Benefits from Utilizing A Conceptual Model of Indoor GIS Based Evacuation Information System

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Abstract

When an emergency situation happens in buildings, the top priority is to ensure the occupant from danger as soon as possible. Achieving that goal is a multifaceted and difficult task. However, current evacuation systems have many deficiencies in dealing with the emergency in multi-level structures. The shortage of abilities to continuously update database, predict the future situation and provide the information to users with contextual information is the limit in current systems. Thus, it is very crucial to introduce Evacuation Information System (EIS), which is able to respond quickly to the emergency, and transfer the information to both the administrator and the occupant. The main purpose of this paper is to build EIS on the basis of the indoor Geographical Information System (GIS). When the emergency happens, EIS gives the instruction to Emergency Response Model (ERM) at once. ERM carries out the order and calculates the optimal evacuation routes, then sends the result to EIS. At last, EIS transmits evacuation messages to the occupant who implements evacuation plan. This paper highlights the benefits of EIS in two aspects. One is that EIS can update the data continuously to support evacuation strategy-making. The other is that it can transmit evacuation messages to both the administrator and the occupant.

Keywords : *Indoor GIS, Evacuation Information System, Emergency Response Model, Spatial Information Control*

1. Introduction

As more advanced construction techniques are applied today, a great number of complicated high-rise structures, which show up one by one, may result in many problems. It is known that many kinds of multi-hazards due to natural calamities, terrorist attacks and other crime take place in micro-scale environments. According to official report of 911, 343 firefighters including 2 paramedics lost their lives during rescuing the occupier, which accounted for 12.46% of the total death toll. From this analysis, the importance of

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evacuation management and plan of high-risk buildings for emergency situation has attracted public attention. However, current evacuation systems have many deficiencies in dealing with the emergency in multi-level structures. The shortage of abilities to continuously update the database in specific space, predict future situation, and provide this information to users with contextual information is the limit in current systems. According to the 9/11 Commission Report, the operators and dispatchers were one of the only sources of information for individuals at and above the impact zone to the tower. Any evacuation strategy can be useless if the occupant are not aware of how the evacuation systems function in an emergency and if the occupant don't have practiced evacuation guidance. Thus, it is very crucial to introduce Evacuation Information System (EIS) which is able to make a quick response to the emergency, and transmit evacuation information to the occupant.

The main purpose of this paper is to build EIS on the basis of indoor Geographical Information System (GIS). When the emergency happens, EIS gives the instruction to Emergency Response Model (ERM) at once. ERM carries out the order and calculates the optimal evacuation routes, and then sends the result to EIS. As the information is continuously updated, ERM can recalculate evacuation routes, generate new evacuation strategy, and send the information to EIS. Based on the information and data analysis, the administrator makes the evacuation decision about how to control the human flow, which part of information should be conveyed to the occupant, and which way should they choose. At last, EIS implements the evacuation plan, and transmits evacuation messages to the occupant. This paper highlights the benefits of EIS in two aspects. One is that EIS can update the data continuously to support evacuation strategy-making. The other is that it can transmit evacuation messages to both the administrator and the occupant.

2. Background

2.1 Current Evacuation System

Evacuation systems are designed as to protect the occupier in emergency situations in a building. The traditional design of the evacuation systems in a building normally follows the prescriptive requirements stipulated in construction regulations. Generally speaking, the traditional security system often includes following systems:

Access control system; It determines who allowed to enter or exit the building, and where and when they are allowed to enter or exit. These can be enforced by door controllers such as a border guard, a doorman, a ticket checker, or with a device such as a turnstile. It may include cards, fingerprints with readers, personal identification numbers (PINs) with keypads, and egress motion detectors. This system can exclude undesirable people and record the entrance information.

Detection system; It is composed of many sensors, effectors and control units that are interconnected. Usually, it includes video motion detectors, infrared, vibration, closed-circuit television, fiber optics, and proximity sensors.

Alarm system; It sounds the alarm once the emergency takes place. Horns, chimes or bells, in combination with strobe devices, are generally used to notify the occupant of a building evacuation.

Emergency guide system; It is designed to allow the occupant to identify the nearby environment and indicate the direction to the exit. Usually it includes the emergency light system and guideboard.

Evacuation simulating system; It makes it possible to display perspective view of the pedestrian movements in indoor space on computer. Also it is a good method of understanding the evacuation performance and evaluating the building safety.

However, the traditional evacuation system is just a predefined system, no matter what will happen, where the emergency takes place and how many occupiers are there. It can't respond to the emergency immediately, and just gives simple instructions. As the emergency situation become more complex and diverse nowadays, it is difficult to deal with the it efficiently. Thus the shortage of the abilities to continuously update the database and provide the occupier with contextual information for their specific places and time is the essence of the problem in current evacuation system.

2.2 Previous Researches on Evacuation Information System

Many researches have been solving evacuation problems. Chalmet et al. (1982) carried out a research on the network models for building evacuation, and Jarvis et al. (1982) focused on dynamic network flow problems. Their ideas have been developed by many other researchers such as Mamada et al. (2003), Kamiyama et al. (2006), and so on. As the emergency situation becomes more and more complex, most of the evacuation models ask for the utmost understanding of the indoor spatial information and the continuous update of evacuation information. Then Chen et al. (2008) pointed out the importance of the information in evacuation. So the establishment of EIS is very crucial to the evacuation both in finding the optimal route and providing communication.

Indoor GIS is the foundation of EIS, especially for the information support system of EIS. Since early 1980s, much GIS-based research has been conducted to resolve evacuation problems at an urban scale, and then been developed to indoor space, such as the space in the multi-lever building, ships, and so on. Then the concept of indoor GIS was formed. Indoor GIS is a system that provides information and mapping applications for a building using the building's plan for each floor together with the building's infrastructure data. And now it has been customized for building and infrastructure management applications, especially for evacuation. Compare with traditional evacuation system, it is easy to find out that indoor GIS has many advantages, especially in real-time and location-aware applications, and its quick response to the emergency. Thus, it can work well in providing dynamic data and implement evacuation plan for EIS.

3. EIS based Building Evacuation

3.1 General Idea

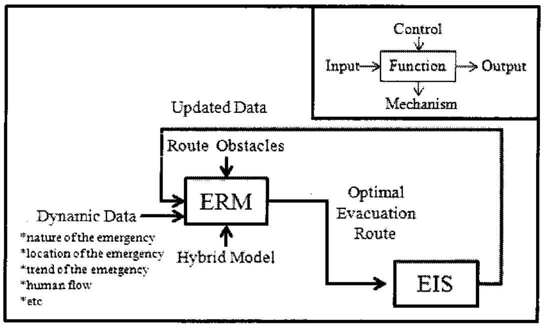


Fig.1. Schematic Presentation of EIS Based Building Evacuation

The Integrated Computer Aided Manufacturing (ICAM) Definition Method (IDEF) is used to develop the indoor GIS based evacuation. In ICAM's definition, each box in the diagram represents a function which could be an activity, action, process, operation, or a transformation. The Input may be any information or material resource. The Output includes entities which result from a process or object which are created by a function. The Control elements are entities which influence or determine the process of converting input to output. The Mechanisms are entities, such as a person or a machine, which perform a process or an operation.

As shown in Figure 1, when an emergency happens, dynamic data are input immediately, and route obstacles are identified. Then ERM calculates the optimal evacuation route, and sends it to EIS. As the emergency is changing all the time, EIS continuously sends the updated data to ERM in order to obtain the new optimal route.

3.2 Dynamic data

The traditional security system mainly focuses on the static data. As inner designs of the building get more complicated than before, the static data can not meet the suddenly intensive needs for the emergency. Movements of pedestrians to a refuge location, as well as total evacuation, require the utmost understanding of the current situation. It is apparent that one of keys to the success of the evacuation is effectively updating the data, which can reflect the real-time emergency information, and be used for effective and highly precise algorithms of

short time emergency prediction. The dynamic data often includes:
(1) The nature of the emergency
(fire/blast/ toxicity/ nature disaster, etc);
(2) The location of the emergency
(floor/ room, etc);
(3) The trend of the emergency;
(4) Human flow (direction/ density, etc);
(5) The present available rescue resources.

3.3 Route Obstacles

A key component of the ERM is the identification of route obstacles, which is the precondition of selecting optimal evacuation routes. Obstacles can be divided into two categories. One is the inborn obstacle existing before the emergency, such as ash-bin, fire extinguisher, equipment, and so on. The other is the new-generated obstacle, such as fire, smoke, toxic gas, collapse structure, congestion of the path, and so on. As fire, heat and toxic gas may cause harm to human body, the smoke may bring down the visibility and slow down the walking speed, and the collapse structure constitutes the danger to the pedestrian, so all these obstacles impose limitations and restrictions on the route selection.

3.4 Emergency Response Model (ERM)

ERM is a combination model that uses building models, route algorithms, and simulation tools to make the evacuation plan. With the data from EIS, ERM can calculate the optimal route, evacuation schedule, and the allocation of human flow, then send the feedback to EIS. Each building has its own appropriate ERM because of different structure complexity, management object, and budget limitation.

3.5 Building Models

Presently, there are several models available for converting a building's architecture structure to a computerizable model with the help of advanced technologies and methodologies. As shown in Figure 2, three building models are popularly used, which are geometry model, symbolic model and hybrid model.

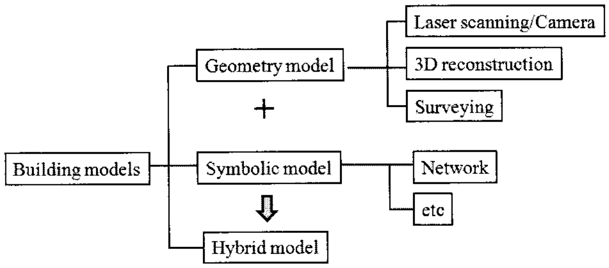


Fig.2. Types of Building Models

Geometry model is often a 3D model that reconstructs the interior scene of the building to give a visual effect to the people. The methods to build geometry model can be generally categorized into three approaches, including laser scanning or camera pictures, 3D reconstruction and surveying.

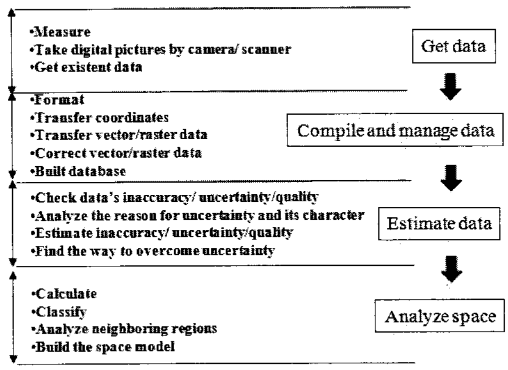


Fig.3. Laser Scanning/Camera Image Process

With respect to building a model by using laser scanning or camera, the popular process is listed in Figure 3. Firstly a great number of building data are obtained in the form of points by using camera or scanner from different directions on the basis of the architecture blueprint. Secondly, proper transfer coordinates is set up to transfer these points into planes and contours. Because an object is often composed of many planes and contours, let alone the whole indoor environment, so the transfer work is a little difficult and time-consuming. Based on the work done before, the preliminary model is built. Since some points are manually or half manually eliminated when planes are identified, the inaccuracy, uncertainty and the quality of the remained data have to be checked carefully to confirm the accuracy of the model in the third step. The last step is to analyze the neighboring regions to obtain the most representative space model.

3D reconstruction often uses 3D software to imitate the real world, which can not easily be represented in words or even through illustrations. 3D reconstruction can show the detail of the inner part of building more precisely than the models that use laser or camera. So far, there is a great deal of software such as AutoCAD, ArchiCAD, Sketch Up, Revit Architect and so on, which helps communicate design proposals more quickly and clearly, offers better design insight through on-demand visualization and analysis, and provides a process that mirrors the real world of building as in Figure 4.

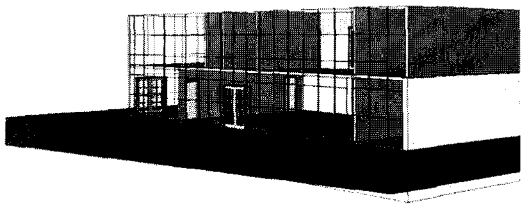


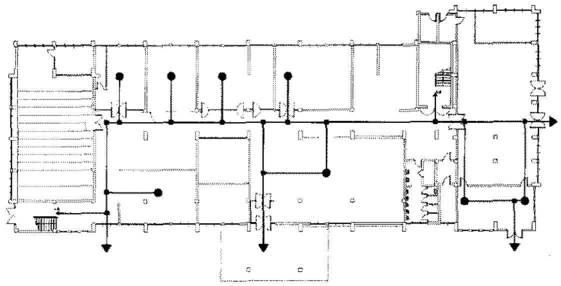
Fig.4. 3D Model of Hanyang Plaza

Of course, if the requirement for the model is not strict, the geometry model can be simplified to few points. In this situation, only some simple surveying can solve the problem.

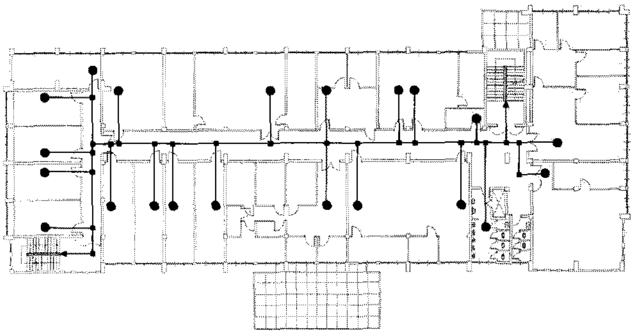
So far, most works of making geometry model are manually or half-manually inputting the geometric information into the computer, so it takes a great deal of time and energy to finish the model. Although it is a bit time-consuming to make geometry model, geometry model is a tremendous marketing tool. And compared with other geometry models, 3D model can graphically simplify complicated concepts and convey complex inter-relationships easily, which are difficult to visualize. Thus, 3D model is more popular.

Symbolic model is a model that use symbol to express the interrelationship of different departments of a building with the help of indoor GIS and digital computers. The network model is widely used in symbolic model.

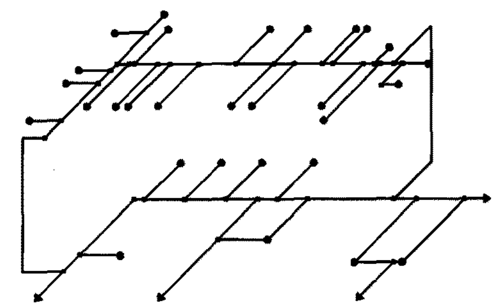
The network model represents each room/crossing/exit in the building with a node, and represents paths with links between nodes. Each node contains much information such as the type of this node, the distance between this node and the next node, the width of the space where the node exists, and so on. Because the network is able to contain the quantity information about the building, it is often used for calculating. For example, in the Figure 5, firstly we use the circle to represent the room, the rectangle to represent the crossing, and the triangle to represent the exit of each floor, and then we could connect the entire floors in one layout. And the distance between any two points can be quickly obtained.



a) The Network of the First floor



b) The Network of the Second floor



c) Network of Hanyang Plaza

Fig.5. Network model of Hanyang Plaza's 1st Floor and 2nd Floor

Hybrid model is a model that combines the geometry model with the network model. On one hand, it's very difficult to extract the route from geometry model so far, while the network model could present the routes in the building well. On the other hand, it takes a long time to understand the network model especially for the people who are under the pressure, while geometry model can be easily recognized. That is why it is necessary to use both models for evacuating. The administrator of the building can use network model to decide the optimal route, while the occupant can use geometry model to find the evacuation route.

4. Indoor GIS Based Building Evacuation Information System (EIS)

4.1 General Structure

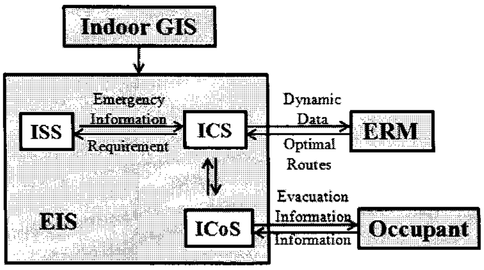


Fig.6. Information exchange between ERM and EIS

EIS is built on the basis of indoor GIS. Generally speaking, indoor GIS has the following functionalities:

(1) Grasping the ever-changing scene of a situation in stricken area;

(2) Rapid discovery and access to disparate internal spatial information sources so as to support crisis response strategically and effectively;

(3) Innate ability to rapidly access and process spatially enabled accurate data to analyze current situation, and utilize emergency simulation to help crisis response;

(4) Sharing information among crisis related organizations and provide information effectively to citizens;

(5) Visual access to make it easily understood.

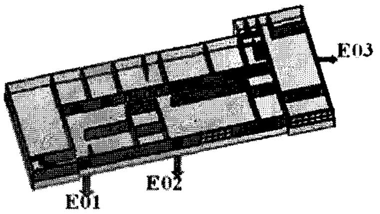
With the help of indoor GIS, EIS is able to prepare information for both daily management and emergency response in micro-space. Obviously the construction for an efficient and effective EIS to meet the requirement of dynamic navigation and prediction is the key point of the evacuation. And the realization of this system refers to three participants including Information Support System (ISS), Information Control System (ICS) and Information Communication System (ICoS).

A good implement of evacuation needs to exchange information frequently between EIS and ERM. Once ISS detects that there is an emergency, it sends the emergency information to ICS. ICS conveys the order and dynamic data to ERM immediately. ERM carries out the order, analyzes the emergency situation, calculates the optimal evacuation routes and possible evacuation strategy, and gives the feedback. ICS makes the final decision and implements the evacuation plan. A good evacuation plan requires for a good cooperation between the administrator and the occupant. Thus, the role of ICoS is very important. On one hand, it transmits evacuation information including the plan and the route from ICS to the occupant. On the other hand it sends feedback from the occupant to the ICS. As the data is obtained continuously, ICS can be accurate and flexible to modify the evacuation strategy according to current situation, which can ensure the success of the evacuation.

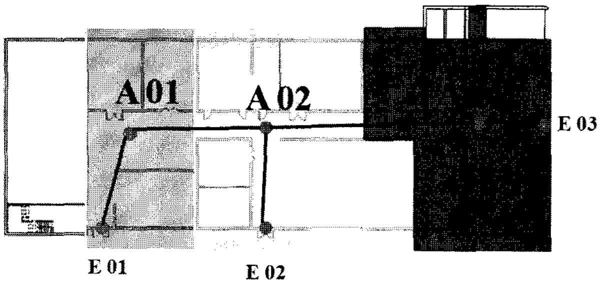
4.2 Information Support System (ISS)

ISS mainly includes GIS technologies such as Global Positioning System (GPS), Telecom and Assisted GPS, Radio-frequency identification (RFID) based location, and many sensors in the building such as the thermal sensor to measure temperature and heat, the mechanical temperature to measure pressure, gas and liquid flow, the chemical sensor to measure chemical proportion, and so on. ISS enables administrator to determine occupants' location, speed, direction, time, and emergency information. Selecting the right combination of detection devices depends on the building's specific needs.

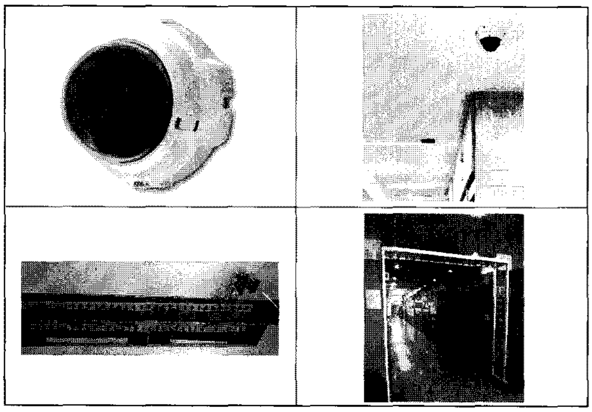
In order to find proper places for installing ISS, hybrid building model should be built on the basis of architecture blueprint and layers. For example, in order to measure the human flow on the first floor of Hanyang plaza, we built the building model of Hanyang plaza, and easily found that there are three exits including E01, E02 and E03 on the first floor in the Hanyang Plaza as shown in Figure 7(a). After considering both the structure and the function of the first floor, we simplified the network model of Figure 5(a), and then divided this floor into three areas which are A01, A02 and A03 as shown in Figure 7(b). Then five cameras and one sensor were chosen to ensure that all the data of three areas can be collected as shown in Figure 7(c). And their site positions are shown in Figure 7(d).



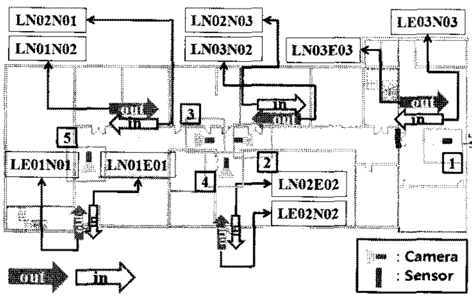
a) The Geometry Model of the First Floor



b) The Division of the First Floor



c) The ISS Devices



d) The Installation of ISS

Fig.7. Installation of Cameras and Sensor in Hanyang Plaza

4.3 Information Control System (ICS)

As shown in Figure 8, ICS consists of administrator, GIS server and database. And the database is further divided into indoor GIS simultaneous database and static database.

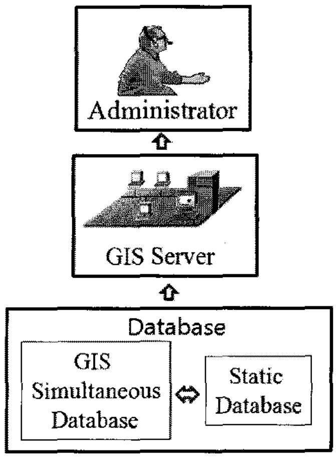


Fig.8. The Information Control System

The static database includes all the static data such as the static network, the equipment allocation, and so on. For example, the area link IDs for Figure 7(d) can be deposited in the static database as shown in Table 1. As camera can measure the persons who come in or go out of this area, IDs for each data can reflect the direction. Thus, ID LN02E02 represents the data of the human flow from Node 02 to Exit 02. Compared to static database, indoor GIS simultaneous database mainly describes the current situation such as dynamic data from cameras and sensors, the dynamic network, the spatial-temporal relations, the pedestrians' relations, and so on.

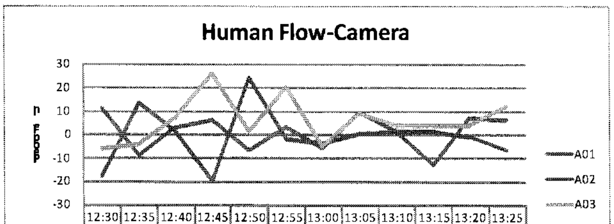
Table 1. The Area Link ID

Camera	People_in	People_out
C1	LE03N03	LN03E03
C2	LN02N03	LN03N02
C3	LN02N01	LN01N02
C4	LN02E02	LE02N02
C5	LN01E01	LE01N01

After obtaining all the relevant spatial information from database, GIS server will deal with the dispersive real time information, simulate the emergency, calculate the most proper routes of the pedestrian, predicts the event trend with ERM, and then sends all the information and result to the administrator. For example, as regard to the human flow in Hanyang plaza, combining Figure 7(d) with Table 1, we can calculate the human flow in the A01, A02, and A03 are by using the following formula:

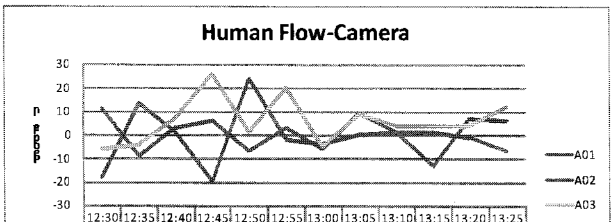
Num_A01=LN02N01+LE01N01−LN01N02−LN01E01
Num_A02=LN03N02+LN01N02+LE02N02−LN02N03 −LN02N01−LN02E02
Num_A03=LE03N03+LN02N03−LN03E03−LN03N02

The human flow data from 12:30 to 13:25 on the certain day are calculated by GIS server as shown in Figure 9(a). To test the accuracy of the data from cameras, the correct data are collected at the same time as shown in Figure 9(b). And the accuracy rate is 90%, which means the data from the camera are reliable.



	12:30	12:35	12:40	12:45	12:50	12:55	13:00	13:05	13:10	13:15	13:20	13:25
A01	11	-9	3	6	-7	3	-6	9	1	-13	7	6
A02	-18	13	1	-20	24	-2	-4	0	1	1	-1	-7
A03	-6	-4	7	26	1	20	-5	9	4	4	4	12

a) The number of Human Flow from Camera



	12:30	12:35	12:40	12:45	12:50	12:55	13:00	13:05	13:10	13:15	13:20	13:25
A01	11	-9	3	6	-7	3	-6	9	1	-13	7	6
A02	-18	13	1	-20	24	-2	-4	0	1	1	-1	-7
A03	-6	-4	7	26	1	20	-5	9	4	4	4	12

b) The Accurate number of Human Flow

Fig.9. Human Flow in Hanyang Plaza

4.4 Information Communication System (ICoS)

ICoS plays the role of the medium between the administrator and the client. Once the evacuation decision is made, the information is sent to the occupant by ICoS. At the same time, the occupant can ask for evacuation information and other requirement. ICoS doesn't only apply wireless technologies such as Cellular, Bluetooth, readers and so on to permit services that are impossible or impractical to implement with the use of wires, but also uses alarm system to warn the occupant. Since the expansion of 3G networks provides constant high-speed internet access perfectly in an era of mobility and real-time responsiveness, ICoS can also be used as navigator for escaping from the origin to the destination. As shown in Figure 10, the evacuation route which is marked as the red one in the mobile devices, can be easily understood and used by the occupant.

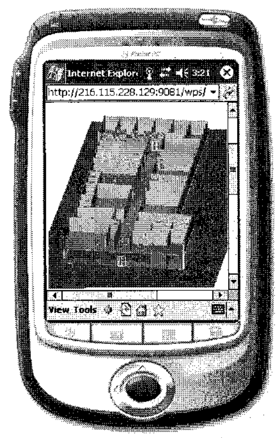


Fig.10. Use ICoS to find the way in Hanyang Plaza

4.5 The Response to the Emergency

The emergency can take place at any time in any place. Based on the long-term data from ISS, the administrator could find regulations such as when is the rush hour in a place, which exit they like to choose, and so on. And according to simultaneous database, the administrator could judge the situation and make the decision. Take Figure 9 for an example, we assume that the emergency took place at 12:45 on that day.

Referring to Figure 9, as restaurants and coffee shops were located in A02 and A03 areas, the human flow changed greatly during the lunch time from 12:30 to 13:00, and became much steadier from 13:00 to 13:25, while the human flow in A01 were always steady. So most people crowded in A02 and A03 areas, and they preferred E02 or E03 to E01 at 12:45. if the emergency took place, and the occupant got the emergency information without the guidance, they may go out at E02 or E03, which might result in congestion and stagnation in A02 and A03 area, and might slow down the evacuation speed. In order to avoid this situation, on the one hand, ICS would evacuate the occupant on the basis of the optimal route, on the other hand, it could advise some occupants who were near E01 to go out at E01 in the A01 area by ICoS.

Thus, the application of EIS can eliminate potential risks which could bring down the evacuation speed to ensure a quick evacuation.

5. Conclusion

Because of the deficiencies of current security system and evacuation system, there is a need to develop more advanced technology which can impose a strict supervision on the building safety, control the indoor information, simulate the evacuation situation, and guide the occupier. Thus, EIS is introduced. This paper highlights the benefits of indoor GIS-based EIS in two aspects. One is that EIS can update the data continuously to support evacuation strategy-making. The other is that it can transmit evacuation messages to both the administrator and the occupant.

The first part of this paper introduces four elements, which are important to the building evacuation. These elements are dynamic data, route obstacles, emergency response model, and building models.

In the second part, EIS could be built with the capabilities provided by indoor GIS and available communication technique. EIS, which can be applied for guiding the occupier in the building, mainly consists of information support system, Information Control System, and Information Communication System. Information Support System offers the information, Information Control System deal with the evacuation information, and implement the evacuation plan, and the Information Communication System makes the communication available.

Combines with indoor GIS, EIS is able to be used for responding to the emergency situation quickly and intelligently. The experiments performed in current study proved the reliability of EIS. Five cameras and one sensor were installed in Hanyang plaza to collect the human flow data. And the data accuracy rate is 90%. As EIS is feasible for evacuation, other successive experiments related to human density and evacuation behavior will be carried out later to quicken the practical use of EIS in the indoor space.

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