A Visualization System for Improving Managerial Capacity of Construction Site

Y. Han[a,1], Y. Yashiro[a,2] and F.Hatori[a,3]

[a] Industry and Water Business Administration Division, Hitachi, Ltd., Japan
E-mail: ye.han.du@hitachi.com, yuichi.yashiro.kp@hitachi.com, fumio.hatori.zq@hitachi.com

Abstract

In this paper, we propose a solution to improve the construction management capacity. Our solution contains three parts: a Location Identification System, a Work Progress Management System, and a Statistical Analysis & Visualization System. The Location Identification System locates the equipment and the worker inside the construction site, by using Bluetooth Low Energy (BLE) Beacon and Android Smart Phone Device. The location information is sent to the server that away from the site. The Progress Management System (PMS) collects the work progress information and transits the information to the server through a wireless network. The Statistical Analysis & Visualization System, which runs on the server, computes the distribution of each worker and saves the result as a heat map density. It also computes the progress ratio and the deviation ratio, according to the original work plan. At last, the system displays the progress ratio and the worker distribution together for each area in the construction site.

Keywords –

Construction Management, Statistical Analysis, Construction Visualization, Location Identification.

1 Introduction

Due to the reduction in the young worker and the coming retirement boom of the skilled worker, EPC project in Japan is facing many difficulties. On the other hand, the large-scale overseas EPC project is still high risk to many companies because of the lack of experience in managing workers from different culture, the undetermined construction capacity of local sub-contractors, the changing global economic environment and the uncertainty & unclearness in contract terms, etc. Therefore, improving the work efficiency and reducing the risk are important tasks for every EPC project.

The construction phase is a very important stage of EPC project. Wang & Hung (2016) [1] analyzed a risk model of EPC project by using the Structural Equation Modeling based method. The result shows that the risk from construction phase is one of the most important risk factors that can cause the project delay.

The rationalization and the standardization of work process are the keys to improve the work efficiency and the managerial capacity of construction site. Comparing to the manufacturing industry, the construction industry has many different features: the non-mass production, the nature dependent, the labor intensive and the changeable layout, etc. These characters result in that many methods and tools developed for the factory are not useful in construction site, e.g., the camera based monitoring system is hard to be used in the construction site because that the re-installation is needed when the layout changes. In the construction site, a lot of work is still paper based and the management is still dependent on the individual skills. Thus, as what has happened in the manufacturing industry, developing some tools and methods to rationalize & standardize the work process is the key to improve efficiency and managerial capacity.

In this research, we focus on the location information, which is one of the most important factors related to the information delivery efficiency [2,3] and the construction management efficiency. We developed a worker movement visualization system integrated with the progress information to provide the worker information (which is invisible before) to the site manager, such that the manager can use the information to rationalize & standardize the work process.

2 Research Method

2.1 Measurement of Workers Movement

In recent years, the development of Internet of Things (IoT) technology allows us to overcome the bad influence of the complex working environment in construction site, which has stopped us to acquire the information of worker.

By using the IoT device, our system measures the worker's movement and collects the statistical results of movement information automatically. The measurement process of our system is automatic such that the system is capable for the large-scale application (over 100 workers). We also developed an animation function for the managers such that they can acquire the dynamic movement information.

2.1.1 Approaches for Positioning

The workers go to the site when the work started and leave the site when their work is finished. The amount of the workers, the position of each worker and the layout of the site are always changing. Thus, we need to develop a proper measurement method which is suitable for the above situation.

The radio wave based approaches for positioning can be divided into three classes: Ultra Wide Band (UWB), Wireless Local Area Network (LAN) and Bluetooth Low Energy (BLE) beacon [4-7]. The principle of the radio wave based method is that using a base station to receive (or broadcast) the radio signal sent (or received) by a moveable device. The position is computed by using the signal strength, the time lag and the antenna angle.

Table 1 Radio Wave Based Positioning Approaches

	UWB	Wireless LAN	BLE Beacon
Power	AC Power	AC Power	Battery
Merit	High Accuracy	Diversion of Wi-Fi Spot	Cheap and Easy Installation
Demerit	Need License and Wiring	Need Wiring	Comparatively Low accuracy
Evaluate	Normal	Normal	Very Good

UWB method and Wireless LAN method need wiring, which may disturb the work and need re-wiring if the site has changed.

The BLE beacon is a radio wave transmitter which can broadcast its own ID through the Bluetooth signal. Comparing to the other methods, BLE beacon based method has the following features which are suitable for construction site:

(1) It is Easy to install to the construction site. The transmitter of BLE signal, BLE beacon is small, light and wireless. It can be put into a small case and installed to the site with a hook. This feature allows us can change the installation location fast if the site layout changed.

(2) It has a long battery life. By using the advanced BLE technology, the maximum battery life can be several years (button cell battery).

(3) The smart phone device can be used as the BLE radio wave receiver. The cost for purchasing the smart phone device is acceptable to a large-scale application. Furthermore, since Bluetooth is a worldwide standard wireless radio signal, the smart phone device can be used all over the world.

According to the above reasons, this small size transmitter is a powerful positioning tool for us to measure the worker movement.

2.1.2 BLE Beacon Based Positioning Method

The Figure 1 BLE Beacon Based Positioning Method shows the three parts of this method.

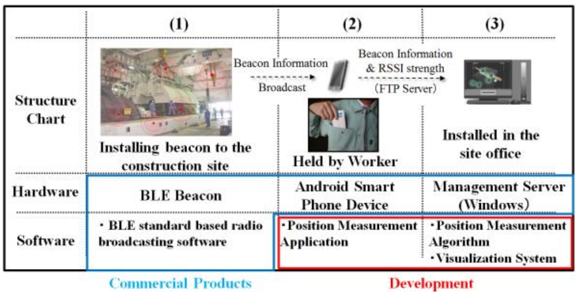

Figure 1 BLE Beacon Based Positioning Method

1. Beacon: each beacon is numbered by a unique ID number and a MAC address. The maximum reaching distance for beacon signal is about several hundred meters at the full power output intensity, which means a less battery life. Thus, by adjusting the output intensity, the reasonable distance between each two beacons is about 10 ~ 20m. The installation location of each beacon is recorded in the server by a 3-dimension coordinate.
2. Device: the smart phone held by the worker keeps receiving the BLE radio wave and recording the signal strength in the format showed in Table 2.

Table 2 Sample of Record File

Time Stamp	Beacon ID	Beacon MAC address	RSSI strength
2017/1/1 8:00:00	Beacon 1	64:FA:18:A7:3D:14:77	-49.0

3. Server: the server receives the record file from the device. The movement of the device is computed by using the beacon installation location record and the signal strength record file.

Figure 2 is the detail of this process.

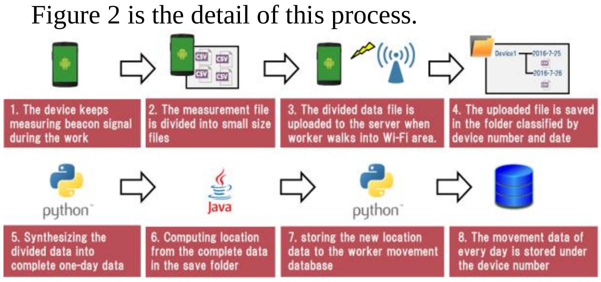

Figure 2 Positioning Process

1. The worker takes the smart phone device and puts

it into the pocket before start working. The smart phone keeps receiving the Bluetooth signal from the beacon.
2. The record file is divided into small parts and stored in the smart phone waiting to be uploaded to the server.
3. When the worker steps into the Wi-Fi area, the smart phone device uploads the divided record file to the server.
4. The uploaded divided file is stored in the server and organized by the device name and the date.
5. The post processing program will automatically starts-up at the designed time (Windows task), merges the divided file into a complete one-day record file.
6. The positioning algorithm is called to compute the movement from the complete one-day record file.
7. The results are send to the designated folder waiting to be stored into the worker movement data base
8. The worker movement database is built in MySQL.

2.1.3 Positioning Algorithm

In the free space, the radio strength attenuates as the distance extended. The relationship between the radio strength and the distance is an exponential function. Thus, we can use this relation to compute the distance between the transmitter and the receiver. But since there are a lot of metals in the construction field, we can't compute the location directly because of the following reason.

Multipath propagation is a phenomenon that results in that radio signals reaching the receiving antenna by two or more paths. In construction site, the main reason of the multipath is the reflection caused by the metals. Due to the influence of multipath, the signal strength we received from the beacon has no exponential relation with the distance, thus we can't use it to compute the position directly.

We developed an algorithm to reduce the influence of the multipath propagation and compute the position of the workers. The input of the algorithm is the complete one-day record file mentioned in section 2.1.2; and the output is a time-related coordinates. The coordinate in the output is the coordinate of beacon installation location, thus the output reflects the nearest beacon where the worker has stayed.

The algorithm consists of three filters, the low-pass filter, the Received Signal Strength Indication (RSSI) strength threshold filter and the distance filter. Figure 3 is the processing flow.

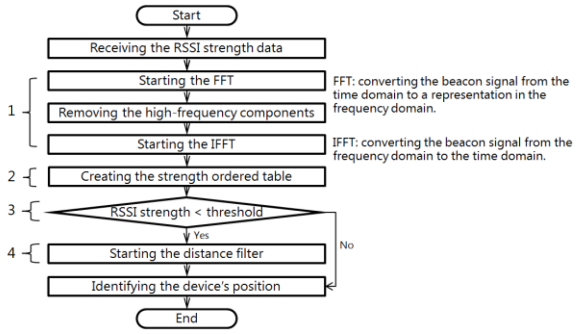

Figure 3 Positioning Algorithm Flow

1. First, the low-pass filter is used to remove the sudden noise and smooth the time-series data.
2. Based on the output of the above low-pass filter, the algorithm creates a strength ordered table for the next process. Table 3 is an example of the strength ordered table.

Table 3 Strength Ordered Table

Time Stamp	1^{st}	RSSI Strength	2^{nd}	RSSI Strength
9:00:00	Beacon 1	-40	Beacon 2	-50
9:00:01	Beacon 2	-40	Beacon 1	-50

3. The RSSI strength threshold filter is designed to remove the constantly noise. This filter computes the signal strength difference between each two beacons and if the difference is greater than the threshold, it will skip the next distance filter. The effect of this filter will be interpreted at the end of this section.
4. The output of the distance filter is the position information. The worker's moving distance is computed at each measuring time, and the position at next time is computed based on an available moving distance of the worker, i.e., if the position result from the RSSI strength threshold filter is impossible for a worker to move in single measuring period, the distance filter will select another proper position from the strength ordered table. Figure 4 is an example of the distance filter.

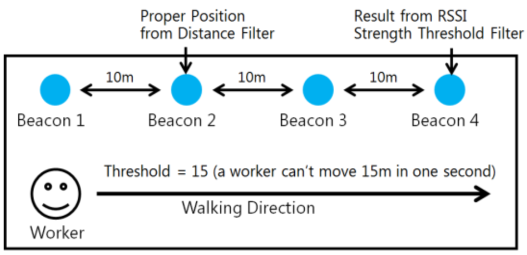

Figure 4 Distance Filter

The effect of the RSSI threshold filter is to remove the influence of beacon installation location. For the example in Figure 5, there is a beacon installed in the corridor and another beacon installed in a room. The worker walks along the corridor and then enters the room. Since the wall will stop the radio propagation, the beacon signal from the room is weak when the worker walking in the corridor. But when the worker opens the door and enters the room, the signal strength will become stronger in an instant. This sudden change may disturb the distance filter: since the distance between beacon 1 and beacon 2 is longer than a man can walk in 1s, the algorithm will give the result that the worker is still in the corridor. If the difference of the signal strength between the beacon 2 and the beacon 1 is greater than the threshold, the distance filter wouldn't be executed and the output is the coordinate of beacon 2.

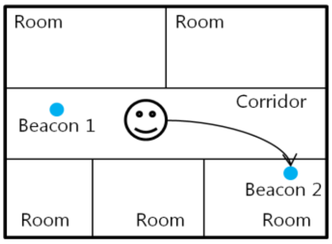

Figure 5 Threshold Filter

2.2 Development of Visualization System

The visualization system reads the movement data from the database and visualizes the data by the heat map, the pie chart and the time series chart. Each of the above visualization method can provide the statistical movement information to the site manager

2.2.1 Worker and Area Information

The system needs to read the worker information and the area information first.

The worker information includes the company name, the occupation, the class name, the worker's name and the corresponding smart phone device ID. All of the above information is stored in an xml file. The system reads the information and constructs the worker check box when starts-up.

The area information includes the area floor, the related drawing and the attributes (like the rest area, the meeting room, the office, etc.). The system reads the area information and creates the area list in the tree structure.

2.2.2 System GUI

In order to provide the movement information to the site manager in an easily visible form, we designed our system to display the statistical results of the worker movement information in three ways: the heat map in the top left, the time series chart at the bottom left and the pie chart in the right. Figure 6 is the image of our system GUI.

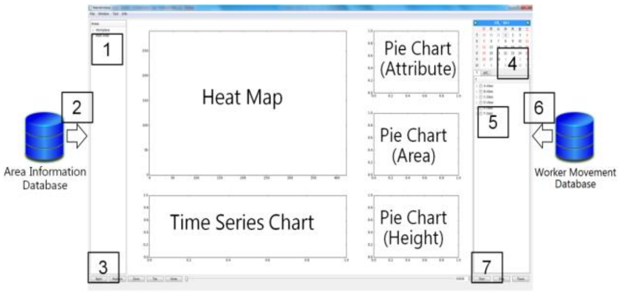

Figure 6 GUI Guidance

The heat map reflects the stay ratio of the worker, i.e., the red area of the map means the worker has stayed at the area for a relative long time. By analyzing the heat map, the site manager can acquire the information about the residence time distribution and find out the useless waiting time.

The horizontal axis of the time series chart is the time and the vertical axis is the beacon number. Since each beacon number is related to an installation location, the time series chart reflects the movement of the worker. The site manager can find out the change of the worker position through the time series chart.

The pie chart is the statistical result of the total stay time. The topmost pie chart is the stay time taken by the area attribute; the middle one is the stay time taken by the beacon installation area; the last one is the statistical result of the heights. The site manager can feedback the work tendency information gathered from the pie chart to the worker arrangement plan.

The usage guidance of the GUI is also showed in Figure 6.

1. Selecting an area from the area list.
2. The system access to the area information database and get the corresponding drawing of the selected area automatically.
3. The corresponding drawing is zoomed to fit the size of the system GUI, and then it is applied to the map area.
4. The analyzer need to select a date from the calendar
5. Checking the check box of the worker. Both a work class and a single worker can be checked. When checking the work class, the visualization will base on the group movement, i.e. the area where the class member gathered is considered as the high stay ratio area. By selecting the work class, the site manager can find out the interference between different occupations and use this information to level the works in different areas.
6. The system access to the worker movement

database and get the worker/class movement data of the selected date.

7. When the analyzer presses the analyze button, the system starts computing the statistical movement information. The total stay ratio of each area and attributes are visualized in the pie chart. The movement is visualized in time series chart. The stay density is computed by using the kernel density estimation method and visualized by heat map.

The system also has animation function. In animation mode, the heat map changes with the play time such that the analyzer can get the information about how the worker has moved. The animation shows the movement amount and the movement path to the site manager, such that the site manager can find out the influence of the site layout and adjust the layout to improve the movement efficiency.

2.3 Development of Progress Information Integrated System

2.3.1 Progress Information

The system reads the progress information uploaded by the Earned value management system which is developed by Hitachi, Ltd. The progress information includes the progress ratio of the entire task and each work step. The total progress ratio is stored into the progress information database associated with the date uploaded.

The progress information is processed in three methods, the total progress, the one-day progress and the deviation between the actual value and the planned value. The total progress data is read directly from the database, the one-day progress is computed by subtracting the total progress of yesterday from the total progress of today. The deviation information is computed by using the work plan data and the progress data.

The visualization of the progress information is also based on the heat map method. In the total progress information, the red area is the area that progressed most. The red area in one-day progress heat map means the most progressed area of single day. The deviation heat map marks the deviant area by the red color.

2.3.2 Integrated Visualization

In the integrated visualization system, the progress information is related with the movement information. The operation process is as same as in the section 2.2.2.

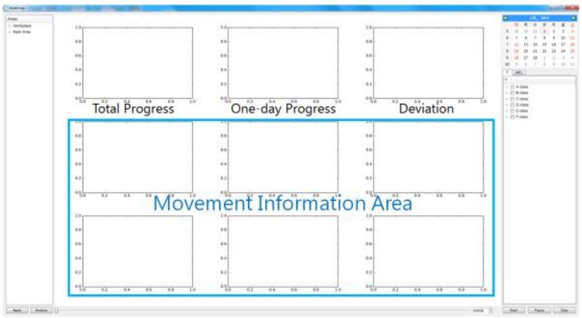

Figure 7 Image of Integrated Visualization

Figure 7 is the image of the integrated visualization system. The top left heat map reflects the total progress, the top medium heat map reflects the one-day progress and the top right heat map reflects the deviation. The movement area consists of 6 heat maps visualizes the integrated movement information of different worker and work classes.

By combining the movement information and the work progress information together, the analysis of the influence of the movement on the progress deviation becomes possible. The site manager can refer to the movement information, which is an important influence factor of the progress deviation.

3 Results

3.1 Improved Positioning Accuracy

We did an experiment to test the effectiveness of our positioning algorithm before the field experiment. The test result shows that our algorithm is efficient to improve the positioning accuracy and the improved accuracy is capable for the site application.

3.1.1 Test Environment

Figure 8 is the drawing of a power plant in Japan where we did our test. There are 3 gas turbines installed in the floor whose size is 150m × 80m. Since this building is surrounded by metal walls, it’s a proper experiment field for our algorithm.

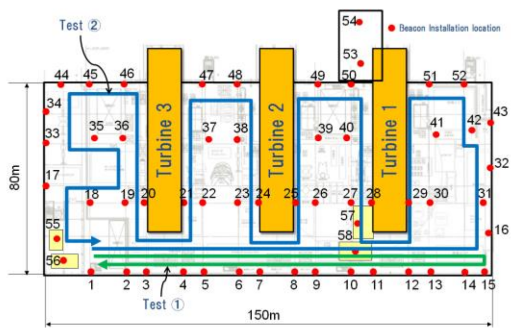

Figure 8 Environment of Efficiency Test

The smart phone device we used is Nexus 5 made by LG Electronics, Inc., and the beacon we used is HRM5011 made by Hosiden Corporation. The output settings of beacon are as follows: output power intensity: +4dBm, output interval: 100ms

The researcher puts the smart phone device into the pocket of working clothes and walks along the following routes at a constant speed:

Test 1: Going and then returning along the path near to the wall.

Test 2: Walking around the turbine floor.

3.1.2 Test Environment

The accuracy is verified based on a video taken during the test. The position showed by the video is considered as the correct position. We compared the result of the raw data and the result of our positioning algorithm to the correct position. The accuracy is computed based on the concordance ratio of the position. Table 4 Test Results is the test result.

Both of the test 1 and the test 2 shows the result that our positioning algorithm can improve the positioning accuracy about 20%. Because of the wide range of the movement in the test 2, the smart phone device affected by more noise than it in the test 1. This is a possible cause for the difference between the test 1 and the test 2.

Table 4 Test Results

Item	Test 1	Test 2
Accuracy of the Raw Data	79.53%	56.97%
Accuracy of the Algorithm	98.86%	76.19%

3.2 Location Measurement Results

3.2.1 Experiment Condition

We did a field experiment to test our system. The experiment field is a construction site, the manager of the site wants the detail of the construction site in order to improve the wok efficiency, i.e., the work efficiency of each class has an obvious difference such that the manager of the construction site wants to find out the difference of each class and optimum the worker distribution. The detail of this experiment is as follows:

1. Research Objective and Period: We measured the movement of 10 field supervisors for 11 days.
2. BLE Beacon: The red circles in Figure 9 are the installation locations of the beacons. We have installed 81 beacons in total. We used the magnetic hook and the dust-proof case to install the beacon to the wall and the pillar. The beacons are installed in a straight line in the path area and tightly in the right workplace area. The bacon we used is “BLEAD” which is made by Houwa System Design Ltd. The output power of the beacon is +4dm and the broadcast interval is 100ms.
3. Smart Phone Device: The smart phone device we used is “Nexus 5” with android version 4.4.0, which is made by LG Electronics Ltd. The scan interval is 1s, i.e. the smart phone device keeps receiving the beacon signal in a second and output the average of the RSSI strength after one second.
4. Operation: We built the FTP server in the site office and installed a Wi-Fi access point near the server. The smart phone device will connect to Wi-Fi automatically when near the access point. There is also a charge station near to the server.

The field supervisor takes the smart phone from the charge station and starts the measurement application every morning. Then they put the device into their pocket while working. The supervisors need to stop the measurement application when they finish their work and go back to the office. We take the device from the supervisor to put them to the charge station. The device will upload the measurement data to the FTP server during charging.

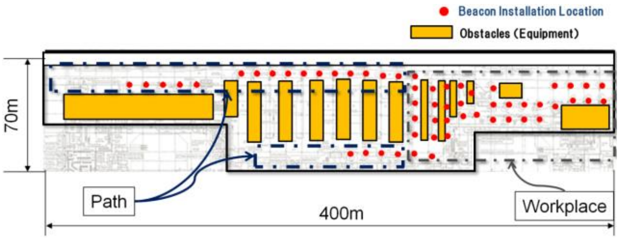

Figure 9 Beacon Installation Locations

3.2.2 Visualization Results of Movement Data

In this experiment, we measured the movement of 10 supervisors. By observing the visualization results of their movement data, we confirmed their work patterns are different. Figure 10, Figure 11 and Figure 12 are some samples of the experiment result.

The heat map has two parts, the top one is the office area includes the main office, the meeting room, the morning meeting area and the rest area; and the bottom one is the drawing of the site.

In the sample of Figure 10, we can notice that the most time of this supervisor is spent in the office work. The time series chart tells us the supervisor didn't walk too much and he is out of the work areas during 9 a.m. ~ 11 a.m..

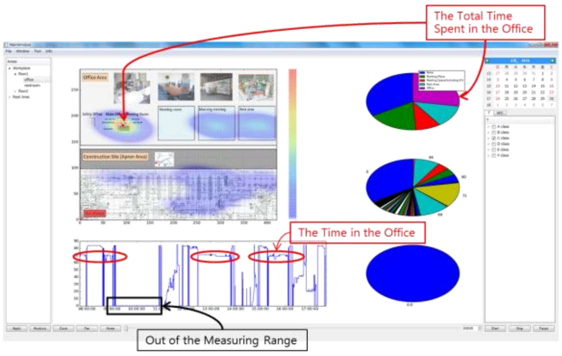

Figure 10 Sample of Field Experiment Result (1)

Figure 11 tells us another movement pattern of the supervisor. In this sample, the heat map shows the supervisor has spent much time in the main office, the morning meeting area and the rest area. This observation result is also supported by the pie charts, i.e., the topmost pie chart shows that the time spent in each area is almost equal. The time series chart indicates the worker has a lot of movement in this day.

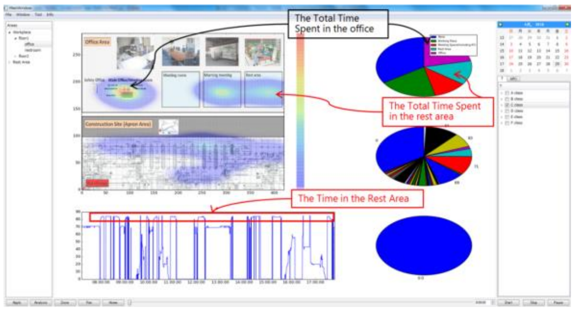

Figure 11 Sample of Field Experiment Result (2)

Figure 12 is different to the above two samples. This sample indicates the worker has concentrated on the site work, both the heat map and the pie chart shows that the worker has spent most of his time at the site. The time series chart also indicates the worker has moved a lot among three areas (Area 1, Area 2 and Area 3)

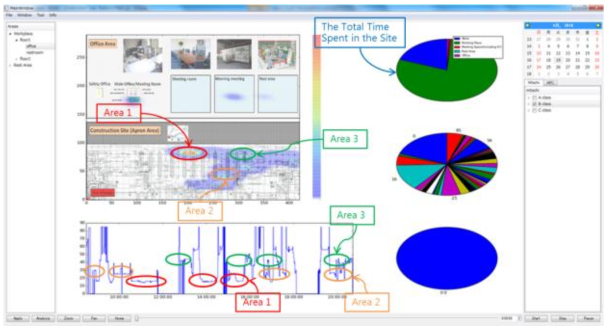

Figure 12 Sample of Field Experiment Result (3)

By observing the above information, the site manager can notice the waste time in waiting, the useless increase of work influenced by site layout and the increasing idle work, etc. After the discussion with the site manager, we have concluded that the visualization of movement is helpful to notice the detail of the site situation.

3.3 Visualization Results of Integrated System

We confirmed our method can visualize different work patterns between workers. In our assumption, the work pattern makes a difference on work efficiency and affects the work progress at last.

Now we can get the movement information from the movement data and the progress information from the progress data separately, but it will be more helpful if we combine them together. Since we can't get the progress information from the customer, we integrate the virtual progress information with the real worker movement data to demonstrate our idea and show the potential of our system.

The example in Figure 13 indicates us the work at area 1 has delayed. At the same time the heat maps in the movement area tell us that most of the workers have spent their time at the office work and no one has worked at the area 1. The site manager can acquire the above the information easily by using our system. Thus the manager can investigate the reason of the increase of desk work and find a solution to solve the problem.

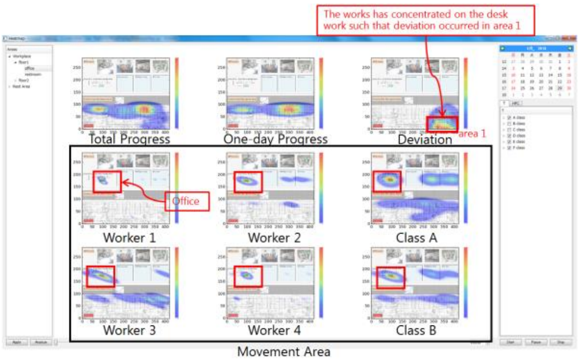

Figure 13 Integrated System

4 Summary

4.1 Conclusion

In this research, we developed a construction site information gathering & visualization system to help improving the information acquisition capacity of the site manager and improve the managerial capacity. The effectiveness of the positioning and the movement visualization is tested on a field experiment. We conclude our system features as follows:

1. The BLE Beacon and the smart phone device based positioning system: The BLE beacon is easy to install & remove because of its light, small and wireless features. Thus, comparing to other methods, our positioning method is suitable for the construction site.
2. An efficiency position computation algorithm: Our algorithm can reduce the noise influence and improve the positioning accuracy without the needs of the calibration. In the effectiveness test, comparing to the accuracy of the positioning result computed from the raw data, the accuracy of the result from our algorithm jumped from 74% to 98% for a local movement.
3. The progress information integrated movement information visualization system: The statistical result of movement is collected automatically and visualized with the progress information.
4. Field experiment based evaluation: The field experiment proved our system is efficient to acquire the worker movement information which can't be acquired before. The effectiveness of the visualization is also proved, the site manager can notice more detail of the construction site than before.

4.2 Future Work

Searching a construction site for a further testing of our system and improving the performance of the visualization methods. Since reducing the loss cost is important to the construction project management, we are going to test our system in some construction projects and valuate the results.

References

[1] Mai Sy Hung and Jianqiong Wang, Research on Delay Risks of EPC Hydropower Construction Projects in Vietnam, *Journal of Power and Energy Engineering*, 21 April 2016.

[2] J. Park, Y.K. Cho and K. Kim, Field Construction Management Application through Mobile BIM and Location Tracking Technology, *33rd International Symposium on Automation and Robotics in Construction*, 2016.

[3] Amir H. Behzadan, Zeeshan Aziz, Chimay J. Anumba and Vineet R. Kamat, Ubiquitous location tracking for context-specific information delivery on construction sites, *Automation in Construction*, 2008.

[4] Andreas Fink and Helmut Beikirch, Analysis of RSS-based Location Estimation Techniques in Fading Environments, *International Conference on Indoor Positioning and Indoor Navigation*, 2011.

[5] Esin Ergen, Burcu Akinci and Rafael Sacks, Tracking and locating components in a precast storage yard utilizing radio frequency identification technology and GPS, *Automation in Construction*, pages 354-367, 2007

[6] Hui Liu, Houshang Darabi, Pat Banerjee and Jing Liu, Survey of Wireless Indoor Positioning Techniques and Systems, *IEEE Transactions on Systems*, 2007.

[7] Hiam M. Khoury and Vineet R. Kamat, Evaluation of position tracking technologies for user localization in indoor construction environments, *Automation in Construction*, pages 444-457, 2009.

[8] Olga Golovina, Jochen Teizer and Nipesh Pradhananga, Heat map generation for predictive safety planning: Preventing struck-by and near miss interactions between workers-on-foot and construction equipment, *Automation in Construction*, 2016.

[9] Aaron M. Costin and Jochen Teizer, Fusing passive RFID and BIM for increased accuracy in indoor localization, *Visualization in Engineering*, 2015.

[10] Aaron Costin, Nipesh Pradhananga and Jochen Teizer, Leveraging passive RFID technology for construction resource field mobility and status monitoring in a high-rise renovation project, *Automation in Construction*, pages 1-15, 2012.