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An extended cost potential field cellular automata model considering behavior variation of pedestrian flow

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HIGHLIGHTS

- The extended cost potential CA model describing behavior variation is presented.
- The quantitative formula between behavior variation and level of tension is given.
- The influences of different factors on evacuation efficiency are explored.
- Some important results are obtained from the numerical simulations.

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ABSTRACT

The original cost potential field cellular automata describing normal pedestrian evacuation is extended to study more general evacuation scenarios. Based on the cost potential field function, through considering the psychological characteristics of crowd under emergencies, the quantitative formula of behavior variation is introduced to reflect behavioral changes caused by psychology tension. The numerical simulations are performed to investigate the effects of the magnitude of behavior variation, the different pedestrian proportions with different behavior variation and other factors on the evacuation efficiency and process in a room. The spatiotemporal dynamic characteristic during the evacuation process is also discussed. The results show that compared with the normal evacuation, the behavior variation under an emergency does not necessarily lead to the decrease of the evacuation efficiency. At low density, the increase of the behavior variation can improve the evacuation efficiency, while at high density, the evacuation efficiency drops significantly with the increasing amplitude of the behavior variation. In addition, the larger proportion of pedestrian affected by the behavior variation will prolong the evacuation time.

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1. Introduction

Recently, the number of accidents caused by crowded people or emergencies has increased year by year. Pedestrian modeling has become one of the most exciting fields in traffic science and engineering [1–4]. Understanding pedestrian flow characteristics beforehand is extremely important in emergency management to improve evacuation procedures and relevant regulations. The dynamic properties of pedestrian crowds, including various self-organization phenomena, have

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been observed and successfully reproduced by various physical methods. However, it is generally known that evacuation exercise under emergency may be difficult than normal pedestrian flow because of the danger and possible crowd disaster caused by incidents. To solve this problem, various modeling approaches to study evacuation behavior have been proposed [5–36].

Generally speaking, pedestrian flow models can be classified into two categories, macroscopic [5–8] and microscopic [9–36]. In macroscopic model, pedestrians are treated as a fluid with the use of partial differential equation, where the dynamic characteristics of the crowd flow are described by average speed, density, location and time. Microscopic model can be mainly divided into three groups: continuous model with a representative of the social force (SF) model [9–14] and discrete model represented by the cellular automata (CA) model [15–32] and lattice gas model [33–35]. The floor field (FF) model first proposed by C. Burstedde et al. [15], which is more flexible to simulate individual pedestrian motion and can reproduce collective behavior of pedestrian dynamics observed experimentally and described by other more complex models, has become one of the most widely used CA models in evacuation research. In general, there are two types of floor fields: the static floor field S and the dynamic floor field D. The static field depends only on the distance measure (from a cell to the destination), and thus S remains unchanged in the evolution. The dynamic field reflects the virtual tracks left by moving pedestrians. Since then, lots of extended or modified FF models [16–32] are proposed by researchers in different aspects, such as the interaction among pedestrians or pedestrians and obstacles [21–24], layout effects of exit or door [25–27], behavioral or group effects [28–30]. In 2012, Zhang et al. established a cellular automata model of pedestrian flow that defines a cost potential field, which takes into account the costs of travel time and discomfort in the journey, for a pedestrian to move to an empty neighboring cell [31]. Without the discomfort term, the resulting cost potential in a cell would simply measure the distance between the cell and the destination, which is independent of time and similar to the static field in the floor field CA model (see Ref. [15]). With the discomfort term, the cost distribution increases with the local density, which is reconstructed at each time step and, thus, is time dependent. In this case, the resulting cost potential field is similar to the dynamic field in the floor field CA model. In 2014, Jian et al. proposed a perceived potential field cellular automata model with an aggregated force field to simulate the pedestrian evacuation in a walking domain with poor visibility or complex geometries [32].

These above mentioned models can generally reproduce pedestrian dynamics under normal situation. However, Helbing et al. [36] found that in situations of escape panics, individuals are getting nervous, i.e., they tend to develop blind actionism. Furthermore, people try to move considerably faster than normal, etc. They think that the transition between the "rational" normal behavior and the apparently "irrational" panic behavior is controlled by a single parameter, the "nervousness", which influences fluctuation strengths, desired speeds, and the tendency of herding. Here it should be noted that there is no precise accepted definition of panic although in the media usually aspects like selfish, asocial or even completely irrational behavior and contagion that affects large groups are associated with this concept [37]. In 2008, Rogsch et al. performed a detailed discussion about "panic" and based on the difficulties of different definitions, they used the following definition to investigate the real origins of some mass-emergencies, namely, "Panic: People flight based on a sudden subjective or 'infected' fear; People are moving imprudently; The cause of this movement cannot be recognized by an outsider" [38]. Up to now, the terminology "panic" is highly controversial and usually avoided. In this manuscript, we use "fear" to describe the above mentioned pedestrians' psychological characteristics when they confront an emergency. Therefore, the previous cost potential field CA model is used in normal situation is insufficient to describe pedestrian emergency evacuation.

In this paper, we mainly focus on how to extend the original cost potential field CA model for pedestrian flow to emergency situations. The paper is organized as follows. In Section 2, we formulate an extended cost potential field cellular automata model considering behavior variation from nervousness. Section 3 gives simulation results and corresponding discussion, followed by conclusions in the final section.

2. Model

The model follows the basic rules of the cost potential field CA model. We consider a room divided into $L \times L$ finite two-dimensional grids. The outer lattices denote the room wall. Each of the other grids can be empty or occupied by a pedestrian and is equivalent to a cell whose size can be regarded as 0.4×0.4 m^2 [15], where L and W are the width of the room and the exit, respectively. As shown in Fig. 1, the black part and the red solid circle denote the wall and pedestrian, respectively. The exit is located at the edge of the wall.

In this paper, the Moore neighborhood [15] is adopted and each occupied cell has eight neighboring cells, corresponding to nine probabilities for the pedestrian in the occupied cell to update his or her position (see Fig. 2). Define the neighborhood set of (i_0, j_0) as

$$S_{i,j} = \{(i, j)|\, |i_0 - i| \le 1,\ |j_0 - j| \le 1\},$$

in which an empty cell set is

$$\bar{S}_{i,j} = \{(i', j')|(i', j') \in S_{i,j},\ (i', j') \text{ is an empty cell}\}.$$

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