A Three-Dimensional Pedestrian-Flow Simulation for High-Rising Buildings

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Abstract. A three-dimensional pedestrian-flow simulation system for optimally designing a floor plan and elevator configuration of a high-rising building was developed. With this simulation system, the pedestrian flow is simulated by synchronizing horizontal traffic on each building floor and vertical traffic in elevators to generate three-dimensional movements of pedestrians in the building. The simulation system comprises an interaction model, in which the horizontal traffic affects the vertical traffic through elevator-calling actions of people, and the vertical traffic affects the horizontal traffic by massive injection of people onto floors from elevator cages. The effectiveness of the developed system was verified by comparing the simulated pedestrian flows with actual flows in two real buildings.

Keywords: Pedestrian flow, Simulation, Elevator traffic, High-rising building.

1 Introduction

The functions of high-rising buildings have recently been increasing in variety. In some cases, a single building contains office space, shopping space, hotel space, and a train station. In these buildings, there are a variety of pedestrian flows, such as fast flows toward the station, excursive flows in the shopping area, and crowd flows in event spaces. In addition to their functional variation, high-rising buildings comprise complicated elevator configurations, including sky-lobby systems and double-decker elevators, for increasing the efficiency of floor usage. Consequently, an optimal floor plan and elevator configuration suitable for these different pedestrian flows is necessary for these high-rising buildings. A system

H. Umeo et al. (Eds): ACRI 2008, LNCS 5191, pp. 417–424, 2008.

for simulating the complicated pedestrian flow in a high-rising building is thus required.

There are several research works on pedestrian-flow simulation in buildings. Okazaki et al. proposed a simulation method using a magnetic field [1]. Burstedde et al. added the concept of a "floor field" to a conventional cellular-automaton model [2]. These pedestrian-flow simulations, including these two research works, are mostly applied to evaluating emergency evacuation from a building, where pedestrian flows that do not use vertical transportation (e.g., elevators) are mainly considered. On the other hand, elevator manufacturers study elevator traffic for improving efficiency of vertical transportation [3][4]. In these studies, solving the "cage-allocation problem" to shorten waiting times in the elevator hall has mostly been focused on.

The pedestrian flows on a building's floors and the elevator traffic, however, affect each other. That is, a pedestrian's arrival time at the elevator hall and entering motion to the elevators determine the elevator up and down motions, and a massive injection of people onto a floor from an elevator cage determines the pedestrian flow of that floor. To evaluate this interaction between floor traffic and vertical elevator traffic, we developed a "three-dimensional pedestrian-flow simulation system." In the following, the configuration of the simulation system is described, and the results of experiments to verify the effectiveness of the system are presented.

2 System Configuration

Figure 1 shows a general block diagram of the three-dimensional pedestrian-flow simulation system. The input data consists of map data and inflow setting data. The map data determines the floor layout of each story of the building. The inflow setting data determines the number of incoming pedestrians at every entrance over a certain time period. The inflow setting data also determines the destination of the incoming pedestrians.

The simulation body consists of modules calculating floor flow, elevator traffic, and their interaction. The floor-flow calculation module uses a cellular automaton model for implementing pedestrian behavior. The elevator-traffic calculation

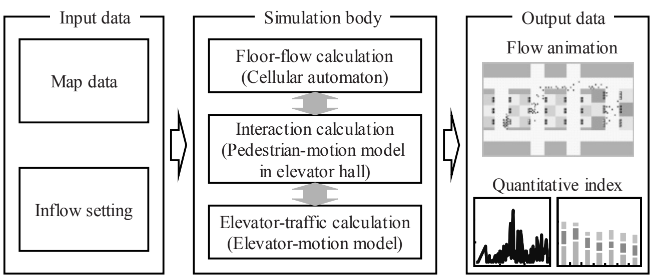

Fig. 1. General block diagram of 3-D pedestrian-flow simulation system

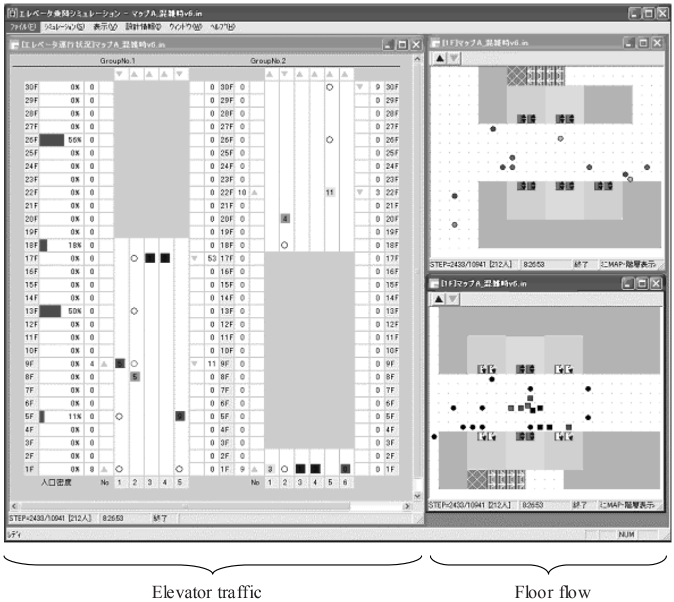

Fig. 2. Example of animated simulation result

module uses an elevator-motion model that simulates the cage motion of elevators by a cage-allocation algorithm. The interaction-calculation module simulates the pedestrian motion in the elevator hall, including elevator calling. Through this interaction calculation, the floor flow and vertical traffic are synchronized.

The simulation results are displayed as animations of pedestrian motions and elevator motions. The simulation results are analyzed to indicate quantitative indexes such as congestion degree and average trip time of pedestrians. Figure 2 shows an example scene of the animated simulation results.

3 Floor-Flow Model

There are several approaches to modeling a pedestrian flow on a floor [1][2]. The cellular-automaton (CA) model is popularly used for pedestrian-flow simulation, because of its advantage that the complex system of crowd dynamics is represented by simple local-neighbor rules [5]. Our simulation system thus applies a cellular-automaton model to simulate several thousands of pedestrians in a high-rising building in a practical time.

In our CA model, the simulation space is divided into square cells, and state variables are defined according to "pathway," "wall," "entrance," "exit," and "pedestrian." The pedestrian cells also have a state variable for walking direction. A pedestrian has one of eight walking directions: four orthogonal and four diagonal. A pedestrian may move in the walking direction or two neighboring

Fig. 3. Walking direction (solid-line) and possible directions of motion (doted-line)

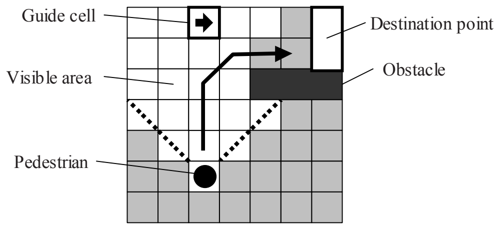

Fig. 4. Visible area set by field of view and guide cell

directions, as shown in Fig. 3. The actual moving direction will be determined by the status of the surrounding cells [6].

A real pedestrian walks while observing the surrounding environment to find their destination. With that in mind, we added a field-of-view model to the CA model in order to simulate acquisition of long-range information. In the field-of-view model, an area visible to the pedestrian (hereafter, "visible area") is defined in front of the pedestrian according to location and walking direction, as shown in Fig. 4. The pedestrian walks toward a target seen in the visible area. The target may be an exit, an elevator, an escalator, a flight of stairs or a room. As in the real world, the target is not visible if it is behind an obstacle. A guide cell is therefore introduced to lead pedestrians to the correct place. When a pedestrian finds a guide cell in their visible area, they walk in the direction indicated by the guide cell.

4 Elevator-Traffic Model

Elevators are usually arranged in several groups, and an appropriate elevator is selected from a group and allocated to a calling order from the elevator hall (hall call). This cage-allocation control, called "group control," avoids concentrating cages to a single hall call. Our simulation system applies such a group-control algorithm in its elevator-traffic model.

Several advanced algorithms for selecting an elevator cage from the elevator group have been developed; however, we adopted a simple algorithm. By means of this algorithm, the cage nearest to the floor of the hall call is selected. The distance between the cage and the floor is calculated in consideration of direction of cage motion and the location of the hall call.

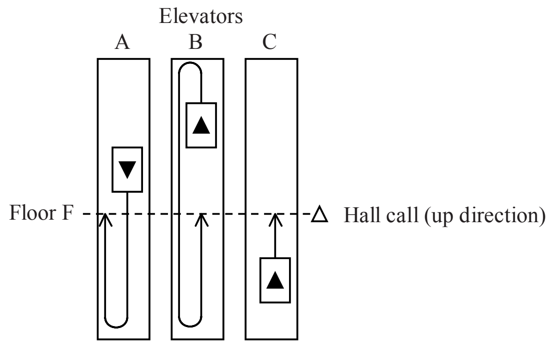

Fig. 5. Logical distances between cages and floor of hall call

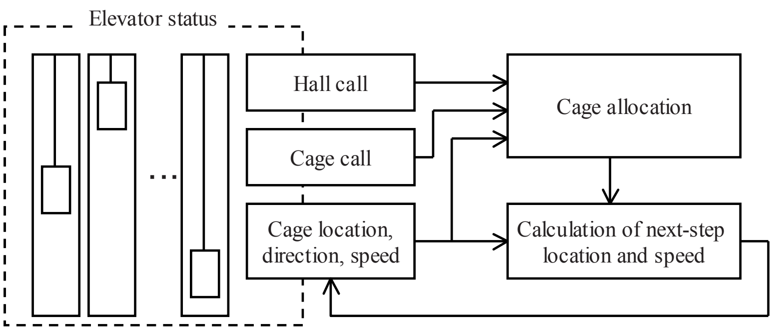

Fig. 6. Block diagram of elevator-traffic calculation

For example, in the case shown in Fig. 5, elevator cage A is nearest to the floor of the hall call in terms of physical distance; however, an additional "turn-around distance" is taken into account in the logical distance, because the direction of cage A's current motion is different from the direction requested by the hall call (hereafter, hall-call direction). As for cage B, the turn-around distances in the upper part and the lower part of the hoistway are taken into account. As a result, cage C is selected as the nearest cage. These turn-around distances are taken into account in order to avoid frequent changes of cage direction (which may confuse the passengers inside a cage).

Figure 6 shows the block diagram of elevator-traffic calculation. The status of each elevator group is defined by status variables, namely, "hall call," "cage call" (destination floors set by pushing floor buttons inside the cage), and "location and speed of each cage". The locations and speeds of the cages are calculated in the "next-step calculation" from current locations and speeds at certain time intervals synchronized with the CA calculation of floor flows. If there is a hall call, a cage is selected by the cage-allocation algorithm, as mentioned above, and assigned to the hall call. When the cage is approaching the assigned floor of the hall call or the cage call, the cage decreases its speed and stops at that floor. The hall call is set when a pedestrian whose destination is different from the current floor destination enters the elevator hall.

5 Pedestrian-Motion Model for an Elevator Hall

It takes a certain amount of time for pedestrians to get on or off an elevator. Accumulation of this ”loading/unloading time” on every floor becomes considerable. To take account of the time loss due to loading/unloading, we implemented a model of pedestrian motion in an elevator hall.

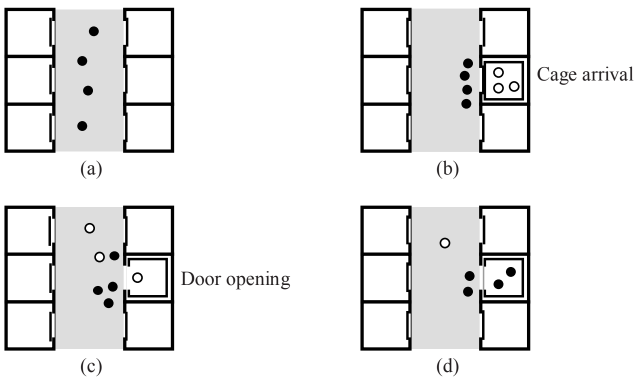

Fig. 7. Four steps of a pedestrian-motion sequence in an elevator hall

Pedestrian motion in an elevator hall consists of the sequence of four steps shown in Fig. 7. When pedestrians are waiting for the elevator, they spread apart in the elevator hall. When an elevator cage arrives or the arrival lamp lights up, the pedestrians gather in front of the arriving elevator. After the elevator doors open, the pedestrians inside the cage get off the elevator, and the waiting pedestrians in the hall get on.

The locations of the pedestrians in the elevator hall are controlled by an attractive force. By changing the force parameter, a spread distribution in the waiting phase and a condensed distribution in the cage-arrival phase are generated. In regards to the getting on/off actions, to avoid unusually quick getting on/off actions, the minimum time interval between a pedestrian and the following one is regulated by a delay parameter.

6 Verification

To verify the accuracy of the pedestrian-flow simulation system, we compared the simulation results to measured flows in real buildings. That is, we investigated pedestrian flows around the start of office hours at two office buildings. General

Table 1. Overviews of investigated buildings

Building	A	B
Location	Tokyo	Osaka
Stories	20	14
Estimated capacity (persons)	3,000	1,500
Number of elevators	12 (2 banks)	5 (1 bank)

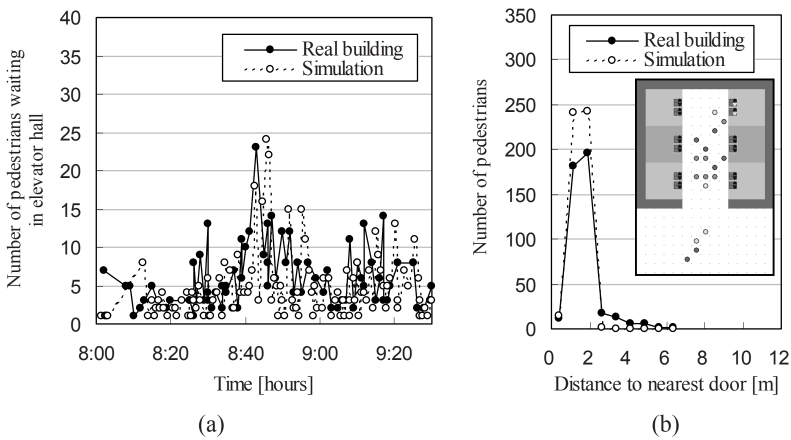

Fig. 8. Verification result on building A

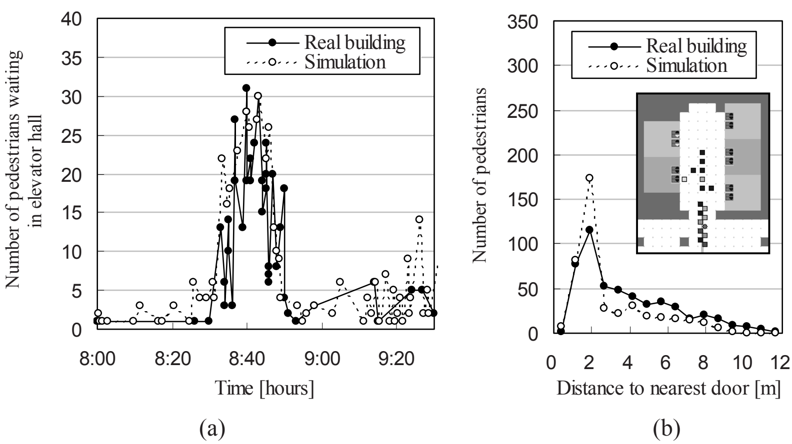

Fig. 9. Verification result on building B

details regarding the buildings are given in Table 1. In the simulations, the inflow data was set equivalent to the real inflow of pedestrians physically counted at the entrance of the buildings. Since the interaction effect between the floor flow and the elevator traffic appears directly in the number and the distribution of pedestrians waiting at the elevator hall, we compared these two factors determined by the simulation and by measurements taken in the buildings.

Figure 8 compares the simulation results and real-building data on building A. The number of pedestrians waiting in the elevator hall on the ground floor, shown in Fig. 8(a), in both sets of data agree well in terms of general trend and peak number. The simulated and real-building distributions of pedestrians in the elevator hall, shown in Fig. 8(b), also agree quite well.

Figure 9 compares the simulation results and real-building data on building B. The number and distribution of pedestrians waiting in the elevator hall also agree well in case of this building. In this case, pedestrians formed a line in the elevator hall during the peak-inflow period; the line formation appears as the long tail to the graph in Fig. 9(b). This "line formation" phenomenon was similarly generated by the simulation.

7 Summary

A three-dimensional pedestrian-flow simulation system for evaluating the interaction between floor traffic and vertical elevator traffic in a high-rising building was developed. With this simulation system, a pedestrian-flow simulation based on a CA model is synchronized with an elevator-traffic model. The simulated pedestrian flows were compared with measured flows in the building in question, and the good agreement between the simulated and real pedestrian flows verify the effectiveness of the simulation system.

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