International Journal of Engineering & Technology, 7 (3.24) (2018) 365-369

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

A Study of RTLS-based Construction Worker Safety Management System Model

Jai-woo Oh[1], Jin-Kyu Kang[2*]

[1]*Department of Health Management & Education, Kyungdong University, Korea*
[2*]*Department of Industrial and Management Engineering, Hanbat National University, Korea*
[*]*Corresponding author E-mail:jkkang@hanbat.ac.kr*

Abstract

Background/Objectives: The purpose is to develop a safety management system using location and context information collected from a sensor module for preventing and quickly responding to accidents involving construction workers.
Methods/Statistical analysis: In order to develop a safety management system that is suitable for construction sites, there is a need to apply appropriate technologies, taking into consideration the site characteristics. The technologies applied in this research were a sensor module comprised of a device that collects beacon signals, a device that collects data on acceleration and angular velocity, and a wireless networking device for providing the collected information; the gateway technology for transmitting the data on location, tile and acceleration obtained from the sensor module via LoRa communication; real-time fingerprint-based positioning technique; and context-aware technology for recognizing a fall by using the data on tilt and acceleration.
Findings: This study was conducted on a safety management system with the aim of preventing accidents on construction sites by providing location-based safety management services to the workers and allowing a speedy response in the event of a fall. To this end, three experiments were carried out: the first experiment was conducted to see whether the alert signal (i.e. vibration) was accurately transmitted inside a danger zone, and it was found that the vibration function of the wearable device worked properly within the designated range; the second experiment checked for errors in the location information of the workers arising from obstacles, and it was found that the alert for the danger zone was properly conveyed within the designated range; and the third experiment checked whether the information of a fall was conveyed quickly upon occurrence, and the results showed that a fall could be identified using the context-aware information from the sensor module and the related algorithm for the information on the fall to be swiftly communicated to the field manager.
Improvements/Applications: 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.

Keywords: Beacon, RTLS(Real-Time Location System), Construction Safety Management, Context Awareness, IoT(Internet of Things)

1. Introduction

Due to the increasing size, height and complexity of building construction, fatal accidents have been occurring more frequently at construction sites. The occupational fatality rate of Korea is among the highest of OECD nations, with the construction industry accounting for 26% of all occupational accidents in Korea. The construction industry, the accident rate of which has been on a steady rise, has become notorious as an industry fraught with accidents. In response to this trend, the Ministry of Land, Infrastructure and Transport of Korea has announced its plans to utilize smart technologies such as Internet of Things (IoT), drones and closed-circuit television (CCTV) in reinforcing safety for construction workers.

With the advent of the Fourth Industrial Revolution, convergence of information and communications technology (ICT) is being researched and applied by diverse industries. IoT, in particular, has taken on a central position of “connection,” which is the key idea of the global ICT sector, and it is being widely applied in various areas to produce considerable physical and economic results in terms of productivity improvement, cost reduction and increased convenience[1]. Within the construction industry, however, IoT is applied in a simplistic manner, and despite collecting diverse types of data extensively, the actual utilization of such data has been minimal. In addition, although the radio-frequency identification (RFID) technology is applied to construction sites, it is not recognized as a technology for construction safety management from the perspective of construction site workers due to the presence of technical limitations pertaining to the RFID tag recognition rate, scope of recognition and mutual communication[2].The aim of this study is to analyze the appropriateness of the beacon technology, which is garnering attention as a location-tracking technology, and real-time locating systems (RTLS) for the purpose of proposing a model for developing a location system that is suitable for safety management of construction workers. The findings of this study are expected to not only improve construction worker safety management with the application of new ICTs, but also lead to the creation of an ICT-applied system for labor and materials management. To this end, the current circumstances of safety management of construction sites and the emerging ICTs will be analyzed. As for the safety management status, the existing management system and RFID application cases will be examined, and improvement measures using RTLS will be proposed as a means to address the derived issues.

2. Related Research

2.1. Safety Management Status of the Construction Industry

In the domestic construction industry, the number of victims involved in occupational accidents has been increasing annually, as shown in [Figure. 1]. Although one could argue that the rise in occupational accidents has resulted from the increased scale of building construction made possible by technical advancements and the subsequent input of a larger number of construction workers, this issue has not be mitigated by safe training and dispatch of safety officers alone.

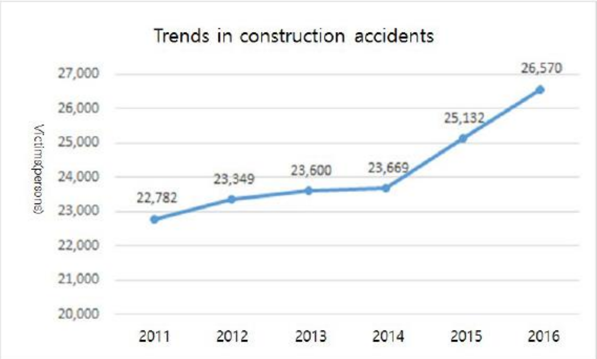


Figure 1: Trends in occupational accident victims in the construction industry

Also, falls and rollovers are the most common types of accidents, and accidents occur at a similar rate every year. Because most of these safety-related accidents happen suddenly, there are certainly limits in safety management. Thus, in order to prevent such accidents on construction sites, there is a need for more aggressive safety management, rather than implementing passive safety measures.

2.2. The Concept of RTLS

The real-time location system (RTLS) technology is aimed at identifying or tracking the location of a person or an object. It typically provides services for identifying the location indoors or tracking the movement of the target[3]. The technologies related to RTLS have been developed due to the growing research interest in the related technologies as a result of the advances in the RFID/ubiquitous sensor network (USN) technology[4]. Research is also being performed on RTLS incorporated with RFID/USN for application in the construction industry. The studies that have been carried out thus far present the possibility of applying RTLS to personnel management, safety management, materials and logistics management and ready-mix concrete management and continually advancing the system for the construction field[5,6,7].

RTLS has been garnering attention with the recent launch of iBeacon by Apple. A beacon, referring to a "device that emits a signal," provides information on its location by emitting light or radio waves in order to prevent collision or to guide the signal receiver. It was initially installed to prevent collision between aircraft and high-rise buildings or on a sea buoy. Later on, it advanced into a smart short-range communication technology used to locate users within a certain range, based on Bluetooth, to enable message transmission and mobile payments. Since 2013, beacons have been applied by the advertising industry to convey product information to shoppers via their mobile phones upon entering the store where the technology has been applied.

The beacon technology has the following characteristics. First, it provides highly precise positioning. While GPS has a large error range from a few meters up to a hundred meters and cannot be used to locate the target inside a building, beacons have an error range of around 5cm and can even be used for indoor positioning. It also has a wide recognition range of up to 50m in radius. Second, it is a mobile low-power technology. The beacon technology is based on low-power Bluetooth technology, and the battery can be miniaturized to a size smaller than a coin and be used for up to 2 years without replacement. Also, since it is a technology applied to mobile phones, it has portable hardware that can receive and transmit information. Third, it has reliable information recognition. Unlike RFID, there are no recognition errors caused by obstacles and impurities.

Such beacon-based positioning technology can be used alone for positioning purposes, but it can exhibit synergy by being combined with other existing positioning technologies. As a result of examining existing studies on the RTLS technology, it has been found that most of such research has focused on field application and performance evaluation and on its utility and possibility of application. Few studies, however, have been carried out on ICT such as RTLS for the purpose of prevent accidents in the construction industry, which has been recording an increasing number of accident victims each year, and there has not been much research to apply RTLS in the field[8].

Unlike the general indoor environment, a construction site is a place where workers must perform their jobs in an environment where various types of equipment and materials exist. If a location tracking technology, taking into account such a dangerous work environment, is developed, it will serve as a useful technology in various fields. By developing an RLTS suitable for construction sites, it can be used for enhancing safety management based on the mechanism shown in [Figure 2]. In particular, it may be used as an effective safety management method on construction sites by tracking and managing the locations of workers, original cause materials and assailing materials in order to prevent accidents[9].

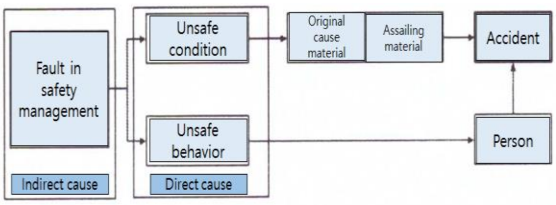


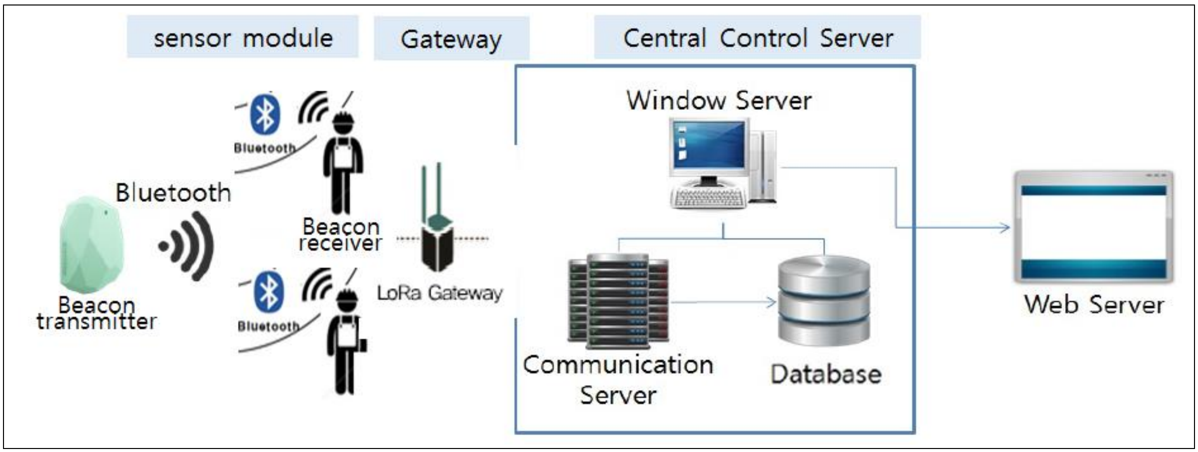
Figure 2: Heinrich's accident mechanism model

In order to mitigate the difficulties in safety management on construction sites, this study was carried out to examine an RTLS using beacon technology, based on prior research on RTLS technology.

3. Research Method

3.1. RTLS-based Safety Management System

Safety training has limitations as a method of improving safety management of workers on construction sites, and there are many challenges to improving worker safety management even with the RFID/USN technology, which is being widely used today. In order to resolve this issue, an RTLS with the application of bean technology was examined in this study as a means to improve worker safety management. The system developed for the purpose of this study is comprised of three elements, as shown in [Figure 3]: a central control server device, gateway and sensor module. For the application of this study, beacon transmitters are installed on a site with a high risk of accidents and the central control server device is accessed via the gateway to detect whether the beacon transmitters are approached by any of the workers. Each of the workers wears a wearable device to which a beacon receiver is attached. When a worker approaches a danger zone, where a beacon transmitter has been installed, the location information of the worker in question is sent to the central control server device through a Bluetooth signal exchange between the beacon transmitter and receiver, and an alert signal is transmitted to the worker in the danger zone. It was deemed that the use of a receiver that could be attached to the body would be most effective, taking into consideration the nature of construction sites, for the workers to wear the receiver at all times.



※ Source: Design and Implementation of Patient Monitoring System for Activity Recognition and Indoor Positioning in Hospital(2018)

Figure 3: Safety management system architecture

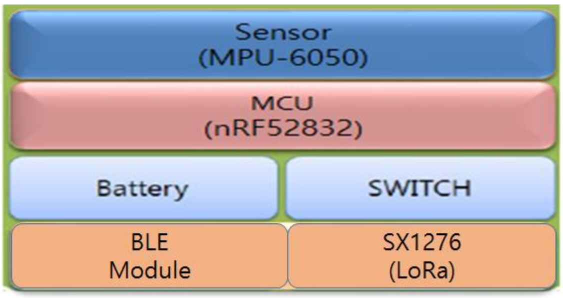
The most important factor in preventing accidents on construction sites is to raise awareness of the potential risks among the workers. Because it is possible to measure and adjust distance by the radio wave signals transmitted between the beacon transmitter and receiver, the system was designed to send a signal to the receiver when the worker wearing the device was within a certain range from the transmitter installed in a danger zone. For instance, the most common accident on constructions is a fall. A transmitter may be installed in an area with a high risk of fall in order to warn the workers approaching this area as a way to prevent falls that occur because workers are not aware of the related risk. Also, the administrator can locate workers using the central control server, which enhances administrative efficiency.

3.2. Application Technology of Safety Management System

In order to develop a safety management system suitable for construction sites, there is a need to apply the technologies examined in Section 2 that are appropriate for the characteristics of construction sites. Safety management system technologies can largely be divided into software and hardware. The hardware can be further divided into a central control server device, gateway and sensor module for information collection. The software, on the other hand, consists of positioning technology for real-time location tracking and context-aware technology for recognizing accidents upon occurrence.

3.2.1. Sensor Module

The sensor module is comprised of a device that collects beacon signals, a device that collects data on acceleration and angular velocity, and a wireless networking device for providing the information that has been collected. In order to scan the beacon for real-time location tracking, the system must have a built-in communication feature with specification of Bluetooth 4.0 or higher. Also, for the purpose of measuring the context-aware data of workers, MPU-6050 (Inven Sense Inc.) was used as the chip for measuring acceleration and angular velocity. MPU-6050 is equipped with a 3-axis gyro sensor and a 3-axis acceleration sensor. In addition, nRF52832 made by Nordic was used as the micro controller unit (MCU). nRF52832 can use SPI and GPIO interfaces, thereby enabling sensor chip and LoRa transmission and reception chip control, and it is equipped with the BLE function, which is characterized by low power consumption when sending and receiving wireless signals. The sensor module architecture is shown in [Figure 4].



※ Source: Inven Sense Inc, Product Specification Revision 3.4

Figure 4: Sensor module architecture

3.2.2. Gateway

The LoRa communication and gateway of the sensor module are of the same wireless network technology and thus are summarized hereunder. The indoor positioning data, tilt data and acceleration data are transmitted via LoRa communication. For data transmission using LoRa communication, SX1276 (Semtech Inc.) was installed as a chip for transmission and reception, as shown in [Figure 4]. In the case of SX1276, the desired frequency and bandwidth can be set within the 137MHz~1020MHz range for communication[10]. The advantages of LoRa communication include the fact that it is suitable for use in a low-power IoT sensor module and there is no need to install many gateways as it is capable for long-range communication. The downside, however, is the low transmission speed. In order to overcome this weakness, it is necessary to minimize the amount of transmitted data. Thus, measurement values that did not change even when the sampling cycle was increased were viewed as meaningless data and were not transmitted as a means to minimize data transmission.

3.2.3. Server Device

The server device of the safety management system filters the information received from the sensor module and processes the data. It performs real-time processing of the location information and context-aware information of workers obtained from the sensor module to be provided to the administrator. It also sends signals to the workers approaching a danger zone for the purpose of preventing accidents. The specification and function of the server are shown in <Table 1>.

Table 1: Server specification and function

Category	Specification
CPU	i7-6700
RAM	DDR4 64GB
GPU	GTX1080 D5X 8GB
Function	Filter the information received from the sensor module and process the data
Characteristic	Perform real-time location information management with the application of a location-tracking algorithm

3.2.4. Location Tracking Technology

The location-tracking method should provide highly accurate indoor location information and have minimal errors resulting from obstacles, considering the nature of construction sites that have an indoor environment and contain many obstacles. As for the networking method, the system should be able to send strong signals across short distances and ensure smooth exchange of signals, while eliminating any information losses and enabling real-time location tracking. Wireless indoor positioning techniques include the range-based technique, fingerprinting technique, proximity-based technique and dead reckoning (DR) technique[11,12]. For such purposes, methods taking advantage of the physical characteristics of electromagnetic waves such as the time of arrival (TOA), time difference of arrival (TDOA), angle of arrival (AOA) and received signal strength indicator (RSSI) are mainly used.

In this study, the fingerprinting technique was used as the location-tracking technique. Fingerprint-based positioning technique is largely comprised of two stages: in the first stage, which is the preliminary data collection stage, the coordinates and received signal strengths arbitrarily collected from an indoor space are stored as a list and a radio map is created on a selected grid, and in the second stage, which is the positioning stage, the list of the received signal strengths and the radio map set up in the previous stage are compared and the location of the terminal is determined based on a sum of the weighted values of the locations with high similarity. In the case of the fingerprint-based positioning technique, the propagation characteristics of the indoor environment are reflected in the radio map, and thus the accuracy is higher than that of the signal propagation modeling method. The fingerprint-based positioning technique is a pattern recognition technique used to determine the location of the terminal using the reference point data with similar signal strengths[13].

3.2.5. Context-aware Technology

In this study, the context-aware technology for fall, which is the most common type of accident on construction sites, was applied. According to the results of an experiment carried out for recognizing a fall, as the body falls to the ground, the gravitational acceleration value drops to 1.0 or less before rising to at least 3.0 due to the impact of recoil when the body comes into contact with the ground, and the time it takes for this to occur is less than 0.8 seconds. The gravitational acceleration value is calculated by applying the equation shown in [Figure 5] using the acceleration along the three axes (a_x, a_y, a_z), the data of which are collected from the acceleration sensor, and the gravitational acceleration (a_{sv})[14].

$$a_{sv} = \sqrt{a^2{}_x + a^2{}_y + a^2{}_z}$$

Figure 5: Equation for calculating gravitational acceleration

The algorithm for recognizing fall by using the gravitational acceleration equation is shown in [Figure 6]. The parameter, FALL_CHK_STATUS, is for checking whether the timer has started in order to recognize a fall, and FallCheckTimerStart is the parameter for checking the time. The FALL_CHK_STATUS parameter checks whether the timer has started to recognize a fall. If a gravitational acceleration value of 1.0 or less is measured when checking for a fall, the fall detection timer is run for 0.8 seconds. When a gravitational acceleration value of 3.0 or higher is measured while the fall detection timer is being run (for 0.8 sec), the event is judged as a fall. When a fall is detected, the SendFallAlert() function is called in order to send a fall detection message. In case a value of 3.0 or higher is not measured during the 0.8 seconds, however, the timer is stopped, and the FALL_CHK_STATUS parameter value is reset to halt the fall detection process.

```
precondition a, FALL_CHK_STATUS
procedure FallCheck ( )
  if ( FALL_CHK_STATUS == false )
    if ( a <= 1.0g )
      FALL_CHK_STATUS = true
FallCheckTimerStart ( 0.8s )
  else
    if ( a >= 3.0g )
SendFallAlert ( )
      FALL_CHK_STATUS = false
end procedure
▷ 0.8 second after fall check timer start
procedure FallCheckTimerHandler ( )
  FALL_CHK_STATUS = false
end procedure
```

Figure 6: Pseudo-code for the fall detection algorithm

3.3. Simulation

The attachable-type wearable device was fabricated by integrating a vibration motor into the sensor module, shown in [Figure 4], as a means to give an alert signal to the worker wearing the device. The reason for integrating the sensor module with a vibration module was to prevent workers from getting into accidents using the data collected from the sensor module attached to the workers. The experiments that were carried out in this study as well as their results can be summarized as follows:

First, an experiment was carried out on the alert given when a worker approached an area in which a transmitter has been set up to warn that it is a danger zone. For this experiment, a transmitter was installed and a danger zone was designated within 5m and 10m radiuses of the transmitter. When a worker approached the danger zone, the attachable device worn by the worker vibrated. The vibration intensity and interval can be programmed, and thus the necessary adjustments can be made according to the circumstances of the construction site in question. Because it may be necessary for workers to work inside a danger zone, a strong vibration may be induced at initial entry into the danger zone and weak signals may be sent at certain intervals thereafter. It is deemed that keeping workers aware of the potential dangers surrounding them by using such signals will be effective in preventing accidents on a construction site.

Second, an experiment was carried out to check the degree to which the signal strength weakened in the presence of an obstacle such as a thick wall and to check for errors in the location information. On a construction site, there are a number of different obstacles such as construction equipment and materials, and such characteristics unique to this type of industrial site must be considered. In previous studies, a limitation to indoor positioning has been described as the numerous errors in location measurements resulting from the thick concrete walls present on the site. In order to verify whether it is possible to resolve this issue by applying the emerging ICT, an experiment was carried out by setting a 20cm-thick concrete wall as an obstacle and setting the radius of the danger zone as 10m. The results showed that the alert signal was properly generated and transmitted within the 10m radius of the danger zone. Afterwards, a steel door was designated as an obstacle, and it was found that the radius within which the alert signals were given properly was reduced to around 8m.

Third, an experiment was carried out to see, in the event of a fall, whether the system could become aware of the context of the fall victim and provide the related information. In the event of a fall, which is the most common type of accident on construction sites, the necessary response measures can be implemented quickly if such event is witnessed and reported by another worker, but this is not the case if there are no other workers around the victim. Thus, in the latter case, the field manager can be informed of the accident by the system examined in this study via the acceleration and gyro sensors of the sensor module applied to the attachable device. After receiving the data on the fall detection, the manager can then locate the victim using the real-time location-tracking technology and respond quickly to the situation.

4. Conclusion

In this study, a safety management system incorporating real-time location-tracking technology with the use of beacons was implemented by using the sensor module built into the wearable device designed for construction workers and applying an algorithm for identifying the context of the workers. To this end, the current safety management situation was examined to analyze the related issues, and theoretical research and experiments were carried out on beacon-based location-tracking technology and context-aware technology.

The safety of construction sites has been managed in a relatively passive manner by documenting daily safety reports and plans and providing safe training to workers. In order to improve the measures, based on the recent advances in information technology, a wide range of systems and technologies such as RFID have been introduced, but there have been technical limitations that prevented any substantial improvements. In order to enhance the safety management of construction workers with the application of IoT-based ICT, there has recently been a need for persons and things to manage their own safety. Thus, in order to prevent accidents on construction sites, a prototype with the application of a real-time location-tracking technology based on the beacon technology and a context-aware technology incorporated with sensor technology for speedy responses was fabricated in this study, and the results of the experiments carried out showed that it would be possible to apply this system in the field.

Although this study centers on an accident prevention system for construction workers and a response system for falls, it will be possible to scale this technology for more comprehensive safety management in the construction field. In addition, taking into consideration of the nature of the labor-intensive construction industry, it will be possible to make construction sites safer and more systematic by integrating the machinery and advanced ICT. The limitation to this study is that the various types of accidents occurring on construction sites were not applied. Thus, it is necessary to systematically analyze the types of accidents that affect the construction industry and to expand the scope of application in future research. By continuing the research on the labor-intensive construction industry and emerging ICT, it will be possible to contribute to the creation of safer and more systematized construction sites by improving safety management of construction workers.

Acknowledgment

This research was supported by the research fund of Hanbat National University in 2018.

References

[1] D. H. KIM, "IoT(Internet of Things)? IoS(Internet of Safety)!", Railway Journal, 2016;19(6): 73~82. Available from: http://www.dbpia.co.kr/Article/NODE07089333

[2] H. W. Cho, J. H. Park, C. S. Lee, "A Survey Recognition and Analysis of Problem on the RFID Technology", Korea Institute of Construction Engineering and Management, 2008;Vol.2008(11), pp. 19-22. Available from: http://prof.incheon.ac.kr:8082/~uicem/pdf/jaikr/kicemst_200811_005.pdf

[3] wikipedia Encyclopedia, Available from: https://ko.wikipedia.org/wiki/%EC%8B%A4%EC%8B%9C%EA%B0%84_%EC%9C%84%EC%B9%98%EC%B6%94%EC%A0%81_%EC%84%9C%EB%B9%84%EC%8A%A4

[4] S. B. Chun, S. Lim, D. W. Lim, M, B. Heo, "Indoor Positioning Technology Trends", Korea Aerospace Research Institute, 2015;13(1) : 127-138. Available from: https://www.kari.re.kr/cop/bbs/BBSMSTR_000000000064/selectBoardArticle.do?nttId=5243

[5] J. M. Yoo, E. S. Park, Y. J. Jun, T. S. Lee, "A Study on the Automation in Construction using and RFID System", Korea Institute of Construction Engineering and Management, 2008;Vol.2008(11), pp. 731-734. Available from: http://www.auric.or.kr/dordocs/cart_rdoc2_.asp?db=RD_R&dn=219725

[6] J. H. Lee, K. H. Park, S. H. Yoon, J. H. Paek, "A Study on the Reduction Plan of Construction Disaster Using RFID/USN Technology", Architectural Institute of K o r e a, 2006: 20(1); 605-608. Available from: http://www.auric.or.kr/dordocs/cart_rdoc2_.asp?db=RD_R&dn=205306

[7] C. H. Choi, "A case study and future directions of Radio FrequenceI Dentification system in A/E/C industry", Korea Institute of Construction Engineering and Management, 2004;Vol.2004(11), pp. 145-149. Available from: http://www.auric.or.kr/User/Rdoc/DocRdoc.aspx?returnVal=RD_R&dn=164128#.W5XWnNFG0VA

[8] J. K. Lee, Y. H. Lee, J. H. Park, M. J. Son, "Experimental Study on Wall Transmission Loss of Electric wave for the RTLS Application of Building Construction Project", Building Construction, 2009;9(1): 95-101, Available from: http://kiss.kstudy.com/thesis/thesis-view.asp?key=3439726

[9] H. T. Ju, K. H. Kim, J. J. Kim, "A Study on The Management of A Building by Applying RFID/USN", Korea Institute of Construction Engineering and Management, 2007;Vol.2007(11), pp. 331-336. Available from: http://www.auric.or.kr/User/Rdoc/DocRdoc.aspx?returnVal=RD_R&dn=214734#.W5XZw9FG0VA

[10] LoRa, Available from : https://www.lora-alliance.org/

[11] R. J. Conejar, H. K. Kim, "Designing U-Healthcare Web Services system", Int. J. Softw. Eng. Appl., 2015;9(3); 209–216.

[12] J. Y. Won, "Proximity sensing based on a dynamic vision sensor for mobile devices". IEEE Ind. Electron. Soc, 2014;62(1): 536–544.

[13] B. H. Kim, J. W. Oh, "Development of healthcare service model using physical information data based on cluster sensing technology", The Journal of Networks, Software Tools and Applications, Cluster Comput(2017), pp. 1-15. DOI : https://doi.org/10.1007/s10586-017-1184-x

[14] Maarit Kangas, Antti Konttila, Per Lindgren, Ilkka Winblad, Timo Jamsa, "Comparison of low-complexity fall detection algorithms for body attached accelerometers", Gait & Posture, 2008;Vol.28(2): 285-291. DOI : https://doi.org/10.1016/j.gaitpost.2008.01.003