A Prototype for a Real-Time Indoor Evacuation Simulation System Using Indoor IR Sensor Information

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***Abstract*—Indoor fire simulators have been used to analyze building safety in the event of emergency evacuations. These applications are primarily focused on simulating evacuation behaviors for the purpose of checking building structural problems in normal time rather than in real time situations. Therefore, they have limitations in handling real-time evacuation events for the following reasons. First, the existing models mostly experiment with artificial situations using randomly generated evacuees, while the real world requires actual data. Second, the operation takes too long to generate real time data. Third, they do not produce optimal results for use in rescue or evacuation guidance. In order to overcome these limitations, we suggest a method to build an evacuation simulation system that can be used in real-world emergency situations. The system performs numerous simulations in advance according to varying distributions of occupants. Then the resulting data are stored in a DBMS. The actual data of people captured by an IR(infrared) sensor network are compared with the simulation data in the DBMS, and the queried data most closely is provided to the user. The system has been tested in a campus building, and the suggested processes are illustrated.**

Keywords-indoor evacuation simulation; DBMS; IR sensor; evacuation guide.

I. Introduction

In order to minimize damage from increasing disasters such as fire, collapse in indoor spaces, many studies on indoor evacuation models have been done to predict pedestrian's evacuation situations. Many evacuation models have been developed to model and visualize the evacuation patterns of the pedestrians. However, the primary purposes of these models are focused on building safety evaluation in such events [1, 2, 3] and they have limitations to be used for pedestrian's evacuation guide or rescue activity at the time of actual situations as follows:

First, existing evacuation models use the virtual human data to perform the simulations. However, in order to use the distribution of the real occupants, it is required for the models to have inter-communication functions with indoor sensors to find out real-time information about the present occupants in a building [4]. It is essential to have information of the present occupants acquired from the indoor sensors if the result data can be used for actual disaster situations. Second, there are time constraints for simulation results to be used in real-time situations. Since many factors, for example, physical and psychological aspects of evacuation patterns and building structures are considered in the simulation, it takes much time to generate simulation results [5]. Third, the main purposes of the most existing models studied previously have been focused on evacuation safety inspection of buildings, or have been developed for research or testing of algorithms [3]. However, if the evacuation simulation results can be used for reference data of evacuation guide or rescue operations, appropriate simulation results (*e.g.* total evacuation time, evacuation routes, the number of evacuees for each exit door, and expected bottleneck spots, etc.) should be created.

In this study, the following methodologies are proposed to solve the limitations described above. First, in order to solve the time constraints of the simulation running time, we used a method to query ready-made data instead of creating data in real-time. In our model, many simulation results are generated beforehand, and from them, results which match up with the similar conditions of the specific situations are queried and visualized. To this end, a large number of simulation results for a variety of situations (*e.g.* occupant information, simulation parameters, disaster occurrence spots, etc.) should be accumulated and stored in a system. Therefore, a DBMS-based simulation management system is required to manage a huge number of simulation results. In this study, we developed a system that can store simulation results in a DBMS. Simulation results about a variety of present occupants distribution by changing the distribution are firstly obtained, and those simulation results are stored in the DBMS. The stored data in the DBMS are transformed to be used for reference data of evacuation guide and rescue operations for evacuees. We present a process to obtain real-time placement information about occupants via inter-operation between the evacuation simulator and indoor IR(infrared) sensors, and then, to generate simulation results based on the information. The actual data of people captured by the IR sensor network are compared with the simulation data in the DBMS, and the queried data most closely is provided to the user. The system has been tested in a campus building, and the suggested processes are illustrated.

II. Related Works

A. Pedestrian modeling

The pedestrian behavior pattern modeling has been studied in various areas [6]. Among them, the social force

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model (SSM) has been used to model pedestrian movements in indoor spaces from microscopic points of views [7, 8, 9]. Also, the cellular automaton (CA) based floor field model (FFM) that generates the similar results has attracted attention [10].

In this study, the FFM-based evacuation simulator was implemented and used, which is advantageous in operation speed [11, 12]. The FFM divides indoor spaces into grid cells, and using two field values, the static floor field (SFF) and dynamic floor field (DFF), pedestrian's movements are modeled [13, 14]. In the study, the basic FFM theory and different parameter values were used and the patterns of pedestrian movements was represented by adjusting the sensitivity parameters of SFF and DFF. In particular, among the parameter values in three situations defined in [15], we used those of the cooperative regime case ($k_s=0.4$, $k_d=0.1$, $\alpha=0$, $\delta=0.3$) by modifying k_s (0.4 to 1.0) in order to increase the moving speed of pedestrians toward exits. These parameters influence the pedestrian movements significantly, and can be set appropriately for various situations to perform simulations.

B. Evacuation models

Previously, many evacuation models have been studied and developed for many purposes such as fire situation analysis, pedestrian pattern analysis and evacuation safety analysis. In [16], many previously developed evacuation simulators were compared and analyzed. In this study, data outputs generated by some representative models among them were reviewed and summarized as follows:

The analysis results showed that most of the models produced initial occupant distribution, total evacuation time, and the number of total evacuees. Also, while some models produced additional information such as building information, evacuees by hourly basis, evacuation time and route by occupants, and the number of evacuees by exit doors per hour, other models such as ASERI and EGRESS even generated the bottleneck spots. Egress Section in FPETool, Simulex, and EXIT89, which were applicable to be used in multi-layered space structures, produced information such as stair information and vertical travel time. The evacuation simulation system proposed in this study should produce the resulting data which is compact to be stored in the DBMS and highly applicable to the actual disaster situations.

Also, existing developed evacuation simulators such as Simulex and buildingEXODUS were mostly commercial programs, which were impossible to modify or add new features. In this study, since generation of the required resulting data and storage of the simulation results in the DBMS were needed, which were not present in the existing evacuation models, an evacuation simulator including the required features should be developed based on the one developed by the authors [17].

C. Indoor occupants detection sensor

In order to find out the indoor occupants distribution or the number of indoor occupants, a variety of sensors such as Infrared (IR) sensors, RFID, heat detection sensors, weight detection sensors, Zigbee sensors, and camera sensors have been used. In [18], using an indoor camera sensor, a method of acquiring the location information of moving objects (pedestrians) was proposed. In [19], using the video information acquired by CCD cameras installed at the exit doors, information of moving objects was obtained too. In [4], a detection system was proposed to find the number of pedestrians and moving direction by measuring heat generated by pedestrians using the IR distance measurement sensor. In [20], a system to trace moving objects based on IR was proposed.

The required information in this study was the distribution of occupants by each room, and accurate location information for each occupant was not needed. Since distribution information of the occupants based on the number of the occupants in each room or hallway was needed, exit or entry information of the occupants was only acquired. A sensor which is appropriate for acquiring the exit or entry information of the occupants is an IR sensor. In this study, a sensor network was configured to collect the actual occupants data by installing IR sensors at certain areas of the campus buildings, which will be described in detail in the next section.

III. SYSTEM DEVELOPMENT

A. Generation and storage of the simulation results

In this study, a large number of simulation results were stored in the DBMS beforehand, and a system was implemented to search and output resulting data for a specific situation through queries. For this, resulting data which can be stored in the DBMS should be selected first, and then a database schema for them should be designed. As discussed in Section II, evacuation simulations were performed using the FFM with some modified parameters in this study [17]. The resulting data to be generated and stored were summarized in Table I.

For more explanation of Table I, basic storage information included initial occupants' distribution, total evacuated occupants and time, and algorithm parameters. For

TABLE I. TYPES OF THE GENERATED DATA

Resulting data	**Information to be stored in DBMS**
Initial occupants distribution	Initial location coordinates for each pedestrian
Total evacuated occupants	Total evacuated occupants
Total evacuation time	Total evacuation time
Algorithm parameters	The algorithm parameters used in the FFM
Evacuated occupants by exit door	Evacuated occupants collected by each exit door
Evacuation route by each room	Coordinates list for the travelled route by selecting a representative occupant for each room randomly
Expected bottleneck spots	Cell occupancy degree value for each cell by calculating pedestrian's occupancy

the initial occupants distribution, simply put, the number of occupants in each room was stored, and initial position for each pedestrian can be stored as cell coordinates in more detail. The total evacuated occupants and time, which are the information provided by most evacuation simulators, were suitable to be stored in the DBMS. The algorithm parameters mean the parameter values of k_s, k_d, α, and δ, which were applied to SFF and DFF in the FFM. These values should be stored because evacuation patterns changed greatly by changes of these values [15].

In this study, together with basic information, additional information which can be required for actual disaster situations was produced as the resulting data which was then stored in the DBMS. The evacuated occupants by exit doors were collected and stored by calculating evacuated occupants by each exit door during the evacuation simulation running. The evacuation route for each room was stored by selecting a representative occupant of each room and storing his/her travel coordinates during evacuation. The reason for the selection of the representative for each room was to minimize data size otherwise too large to be stored in the DBMS. Finally the expected bottleneck spots represented information about bottleneck which can be occurred during evacuation at the hallways, doors or exits. In this study, the number of pedestrians occupied in each cell was recorded and this data was called the cell occupancy degree. If the distribution of the cell occupancy degree in an indoor space is known, then areas where pedestrians were crowded can be estimated. Figure 1 shows the visualization of the cell occupancy degree. The figure represented the cell occupancy degree by dark colors and showed that occupancy was most frequent at the lower exit. Based on this information, it can be estimated that which areas are likely to have bottleneck.

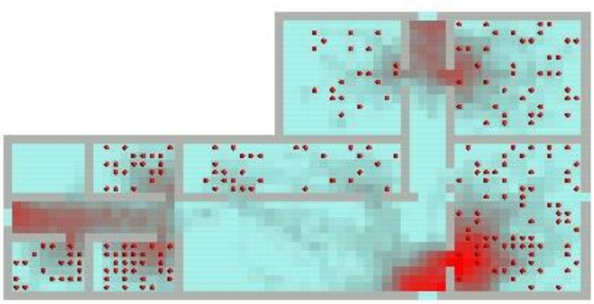


Figure 1. Example of cell occupancy

TABLE II. DBMS SCHEMA

Table	Schema
Sensor Detection Occupants	ID, Person, Type(FK), Time, TotalPerson
Sensor Type	ID, TypeDescription
Simulation Results	ID, Building, Person, TotalPerson, Exit, Time, Alpha, Delta, Kd, Ks, SecPerTick, AgentPathLog, CellOccupationValue, PersonLocation

In order to store the resulting data described above in the DBMS, a schema should be designed. Table II shows the table schemas in the DBMS. It consisted of three tables of sensor detection occupants, sensor type and simulation results. The sensor detection occupants table can store the number of detected occupants by hour and the recorded time as well as the total occupants. The sensor type table is information about the sensor location in which space it was installed. The simulation results table was designed as described above.

B. *Capturing indoor occupants distribution using the exit and entry detection*

In order to utilize the simulation data in an actual disaster situation, simulation results generated using the actual occupants distribution are needed. Therefore, sensor technologies applicable in indoor spaces should be used to find out the indoor occupants distribution. As an appropriate sensor for capturing indoor occupants distribution, infrared sensors were selected. The data which were transferred to the server through the sensor were detection time, detected exit and entry occupants in real-time, and the number of cumulative occupants.

The transferred data were designed to be stored in the DBMS. Since a connection to the sensor can be disconnected when an actual disaster occurs, the system was designed that the exit or entry occupant data detected by the sensors were stored in the DBMS in the server first, and then the occupants distribution information at the specific time was queried and fetched.

C. *Matching between the evacuation simulation results and the detected occupants*

Section 3-A showed how the resulting data to be generated for the evacuation simulation were defined, and a database schema for the simulation results was designed to store the data. Section 3-B summarized that an infrared sensor network was built and detected occupants information was stored in the DBMS.

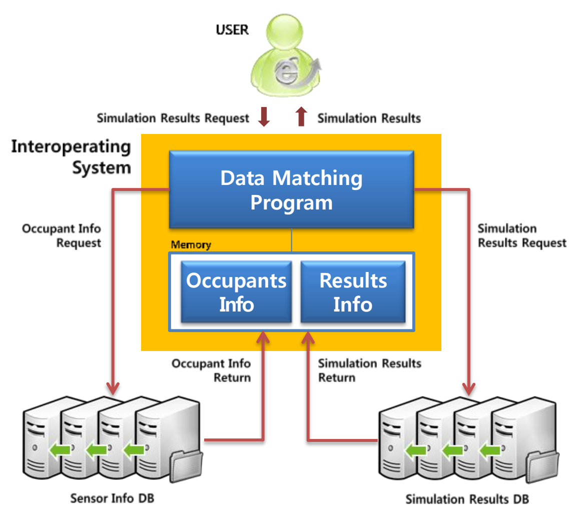
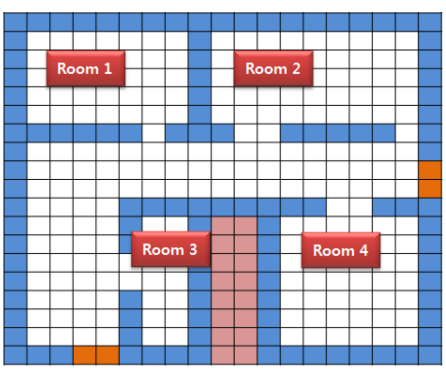


Figure 2. Configuration and flow of the matching system

Figure 2 shows a configuration and data flow of the matching system between real-time occupants data by sensor detection and the simulation results proposed in this study. The interoperating system has a data matching program, which performs queries and returns the query results by connecting to the simulation results database that stores the simulation results and the sensor detection occupants database that stores the exit and entry occupants information detected by the sensor. The sensor detection occupants DB stored the exit and entry occupants information of each room detected in every 5 minutes. The simulation results DB stored the simulation results generated beforehand according to various combinations of occupants. In this study, among the various factors which influence the simulation results, the occupants distribution was focused so that simulations were run by changing combinations of occupants and its results were stored in the DB. Figure 3 shows an example of different combinations of occupants distribution. After all the possible combinations of distributions, each of which is composed of a set of occupants numbers in building rooms, were established, a simulation was run for each case. Then, the results were stored in the database table.

To explain the system's flow, first, a user requested a simulation results at the specific time such as the disaster occurrence situation. Then, the interoperating system requested the occupant information from the sensor detection occupants DB in order to obtain the occupants combination information at the closest time with the requested time. The requested occupant information was returned to the system, and stored in the memory. Next, in order to have the simulation results which were performed with the closest occupants combinations of the obtained occupants distribution information, the results were requested from the simulation results DB. Then, requested simulation results were returned to the system, and finally delivered to the user.



Case	Room 1	Room 2	Room 3	Room 4
Case 1	5	0	0	0
Case 2	5	5	0	0
Case 3	5	5	5	0
Case 4	10	5	5	5
Case 5	10	0	5	0
Case 6	10	10	5	10
Case 7	0	0	10	5
⋮	⋮	⋮	⋮	⋮

Figure 3. Different combinations of occupants distribution

IV. SYSTEM TEST

A. *Development of the DBMS and the system*

A DBMS was used to store the simulation results and the sensor detection occupants information as described in the previous section. In this study, PostgreSQL was used as the DBMS [21]. The DBMS consisted of three tables such as IRSensor(storing occupants information detected by the sensor), SimResult(storing the simulation results) and SensorType(storing the configuration type of the sensor). Each schema for the tables was configured as described in Section III.

Next, based on the evacuation simulator which was developed by [17, 22], the revised evacuation simulator proposed in this study was developed. There were two features required for the evacuation simulator: one is an automatic iteration by changing various occupants combinations, and the other is to store the result data in the simulation results DB after completion of simulation running.

Using the developed simulator, simulation results according to the various occupants combinations were stored in the DBMS. Since it was not practical to constitute all the possible combinations from occupants of rooms, some increments (i.e. 5 as shown in Fig. 3) were used. Then, using the developed DBMS, the matching system was developed to fetch the simulation results. This system followed the configuration and flow as explained in Section III-C. To obtain the sensor detection occupants information at the specific time, queries with time information were used. The numbers of occupants stored in the DB, with which simulations were run, were integers with some increments as shown in Figure 3 (*e.g.* 5, 10, 0, 5, etc.), while those captured by the sensors were the actual numbers of people located in rooms (*e.g.* 4, 7, 1, 2, etc.). Therefore, it was not possible to expect to find two sets that match exactly. To find the simulation results generated by using the occupants distribution similar with the captured occupants information by sensors, the Euclidean distance was used, which calculates the difference between the number of the occupants of each room and the one that was captured by sensors as

$$\mathrm{Dist}(d_i, d_j) = \sqrt{\sum_{k=1}^{n}\left(w_{ik} - w_{jk}\right)^2} \quad (1)$$

where d_i, d_j are the occupants distribution in the DB and the sensor, and W_{ik}, W_{jk} are the number of occupants in room k in the DB and the sensor respectively. The lower the value, the higher the similarity between the simulation results in the DB and the occupants information from the sensor at the specific time. Then top 20 result data were displayed to the user. Basically, this information was provided in a text format, and additional information was displayed through the detailed information window.

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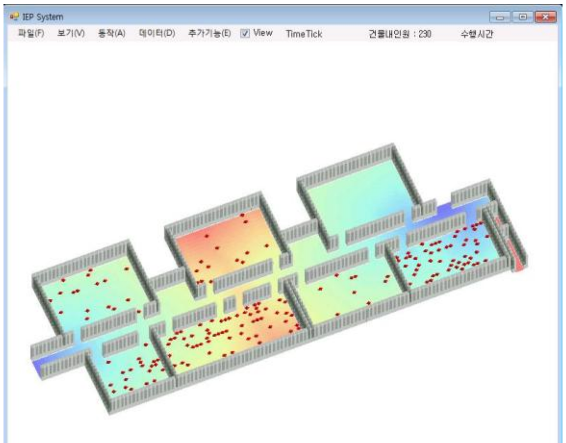

Figure 4. Main interface of the evacuation simulator

B. *System test*

To evaluate the developed system, a part of the campus building was selected as the test area. It consisted of seven lecture rooms and a hallway, and infrared sensors were installed at all doors to detect the exit and entry occupants in the lecture rooms.

Figure 4 shows the main interface of the evacuation simulator used in the study. The figure displays the interface before input of building data and simulation running. When simulation was running, virtual evacuation was performed and the resulting data were stored in the DBMS. Approximately, 20,000 times of simulations were performed. After simulations and database storage were finished, the matching process was performed. Figure 5 shows the main interface of the matching system. The figure displays the result after matching was done with the occupants data detected by the sensors. According to the calculated scores, top 20 results were generated with basic information as a text format. The time taken for search execution was approximately 0.5 second, which showed very short time compared to the actual simulation running time.

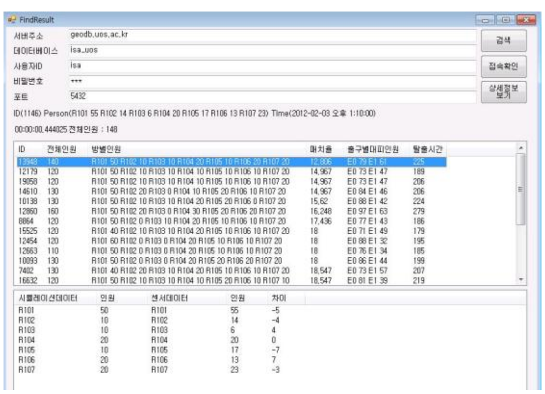

Figure 5. Main interface of the matching system

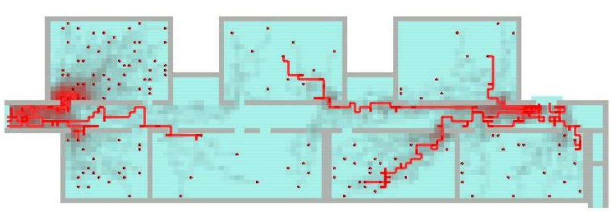

Figure 6. Visualization of the result data

Figure 6 shows the visualized scene of the result data. The points represent the initial positions of the occupants, and the dark colors in the floor represent expected bottleneck spots as indicated by the cell occupancy rate. The figure showed more occupants were crowded in the left hallway. The lines represent the evacuation routes which were traveled by an occupant of each room which was randomly chosen. By these lines, it can be estimated that which routes were chosen to evacuate for occupants in each room.

V. Conclusions

In this study, a real-time evacuation simulation system was developed by using indoor sensors and DBMS. By using infrared sensors, the actual distribution information of occupants was detected and applied. Also, the evacuation simulation results were stored in the DBMS, and the simulation result data, which was corresponding to the occupants distribution at the specific time, was provided by matching with the sensor detection occupants. In addition, types and configuration for the simulation result data were defined, and a visualization module for the result data was developed.

In this study, we demonstrated that evacuation simulation results can be used in not only evacuation safety evaluation of the building but also application to the actual disaster situation through our proposed system. Using the indoor sensor technology and obtaining simulation results through fast DBMS matching, limitations of the existing models inapplicable to real-time events were overcome.

In this study, a sensor network was configured, and evacuation simulation results were obtained by focusing on the occupants distribution combination. In the future, not only using the occupants distribution combination but also by capturing the characteristics of the occupants (*e.g.* age, sex, disposition, etc.) via sensors, our proposed system can be improved further to obtain the simulation results which incorporate the characteristics and distribution of the occupants.

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