S17-1

APPLICATION OF WIFI-BASED INDOOR LOCATION MONITORING SYSTEM FOR LABOR TRACKING IN CONSTRUCTION SITE - A CASE STUDY in Guangzhou MTR

Sunkyu Woo[1], Seongsu Jeong[2], Esmond Mok[3], Linyuan Xia[4], Muwook Pyeon[5], and Joon Heo[6]

[1] Master's Course Student, Department of Civil and Environmental Engineering, Yonsei University, Seoul, Korea
[2] Master's Course Student, Department of Civil and Environmental Engineering, Yonsei University, Seoul, Korea
[3] Professor, Department of Land Surveying and Geo-Infomatics, The Hong Kong Polytechnic University, Hong Kong, P. R. China
[4] Professor, School of Geographical Sciences and Planning,Sun Yat-sen University, Guangzhou, P. R. China
[5] Associate Professor, School of Civil Engineering, Konkuk University, Seoul, Korea
[6] Associate Professor, Department of Civil and Environmental Engineering, Yonsei University, Seoul, Korea
Correspond to jheo@yonsei.ac.kr

ABSTRACT: Safety is a big issue in the construction sites. For safe and secure management, tracking locations of construction resources such as labors, materials, machineries, vehicles and so on is important. The materials, machineries and vehicles could be controlled by computer, whereas the movement of labors does not have fixed pattern. So, the location and movement of labors need to be monitored continuously for safety. In general, Global Positioning System(GPS) is an opt solution to obtain the location information in outside environments. But it cannot be used for indoor locations as it requires a clear Line-Of-Sight(LOS) to satellites Therefore, indoor location monitoring system could be a convenient alternative for environments such as tunnel and indoor building construction sites. This paper presents a case study to investigate feasibility of Wi-Fi based indoor location monitoring system in construction site. The system is developed by using fingerprint map of gathering Received Signal Strength Indication(RSSI) from each Access Point(AP). The signal information is gathered by Radio Frequency Identification (RFID) tags, which are attached on a helmet of labors to track their locations, and is sent to server computer. Experiments were conducted in a shield tunnel construction site at Guangzhou, China. This study consists of three phases as follows: First, we have a tracking test in entrance area of tunnel construction site. This experiment was performed to find the effective geometry of APs installation. The geometry of APs installation was changed for finding effective locations, and the experiment was performed using one and more tags. Second, APs were separated into two groups, and they were connected with LAN cable in tunnel construction site. The purpose of this experiment was to check the validity of group separating strategy. One group was installed around the entrance and the other one was installed inside the tunnel. Finally, we installed the system inner area of tunnel, boring machine area, and checked the performance with varying conditions (the presence of obstacles such as train, worker, and so on). Accuracy of this study was calculated from the data, which was collected at some known points. Experimental results showed that WiFi-based indoor location system has a level of accuracy of a few meters in tunnel construction site. From the results, it is inferred that the location tracking system can track the approximate location of labors in the construction site. It is able to alert the labors when they are closer to dangerous zones like poisonous region or cave-in..

Keywords: Construction Labor Tracking; WiFi; Fingerprint; RSSI; Tunnel; Indoor location system, WLAN

1. INTRODUCTION

Safety is one of the biggest issues in construction sites. Construction industry has a lot of potential dangerous areas. Although the risk is reducing in site as the development of technologies, there are still risks. For a secure management, tracking location of construction resources such as labor, material, machinery, and vehicle is important, to control and manage the situation of site and to recognize where are the resources. The materials, machineries and vehicles could be controlled and moved by computer or driver, whereas the movement of labors does not have fixed pattern. So, the location and movement of labors need to be monitored continuously for safety.

Tunnel construction site generally has a high risk about dangerous zone such as cave-in or falling rocks. However, status of workers in site was indicated on board such as

Figure 1. The status board was showed just only worker's destination.

Figure 1. Workers' Status Board

In general, Global Positioning System (GPS) is an opt and a precise solution to obtain the location information in outside environments. However, GPS cannot be applied to indoor surrounding such as building, underground, high-rise area, and so on, because of the characteristic which it needs a clear line of sight (LOS) to satellites. Therefore, it needs alternatives to obtain indoor position information.

For an indoor positioning, several systems are developed based on various technologies such as infrared (IR), ultrasound, video surveillance, and radio signal. For example, Active Badge system uses ceiling-mounted infrared sensor detectors to detect signals from a mobile station's mobile station [1]. The Cricket system uses ultrasound and RF receivers for location estimation [2]. RF-based system is also studied such as SpotON [3] and LANDMARC [4].

In these several systems, WLAN based system has advantages in economical aspects, signal range, and stability by comparing with other techniques [5]. There are various applications of WLAN based positioning system. Both of RADAR [6] and Placelab [7] are the system which use the mean Radio Signal Strength (RSS) vector to represent fingerprint localization. Swangmuang and Krishnamurthy [8] proposed an effective location fingerprint model for wireless indoor localization. However, case study is rare that the system is applied to real construction site.

This paper presents a case study to investigate feasibility of Wi-Fi based indoor location monitoring system in construction site. The case study was performed in a tunnel construction site that is one of the indoor conditions. The system was constructed based on fingerprint method.

2. BACKGROUND TECHNOLOGIES

2.1 WiFi-based indoor positioning system

Bose and Foh [9] classified local positioning method into Angle of Arrival (AOA), Cell Identity (CI), Time of Arrival (TOA), Time Difference of Arrival (TDOA), and a method using signal strength.

Angle of Arrival (AOA) is a method to calculate receiver position using triangulation by sensing angle of signal from Access Point (AP). It needs a specially-designed antenna and has a property which is easily affected by multipath. Cell Identity (CI) has the use of coverage which has most powerful signal strength. However, this method is able to know only approximate position. Time of Arrival (TOA) make use of the round trip time of signal from AP to receiver. The position of receiver is calculated by using the time and trilateration. Time Difference of Arrival (TDOA) utilizes the time difference between APs which are synchronized. For realizing TOA and TDOA, it requires a high accurate timer. In particular, TDOA is necessary to have a skill which is able to synchronize timer with each AP.

On the other hand, Received Signal Strength (RSS) based positioning method can be classified into fingerprint model and path loss model. Fingerprint model uses the characteristic of signal strength which is changed depending on position of AP. Meanwhile, Path Loss model uses a relation of signal strength and distance between APs. It is possible to guess the distance between AP and receiver using modeling of this characteristic.

2.2 Scalar Adaptive Kalman Filtering Algorithm

In this WiFi-based indoor positioning system, it is necessary to use scalar adaptive Kalman filtering algorithm for reducing signal noise and making up for signal loss. Main equations of Kalman filter can be expressed as follows [10]:

Prediction :

$$\hat{x}_{k+1/k} = \Phi_{k+1,k}\hat{x}_{k/k} \quad (1)$$

$$Q_{x(k+1/k)} = \Phi_{k+1,k} Q_{x(k/k)} \Phi^{T}_{k+1,k} + \Gamma_{k+1,k} Q_{x(k/k)} \Gamma^{T}_{k+1,k} \quad (2)$$

Updating :

$$\hat{x}_{k+1/k+1} = \hat{x}_{k+1/k} + K_{k+1}\left(L_{k+1} - B_{k+1}\hat{x}_{k+1/k}\right) \quad (3)$$

(4)

(5)

k : denotes epoch number

x_k : state vector at epoch k

L_{k+1} : vector of observation at epoch k+1

B_{k+1} : design matrix for observation

V : observation noise

$\hat{x}_{k+1|k}$: predicted state vector

$P_{x(k+1|k)}$: variance matrix for $\hat{x}_{k+1|k}$

K_{k+1} : gain matrix

$\hat{x}_{k+1|k+1}$: estimation of filtering

$P_{x(k+1|k+1)}$: variance matrix

Generally, Kalman filtering algorithm is composed of a prediction phase and a updating phase. These two phases are continuously updated through a feedback process.

2.3 Structure of WiFi-based positioning system

Generally, the WiFi-based positioning system using fingerprint method is configured as two parts: training mode and tracking mode. The structure of system is illustrated in Figure 2. In training mode, the signal strength data from APs was calculated using adaptive Kalman filtering algorithm for removing the effects by multipath effects, dead spots, noise, and interference. To predict the distribution of signal, interpolation was adjusted. Processed data would be stored as database in a server computer. It is called 'Radiomap'. In Figure 3, it shows change of signal distribution as training process. Figure 4 shows the data flow of positioning system from tag to server.

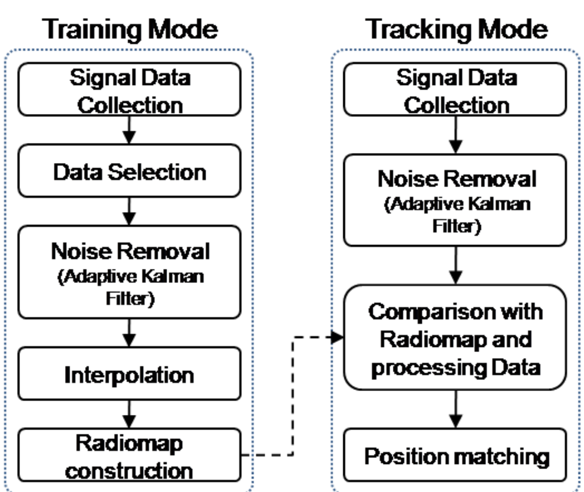

Figure 2. Structure of Developed System

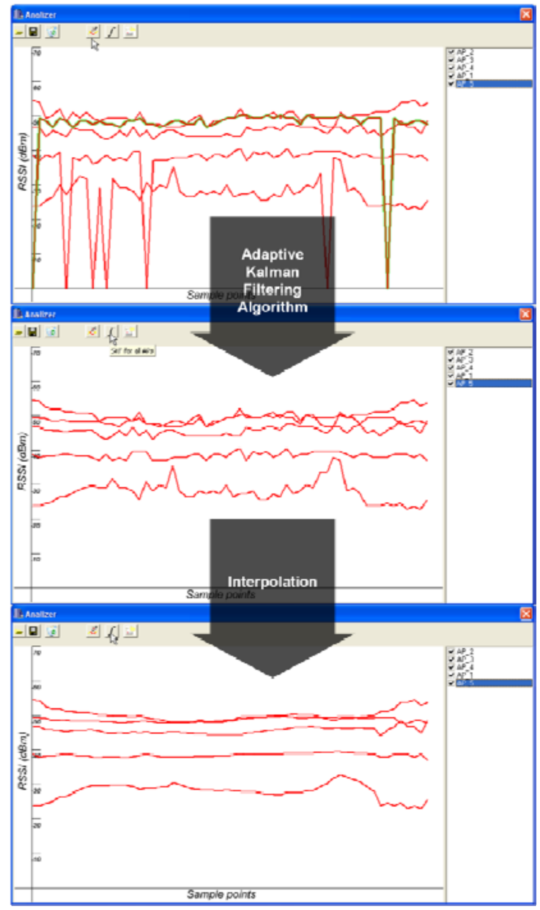

Figure 3. Data Processing in training mode

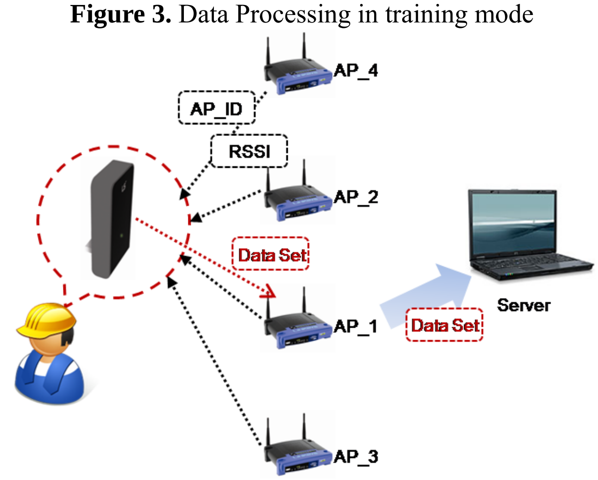

Figure 4. Data Flow of Positioning System

3. EXPERIMENTAL PLAN

3.1 Equipments for experiment

The active RFID tag was used for collecting the signal strength and ID from Access Point (AP). The tag resends the information, radio signal strength and ID of AP, to the server computer through wireless network. The tag was attached on backside of worker's helmet for reducing effect of human body about Radio Signal Strength (RSS) (Figure 5).

WRT54G ver.7 model (Figure 6) of LINKSYS as access point. Its operating temperature ranges from 0°C to 40°C, and the operating humidity ranges from 10% to 85%(non-condensing)[11].

Figure 5. RFID Tag on Safety Helmet

Figure 6. Linksys WRT54G ver.7[11]

To study the WiFi-based positioning system in construction site, HP compaq 8710p laptop computer was used. The computer received signal information from RFID tag though wireless network, and the signal information was calculated and stored in it.

3.2 Methodology

The experiments were conducted in a shield tunnel construction site at Guangzhou, China. The experiment was classified into 3 phases as follows:

First, we have a tracking test in stairway area of tunnel construction site. The geometry of APs installation was considered by around environments. Four APs were installed for test; their height of installation was about 8 m high from each floor. Experiment was performed using one and more tags. APs were installed along the pathway and fixed. The geometry of APs installation is illustrated in Figure 7. The real length of each section of pathway was measured by tape and the figure was drawn with CAD to ensure the same scale of features. The side-view of entrance was used to represent the pathway of entrance except for sector 1 which is perpendicular to other walkways (Figure 8).

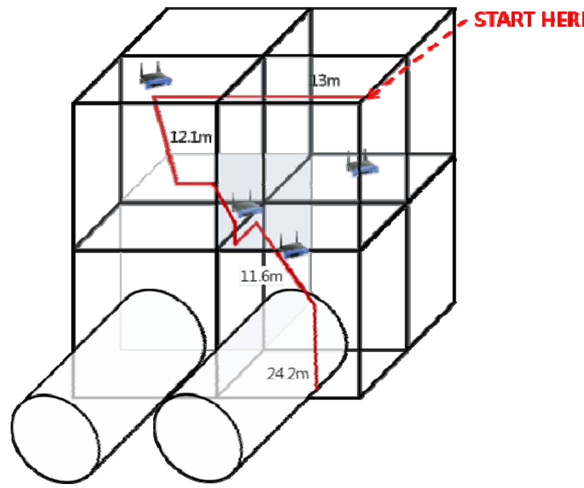

Figure 7. Installation of APs (Stairway area)

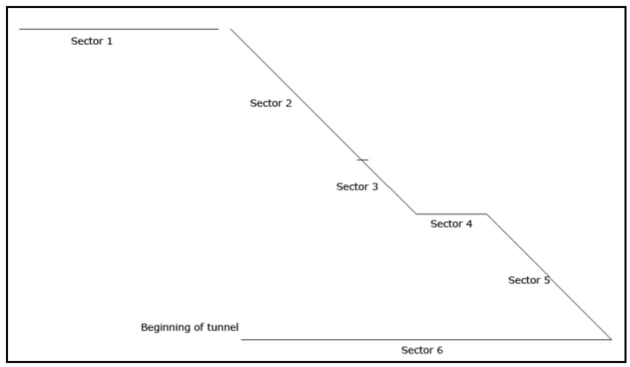

Figure 8. Map drawing in System(Stairway area)

Second, APs were separated into two groups, and they were connected with LAN cable in tunnel construction site. The purpose of this experiment was to check the validity of group separation strategy. One set of APs was installed around the entrance and the other one was installed inside the tunnel. The installation position of APs was showed in Figure 9.

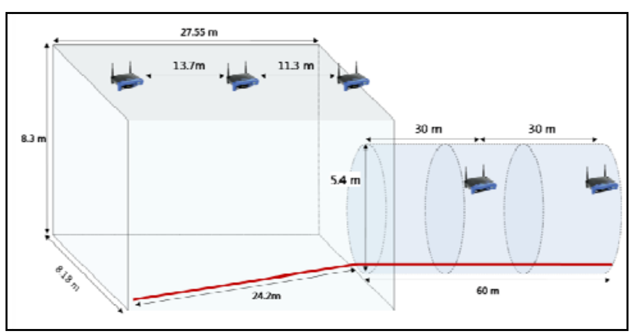

Figure 9. Installation position of APs (Entrance area)

Finally, the system was installed in the boring machine area at the very end of the tunnel, and checked the performance with varying conditions (the presence of obstacles such as train, worker, and so on). Diameter of tunnel was 6 meter. In the Figure 11, Red area represents the zone of the boring machine which is not accessible. Blue area is a passage which is used by workers. The width of passage was about 50 cm. The total length of the boring machine area was about 80 m. The APs were installed at 2 m height. Middle part of vertical direction was a pathway which was used for way of the train which moved soil and stone after boring.

Paths were decided considering section. Signal data was collected using RFID tag when there is no train on railway. In pre-survey, train affected the signal delivery. Because of absence of train, the signals of outer APs of boring machine area sufficiently reached to the inner area. This showed that we have to consider the effect of obstacle such as train in narrow area when we collect the signal strength. Figure 11 showed positions of APs and the pathway which was used for experiment.

Figure. 10. Pathway of Target Area (Boring machine area)

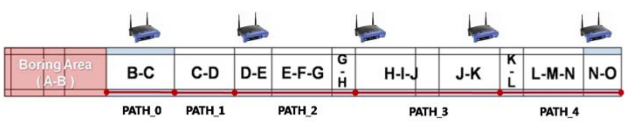

Figure. 11. Drawing Map of Boring Machine area

Figure. 12. Position of Installed APs (Boring Machine area)

For checking the accuracy of this system, the calculated position by program was compared with real position of some static points which locations were already known in real time. Target area was consisted of several sections. Static points were decided to be located in boundaries of sections for accuracy test.

4. EXPERIMENTAL RESULTS

In the first and the second experiments, we checked stability of the system depending on direction of AP installation. The first test was related to vertical direction, and second one to horizontal direction.

In stairway area, the tag was fixed on one place and stood still. Figure 13 shows the changing of vector's norm with respect to time. Red dotted line means the point's location calculated that result was not stabilized, while blue solid line stands for stabilized results. The standard deviation of this measurement was 10.59m.

Two Wireless tags were used for tracking experiment to observe performance of the program. They were fixed on the safety helmet and placed on the position. The positions of tags were tracked by using same RSSI data when tracking only one WiFi tag in the previous test. The refresh rate of tags' location was about 1Hz, which was almost the same as when tracking only one tag. Tracking result was recorded in a log file and analyzed. In figure 14, calculated standard deviation was 6.89m for one tag, and 4.53m for another.

The second experiment was performed from end of stairway to inside of tunnel. The dimension was measured and map was drawn with appropriate scale. Norm of location vector was analyzed by calculating its standard deviation. The result is 0.63m at the beginning of path, 1.6m at the 1/3 point of path, 4.38m at 2/3 point, and 1.30m at the end of path. As in the first experiment, it showed lots of outliers, which means significant miscalculation of tag's location. That is because of characteristic of the tag which has good sensitivity in horizontal direction.

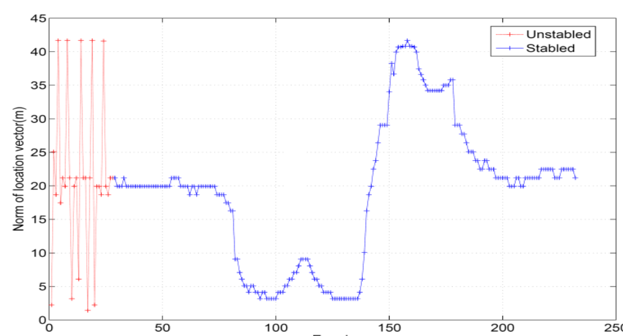

Figure. 13. Change of Location vector's norm (static point)

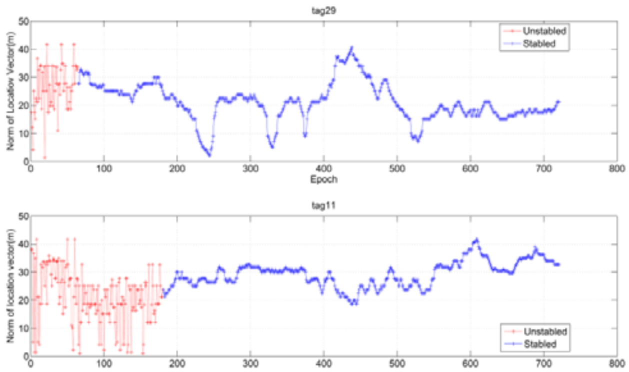

Figure. 14. Change of Two Tags' Calculated Result (static point)

Final experiment was accomplished in boring machine area. As the result of test, the system was shown a gap about 11 meters as maximum in the specific points. But, the position difference of target changed within 5 meters soon. It took over 15 seconds to be under 5 meter difference. The patterns of convergence were drawn in figure 15.

As a final product, an integrated labor position monitoring system was developed. The stairway area and the boring machine area are presented in Figure 16 and Figure 17. Respectively, where the helmet signs represent the location labors. It can be better substitute of the workers' status board in figure 1. It can be installed and controlled at a construction manager's office or other sites where the monitoring of labors are crucial for the operation.

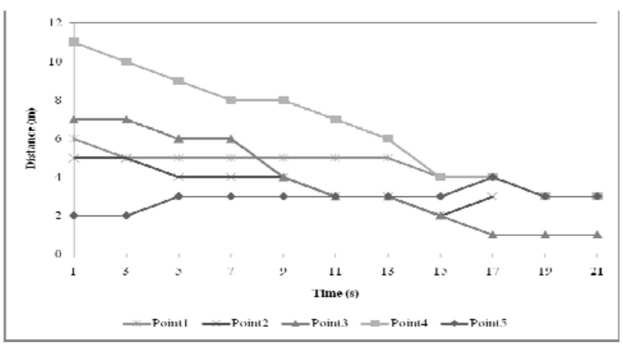

Figure. 15. Distance Error (Boring Machine area)

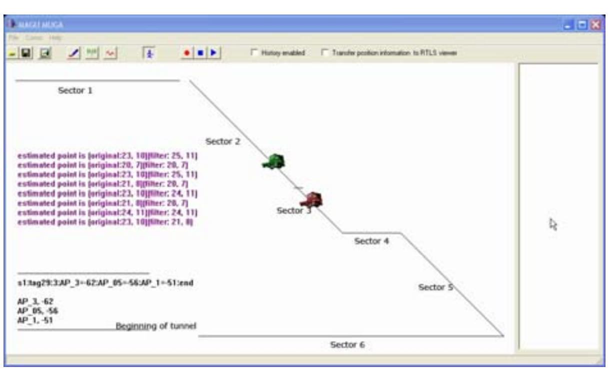

Figure 16. Developed WiFi-based Positioning System (stairway area)

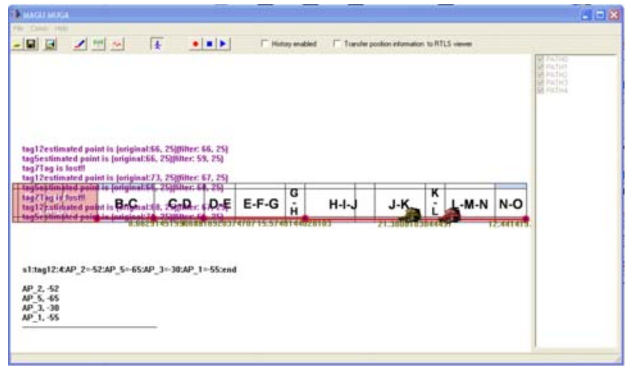

Figure 17. Developed WiFi-based Positioning System (Boring Machine area)

5. CONCLUSION

In this study, we investigated feasibility of the WiFi-based indoor positioning system in construction site. Experiment was accomplished at tunnel construction site in Guangzhou, China. The experiment was organized of three phases as stairway area, entrance area, and boring machine area. The system was tested an accuracy of system using known static point.

Experimental results showed that construction environment affected the signal distribution of WLAN signal. In the first test, standard deviation of signal vector norm was 10m. However, this tendency of signal distribution was different in second test. In the second and the final experiment, system presented standard deviation as a few meters. This is because of characteristic of RFID tag to be stable in horizontal direction. In the boring machine area, the accuracy ranges in a meters.

From the results, it is inferred that the location tracking system can track the approximate location of labors in the construction site. It is able to alert the labors when they are closer to dangerous zones like poisonous region or cave-in. This is showed that the possibility of interchange about traditional management system in tunnel construction site as Figure 1. In addition, this system could be used for not only tracking labors but also finding locations of other construction resources such as vehicles and materials.

For the future study, it would require additional tests for the comparison of several filtering and interpolation algorithms for reducing the processing time as well as for enhancing positioning accuracy of the system. Moreover, some improvements would be required for the integrated labor position monitoring system, which is currently in a rudimentary form.

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