System Development of an Augmented Reality On-site BIM Viewer Based on the Integration of SLAM and BLE Indoor Positioning

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Abstract –

Traditionally, when an engineer wants to use Building Information Model (BIM) on-site to support tasks for construction or maintenance, the common approach is to use a tablet or a notebook to run a BIM viewer, thus requiring manual operation for model manipulation. In addition, the BIM presented through the screen and the actual on-site visual are in two separated views, and thus the two are less likely to be synchronized. Augmented Reality (AR) superimposes virtual objects or information that can be interacted with onto real world images or videos. Therefore, this study applied AR to superimpose BIM with an indoor industrial environment for a more immediate and intuitive integration of the physical site and BIM. At present, most applications of combined BIM with AR uses marker or marker-less image recognition to superimpose virtual content using feature points of the marker or object image as an identifier. If the identifier moves outside the device camera view, the virtual content will not appear. With advances in AR, a new AR mode is introduced in this study based on simultaneous localization and mapping (SLAM). Based on this technology, the virtual BIM is placed based on the device's understanding of the environment and then superimposed onto real objects in the scene without any identifiers. A manual method is proposed to align a chosen BIM component to a corresponding real object. Based on the alignment, the system calculates the angle and position to accurately superimpose the BIM on the virtual environment, with these locating characteristics recorded for future use. Since the load and display of an entire BIM model is not necessary and is inefficient in the context of indoor AR applications, the model is divided into room models, and the system only overlays the corresponding room model for a specific room. This is achieved through a combination with the Bluetooth Low Energy (BLE) indoor positioning technology, so that the room in which the user is located can be immediately identified and the corresponding room model can be loaded.

Keywords –

Building Information Model; Augmented Reality; Simultaneous localization and mapping; BLE indoor positioning

1 Introduction

For previous approaches for viewing BIM data, it is generally necessary to use related software, such as Autodesk Revit, Navisworks, Tekla Structures, etc. Moreover, these types of BIM software are traditionally designed for users to operate in an office setting; if it is required to view BIM data during the project maintenance stage, engineering personnel need to configure a lightweight handheld device, such as a tablet or high-end notebook, as a BIM viewing tool. This viewing method results in two problems: (i) BIM software cannot automatically present the model information required by engineering personnel, and (ii) the presented image in the BIM viewing tool and what is visually seen by on-site engineering personnel are two different images, resulting in difficulties in reconciliation.

Recently, Augmented Reality (AR) as a visual technology has risen in prominence. AR can combine the virtual world and the real world on the screen of a specific interactive device. Virtual text, graphics, or 3D models can be superimposed on true images. Based on this technology, the 3D virtual model from BIM can be superimposed onto the image of the project site. There is many applications of Augmented Reality system development for BIM [1, 2, 3, 4]. For example, during the construction and maintenance stages, an integrated on-site BIM model can be used to present construction progress models at different stages for project management. Additionally, during road maintenance and repair, the state of an underground pipeline can be determined using AR without the need for excavation, thus avoiding losses caused by accidentally excavated pipelines. There also have been broad applications in project operation and maintenance stages, such as in previewing indoor renovations using virtual models or indoor route navigation in large buildings. In essence, AR applications of BIM are typically in indoor environments. Thus, model fitting and accuracy will be a major challenge.

To solve the problem of indoor positioning accuracy, this study uses simultaneous localization and mapping (SLAM) through the combination of visual-inertial SLAM (VI-SLAM) with BIM in AR. SLAM was first proposed in the field of robotics, enabling robots to understand their surroundings during movement, using repeatedly observed feature points to locate their own position (simultaneous localization) and constructing a map based on environmental cognition (mapping). The development process of SLAM also ranges from the earliest sonar and light measurements to the current SLAM based on inertial measurement unit (IMU) and visual measurement technology (VI-SLAM). Recently, an Augmented Reality technology based on VI-SLAM has been developed [5].

This study proposes an overall conceptual framework for a pre-processing system and the user mode. The design of the system concept is conducted according to the abovementioned background and motivation, with the primary application being for the project maintenance stage. To address the effectiveness and localization problems of BIM models for project maintenance when coupled with an on-site inspection, this study introduces AR technology based on SLAM, using its characteristics to optimize the stability and fitness of the AR system as well as for spatial locating via Bluetooth Low Energy (BLE) and acquiring required data through a database. This is so that the cloud data for the room can be loaded immediately to fit the on-site BIM room model.

2 System framework

To effectively meet the abovementioned requirements, a pre-processing (pre-positioning) system is developed before the AR system operation. This pre-processor includes model processing, Internet of Things (IoT) and model data processing, a positioning system, and a model-fitting AR system, with the goal that every building object only needs to be undergo the pre-processing operation once, as well as an AR engineering maintenance system. After completing the pre-processing, the AR system can be used to directly with the model and assist in maintenance operations.

2.1 System pre-positioning operations

This study integrates BLE indoor positioning technology, IoT indoor monitoring technology, and cloud technology as developed previously by our research team, and transplants these technologies to an iOS platform for development. Based on SLAM AR, the Augmented Reality system is redesigned, adding Raspberry Pi into the IoT system for value-added applications to optimize and adjust the BLE positioning mode. The pre-position operation only is required to be performed once, with the expected results obtained without further pre-processing. Before system operation, it is necessary to use Autodesk Revit as a tool to establish the model of a building. This system takes the BIM model of the Second Engineering Building at the National Taiwan University of Science and Technology as an example, with sensors laid out within the required space.

2.2 Model data and sensor data processing

A BIM model has various components such as walls, beams, columns, equipment, etc., and furthermore, every component is configured with numerical data. To import the components contained in a case model into a database, the case statement for itemized components must be exported as a text file. The component data, indoor positioning device and room information, room name, floor number, address, and other related building information are collated into the storage configuration logic of HBase in compliance with the database format used in the laboratory. The component information will be consolidated into an HBase database format through an automated processing program to facilitate future uploading.

For the IoT indoor monitoring data of an on-site room, the perception layer consists of mainly the Arduino microcontroller. Various sensors such as a humidity sensor, water-dripping sensor, and an illuminance sensor are configured with Arduino to collect environmental monitoring data in the space where they are located. The network layer is the XBee communication module, which is connected to the Arduino through the Arduino-XBee Shield to form a ZigBee transmission node with various sensor modules. The Raspberry Pi also needs to be connected to the XBee communication module to form a data-receiving node, transmitting sensor information in the network to the Raspberry Pi through the ZigBee network system. The data is collated and uploaded to HBase via a server-side personal home page (PHP) through a wireless network, thereby realizing the sensor wireless network transmission framework. The above two data processing flow procedures are shown in Figure 1.

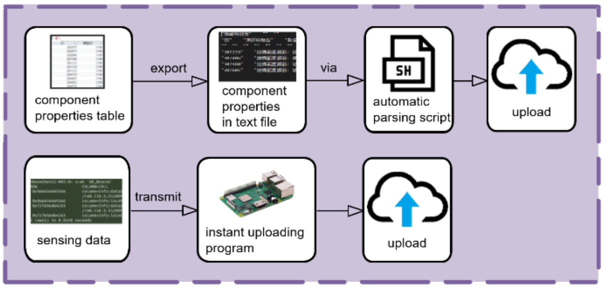

Figure 1. Data processing flow procedures.

2.3 Model processing flow procedure

After a completely established BIM model is exported, problems in material loss are present. If is used directly in the Augmented Reality system, challenges will arise in identifying components. It is necessary to re-render the BIM model material through the 3ds Max material editor and import it into the Unity development platform, so that the identification is correct. An overall BIM model needs to be manually segmented, cutting the model into floor models to be used as floor mini maps of floors. The model is further segmented into room models for the AR system to use for visualization. Finally, the model is converted to a Unity server transfer format through a Unity AssetBundle and uploaded to the server. In future uses, after a user enters the positioned space, the model can be created, deleted, and subjected to other functions during the execution of the AR program through the wireless network, maintaining a stable memory usage in the handheld device. The flow process is shown in Figure 2.

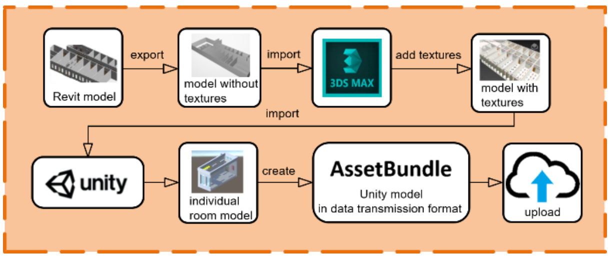

Figure 2. Model segmentation flow process.

2.4 AR pre-processing system

The pre-processing system is used to construct a mapping and record the placement of components. In a fitting operation, when a room to be scanned is entered, the system will first locate the room. After the cloud scanning of spatial points is completed, a selection list of components is produced, and all the components in the room will be listed for the located room. Next, the components to be fit are selected from the list of components. When the model is fit and placed in position visually, the system will calculate the moving distance and rotation angle. When clicking the upload button, the point cloud information file stored in the point cloud map will be uploaded to the server for storage, and the model with the relevant map location information will be stored in the database synchronously. The pre-processing operation procedure is shown in Figure 3.

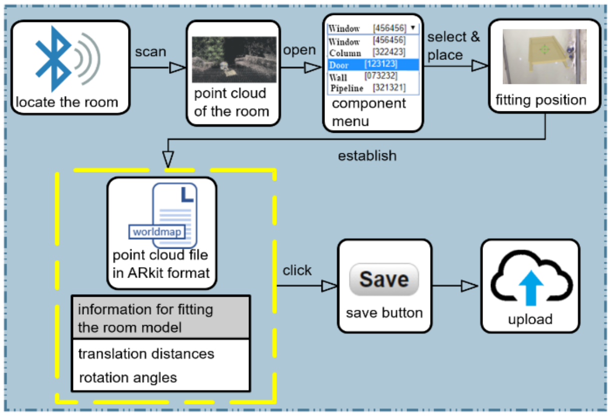

Figure 3. AR pre-processing system operation flowchart.

2.5 AR system operation flow process

The system operation starts mainly after the pre-positioning operations are completed. A user's on-site operation through the proposed system is mainly divided into three parts: indoor positioning, model fitting, and AR presentation. An overall framework of the first two parts is shown in Figure 4.

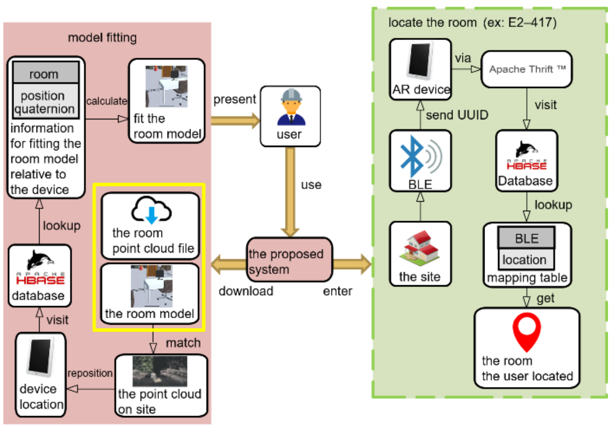

Figure 4. Model fitting flow process (left) and room positioning flow process (right).

In the positioning operation, a user entering the project site can wear a mobile device equipped with the proposed system. The device will receive multiple universally unique identifiers (UUID), with the signal strength transmitted by Beacon devices at each time step. The UUID will be sorted following the received signal strength and ranked from the strongest to the weakest. If the frequency of a Beacon device signal strength per time step is ranked the highest, that UUID will be the UUID of the room. The system will access the Hbase database through functions provided by Apache Thrift, search for the corresponding room position inside the BLE data table, and set it as the system positioning location, as shown in Figure 4 (right).

After a user completes the positioning, the system will download the files corresponding to the room from the server (the point cloud information file that contains the stored point cloud map of the room and the room model file with the pre-position processing). After loading the point cloud information file, the system will compare the feature points in both the point cloud map and the actual environment, and then recalculate the relative position of the device in the point cloud map. Thus, the model will obtain the position and angle of the model relative to the device through the database, and then the room model is fitted to the corresponding position in the point cloud map. The user can see the virtual model overlaid onto the actual environment through the device camera. The flow process is shown in Figure 4 (left).

After the AR model is presented on the system screen interface, users can click on the Revit component model by tapping on the screen. The system will send the Revit ID of the selected components to HBase, search for the corresponding component data parameters, attributes, categories, and other component information via the ID, and transfer the data back to the interface to be viewed by user. From this, if the model is a sensor, the historical data for the sensor can be obtained. Set directly on top of a map, a virtual camera exclusive to the mini map can view the location of the device on the map using an orthographic projection, and thus a mini map navigation mechanism is formed. The complete function flow process is shown in Figure 5.

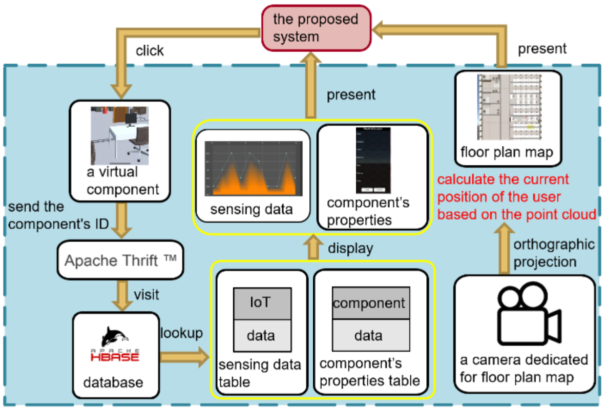

Figure 5. AR presentation flow process.

3 System operation mechanism

The operation mechanism is divided into five sections: BIM model processing method, IoT indoor monitoring sensor group setup, AR preposition processing system mechanism, HBase database configuration, and auxiliary tools.

3.1 BIM model processing method

According to the system requirements, a Revit model of the study site must be first established. Before introducing the BIM model into Unity, the model and component information must first be exported separately. The model must be stored on the HTTP Server in the Unity Asset Bundle format for users to download the model through a wireless network during program execution; component information must be processed before it can be stored in HBase.

Before the Revit model is introduced again into Unity, the model needs to be exported first into a readable format by Unity. The designed system uses the FBX format, while the Revit model is exclusive to the Autodesk software suite. If other software is used for model viewing, the model will not display properly. To resolve this problem, the model must be converted. The designed system uses Autodesk 3D Studio Max (3ds Max) for model conversion.

Considering that the mobile device hardware paired by the user on the project site lacks computational power to process the sizable model and the large-scale rendering of the 3D model, the model is segmented following the room being cut in Revit, as shown in Figure 6.

Figure 6. Schematic diagrams of segmented rooms.

If the attributes of the BIM components are to be imported into the database, processing is necessary. First, the component must have an identifiable code for subsequent component search, and while component itself in Revit is configured with an ID, it is a hidden attribute. At the model establishment stage, the designed system uses the Dynamo extension plug-in to place the attribute members into the ID of each component.

3.2 IoT indoor monitoring sensor group setup

Data transmission of the proposed system uses the Arduino board in combination with sensors, thereby reducing the cost of laying out hardware. The sensor components include an Arduino development board, a number of environmental sensors, the BLE indoor positioning module, and XBee communication module (data transmission). The data processing components include the Raspberry Pi, the XBee communication module (data reception): through the Wi-Fi network module of the Raspberry Pi, the monitoring data received by the XBee module is uploaded to the database storage in the remote server.

3.3 AR pre-processing system mechanism

After entering a room, the positioning of the room can be conducted through this pre-processing system. After confirming the location of the room, the scanning of the point cloud for the 3D space can then be carried out. After the scanning is complete, the point cloud file is uploaded to the server for storage and linked to the database.

Next, it is necessary to record the position of the model in three-dimensional space. First, the user must select the component to be fitted and manually place the component at the true position of the object. Next, the system will calculate the relative position of other remaining components per the position of the manually placed component.

The manual alignment is done through a perpendicular projection from the right center of the screen through a ray. The ray is parallel to the normal vector of the screen plane. If the ray touches the plane of system detection, the right center of the component will be fitted to the position of the system detection ray projection and the model will fit to the parallel plane, as shown in Figure 7.

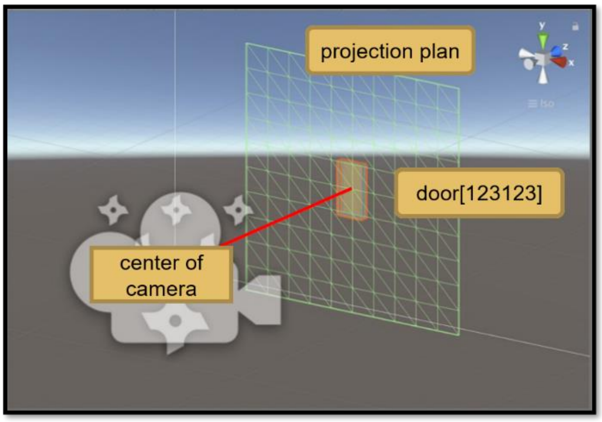

Figure 7. Schematic diagram of the manual model alignment.

After the user performing the pre-positioning enters the room, the system will automatically locate the room where the operator is located, and the room model will be downloaded into the system. After the download is finished, the overall room model will be placed into a point cloud map as a far spot that is invisible to the naked eye. The initial coordinates for this far spot is (10000, 10000, 10000), and for the angle, to avoid the problem of not being able to rotate normally because of gimbal lock, the angle is computed using quaternions with an initial value of (0, 0, 0, 0). When the operator completes the fitting of a single component, the system will calculate record the relative offset of components for the entire room according to the offset of the fitted component. As shown in Figure 8, room model distance before rotating ΔQ is not equivalent to the sub-component distance. After rotating ΔQ, where ΔQ represents relative rotation angle between two components, room model distance is equivalent to the sub-component distance, as shown in Figure 9. The overlaid views in the proposed AR system are shown in Figure 10.

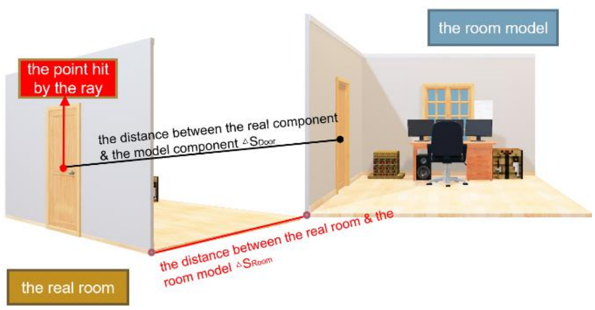

Figure 8. Room model distance before rotating $\boldsymbol{\Delta Q}$ is not equivalent to the sub-component distance.

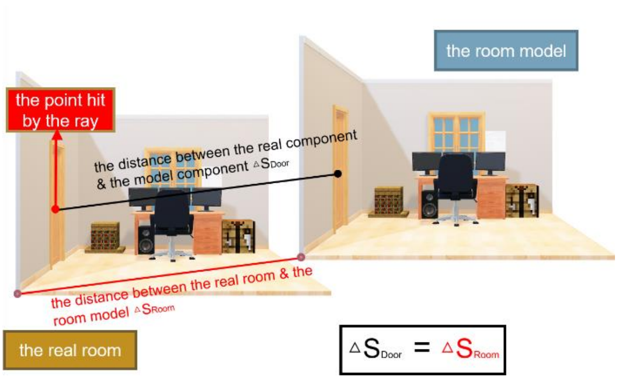

Figure 9. Room model distance after rotating $\Delta \boldsymbol{Q}$ is equivalent to the sub-component distance.

Figure 10. The overlaid views in the proposed AR system.

3.4 HBase database configuration

This study assumes that the system application scope is quite large. In practical applications, the dataset may be very large. The designed system adopts Apache HBase, a non-relational database, as a data storage tool, which can allow multiple users to quickly obtain the stored data. The data storage structure is configured according to the system specifications shown in Figure 11.

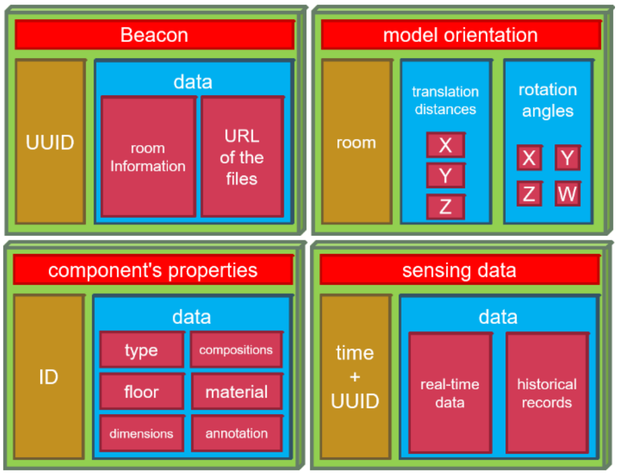

Figure 11. Beacon device data sheet configuration (upper left), model position data sheet configuration (upper right), component information data sheet configuration (lower left), and sensor data sheet configuration (lower right).

3.5 Auxiliary tool mechanism

The AR virtualization for the sensors is similar to presenting the BIM model generally. The sensor models must be first designed and built, as shown in Figure 12. The representative meaning of the models can be intuitively understood by the user.

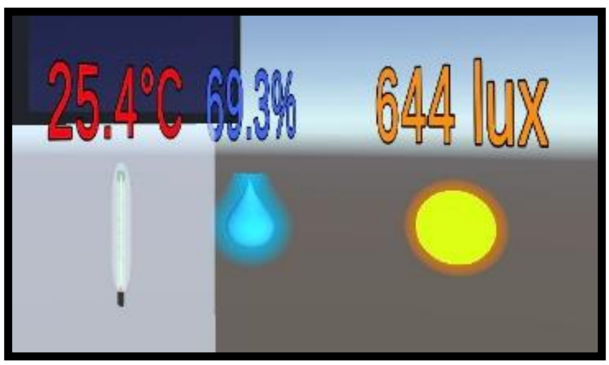

Figure 12. Real-time AR presentation of the sensor measurement data.

When the user taps the model, the system shows the historical data, as shown in Figure 13. To check for abnormal temperatures, the date can be selected. Vertical axis of the chart is the temperature with unit of ℃; horizontal axis is the hours with a range of 0-23.

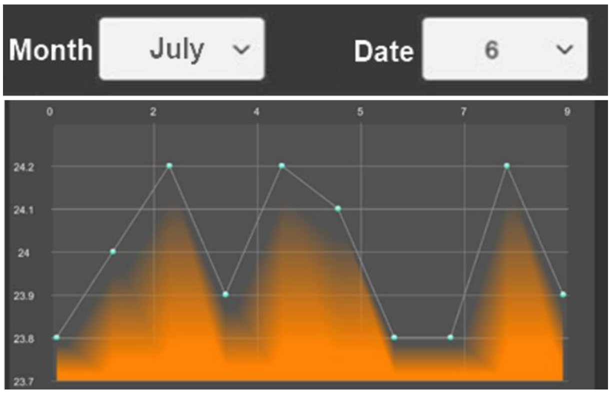

Figure 13. Sensor chart and selection list example.

Users can find a navigation map from the map navigation icon at the lower right of the display. The red sphere is the user's location, which helps the user to understand their current location. After the system locates the room, the system will download the model of the floor from the server and place it on the mini map user interface (UI) layer for viewing. After the room model is completely fitted through the point cloud map, the system will know its relative position between the model and the device. The red sphere is placed on the relative position of the device inside the floor model, and a mini map camera is set directly above the sphere to illuminate the position of the red sphere as an orthographic projection, forming a two-dimensional planar map as shown in Figure 14.

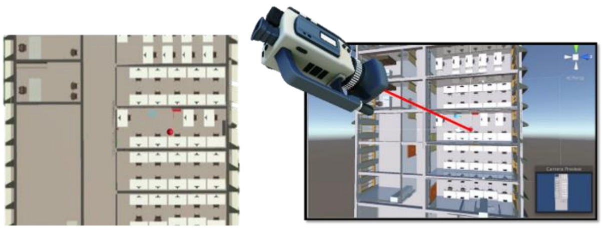

Figure 14. Schematic diagrams of the mini map UI and the orthographic projection mechanism.

4 Verification of system effectiveness

4.1 Effectiveness of program execution

Taking the overall model of the Second Engineering Building as an example, a comparison is conducted on the AR presentations for the unsegmented model and the model placed on the server side after segmentation. The influence of the rendering model on overall system effectiveness is considered, with Xcode Monitor used for monitoring.

iPhone XR is a handheld device with mostly high-end specifications among handheld devices in the current market. The graphics processing has excellent performance in more areas. According to a comparison of the results, the memory usage of the model-processed version is approximately 26.83% of the original model. Using the frame rate to reflect the graphics processing power of the handheld device, the model-processed version reached 205% of the original frame rate, with 60 frames per second (fps) being the current standard of high-resolution TV. Model segmentation is still necessary for the hardware equipment specifications on current handheld devices.

4.2 BLE room positioning verification

For the verifying the indoor positioning of this system, two Beacon devices continuously emitting Bluetooth signals were placed in two adjacent rooms, with the Beacon devices separated by a wooden wall. Enabling the Beacon devices to interact with each other verifies whether the positioned room can be located under the situation where there is mutual interference. Positioning was conducted at the furthest and nearest spots from the Beacon devices in the two rooms and the nearest and furthest positioning results within the same room to calculate the success rate of the positioning. From several tests, an approximate accuracy of 100% accuracy can be obtained.

4.3 Model fitting accuracy

This study conducted a model fitting accuracy test in an office room of the E2 building at Taiwan Tech. The center of a door in the room was taken as the reference point for accuracy measurement. The way to measure fitting accuracy is as follows. Figure 15(a) shows an actual door, with a reference point set at the center of the door. A reference point is also set at the center of the virtual door model. Using the AR pre-processing system for model fitting, shown in Figure 15(b), the reference point has an offset of D1. By comparing the offset of D1 obtained from the observed door at the same actual position, the degree of fitness is calculated in a quantitative approach. The system offsets were measured at two observation points. The first point was at a distance of 109 cm perpendicularly from the reference point of the target component, and the second point was at a distance of 252 cm from the reference point of the target component in the direction of a 60 degrees offset.

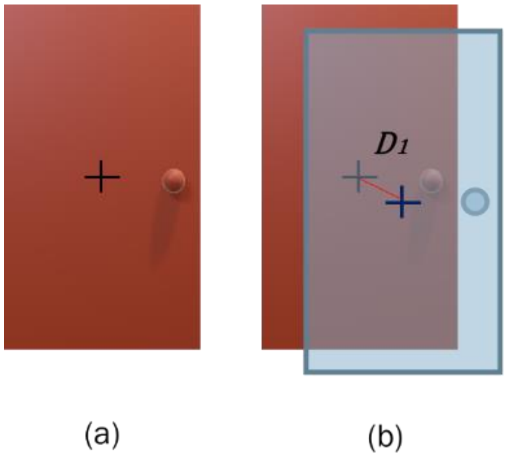

Figure 15. Schematic diagrams of the fitting, with the center of the door taken as the reference points (a) Actual door, (b) fitting of the AR pre-processing system model door.

An average offset can be determined from the statistical results shown in Table 1. The fitting accuracy of the new system can reach errors on the order of millimeters in a single room, with the degree of fitting being more accurate. This degree of errors is acceptable for application at the maintenance stage.

Table 1. Average offset results.

Offset angle	Average offset of x (cm)	Average offset of y (cm)	Normalization of x	Normalization of y
0°	0.0353	0.1623	0.0395%	0.1819%
60°	0.1693	0.2258	0.1898%	0.2531%

5 Conclusions

This study proposes an Augmented Reality system based on SLAM for a marker-less system, and develops a set of AR pre-processing and AR presentation systems to enhance the integration stability of virtual and actual worlds. Moreover, the BIM model and the on-site environment are combined, so that information can be presented to the user on a same interface, information is automatically transmitted to the user, and the complexity of the human-machine interface is reduced, thereby resolving the inconvenience of BIM model on-site operation as mentioned in the study motivation.

Furthermore, in the indoor positioning based on BLE, using a more stable approach than previous research for locating a user's positioned space and loading the room point cloud map and room model based on the positioned room, the subsequent development of AR pre-positioning system and AR presentation system were based on this foundation, thereby reducing system operation complexity. Using rooms to segment the model and point cloud map, pre-storing files in a remote server, and using the database to store the file links and room effectively reduces the system usage space and memory usage during program execution and reduce graphics processing load, thus improving system effectiveness. This framework is taken to propose an augmented reality BIM fitting system that is stable and applicable to a wide range of spaces.

Finally, the designed system uses a Raspberry Pi as the central coordinator. After obtaining all the sensing data, the data is uniformly processed through a regularized program, and then the numerical data is transmitted through the Internet and stored in a database. The integrated application of sensors in augmented reality proactively presents environmental information to the user.

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