Using BIM and Sensing Mats to Improve IMU-based Indoor Positioning Accuracy

C.-H. Chen[a] and I-C. Wu[a]

[a] Department of Civil Engineering, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan
E-mail: 1106312108@nkust.edu.tw, kwu@nkust.edu.tw

Abstract –

Currently, numerous approaches to Indoor Positioning Systems (IPSs), such as RSSI (Received Signal Strength Indication), fingerprint, PDR (Pedestrian Dead-Reckoning), and image recognition, have been developed. But each individual positioning method has unique drawbacks. In this study, we provide an IPS with a novel combined positioning method that applies Building Information Modelling (BIM) and Internet of Things (IoT). We employ an Inertial Measurement Unit (IMU) to track people's positions. We then utilize a BIM model that has information (semantic and geometric) and a sensing mat to eliminate IMU drift error in the positioning process. The demonstration field is a research office, and test results show that the BIM based positioning constraint can effectively filter IMU cumulative error along with time; thereby, positioning accuracy can be controlled to a range of 30cm × 30cm. In sum, this paper proposes a new positioning method that compensates for the weakness of the IMU. In the future, this system can be applied to people management, such as telecare for older adults.

Keywords –

BIM; Indoor Positioning System; IoT; IMU; Sensing Mat

1 Introduction

Building Information Modelling (BIM) is widely used in Architecture, Engineering, Construction. BIM not only contains 3d data for visualizations but also provides object geometry and attribute data for the planning, design, building, and operation and maintenance stages of a building's life cycle [1]. Currently, BIM is most often used in the early stages of the project life cycle [2]. Furthermore, person tracking and positioning have potential benefits in later stages of the project life cycle. The IPS (indoor positioning system) has been developed by researchers because the ability to locate and track people could be useful in the Operations & Maintenance (O&M) stage, such as in emergency response [3]. Multiple techniques for acquiring the positions of people have been developed. IPSs are classified into two categories: absolute tracking and relative tracking [4]. Absolute positioning systems can be further classified according to their methods, such as RSSI-based, fingerprinting-based, image-based, and floor-based methods. Both RSSI and fingerprint methods use wireless signals, namely, Wi-Fi, BLE (Bluetooth Low Energy), and magnetic fields, to compute distance, and then they utilize triangulation to acquire an estimated position of a target, or they use a pre-built signal map in an offline phase to compare online signal strength data with map data to estimate position [5]. However, these methods have some drawbacks: (1) Positioning accuracy is affected by variations in signal due to environmental changes, such as people walking or changes in furniture layout, and (2) The offline phase of the fingerprint method is a time-consuming and tedious task. Image-based methods also have some drawbacks: (1) Positioning accuracy is affected by image quality, which varies with environmental factors such as light intensity, and (2) The positioning ability is invalid when targets move out of range and multiple objects need to be tracked in several video fields of view [6]. Lastly, the floor-based method that located object (people or furniture) through measure pressure to detect object position on surface of floor, that through variation of surface pressure in every pixel of floor to know flow of people, but this method has a drawback that cannot aware specific character [7]. The relative positioning method, which uses the Inertial Measurement Unit (IMU), is widely used in personnel tracking, but the IMU has a problem of error accumulation that leads to serious drift error over time [8]. As noted above, each IPS has limitations. The objective of this paper is to propose a method that employs BIM model information and IoT technology to eliminate IMU positioning error and thereby to achieve an IPS with high accuracy and stability.

2 Methodology

To avoid the drawbacks of existing methods, we propose a positioning method that combines IoT and BIM technology to achieve high accuracy, real-time indoor positioning. The system was developed with the Revit API in the Microsoft .NET framework. The flowchart of the indoor positioning processes is shown in Figure 1.

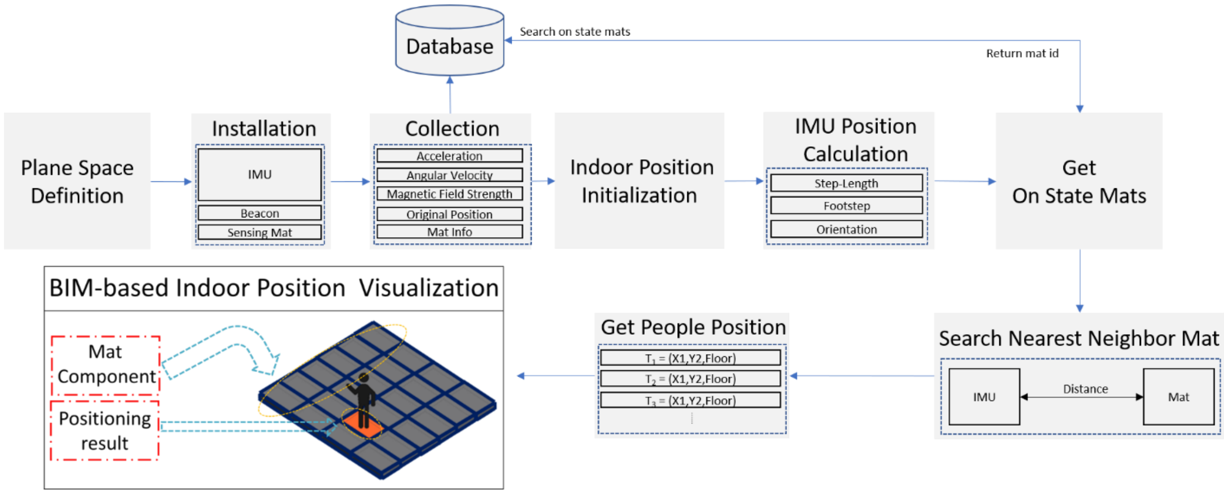


Figure 1. Research workflow of the proposed indoor positioning system.

In this process, we first defined the positioning space for demonstration and constructed a BIM model with Autodesk Revit. The model included a mat model having geometric shapes and specific parameters. Next, we installed sensing mats equal in size to the mat components in the defined space. The Beacon was installed on the door, and IMUs were worn by people. When sensor data were collected, the data of the sensing mats were output to a database. The Beacon's original position and the data on 3-axis acceleration, angular velocity, and magnetic field strength of the IMU were directly output to the positioning server. Upon receiving the original position data, the program initialized the position and utilized IMU data to calculate step-lengths, footsteps, and orientation to obtain the position of the IMU. Once the IMU position was determined, the positioning server searched for all the on-state mats in the database and got each mat id. The program also compared distances between the IMU and each on-state mat. After that, the mat at the shortest distance from the IMU was chosen as a person's position, and this position was used as a new original position for calculating the next position. Finally, the people's position results were displayed with highlights in Revit.

3 Experiment

In this chapter, we describe the entire experiment process, which is divided into four parts that are discussed separately.

3.1 Experimental site

The experimental site was in the research office of the Department of Civil Engineering at National Kaohsiung University of Science and Technology, as illustrated in Figure 2. In this experiment, we mainly focused on whether the reality sensing mat in cooperation with the BIM sensing mat component could effectively constrain IMU-based positioning error. Therefore, since positioning range was not the main topic of this study, we only used 9 block sensing mats in the experimental site.

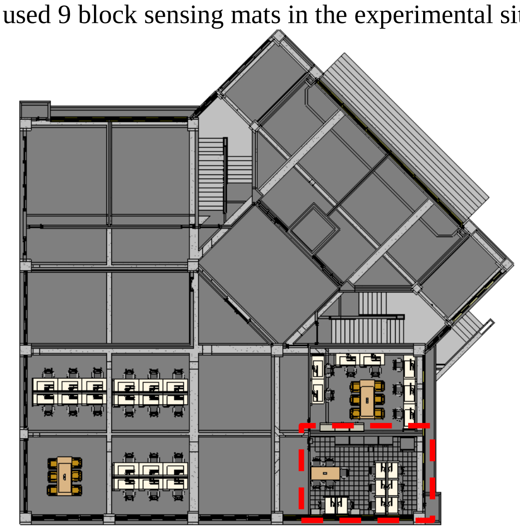


Figure 2. Experimental site

3.2 Sensor installation

The function of each sensor is shown in Figure 3.

The Beacon product model (USBeacon), which served as the original position in this study, was placed on the doorway of the room, as illustrated in Figure 4. The USBeacon is like a broadcast tower that transmits Bluetooth signals ceaselessly to provide UUID = fix, Major = 2, Minor = 2 for an IMU-based positioning system to initialize positions. These parameters stand for building, floor, and room, respectively.

In this study, IMU module is used to overcome the people Identification problem of floor-based method. The IMU product model was MPU-9250. The MPU-9250 can sense 3-axis acceleration, 3-axis angular velocity, and 3-axis magnetic field strength. The IMU device outputs necessary positioning data to the positioning server for a follow-up PDR algorithm to calculate an estimated position. In this study, the IMU was placed on the wearer's foot to easily count footsteps. An MCU (Microcontroller Unit) received raw data from the IMU sensor and the RSSI (received signal strength indicator) from the USBeacon. The MUC product model was ESP-32S. Once the ESP-32S entered the proximity detection range of the USBeacon, which was determined by RSSI value, the ESP-32S sent IMU data packets to the positioning sever via socket interface with UDP (User Datagram Protocol). UPD was used for data transmission because its transmission speed is faster than that of TCP (Transmission Control Protocol).

The sensing mat was the main feature in this study, so the relevant discussion is further divided into 4 points.

1. Composition of Sensing Mat: As shown in Figure 5, the sensing mat had a simple design using cheap materials such as sponge, cardboard, aluminum foil, and a mat. The design was inspired by button devices; the sensing mat is designed as an enormous button. The working principle of the sensing mat is 2 wires placed on the aluminum foil on the back of the mat and aluminum foil on the cardboard, respectively. When people step on the mat, the circuit is completed and the sensing mat will show an "on" state. While the sensing mat is in the "on" state, the Arduino YUN sends data to the positioning server database. To avoid accidental contact and erroneous updates, we used an elastic sponge material to separate the mat from the cardboard.
2. Figure 6 presents the installation positions of the sensing mats. We used 9 block sensing mats to verify the fusion algorithm that we proposed.
3. The sensing mat parameter design is shown in Figure 7. The parameters included UID, Room and Time respectively. "Room" indicated the room number where the sensing mat was located, "UID" was the identification number of each sensing mat, and "Time" was a timestamp for each "on" state. These parameters were used in the follow-up database search.
4. The sensing mat component design in the BIM model is shown in Figure 8. We created the UID parameter as the mapping condition for an actual sensing mat to extract coordinates from the sensing mat by UID parameter.

	
USBeacon	MPU-9250
	
Arduino YUN	ESP-32S

Figure 3. Sensors overview

Figure 4. The installation location of the USBeacon

Figure 5. The composition of a sensing mat

Figure 6. Sensing mat installation positions

UID	Room	Time 1
3	202	2019-01-23 22:29:44
6	202	2019-01-23 22:29:40
2	202	2019-01-23 22:29:37
4	202	2019-01-23 22:29:24
1	202	2019-01-23 22:29:21
8	202	2019-01-23 22:29:17
9	202	2019-01-23 22:29:14
7	202	2019-01-23 22:29:11
6	202	2019-01-23 22:29:09
8	202	2019-01-23 22:29:06
5	202	2019-01-23 22:29:03
4	202	2019-01-23 22:29:01
1	202	2019-01-23 22:28:58
3	202	2019-01-23 22:28:55
2	202	2019-01-23 22:28:53

Figure 7. Sensing Mat Database parameters

Figure 8. Sensing Mat component parameters

3.3 Positioning calculation

In this section, we generally introduce the IMU-based PDR algorithm and cooperation of the IMU with the BIM algorithm. Because the PDR was not a main research focus, we used an idealistic method to estimate position. The following sections describe the calculation processes for positioning.

3.3.1 IMU device position calculation

This research employed the Pedestrian Dead-Reckoning (PDR) algorithm. The PDR algorithm requires 3 positioning parameters: step length, orientation, and footsteps. In this study, we fixed step length at 30 cm. We employed Madgwick's method to obtain orientation components including roll, pitch, and yaw [9]. Lastly, we used total acceleration to count footsteps by threshold, and then we could calculate the estimated positions of the people. Figure 9 illustrates the concept of the PDR algorithm. Starting from the target's original position, the target's position at every moment is calculated as equation (1) and (2)

$$X_{k+1} = X_k + S * sin\,\theta_k \tag{1}$$
$$Y_{k+1} = Y_k + S * cos\,\theta_k \tag{2}$$

where (X_k,Y_k) is target's position at k time, S denotes the target's step length, and θ is orientation of the movement, and the θ value is as above-mentioned yaw that is from Madgwick's method, due to the position calculation is not involved three-dimension, therefore we only extract yaw as azimuth to calculate position.

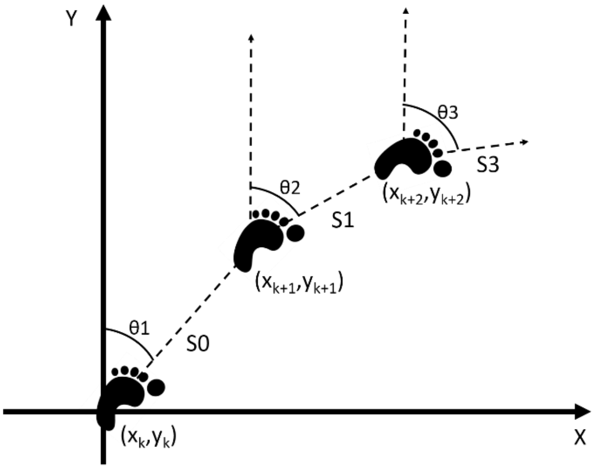


Figure 9. Pedestrian Dead-Reckoning algorithm

3.3.2 Fusion algorithm using Sensing Mat and BIM model

When the IMU device coordinates are calculated completely, we search the database for sensing mats in the "on" state. Next, we compare the sensing mat component from Revit to get a corresponding sensing mat component with the sensing mat UID parameter. Then the distance between the IMU and each sensing mat component coordinate is calculated. The process is illustrated in Figure 10. Afterwards, the sensing mat component with the shortest distance is taken as the final estimated position of the IMU. This final position is used to calculate the next position continually. Whenever the final position of the IMU device is calculated completely, the sensing mat will be highlighted in orange. If not, the sensing mat with the final position is restored to its normal color.

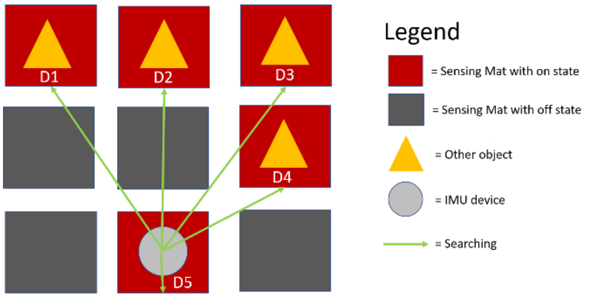


Figure 10. Searching process diagram.

3.4 Demonstration

As shown in Figure 11, we developed the IPS "Start" button in the Revit API and then defined the sensing area. When the user triggers the "Start" button, the program is launched. It starts a new thread in Revit to monitor port 3333. When a target enters the room (Room 202), the ESP-32S obtains original position information for that room, including UUID, Major, and Minor from USBeacon, and then via UDP sends a packet marked “202” to the positioning server. When the positioning server receives the original position of the target in Room 202 and starts receiving IMU sensor data of the target, the IPS will execute the indoor positioning process.

We tested some different states in the system, as shown in Figure 12. Starting in the lower right corner, the test path is shown in Figure 12 (a), (d), and (e). First, we tested the straight path state, then we tested the stretching across one block sensing mat state, and finally, we tested the diagonal path state. The results indicated that the IPS could correctly identify the position of the IMU device in the straight path, stretch across and diagonal path states.

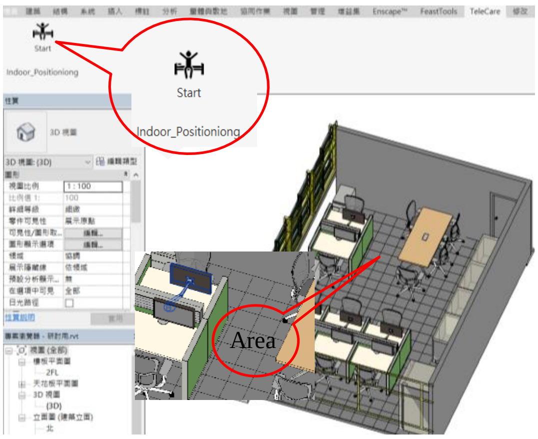
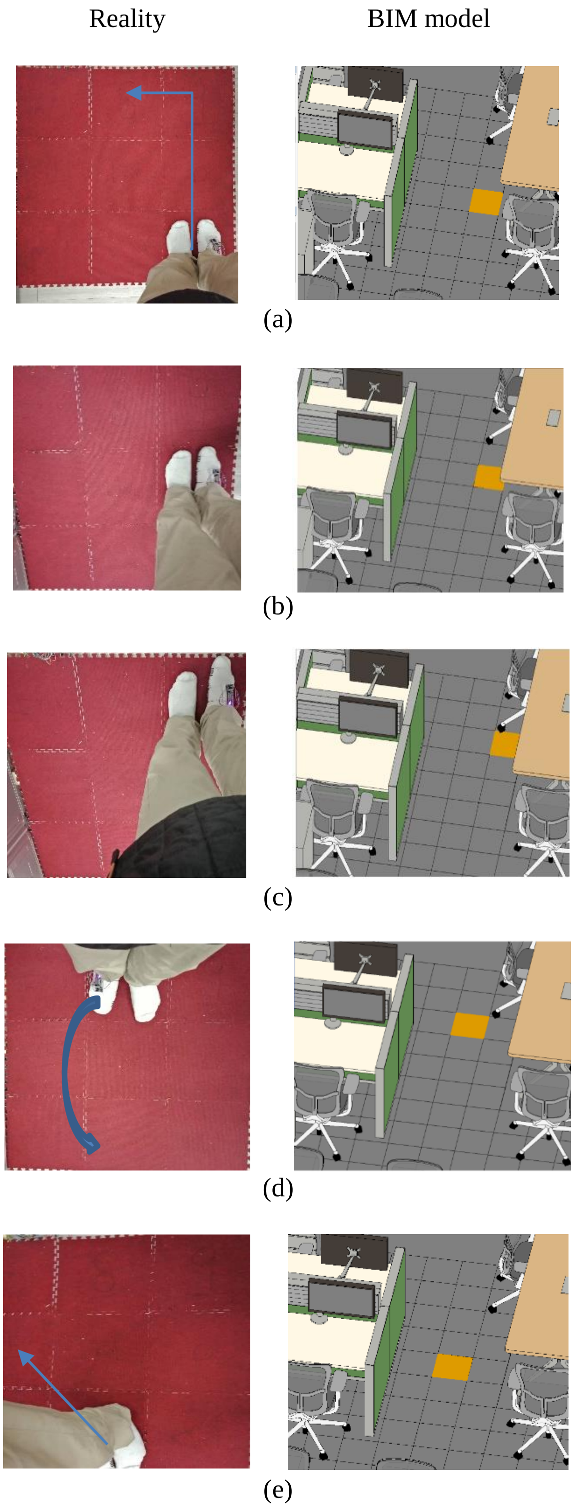
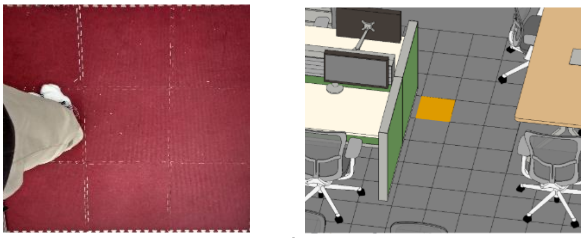


Figure 11. IPS GUI and visualization in Revit.





(f)

Figure 12. Test case for different walking states in Indoor Positioning System.

4 Conclusions

In this study, we used a simple method to fabricate sensing mats for use as sensors to detect the movements of people and employed a BIM model for integration and visualization to improve IMU-based positioning accuracy. The system presents these following characteristics: (1) simple materials to make sensing mats and easy installation; (2) improved accuracy to 30cm x 30cm zones; (3) a BIM model for visualizing indoor positioning data so that the user can easily know the locations of targets.

In the future, this system can integrate physiological sensors, such as heart rate sensors and blood velocity sensors, to automatically monitor people's conditions. If people have accidents, the system will notify the user or a caregiver. This idea may find application as a nursing home management system for monitoring elderly residents.

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