BIM-Image-Based Indoor Localization Prototype

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Purpose In order to provide an economical indoor location detective technique, this study is uses photo images as the indoor spatial identification tags associated with the spatial information of the existing building information model (BIM), so that users can identify their locations via the camera on mobile device based on the real images. **Method** Unlike the wireless and radio frequency identification based indoor positioning techniques, this study applied the image recognition technique to indoor location detection. Three functional modules, namely, (i) BIM object location collector, (ii) spatial image management module, and (iii) vision-based location recognition module are developed. BIM object location collector takes the responsibility to automatically collect the location data from the IFC (Industry Foundation Classes) dataset of the existing BIM. Firstly, the spatial image management module provides an interface to clients for collecting spatial photos in buildings, and bind them with the location data transferred from the original buildinginformation model. Secondly, the recognizable features of the spatial photos can be analyzed by the visionbased location recognition module which is developed based on the D'fusion studio. According to the analyzed image features, the vision-based location recognition module can then recognize the frames of the visions captured by the mobile device camera. Once the frame is recognized, the corresponding spatial data can be retrieved. **Results & Discussion** Based on the designed architecture, a BIM-vision-based indoor localization prototype was developed as an android platform application running on the mobile device such as smart phones and tablets. Technique feasibility is continuously tested in the current phase. According to the basic test results, the prototype can identify the indoor locations of decorated spaces; however, once the indoor spaces lack of recognizable features, such as the empty spaces with blank and monotony walls, the recognition function failed. To overcome this defect, the Quick Response (QR) code, the trademark for a type of two-dimensional code, is used as a substitution of the photos for this prototype. Besides, since the location data is transferred from the existing building information model, data consistency can be ensured. In the future, the economic feasibility of this prototype will be analyzed to evaluate the cost-benefit ratio.

Keywords: *indoor localization, BIM, image recognition, IFC*

INTRODUCTION

The necessary of the indoor localization for maintenance phase of buildings is increased due to more facility management requirements such as administration of equipment, maintenance service, building health management and indoor emergency navigation requirements[1]. Because building spaces serve different functions with multiple facilities and equipment, the building administrator and maintenance engineers have to grasp the facility data distributed to building spaces and determine the maintenance strategies based on the space oriented information. However, because of the multiformity of building spaces, the facility management staff could not always connect facility management data, e.g. equipment repair records, to building spaces. Without the connection with the building spaces, the information is deficient for the facility management usage. Providing space information to facility management staff automatically could overcome this circumstance. On the other hand, space localization is also a critical technology for intelligent buildings. Proper services could be provided to the occupants if the user's location is detected automatically. Accordingly, this study was aimed to develop an indoor localization system for building maintenance and operation usages.

Several researches of positioning and localization technologies have been down well for outdoor and indoor applications. The Geographic positioning system (GPS) is the common technology adopted for positioning. While some studies have tested GPS which provides an accuracy of around one meter, it is costly and cumbersome which needs fixed ground stations and is only efficient outdoors[1]. Wireless LAN (WLAN), ultra-wide-band (UWB), and radio frequency identification (RFID) have been combined for an emergency navigation system in complex buildings[1]. Using image recognition technology, an outdoor/indoor vision-based localization system was developed for blind pedestrian navigation assistance[2]. Besides, several real-time localization systems (RLTS) based on distributed wireless sensor networks or RFID have been tested for indoor human position sensing[3-7]. However, combining different positioning technologies not only brings more complexities in system integration and user interface, but also inherits the natures of the costly initial investment and maintenance/operation costs, i.e., the total cost increases directly in the great space

amount building. Moreover, additional devices are needed for users, such as RFID readers[5-7], sensor receivers etc., which would reduce the usability of the systems.
Generally, spaces in buildings have their specific image features. Therefore, using space images as space identification tags might be an alternative for indoor localization. Images could spend less expenditure for indoor localization, comparing with the previous localization technologies. On the one hand, images spend no direct cost; on the other hand, image retrieving with mobile devices, such as digital cameras and smart phones with cameras, is relatively easy and convenient. Few additional devices would be used for taking images to identify indoor locations.
Moreover, combining indoor localization system with the building information model (BIM) is necessary for building maintenance and operation usages. Not only because BIM is the state-of-the-art technology for construction industry, but also this facilitates the reuse of the design and construction information in the BIM model and increase the integration capability with other facility management information systems.
Consequently, this study aims to implement the idea of using indoor space images as the space identification tags, so that users can detect the symbolic locations (not physical position) of spaces by image recognition technique. Moreover, by combining with the existing BIMs, the necessary space relative data for facility management can consistently be retrieved after the location detected.
In the following sections, the architecture of the prototype is addressed firstly. Secondly, the system design and implementation for the prototype are described to validate the technological feasibility of the proposed architecture. Subsequently, the system test and discussion including system localization capability and brief economic analysis are illustrated.

BIM-VISION-BASED LOCALIZATION PROTOTYPE ARCHITECTURE

To combine BIM data with space image information, the client-server architecture is referred for development of BIM-Vision-based localization prototype. Figure 1 illustrates three main components schemed in the prototype, namely, (1) Spatial image database, (2) Spatial image management module, and (3) Visio-based recognition module.
The spatial image database is the space-related data collection providing the connections between the space relative data imported from the IFC (Industry Foundation Classes) files derived from the existing BIM model[3] and the space feature image information retrieved form users. The spatial image management module running on Android platform, the operation system of mobile devices, provides functions to collect the space photo images in buildings, and bind the images with the space data in the spatial image database. Then, the vision-based localization module developed based on the D'fusion studio [4] can identify the locations by recognizing the images in the vision captured with the camera on a mobile device and then retrieve the corresponding spatial data from the database.

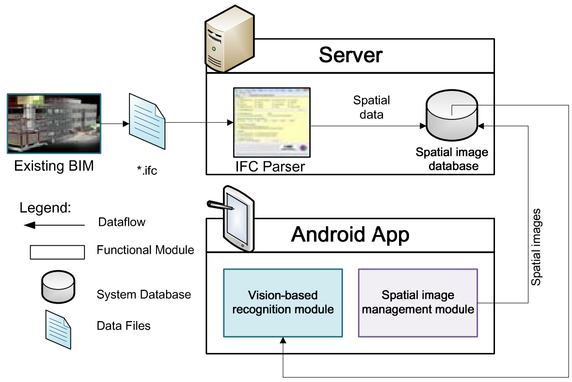

Fig.1. System architecture

PROTOTYPE DESIGN AND IMPLEMENTATION

Based on the proposed architecture in Figure 1, a prototype was developed following the system design and implementation process.

System design

The details of the three primary components in the prototype are described as in this section.

Spatial image database

The spatial image database is the storage of the relationships of the space and image data, where the space data was imported from the BIM model and the image data was collected by the system users. With this database, once the space image was recognized, the system can retrieve the space relative information via the relationships. The entity-relationship model of the database was schemed as Figure 2 shows. The relationship between "Space" and "Image" entities is the key connection for space localization function. The space relative information, such as structural elements, facilities elements, etc., could be optionally added to the database for facility management utilizations.
The Figure 2 shows illustrates the relationships between spaces and their corresponding objects in the IFC file derived from the BIM model. The space information including the space name, space's GID (Global ID) and the Cartesian point of space, are imported to the "Space" table in the database; the additional elements' information, such as windows, structural elements, facilities, and the spaces their belong to can be also optionally imported to the corresponding tables.

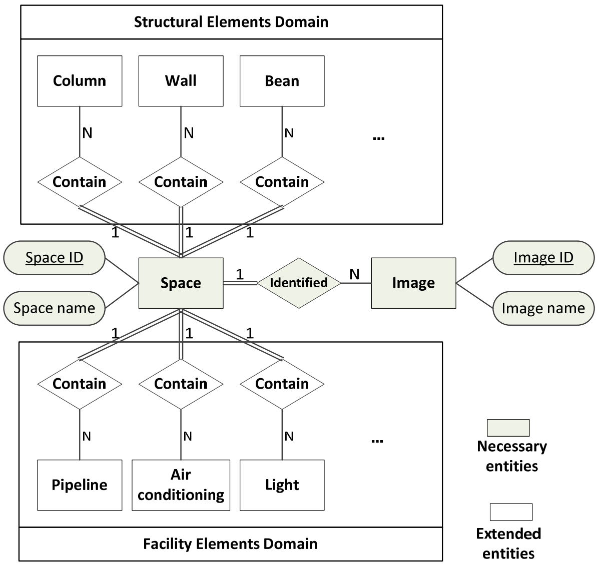

Fig.2. ER model of the spatial image database

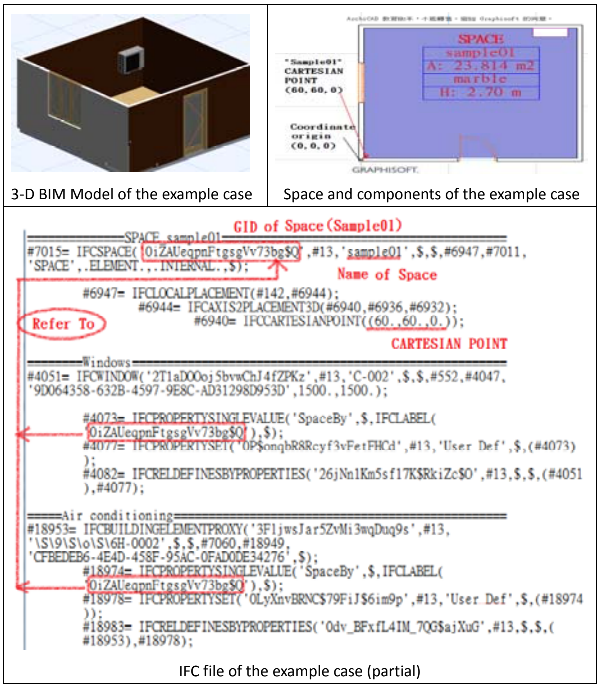

Fig.3. IFC space tag (example, partial)

Spatial image management module

The spatial image management module is a functional module designed for space images collection using mobile devices. Since the collected images should provide enough features for space identification, this study proposed the concept of “space recognition image set” to increase the robustness of indoor localization (shown in Figure 4). Instead of using single image for recognizing a space, an image set including three space photos taken from three different view angles is collected. According the multi feature images in a space recognition image set, the system can identify a space with more features which would prevent the identification fail due to a lack-of-feature space image. In our cases, bringing more photos to a space image recognition set increases the probability of successful space identification; however, it also increases the calculation loading of the program running on mobile devices. According to the computation capability of current mobile computer devices, three images in a space recognition image set could be a proper tradeoff.

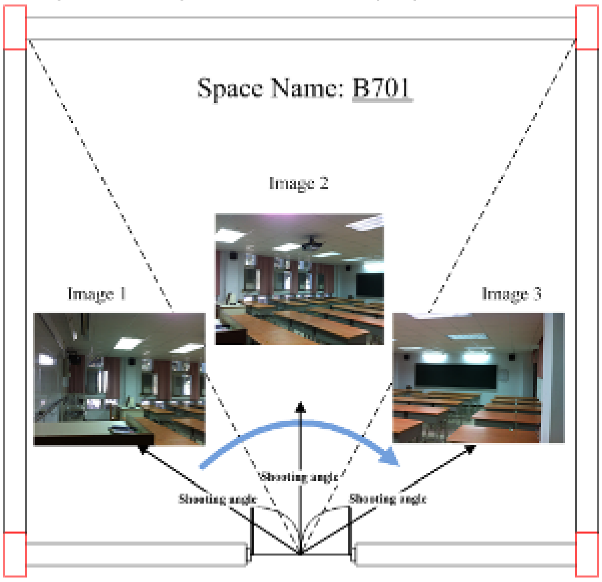

Fig.4. Space recognition image set

Accordingly, the sequence diagram of the spatial image management module was schemed to assist users create space recognition image sets of all building spaces. In Figure5, once the space recognition image set is created, users need to pair it with space name instantly on the mobile device. Once the pairing relationship of the space recognition image set and space was identified by users, the images and relationship information will be transferred to the spatial image database via 3G or Wi-Fi network.

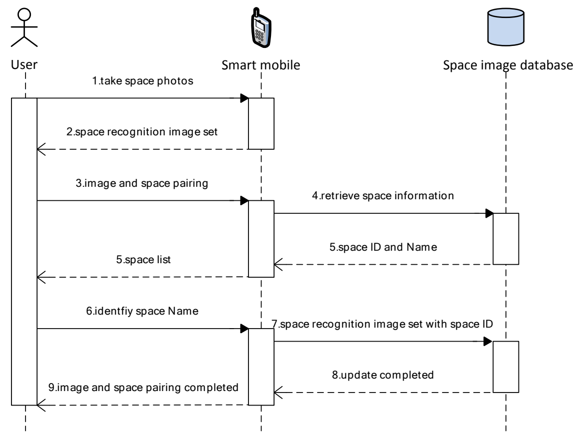

Fig.5. Space recognition image set photographing and space pairing sequence diagram

Vision-based recognition module

The vision-based recognition module is the kernel of the prototype system running on the mobile computer device which takes the responsibility to identify the space using the created space recognition image sets. Image recognition and space fitness (SF) calculation are two functions of this module. Figure 6 shows the identification procedure of this module. Users need panoraming of the space with camera-embed mobile computer device, and the functional module will recognize each image frame in the captured vision. Once a feature image in the space recognition image sets is recognized, the space fitness value (SF_i) corresponding to the space i will be calculated with Eq.(1).

$$SF_i = NRI_i \times 33.3\% \qquad (1)$$

where SF_i ($0 \leqq SF_i \leqq 100\%$) is the space fitness value of the recognized space i. NRI_i ($0 \leqq NRI_i \leqq 3$) is the number of recognized images of the space recognition image set of space i.

As the panoraming is finished, the space would be identified according to the space recognition image set with the highest SF value, and then the corresponding space relative information could be retrieved via the identified space ID from the spatial image database.

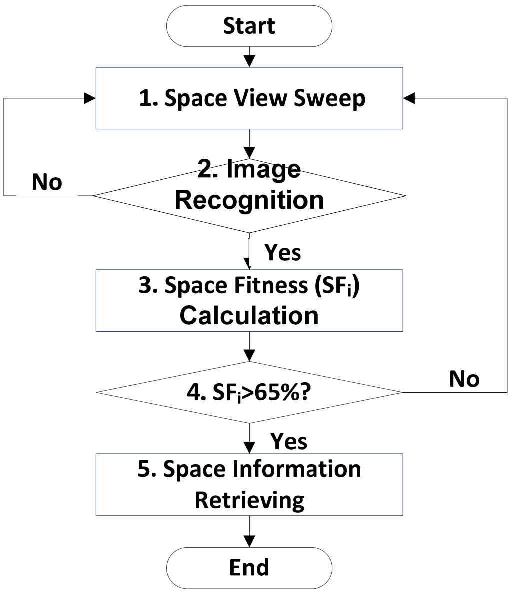

Fig.6. Image-based space localization procedure

System Implementation

According to the system design results, three primary functional modules were implemented on Microsoft® windows and Google android operation systems. Figure 7 shows the implementation of spatial image database on MySQL database server running on the Microsoft® windows 7 operation system. To import data from BIM model to the spatial image database, this study adopted the IFC Parser [7] to transfer the IFC files, exported from BIM models, to the database semi-automatically.

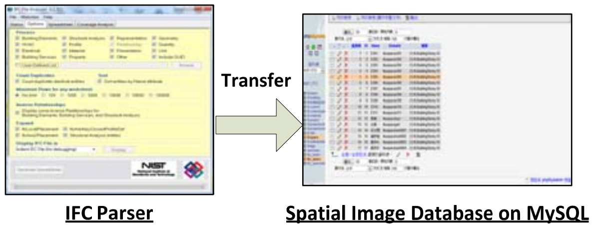

Fig.7. Export data from IFC file to Spatial image database

Meanwhile, an App (Application) including spatial image management module and vision-based recognition module was implemented running on the android smart phone. Figure 8 shows the space photographing function to create a recognition image set of a space, where an instruction will appear guiding users to take three images to generate a space recognition image set (step 1~2 in Figure8). Once the image set is created, it should be paired with its corresponding space name (step 3 in Figure 8), so that the recognition image set can be used as the space identification tags in the system.

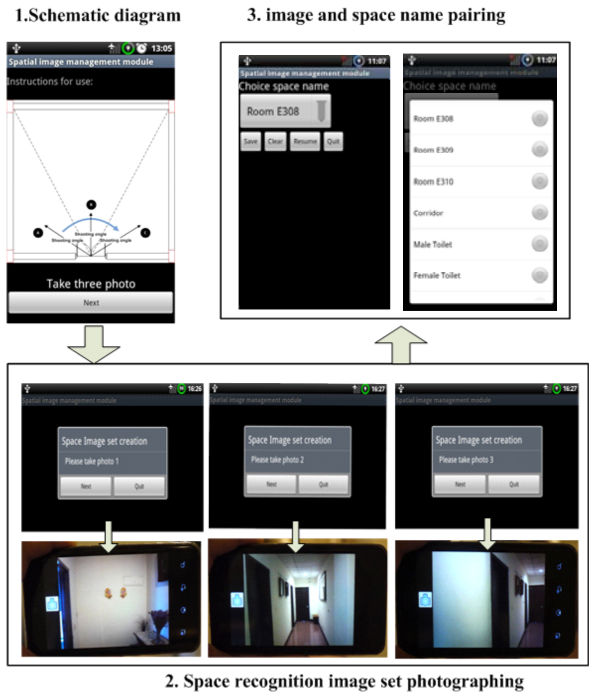

Fig.8. Space photographing function

Finally, the vision-based recognition module was implemented with the D'fusion studio which is a commercial Augmented Reality (AR) development tool[6]. By using the image recognition components of D'fusion studio's library to recognize images in the visions according to the pre-created space recognition image sets. Figure 9 shows the image recognition procedure for indoor localization. The recognized space information will be revealed on the screen in real-time. Users can easily get the space information by panoraming in the space with the camera on the smart phone.

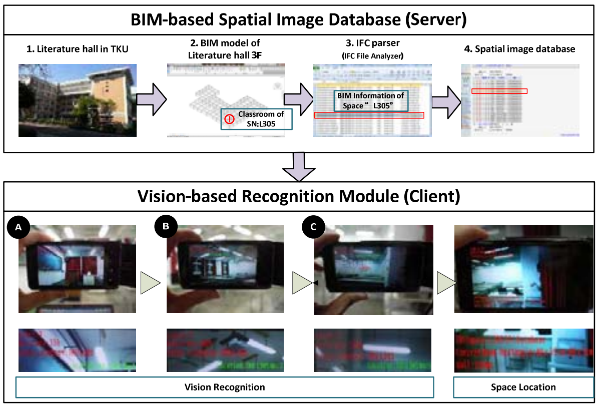

Fig.9. Indoor localization function

System Test and Discussion

System Test

To understand the identification capability, a preliminary experiment including 61 test spaces was finished using the developed prototype system. Since the space identification capability differs by space environments, we classified the test cases into 8 space categories as shown in Table 1. No case was identified successfully in the not-decorated room and similarly-decorated rooms. This is an obvious result due to the limitation of image recognition; i.e. the rooms with blank walls, similar layouts and decorations provide either insufficient or similar image features so that image recognition program could not identify them accurately. In the other cases, 60% ~ 85% spaces can be successfully identified with 60% to 80% SF values, and the failure cases, except not-decorated room and similarly-decorated rooms, the prototype can all be identified successfully by recreation their space recognition image sets.

Table.1. Prototype Test result summary table

Space type	Space Samples	Space identified	Average SF
Not-decorated room	10	0	0%
Decorated room (similar)	10	0	0%
Decorated room (not-similar)	10	8	75.9%
Corridor	10	7	66%
Atrial	6	5	71.5
Hall	5	4	72.6
Outbuilding	5	4	79.2
Independent open space	5	3	59.4

Discussion

According to the test results, following discussions are described:

1. Using space images as location identification tags have the potential capability to be the alternative method for indoor localization (space detection). However, to make up the insufficiency resulted from the limitation of image recognition, the Quick Response (QR) code, the trademark for a type of two-dimensional code, could be used additionally to be the “Artificial” space recognition image set. That is, QR codes could be attached in the non-decorated and similarly-decorated spaces to indicate the space names so that the location can then be accurately identified by the image recognition technology with the same mobile devices.
2. The feature richness of the space images determines the localization accuracy. If necessary, more than three images could be added to the space recognition image set to provide more space features. However, this would increase the calculation loading for image recognition on the mobile devices. Besides, the localization capability using image recognition technology would be influenced by some environmental conditions, such as lights and variability of spaces.
3. Using images for indoor localization could be relatively inexpensive than other indoor localization technologies. A rough economic analysis for three indoor localization/positioning technologies, namely, (1) RFID-based indoor localization method[1-8], (2) wireless sensor network indoor positioning system[9,10] and (3) image-based indoor localization (this study), was fulfilled to understand the economic capabilities of each technologies. The total costs including the fixed and variable costs of three applications were estimated according to the proposed models in the literatures. Figure 10 illustrates the relationship between the total costs and application area in buildings for each alternative. For RFID-based and wireless sensor network positioning technologies, the total costs increase more rapidly by application area than image-based indoor localization method. According to the rough estimation in Figure 10, as the application area is less than 10870 m^2, wireless sensor network positioning method would be the economic choice, while the image-based localization method should be more economical for large area applications.
4. Combining Indoor localization system with BIM is a proper strategy to improve the additional-value of indoor localization system. However, the relationship between entities and spaces in BIM models should be created preliminarily in the design phase.

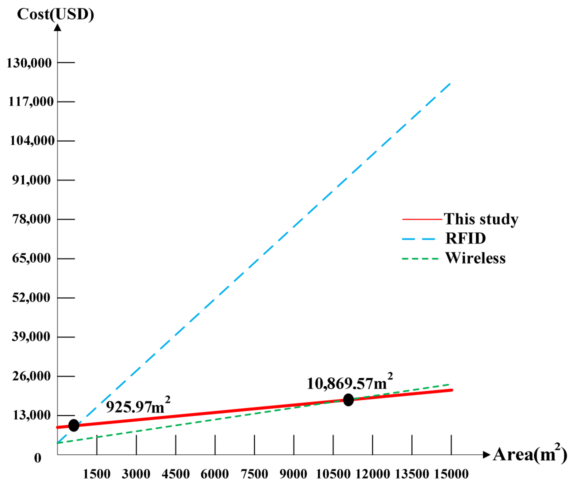

Fig.10. Total cost estimation of current indoor positioning/localization technologies

CONCLUSION

Based on the idea of using space images as the indoor space identification tags, this study adopted the IFC File Analyzer[7] and D'fusion studio development tools to facilitate the BIM-Vision-based indoor localization prototype. The spatial data in the existing BIM model can be transferred to the prototype via IFC files. Accordingly, the space information of system can be synchronized with the BIM model and the space relative information could also be imported to the system for more facility management functions in the future.

The proposed prototype system was tested to be a potential alternative method of indoor localization because the identification accuracy (60% ~ 80%) of the system is acceptable (for a prototype), and the economic analysis revealed the image-based indoor localization method could be an economic alternative for large scale buildings.

However, the capability of image recognition technology limits the application of the prototype. For now, the prototype has no function for the spaces with few or similar features, such as non-decoration rooms and similar-layout/decoration spaces. Therefore, the QR code is the alternative way to make up this functional gap for image-recognition-based localization technology.

Summarily, the indoor localization method proposed in this study is functioned as a space detector. Lack of the positioning mechanism, the coordinate location can't be provided by current application. However, combining with the Inertial Navigation System (INS), the advanced indoor positioning system could be implemented in the future.

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