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Prototype Development of a Spatial Information Management System for Large-scale Buildings

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Abstract

This paper presents a new model of a management system for large-scale buildings. Unlike previous systems for building management, the proposed system aims to deal with both static and dynamic spatial information in a single framework. For this purpose, 3D CAD, 3D GIS and image processing are integrated together. In the proposed system, the geometrical information of a building is managed by GIS using a database built from 3D CAD. Also, the dynamic spatial information (i.e., flow size of pedestrians) is obtained using image processing. We implemented a prototype version of the proposed system to a real environment and it showed promising results for a running system covering a wide area.

1. Introduction

With the growth of industrialization, buildings of metropolitan areas are becoming increasingly larger and more complex. The advent of large commercial buildings and multi-complex buildings has produced requests for a means to manage the utilization of spaces and to achieve public safety efficiently and effectively.

In the aspect of safety management, Visual Surveillance Systems (VSS) have been widely utilized. The conventional VSS consist of a number of distributed cameras and a control room. The video streams are transmitted to the control room keeping observation task totally under the control of human operators. Recently, to overcome the limitation of conventional surveillance systems, there have been efforts to embed intelligence to surveillance systems. In these Intelligent Video Surveillance Systems (IVSS), specific events are detected from the input of CCTV cameras to prevent accidents or crimes [1−3]. Threat assessment, object tracking, behavior understanding, and crowd analysis are common topics in IVSS.

For facility management, Building Management Systems (BMS) have played important roles [4]. BMS offers automatic monitoring and control services of buildings such as lighting, air conditioning, or energy management. Sensors, controls and communication are essential components for realization of such systems. Also, recently, researchers have focused on Building Information Modeling (BIM) as a means to manage buildings [5]. BIM integrates information and properties throughout the lifecycle of a building, including design, construction, operation and management. For this purpose, BIM usually adopts 3D building modeling software.

In this paper, we propose a building management system for large-scale buildings. The proposed system, named SIMS (Spatial Information Management System), aims to deliver spatial information of large buildings to users and administrators of the building. The spatial information includes not only static information like basic structures and facilities of the building, but also dynamic, time-varying information such as the amount of pedestrians in paths of the building. To achieve this, SIMS combines 3D CAD, 3D GIS and image processing techniques together. The structural information and facility information are managed by GIS. To create a GIS database, the basic structural information of a building is automatically extracted from commercial 3D CAD. Also, the sizes of pedestrian flow are estimated in real-time from CCTV inputs. The proposed system can support both facility management and safety management by integrating GIS, 3D CAD, and image processing to a single system.

The remainder of this paper is organized as follows. Section 2 gives an overall review of the proposed system. In Section 3, we explain the 3D CAD and 3D GIS in our system. Section 4 describes the image processing technique to measure the size of pedestrian flow. Section 5 introduces the implementation of the prototype system and Section 6 concludes this paper.

2. System Overview

2.1. System Architecture

Figure 1 shows a diagram of the proposed system. In the proposed system, videos are captured from distributed network cameras. The acquired video streams are delivered to image processing units and image processing units estimate the size of pedestrian flow from the input video streams in real-time. This flow size information is transmitted to the flow database for storing and further analysis. The GIS database contains the information of a building including the basic structures and dimensions (such as rooms, halls, doors and passages) and attributes of the spaces (such as name and usage of the space or opening hour). Structural information for GIS is extracted from 3D CAD automatically. The system control unit provides the functions for building management and information services by combining data from flow DB and GIS DB. It also includes a graphical interface to interact with the administrator and general-users.

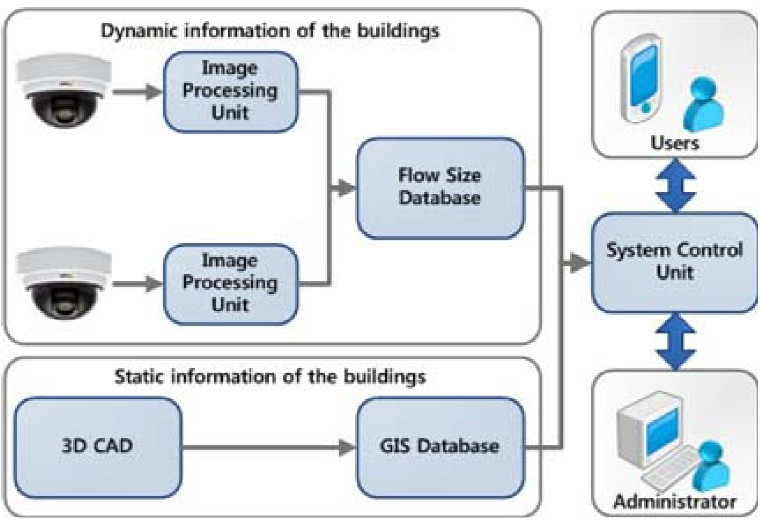


Figure 1. Diagram of the proposed system

2.2. Main Functions and Utilizations of SIMS

The main functions and possible utilizations of our proposed SIMS model can be described and understood as below.

Space Utilization Management: With the aid of GIS, it is able to monitor the condition of building utilization at a glance. Also, the pedestrian flow information offers a means to analyze flow patterns. Adopting GIS and flow statistics together, the administrator of a building space more effectively performs space planning, expansion of facilities, and arrangement of rents.

Safety Management: The pedestrian flow information can also be used detect unusual events. That is, the flow levels are monitored continuously and an alarm is occurred if the flow level is extremely high or quite dissimilar from its normal statistics.

Information Service: With a Web-based interface or kiosks, general users can connect to the system to get information services. They can find specific facilities and can also retrieve a path to a desired position.

Evacuation Guidance: In catastrophic situations, fast and proper evacuation guidance is essential to reduce casualties. Using the spatial information and flow information together, it is possible to guide people to evacuation while avoiding severe bottlenecks.

3. 3D CAD and 3D GIS

A geographic information system (GIS) is a tool that offers storing, retrieval, analysis and display for geographic data and its attributes. GIS is not only a tool for data display, but also a management tool or a decision support system [6]. GIS has been widely used in urban planning, utility management, and transportation systems.

To build a GIS system, it is first required to acquire spatial data of the target object or area. Generally, digitizing, surveying or scanning are used to achieve this goal. In our work, we extracted the spatial data directly from 3D CAD data. For this purpose, we developed a plug-in program for a commercial CAD tool. Basic structural information such as data defining rooms (i.e., positions of edges and corners, depth and length of walls) or openings connecting rooms (i.e., positions of doors/windows, width and heights) is automatically extracted from CAD data, but their attributes are specified manually. Then the generated spatial information is exported to an XML file to be fed to the GIS module.

For the 3D CAD tool, we used ArchiCAD, which is BIM CAD software by Graphisoft. Also, for GIS, IntraMap3D, which is a GIS engine developed by KSIC [7] was adopted. Figure 2 shows an example of the plug-in program added to ArchiCAD. Figure 3 shows examples of the extracted spatial information. Figure 3 (a) is an example of a 3D CAD model drawn in ArchiCAD and Figure 3 (b) represents the spatial information for the 3D model given in an XML file.

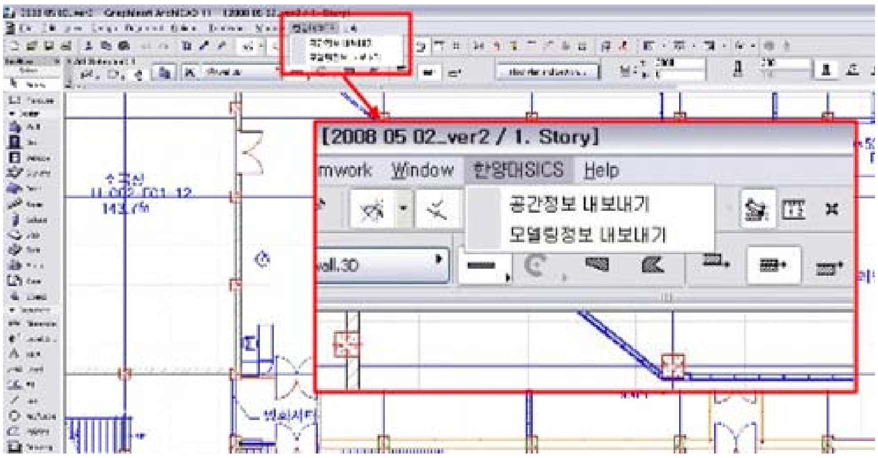
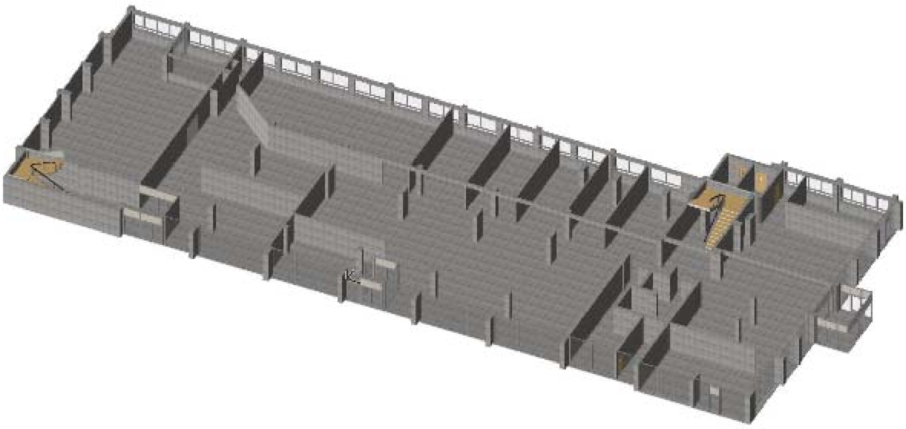


Figure 2. Add-on plug-in for ArchiCAD to extract spatial information



(a)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      </Opening>
    </Zone>
```


(b)

Figure 3. A result of ArchiCAD plug-in: (a) 3D CAD model for a building and (b) spatial information extracted in XML

4. Flow Size Estimation

In this section, the image processing method for pedestrian flow size estimation is introduced. In the method, the number of people who pass a predefined line, called a *virtual gate*, is counted automatically. Figure 4 shows examples of the virtual as white lines.

(a) (b)

Figure 4. Examples of virtual gates

In our work, to estimate the size of pedestrian flow, we took a statistical method that counts the number of people, who have passed through the gate, using the amount of foreground pixels observed on the virtual gate. Compared to previous detection-based methods [8][9], this statistical approach requires much less computation making it attractive to real applications.

The block diagram of the pedestrian flow estimation method is represented in Figure 5. First, image features are obtained from input frames in the feature extraction step. Foreground pixels and motion vectors are employed for image features here. Once the image features are calculated, feature integration follows. In this step, the sizes of the moving objects are estimated from the foreground pixels on the gate line. Then the size of pedestrian flow is calculated from the estimated size of the foreground objects that have passed.

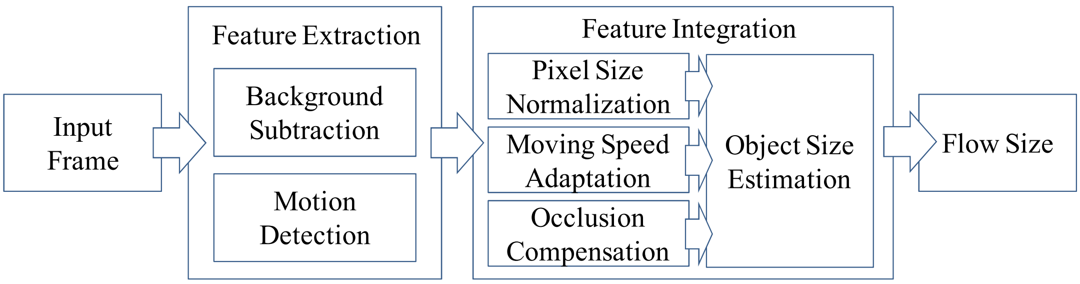
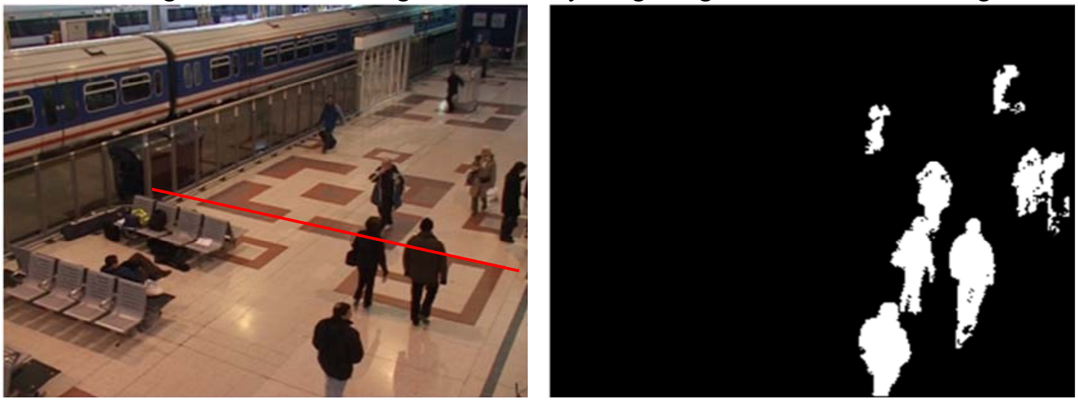


Figure 5. Block diagram of the pedestrian counting method

Figure 6 shows an example of background subtraction. Figure 6 (a) is the source image and Figure 6 (b) is the result of background subtraction. The number of pedestrians is estimated using the size of the foreground blobs by integrating features on the virtual gate.



(a) (b)

Figure 6. An example of background subtraction

However, the number of pedestrians cannot directly be estimated from the size of moving objects because of some distortions. Hence, a series of compensations are performed in the feature integration step. The first one is pixel size normalization. As shown in Figure 7 (a), people in different positions appear at various sizes due to camera projection. This problem is resolved by pixel size normalization. Secondly, different moving speeds of people can yield variations of object size since features are observed only at the virtual gate line in our method. We use moving speed adaptation to overcome the problem of different moving speeds of people. Finally, occlusions (shown in Figure 7 (b)) also prevent the estimation of the number of pedestrians by disturbing the observation of the foreground pixel count. The pixel loss occurred from occlusion is avoided by occlusion compensation in our method. More details of the flow size estimation method can be found in [10].

(a) (b)

Figure 7. Difficulties in estimating object size: (a) size variation and different moving speed;, (b) occlusion between people

5. Implementation of Prototype System

We installed a prototype version of the proposed system in a building at Hanyang University, Korea and tested the system for 8 days. The test area covered 935.25m^2, and 13 shops and restaurants are located along a main pathway. Also, the test area has 3 main gates. Figure 8 shows a schematic of the test area and positions of the installed cameras.

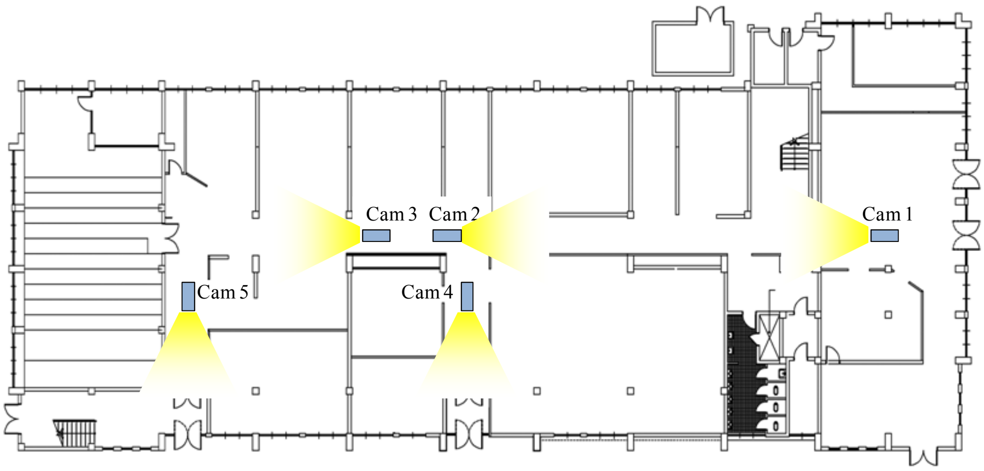


Figure 8. Schematics of test area and camera locations

For video acquisition, AXIS 216FD network cameras were used. These cameras were directly coupled to internal Ethernet and transmitted video streams in MJPEG format. The resolution and frame rate of video streams were 320x240 and 15fps. For image processing, a Pentium IV 2.4GHz PC was used. Only two of the image processing units were able to process the input of five network cameras in real-time. Computed flow size data was transmitted to a separate database server.

Figure 9 shows an example of the observed flow during test period for "Cam 1" in Figure 8. In the figure, the horizontal axis represents time variation and the vertical axis indicates the number of pedestrians. For display purposes, flow sizes are summed up every 30 minutes. Also, as shown in the figure, peak pedestrian flow appeared around noon. Also, it can be noticed that the size of the pedestrian flow was reduced almost to less than half during the weekend.

For quantitative evaluation, we also compared obtained flow size estimation results with manually counted pedestrian number. A manual count took place twice, 30 minutes each, around the busiest period of time. Table 1 shows the comparison results. As shown in the table, most of the experiment showed a relative error less than or about 5%. However, camera 4 showed a relative error of 17% from 12:00 to 12:30. This large error rate was induced by people hovering around the gate line, which was set in front of a restaurant.

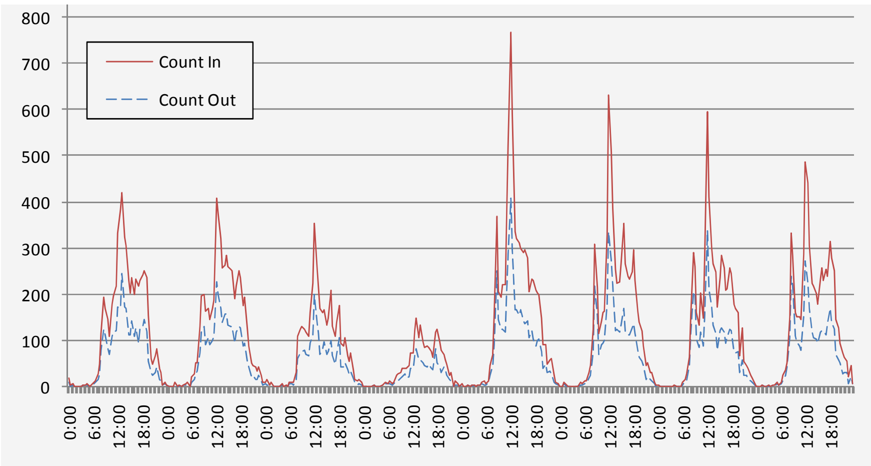


Figure 9. An example of flow size estimation result

Table 1. Flow size estimation results

Camera ID	Time	Ground Truth		Flow Size		Relative Error	
		In	Out	In	Out	In	Out
Camera 1	12:00-12:30	185	151	193	154	4.32%	1.99%
	13:30-14:00	191	152	177	152	7.33%	0.00%
Camera 2	12:00-12:30	160	148	148	143	7.50%	3.38%
	13:30-14:00	147	137	143	140	2.72%	2.19%
Camera 3	12:00-12:30	141	140	137	136	2.84%	2.86%
	13:30-14:00	99	102	103	101	4.04%	0.98%
Camera 4	12:00-12:30	70	73	80	86	14.29%	17.81%
	13:30-14:00	67	49	66	52	1.49%	6.12%
Camera 5	12:00-12:30	51	59	52	55	1.96%	6.78%
	13:30-14:00	79	77	75	69	5.06%	10.39%

6. Conclusions and Future Works

In this paper, we presented a new concept for a building management system. In the proposed system, static spatial information (geographical information) of a building is managed by GIS and dynamic spatial data (pedestrian flow) is obtained by image processing. To acquire spatial data for GIS, we developed a plug-in module that extracts the basic measurement data of a building from 3D CAD data directly. The size of pedestrian flow is automatically extracted using an image processing technique in real time. We implemented a prototype version of the proposed system to a real environment. The prototype system showed that both static and dynamic spatial data can be properly obtained from the proposed system.

Even though the prototype version of our system showed promising results, it was not sufficient to fully realize all the utilization scenarios described in section 2 of the paper. Currently, we are expecting to expand our work to a large-scale system. To achieve this, the following will be considered. First, methods that use extracted flow size in a global manner will be studied. They will include statistical analysis tools and optimal path computation for evacuation guidance. Secondly, for the image processing algorithm, efforts to lower the computational cost will be carried out. Also, researches for event detection to increase safety management functionality of the system will be performed. Finally, HCI will be emphasized to make the system more useable. For this, web-based interfaces will be developed to interact with general users.

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