# An Integrated GIS and Wi-Fi Based Locating System for Improving Construction Labor Communications

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**Abstract – Locating construction assets such as equipment and workforce during construction are critical for improving safety and productivity. The current indoor locating practices utilize real time locating system by alerting staffs when entering hazardous, high risk, or off-limits areas. This is a risk based study by means of probability analysis based on the distance of the worker from hazard. Not much attention has been given on communication especially on improving two-way communication between workers and supervisors in conjunction with tracking them in a 3D environment for forensic purposes and performance analysis. The aim of this study is to develop a Wi-Fi-based positioning and communicating system for indoor positioning with radio communication systems which is called the Voice Communication and Locating System (VCLS) and integrate it with other applications namely BIM and GIS. The BIM and GIS are used for displaying the positions of mobile devices for tracking the workers in a proposed area. The system development process includes determination of the functionalities of VCLS components and the interrelationships between them presenting a 3D environment. A series of experiments were carried out at a current facility at the University of NSW. The initial results of this on-going study shows that VCLS has the capability to track the approximate locations of workers in 3D environment. The integration of VCLS and GIS is extremely valuable to construction users, because it increases the communication quality and efficiency of their interaction on construction site.**

**Keywords – Voice Communication and Locating System; Construction Site; Real-Time System; BIM; GIS.**

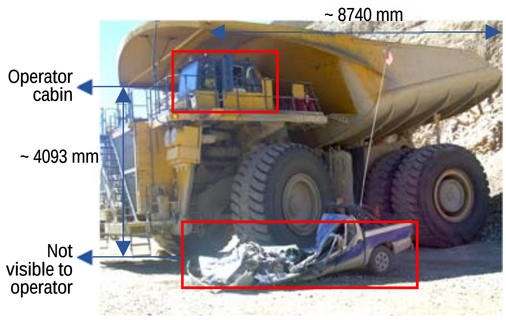
## 1 Introduction

Real-time locating system (RTLS) is a part of contemporary topic as it is one of the fastest growing technology markets. RTLS has been considered as a highly effective tool for tracking and monitoring the location of materials and vehicles in different businesses such as healthcare and transportation. For example, the Veterans Affairs Department of the US Government planned $550 million for utilizing RTLS to improve efficiency, track equipment and monitor employees in hospitals. This technology is advancing and the new generation of Global Navigation Satellite Systems will provide coded signals, which would offer cheaper receivers with millimeter in precision applications in the future. Receiver devices cost will drop while the complexity of the technology will rise. It means that the availability of the technology, wider application and consequently the market penetration will increase.

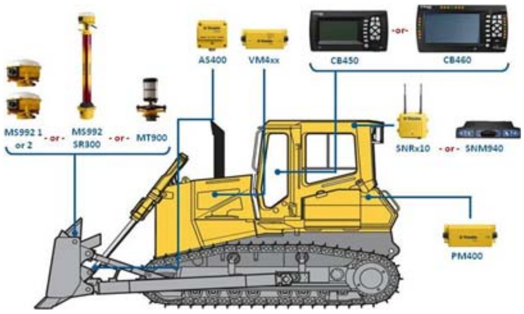
One of the main challenges of construction operation is the communication and the ability of operators to identify obstacles around them. Any deficiency in communication with workers and plant operators on site may cause accident and damage. Figure 1a shows a dump truck crashes on a security patrol car on site. On the other hand, there are many advance technologies such as machine control system which can be used on construction site. For example, Figure 1b shows some of RTLS standard technologies such as global positioning system (GPS) and other sensors, which are applicable for earthmoving vehicles. Some pioneers currently utilise only the standard navigation technologies, which is a one-way communication system for single equipment. A wider range of new RTLS technologies including novel sensors and devices enable two-way communication have practically not been investigated nor widely tested in construction operation management. Application of

RTLS technology in construction industry is still in the early stages due to the characteristics of the construction site.

The locating and tracking systems have gradually become important and can be widely used for monitoring workers and vehicles to enhance productivity and safety if the obstacles be identified and resolved [1]. This study aims to develop and evaluate the applications of RTLS for construction operation purposes by testing the selected RTLS in a laboratory and on the field.




a) Dump truck without RTLS




b) Dual GPS with laser augmentation and Universal Total Station suitable for Dozer

Figure 1: A dump truck without RTLS and a sensor enabled dozer in earthmoving

Exploring the application of complex technologies including new RTLS technologies is an increasingly important area of research from government and construction industry perspective. From government perspectives, national policy makers make efforts to encourage the construction industry main players to increase the adoption of modern technologies in order to enhance safety, productivity and accuracy. For example, Australian Construction Vision 2020 encourages the construction industry to move to partner with other industries to facilitate digital technology diffusion to the industry [2] The U.S. General Service Administration recently started encouraging their projects to use modern technologies as a prominent vehicle for acquiring building digital data [3]. Therefore, there is a rising desire among policy makers and academics to promote rapid digital technology implementation. RTLS is one of the most efficient tools to generate digital data for tracking and positioning in construction.

From the construction industry perspective, there are many evidences show that utilization of RTLS as a digital navigation and time technology potentially improves productivity and safety in construction, and so its new applications should be explored. For example, Grau et al. [4] reported that the average work time spent per component for a boiler on a construction site is 36 min in traditional tracking process, and they improve the amount of time to 4 min by using a RTLS-based tracking system and this potentially saves $120,000 for the task and save $12.5 per tag. Talavera et al. [5] estimated an annual saving of US$412, 057 for a steel production company by utilizing a RTLS technology (i.e. Radio Frequency Identification) for shared inventory allowing forklift operators to place the finished product anywhere on the production site in order to maximize the utilization of the storage area. The potential benefit of RTLS justifies the necessity of future research to determine the customized solutions in construction operations.

## 2 Real-time Location-Based Systems

The current literature mainly focuses on a wide range of the common geospatial technologies such as radio frequency identification (RFID), ultra-wide band (UWB) tags, geographic information systems (GIS), and global positioning systems (GPS). This study investigates among others; sorting information capability, receiving the stored information, communication between the workers and devices, modifying errors and transferring information to wireless local area networks (WLANs). This section reviews the relevant literature, and mainly focuses on the current practices of workers' communications.

In construction, some papers discuss the importance of the local area network and global positioning system (GPS) using Wi-Fi and ultra-wide band technologies [6]. For example, Khoury and Kamat [6] demonstrated the ability of Indoor GPS to estimate users' location with a low uncertainty about two centimeters. However, many other locating sensors have not been tested on construction sites. UWB also has known as an effective real time locating system for construction purposes. For example, Cheng et al. [7] use the UWB tools for a 3D material tracking in construction projects. However, in their discussion, other sensing technology such as laser scanners can easily identify open space areas better than UWB for creating spatial models. They also discussed the need to test other tracking technologies to complement the current limitations of UWB technology in terms of mobility and range. Zhang et al. [8] study tests on GPS data logger attached to the construction hard-hat of a concreter who was pouring cast-in-place concrete columns, show that the data logger has a comparatively low accuracy in an indoor area, and it is suitable for outdoor environment. There is a need to test a wider range of sensor technology for indoor construction application. In addition, GPS based system is more suitable for larger assets tracking and monitoring due to economic factor as the system is more expensive. Therefore, there is a need to replace these expensive technologies with other technologies for construction projects. Table 1 summaries key characteristics of these technologies in construction.

Table 1: Comparing three main technologies for construction purposes

| Technology | Data acquisition | Dependency of the technology | Way |
|---|---|---|---|
| RFID | Accurate and timely information about shipping and receiving [9] | Needs other tools to be accurate [10] | One way |
| UWB | Communicating receivers and tags over a large bandwidth [11] | Independently provide an accurate location | One way |
| GPS | Low accuracy in indoor area [8] | Should be attached to objects | disconnections [12] |

## 3 Methodology

This paper attempts to implement a model to improve workers' communications in construction sites using real-time locating systems. Based on the literature, the overall process for real-time locating is proposed consisting of using tag, collecting data, and process. In the data collection step, an educational building under renovation at the Kensington Campus of the University of New South Wales has been chosen. In order to implement the proposed system for construction operations, the voice communication and locating system (VCLS) is developed in the first place. The research scope is limited to explore the potential of the locating systems for improving the worker communication in the construction projects to enhance safety or productivity. In order to accomplish this objective, the VCLS is developed as a guide to implement the sensors at UNSW campus both in the laboratory (as the pilot study) and the filed. VCLS consists of following steps, which all have to be performed to obtain system integrity generating useful data:

Step 1: Setting the Goals and System – the goals and functionality of the system is determined at the first step.

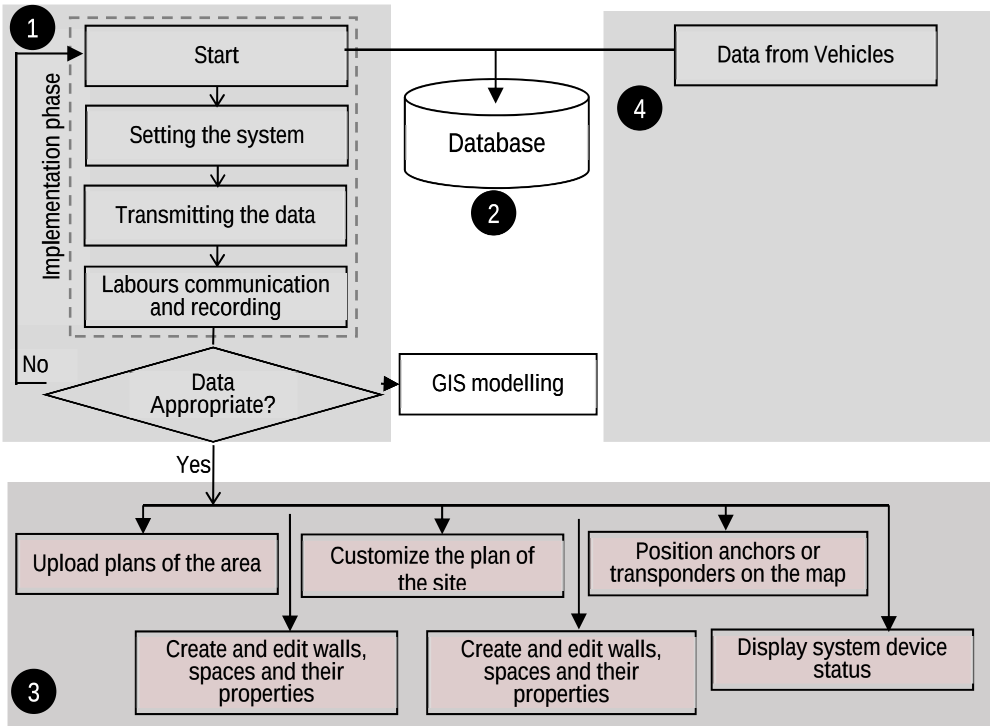



Figure 2: The flowchart of the system including data acquisition and applications

Step 2: System Segmentation – the mission to employ RTLS in construction operation is broken down into segments which will be executed and tested.

Step 3: Determine Performance Factors – the key performance areas of RTLS is defined such as efficiency (e.g. connect to Wi-Fi, standard loading time, work time), reliability (e.g. lost time, duration of defect, route reliability), productivity (e.g. orders picked per time) and visibility (e.g. location of objects, status of the objects, display the current order and progress in order).

Step 4: Development of Prototype Application – the prototype will be designed that can cover different factors such as metric specification, graphical representation, data collection plan, and utilization. The prototype can include: base station (Anchor), tag, sentry, data transmission channel (Data Channel), the positioning . The data acquisition sub-system includes intercom, which is equipped with a built-in tag. The VCLS is configured via web-client application. The web-client application enables the user to browse locations of workers and/ or machineries on the map, device information and additional data provided by the system. Table 2 shows the details of the instruments are used in our experimentations such as access points, sentry cradle, built-in tags and analyzer.

Table 2: A list of VCLS components and instruments

| | Instruments | Specification | Units |
|---|---|---|---|
| 1 | Indoor access point | 5V, 1A, connector 5.5/2.1 (“+” inside) | 6 |
| 3 | Sentry Cradle | 12V, 0.5A connector 3.5/1.35 (“+” inside) | 3 |
| 4 | Intercom RIO | Oval - Micro USB – 5V, 1A, Square - 5V, 1A, connector 5.5/2.1 (“+” inside) | 3 |
| 5 | Analyzer | 12V, 0.5A connector 5.5/2.1 (“+” inside) | 1 |
| 6 | Portable screen | 21” (at office) and 16” (in the field) | 3 |
| 7 | Smart phone | Samsung Galaxy | 1 |

engine server (Location Engine), RIO Intercom. The RIO intercom will be used to determine the location of the object (i.e. vehicle or employee) and allow two-way communication between the person and his supervisor anytime when he is moving. This device also allows the person to connect the telephone network.

Step 5: System Implementation – the system will be used in the lab and/or field and the observations will be reported.

## 4 VCLS Architecture

The voice communication and locating system (VCLS) includes three main phases: data acquisition sub-system and transmission, data storage and processing, real-time visualization and application as shown in

## 5 VCLS Implementation and Results

The developed VCLS was tested four times in the laboratory and two times in the field. Figure 3 shows the field test area in the sample building and the drawing of the selected area on the 3rd and 4th floors. The area includes windows, doors and stairs area and it is complex enough to explore the accuracy of the work in different architectural environment. Figure 3 shows the experimentation area including anchors and other devices.

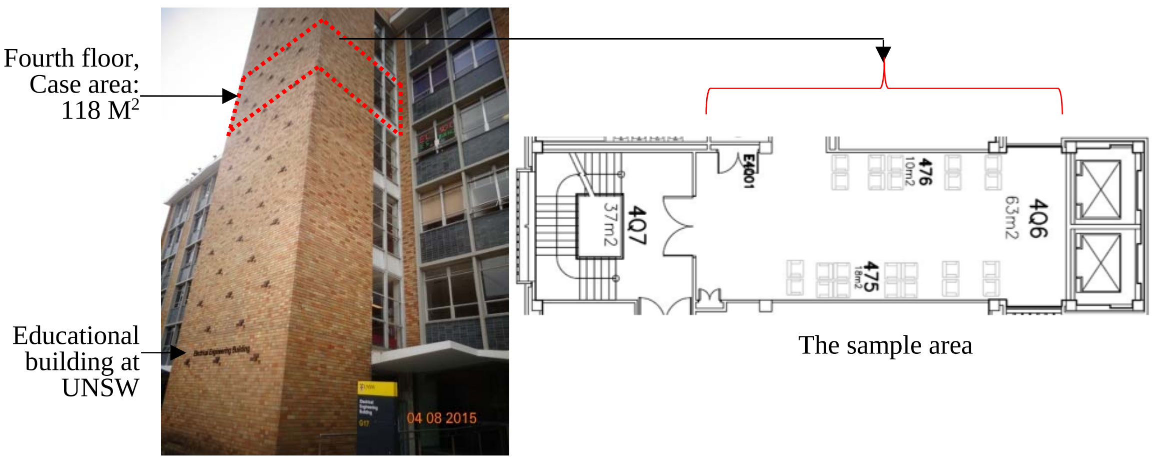



Figure 3: The sample location and layout plan

Figure 4 shows the setup details of the proposed system. Six access points (1 to 6) were installed in

The experiment includes collecting data from tags on level 4.

different places in the selected area in level 4. Sample of Figure 4.

The intercoms with built-in tag allow workers to communicate with other and enable us to identify the current location of the workers as signals are transmitted via the anchors, intercoms and tags. The workers' location is visible to all colleagues and the site manager via the system's monitor.

It takes five minutes to lock in the devices after the connection has been established. All hardware devices will be online once the setup process is completed and VCLS is launched. Each device will automatically lock-in and displayed in the web-application side bars. The intercoms on display can be manually selected by setting filters on the left sidebar, which helps supervisors to monitor specific tags.

**Error! Reference source not found.** shows the web-application's interface includes the following key intercoms with built-in tag are shown in elements: Top toolbar, Sidebar, Map area.

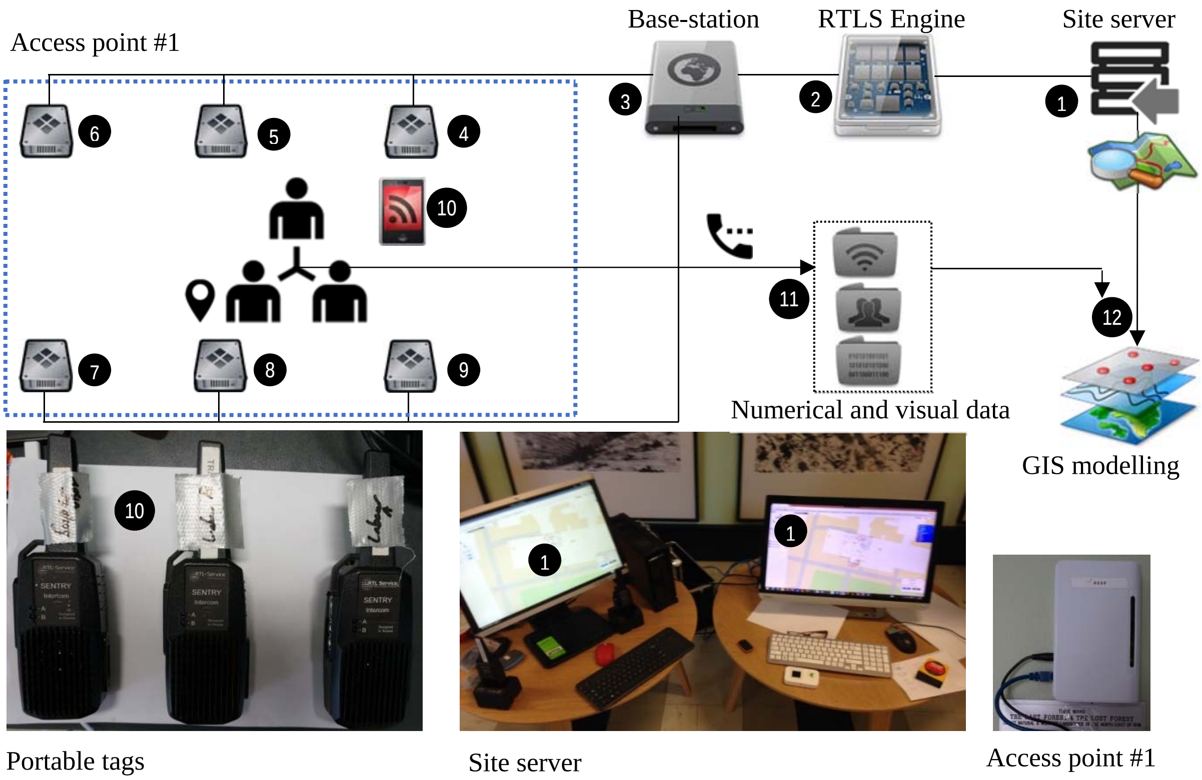
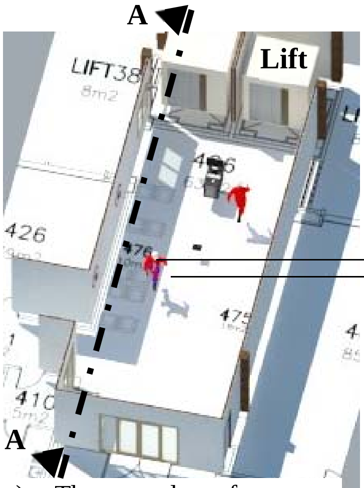


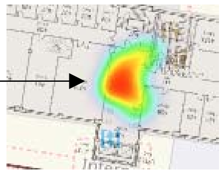

Figure 4: The VCLS architecture including all devices utilized in the field experimentation



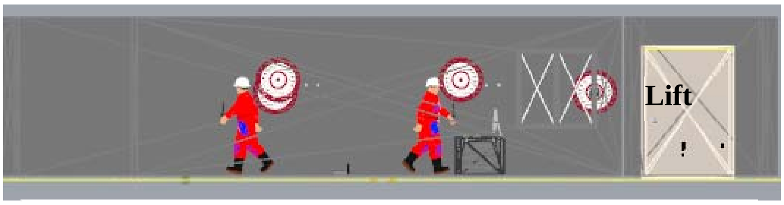

a) The result of system implementation

b) The online application launch with smart phone

c) Web application system interface. All active and inactive tags are shown on the left sidebar, where details can be viewed by expanding the menu.



d) Heat map of the intensive area of workers




e) Section A-A showing access points and the workers

Figure 5: The visual representation of the results in the field

Figure 6 shows the result of tracking three labors in GIS environment. The figure shows 10 spot for each labor with 10 seconds interval. The total time for each labor is 90 seconds. The distance analysis also shows when the labors are working closer to each other in time intervals 3 (after 20 seconds) and 5 (after 40 seconds), and further distance in time intervals 1, 4 (after 30 seconds), 10 (after 90 seconds). The result shows three sets of data for each labor. Data recorded were the communication between labors and the location data in conjunction with the verbal data. This is important because all activities on site can be recorded and used for forensic purposes. The implemented measurement system will assist project managers to obtain detailed knowledge of workers' conditions on construction site periodically. Jiang et al [12] intend to measure the labor consumption in a dam monolith project using GPS and GIS. However, they reported communication failures in various positions in the project due to obstacles interrupting communication between the receivers and satellites.

We did not experience such interruptions because the system doesn't need to communicate with satellites. **Error! Reference source not found.** briefly shows the contribution of the paper in the body of knowledge in construction.

The field experimentation also shows that there are some limitations that should be addressed in next experiment. The data can be stored in the GIS environment but it cannot be dynamically tracked in GIS. The verbal communication also cannot be stored or analyzed in GIS and there is a need to investigate any other environment to store and analyze this type of data.

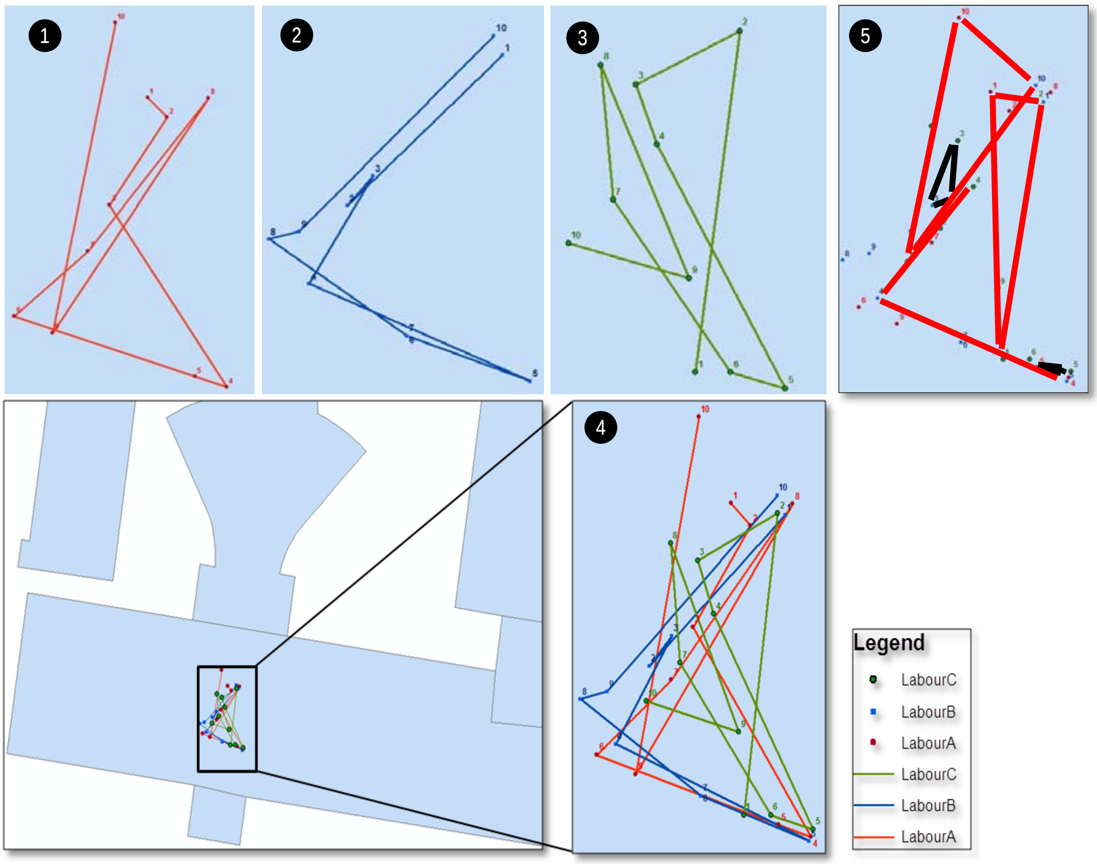



Figure 6: The results of tracking 3 labors (A, B and C) in ArcGIS with 10 seconds time interval, 90 seconds altogether

Table 3: Advantages and limitations of VCLS comparing the current practices

| Our VCLS advantage or limitation | Example of current practices | Limitation or advantage of current practices |
|---|---|---|
| Wi-Fi-based locating system and do not need the satellite connections | GPS is used in a dam in china [12] | Communication fails reported, because of obstacles interrupting communication between satellite and receivers [12] |
| Supervisors and labours can communicate (two-way) while the system shows their location | Locating systems are used for alerting and messaging which is an one-way communication [12] | |
| The system shows who is in the hazardous or off-limits areas. | Chirp Spread Spectrum (CSS) is developed to alert labors [13] | Li et al. [13] reports the system is practically cannot be used in construction sites and needs to be further developed |
| The system is Linux based and can be customized for any projects | The systems are not open source | |
| VCLS require less than $300 to equip each person | UWB and Indoor GPS are used for locating users in sites [6] | Using both UWB and Indoor GPS are expensive and require significant time and effort to provide sufficient coverage in the site, for example individual receivers are $2195 each [6] |

## 6 Conclusion

The purpose of this paper was to implement the proposed framework of the VCLS that can be utilized for two-way communication i.e. between labors and supervisors and in conjunction with tracking them. This study intends to improve the communication quality on construction sites for safety and forensic purposes. A series of laboratory and field experimentations were utilized to test VCLS in different situation. The result shows that VCLS is a useful platform for construction sites, since it provides two-way communication between workers while at the same time, the location of workers can be tracked by the main server. The system has adjustable time interval of voice and track recording varying from 2 seconds to 15 minutes and equipped with heat map analysis showing the most concentrated areas of workers' activities in the designated area. Furthermore, the study also presented the initial 3D models in GIS which needs further work to evaluate the feasibility of a semi-automated process. The finding is important because there is a need to offer solutions in which voice and visual data can be integrated for improving the overall construction performance.

## 7 Acknowledgements

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