Physica A 436 (2015) 45–61

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

A multi-grid model for pedestrian evacuation in a room without visibility

Shuchao Cao [a], Weiguo Song [a,*], Wei Lv [b], Zhiming Fang [c]

[a] *State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei 230027, China*

[b] *Research Center for Crisis & Hazard Management, Wuhan University of Technology, Wuhan 430070, China*

[c] *Shanghai Key Laboratory of Engineering Structure Safety, Shanghai Research Institute of Building Science, Shanghai 200032, China*

HIGHLIGHTS

- The experiments on pedestrian evacuation without visibility are conducted.
- Typical behaviors are found from the experimental observation.
- A multi-grid model is proposed to simulate evacuation without visibility.
- Typical behaviors observed in the experiments are reproduced by the model.
- Pedestrian trajectory is analyzed in both qualitative and quantitative methods.

ARTICLE INFO

Article history:
Received 23 November 2014
Received in revised form 4 May 2015
Available online 11 May 2015

Keywords:
Pedestrian flow
Evacuation
Pedestrian experiment
Multi-grid model
Visibility

ABSTRACT

The evacuation process from a room without visibility is investigated by both experiment and modeling. Some typical characteristics of blind evacuation, including the preference of choosing left-hand side direction and following behavior, are found from the experiment. Meanwhile, different strategies of conflict resolution are observed in the experiment. Based on the experimental observation, a multi-grid model for evacuation without visibility is built in this paper. Simulation results of the model agree well with the experiments. Furthermore, the effect of exit width, number of exits and initial density on evacuation are studied, and results show that exit width has little impact on evacuation time and increasing number of exits is an effective way to decrease evacuation time. Finally, simulations of evacuation under normal and no visibility are compared, and the differences for two conditions are predicted. The comparison results also demonstrate that the blind evacuation is much slower than evacuation under normal visibility, which is match with the practical experience. A similar point is that the distributions of time interval in both situations satisfy power-law relation approximately. The study may be useful for understanding the egress behaviors and developing efficient evacuation strategy and plan to guide pedestrian evacuation without visibility.

1. Introduction

During the last decades, pedestrian evacuation has become an interesting and important societal issue. More and more attention has been paid to the safety of people's lives during the evacuation. Nowadays, experiment and simulation modeling

* Corresponding author.
E-mail address: wgsong@ustc.edu.cn (W. Song).

http://dx.doi.org/10.1016/j.physa.2015.05.019
0378-4371/

are the main methods of studying evacuation, and many evacuation models have been built by researchers, such as the social force model [1–6], cellular automata models [7–12], fluid dynamic models [13–15], lattice gas models [16–22] and network-based models [23–26]. These models can reproduce typical pedestrian behaviors such as faster is slower [1,2,27,28], herding behavior [2,7,17,29], lane formation [18,30,31] and self-organization [32–34], and capture microscopic and macroscopic characteristics of pedestrian traffic.

In order to study the evacuation process in more detail, researchers have also paid more attention to finer discrete model, in which a pedestrian occupies more than one lattice site. Kirchner et al. [16] had studied the discretization effects in cellular automata model by reducing the cell size. Song et al. [35] quantified the force concept of the social force model and built a multi-grid model. They also investigated the effects of finer discretization on pedestrian dynamics using the multi-grid model and found that the evacuation time was associated with the cell size and the length of the time step [36]. Weng et al. [17] investigated crowd flow going outside a hall with a small-grid analysis model. In these models, typical phenomena of evacuation such as jam and block were reproduced and higher simulation efficiency was achieved. Zhang et al. [29] improved the multi-grid model by considering the pre-movement time of each pedestrian, adopting variable velocity and using a new updated procedure and there was good agreement between the simulation results and the experimental results. Fang et al. [37] studied exit-selecting behaviors during pedestrians leaving a teaching building using multi-grid model and found that pedestrians preferred selecting the closer exit even though the other exit was only a little far, and he also investigated the routes of pedestrians in fires, and the evacuation times in scenarios with different fire intensities, pre-movement times or door width coupling with effects of fire products [38].

Most studies focus on pedestrian evacuation in normal situation with good visibility [6–10,12–14,16–20,28–31,33–37,39,40]. However, fire accidents, terrorist attack or other emergencies can make the situation different and smoke or a failure of the electrical power supply will reduce visibility significantly. Helbing et al. [2] simulated a situation in which pedestrians with limited visual field were trying to leave a smoky room. Yue et al. [41] presented a cellular automata model to simulate pedestrian evacuation in room with affected visual field. Kobes et al. [42] studied the way finding during fire evacuation from an analysis of unannounced fire drills in a hotel at night. Jeon et al. [43] analyzed human behavior characteristics and evacuation performance change through the experiments under evacuation environment where smoke influenced visibility. Nguyen et al. [44] presented an agent-based evacuation model with smoke effect, and the simulation results were confirmed by the metro supermarket. However, it should be noted that the evacuation with limited or partial visibility is different from situation without visibility. Pedestrians have a relatively good idea of the direction to follow other pedestrians and the conflicts between them may be reduced under limited visibility, while they cannot see anything and know nothing about the environment around them during evacuation without visibility, therefore, it is very important and necessary to study pedestrian evacuation without visibility. Isobe et al. [45] investigated the evacuation process from a room with a single exit under the condition of no visibility and found the disoriented students exhibited a distinctly different behavior compared to a situation with good visibility. On the basis of the experiment, Nagai and Nagatani [46,47] surveyed the effects of exit configuration, the initial position, drift, and scenario on the mean escape time by using the biased random walk model. However, the sample size in their experiments is too small, which limits the reliability of the results. Guo et al. [48] studied the route-choice behavior of pedestrians during evacuation from a classroom under condition of good and zero visibility, and a proposed microscopic model with discrete lattice space was used in the simulation. Theoretical analysis without visibility was presented in Ref. [49].

To the best of the authors' knowledge, research on evacuation without visibility is not enough. More importantly, although the models built among the existing research on blind evacuation can reflect some characteristics of blind evacuation, there are still some problems such as selection of movement direction, conflict resolution and velocity change on microscopic level need to be considered carefully during blind evacuation. Thus in this study, we investigate the blind evacuation by using experimental and modeling methods, and try to build a multi-grid model to predict pedestrian's movement without visibility.

We mainly focus on three questions during the blind evacuation: how do pedestrians choose the movement direction; how do pedestrians solve the conflict when they encounter; how does velocity change before and after pedestrians touch the wall. The rest of this paper is organized as follows. In Section 2, we provide the details of the experiments. A multi-grid model for blind evacuation is built in Section 3. Evacuation time and trajectories of pedestrians in experiment and simulation are compared to verify the model in Section 4. In Section 5, numerical simulations are carried out and the results are discussed. Finally, in Section 6, we close the paper by summarizing our findings and discussing our future research in the area.

2. Experiment

2.1. Overview of the experiments

The experiments were conducted on an event square illustrated in Fig. 1 schematically. The size of the scenario was 8×7 m. Two video cameras numbered 1 and 2 were located on the roof of a teaching building, and they recorded the whole evacuation process from different angles. The experiments we analyzed in this paper could be divided into two parts: (a) experiment A, the escape of only one participant from a scenario with one exit and the exit width was 0.5 m, (b) experiment B1 and B2, the evacuation of thirty students from the scenarios with one exit, and the exit width was 0.5 m and 1.5 m respectively as shown in Fig. 2. Thirty participants were recruited from the university and their average age is about 24 years.