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A cellular automata model for high-density crowd evacuation using triangle grids

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HIGHLIGHTS

- Maximum crowd density of 8 people/m^2 can be simulated.
- The triangular mesh makes the model have better spatial adaptability.
- Pedestrians have more movement directions in the model.
- Experiments proved that the simulation results have high reliability.

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ABSTRACT

In this paper, according to the characteristics of evacuation in high-density crowd, a new triangular grid cellular automata model is proposed. In this model, the maximum density of crowd can reach to 8 person/m^2 which is measured by the experiment. And pedestrians can move to 14 directions if there are no obstructions around them. Meanwhile, this paper proposes the concept and calculation rules of moving potential in the moving field. The moving potential provides reference for the movement of a pedestrian. Through the comparison of the measured values and the simulated values of an evacuation process in a building, it is proved that the model can accurately simulate the evacuation process of high density crowd.

1. Introduction

In recent years, hundreds of casualties have been caused as a result of stampede caused by high density crowd, such as Madhya Pradesh in 2013, the bund of Shanghai in 2014 and Saudi during the 2014 Hajj. Therefore, pedestrian evacuation dynamics (PED) has become a hot research issue, and the relevant research mainly focuses on the basic data or phenomenon of evacuation based on experimental or observation methods and the evacuation model of crowd [1–9]. In experimental and observational studies, Helbing analyzed video recordings of the crowd disaster in Mina/Makkah during the Hajj on January 12, 2006 [10], and pointed out that the highest density of pedestrian is up to 9 person/m^2 in the disaster. Marija Nikolić analyzed data from the underground station in Lausanne [11], Switzerland and Daamen conducted large-scale evacuation experiments [12]. Their research results show that the density of pedestrian ranges from 0 to 7 person/m^2.

However, time and resources spent on evacuation experiment and observation are relatively large, and it is difficult to extract relevant observational data, and it has certain limitations in repeatability and operability [1,13]. Computer simulation technology can safely and effectively visualize the movement process in complex conditions and reproduce the simulation.

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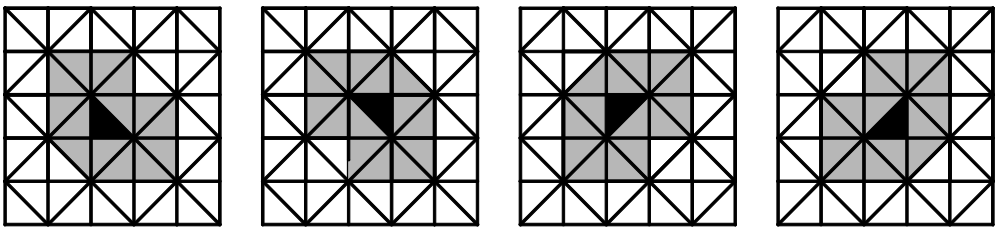

Fig. 1. The cellular automata neighbor model of triangular mesh in four positions.

Therefore, with the development of computer technology, the research of evacuation models has become an important research direction. Up to now, dozens of evacuation models have been published, some of which have been commercially available, such as Simulex, Steps, BuildingExdous and so on [9]. In general, these PED models can be classified into two categories: continuous model and discrete model [14]. Continuous models are based on functions or differential equations to describe the evacuation process of pedestrian, such as fluid mechanics model, magnetic field force model, social force model, etc. Discrete models discretize time and space, and people move in this discretized space–time based on certain rules. The discrete model can be divided into two categories: rough grid model and fine grid model. Rough grid models, like Evacnet4 and TimtexI are based on the idea that building structure is compared to pipes according to its characteristic and pedestrians are compared to water flow in pipes. The fine grid model divides the building plane into grids, and the pedestrians move in these grids according to the rules established in advance, such as CA models and lattice-gas models.

At present, continuous model has been used to study the evacuation of high density crowd and some achievements have been achieved. Qu studied approaches of modeling crowd evacuation process and dynamic behavior characteristics based on the heuristic force-based model and user optimal criterion [15,16]. Zhao presented a kind of high-density crowd evacuation model based on swarm intelligence theory [17]. Mohamed H, Dridi applied an evacuation simulation software called PedFlow based on microscopic model to high-density crowd evacuation study [18,19]. However, continuous model has a large amount of calculation, which is more suitable for the study of the micro behavior of the pedestrian movement under the smaller scene.

Compared with the continuous model, the discrete model can also describe the individual's motion characteristics, and can only consider the impact of small-scale environment on the movement of people [20], thus significantly reducing the amount of computation and having unique advantages in large scene simulation. Many researchers applied the discrete model to the simulation of large scenes. Ansgar Kirchner presented simulations of evacuation processes using a cellular automaton model for pedestrian dynamics [21]; Xiaoping Zheng applied cellular automaton model to simulate the evacuation process in a square [22]; Ahmed Abdelghany presented a hybrid simulation-assignment modeling framework for studying crowd dynamics in large-scale pedestrian facilities [23]. These discrete models greatly reduce the amount of calculation, but the accuracy is relatively low. The reason is that the movement direction of the pedestrian is restricted to the grid. Usually, they divide the space into rectangular grids with a certain density. The pedestrian can only move from a grid to another adjacent grid according to the rule of motion, while the maximum number of adjacent grids is 8, so the movement direction of the pedestrian is generally no more than 8. In real evacuation scenarios, the movement directions of a pedestrian are actually more than 8. This affects the accuracy of the simulation, especially in high-density crowds.

To solve this problem, we developed a new type of evacuation model based on CA models. The main advantage of this model is that it divides the simulated space into triangular grids. So that the movement direction of the pedestrian is extended from 8 to 14, which is more suitable for pedestrian movement. In the model, the maximum density of crowd can reach to 8 person/m^2. According to the comparison with the experimental value, the model can simulate the evacuation process accurately.

2. Establishment of evacuation model for high density crowd

2.1. Basic characteristics of the model

The model studied in this paper is based on two-dimensional cellular automaton. The spatial grid division of the traditional two-dimensional cellular automata usually consists of three types: regular triangle, square and hexagonal. And neighbor models are usually divided into Von Neumann types, extensional Von Neumann, Moore and extensional Moore [24].

In this research, cellular space is divided into several triangle grids as shown in Fig. 1 which are different from traditional models. Every isosceles right triangle can become an independent cell. As shown in Fig. 1, the cell is divided into 4 types according to the different direction of the triangle, the black triangle represents the current cell, and the gray triangles around it are its neighbors. It is observed that each cell that is not on the boundary is connected to the surrounding 14 cells.

Compared with the traditional CA model, the new cellular automata model of triangular mesh has three characteristics and advantages.