given visual images, drivers can behave more rationally even with less experience. Unfortunately, this imagine based technic cannot be used in construction site directly for workers since their sight needs to focus on the task rather than the imagines. Compared with other sensor, the transmission range of ultrasonic is relatively short, 2.7m is not enough in complex environment like construction site[12]. As for radar, the cost will be too high to make a good use of it in workplace. Because many activities in construction site are carried out indoor, or sometimes congested together, GPS cannot work well in necessary conditions in site[13]. New Bluetooth Low Energy has a good performance in either indoor or far range conditions, the BLE sensor integrate GPS function which can allocate outdoor position and BLE can be used in indoor signal transmission.

1.3. Research gap

Many researches applied SA theory to improve human SA behavior since it developed. Naderpour, Lu et al.[14] design a system to help with it. In their system, they focused on the first two step of SA,
providing external information procedure to retrieve more data in the given condition and people can assess situation around him/her more concisely. Concretely, the first process of their system is to identify a dominated aspect of situation for someone’s SA; the second process is to standardize a procedure to assess the situation data; the third process is to come up with a support system structure to help with the assessment and evaluate the proposed system. Sensors were used to extend the range of information-searching and as a way to support SA. But the problem is the signal needs to be sent manually, which is not an appropriate choice for construction site use.

Construction site is a dynamic environment where workers will keep facing different risks. When workers deal with the risks around him/her, SA ability is a vital factor to make someone behave safely or make a safe decision when an accident happened. Many researchers have analyzed the function and procedure of SA and applied the theory into various safety management fields. Compared with other sensor technics used in SA support, BLE beacon has unique characters which the quality and usage are more applicable when used in construction site. To this end, there exists a gap between alarm system which can help with SA ability and applying BLE beacon sensors. This research is to develop a beacon sensor alarm system to help workers in construction site to improve SA ability.

2. Methodology

This research is to develop an alarm system to improve construction worker’s situation awareness. The system provides another way to approach safety management in construction site. In order to develop the system, the author needs to collect hazard data in construction site and input the data into software for assessment the situation surrounding the user. Besides, in accordance with the usage of beacon sensors in mining industry, this system also deployed the sensors as a collector for raw data. In addition to data-collecting, the BLE sensor also advertised the data to receiver by BLE package. The worker will take a receiver, the receiver will work as a micro-computer, once get the data from beacon, a IoT app in the receiver will process the data and send the reflection trigger to server for alarming and recording.

There are two parts in data collection, the first part is to identify hazards source in construction site as a basic step to deploy the sensors. The second part is to fetch and analyze the raw data from sensors. As for data collection, this research identified hazard data from literature, construction codes and industry guidance as well as related laws. On the other hand, since the government department has safety management database or related online reports, the author also retrieved these files to get hazard information. Since BLE sensor will send data including Bluetooth energy power, position, temperature, battery volume and acceleration, the distance can be calculated by the Bluetooth energy. Based on the distance information, the responding process will active in two ways, one is to send alert to workers who are in danger, another is to send the data package to manager for the further usage.

The author has developed an online IoT application on the back end of Estimote, which uses JavaScript to perform data processing. The first step is to get the distance between workers and the hazards. Since one BLE beacon can receive the other Bluetooth packages, of which the RSSI can be used to calculate the distance according to the general estimation model expressed as:

\[
\text{RSSI} = -10n\log\left(\frac{d}{d_0}\right) + A + X_\phi, \tag{1}
\]

where Gaussian-distribution random variable \(X_\phi\) is taken as mean value 0, \(n\) takes 2. In addition, and average measured power \(A\) is the RSSI from a fixed point at a distance \(d_0\), so it can be simplified as 1 meter for convenience. As such, the algorithm in IoT application is showed below.
Algorithm 1: LTE Beacon Sensor Distance Algorithm

| RSSI (i): RSSI value in Package(i) |
| Type (i): the type of Package(i) |
| ID (i): Identifier of Package(i) |
| MP(i): measured power of Package(i) |

**Input:** Package(i), Beacon ID, $I(i)$

**Output:** Average Distance

1. function Dist(i)
2. Dist(i) = $10^{(\frac{RSSI(i) - MP(i)}{-20})}$
3. end function

4. Scan BLE Package
5. if Type(i) == 'est_lot' then
6. if ID(i) == Beacon_ID then
7. if Package(10) == True then
8. $I(1)$ = Dist(i)
9. $I(2)$ = Dist(i+1)
10. $I(3)$ = Dist(i+2)
11. ...
12. $I(9)$ = Dist(i+8)
13. $I(10)$ = Dist(i+9)
14. Average Distance = ($I(1) + I(2) + I(3) + ... + I(9) + I(10)$) / 10
15. end
16. end
17. end

The following is to make a good use of the distance data. When the distance is assessed to be in dangerous status, the reaction process steps in. The responding process was designed in the database, where the reaction regulations and measurements differ from distance signal values that sent by sensors. The responding activities include acoustic alert to make worker notice the environment and send data to backend system to remind managers that someone perform unsafety behaviour like the figure 1 shows.

Figure 1 Overview of the reaction system.
Compared with traditional safety management, this system avoids the dependence on the site management personnel in the construction safety management. The beacon sensor will keep sending the Bluetooth signal to BLE sensor will begin processing the signal in time without judge by human. It will be a rapid response system to give workers a more efficient safety guarantee. When hearing the siren, the worker will notice that he/she is in bad environment condition to which someone will need pay more attention to keep safe. On the other hand, the event data which will be sent to safety managers and restored provide an appropriate opportunity to collect accident data. The data can be used to tool box meeting, induction training and analyse the weakness point in construction site.

3. Conclusions

Construction site has always been a dangerous workplace among all the industries where various injuries and fatalities occur all the time. Even though there are a lot of policies and regulations aiming at different construction process to focus on safety management in construction site, ubiquitous hazards still challenge the workers and safety supervisors. In accordance with the situation awareness theory, there are three steps for human to deal with the hazards, perceive, comprehend and take action. The chance of injuries and fatalities would increase a lot if either of them goes wrong or is underestimated.

In order to help people who in complex environment workplace like construction site, this author proposed a BLE beacon sensor alarm system to help workers improve safety behaviour and help supervisors get a better perception of safety-compromised activities. The system is based on the calculation of distance between hazards and workers which can be received by BLE beacon sensor. When the safety distance is compromised, the reflection process will be triggered to remind the workers who is in danger by the estimation of system database. In addition, the safety supervisors or related managers will also get the alarm from system in case the worker still unable to pay enough attention to the hazard. The unsafety behaviour or safety-compromised activities happened in site can be recorded in the safety management log for the further research and treatment. Furthermore, the system may integrate thermal, acceleration and position function together to give practitioner a better perception of situation around the workplace and record all these data into database to optimize the efficiency and quality of construction safety management.

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