Physica A 515 (2019) 47–56

Contents lists available at ScienceDirect

Physica A

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

An extended cost potential field cellular automaton model for pedestrian evacuation considering the restriction of visual field

Xingli Li [a], Fang Guo [a], Hua Kuang [b,*], Zhongfei Geng [a], Yanhong Fan [a]

[a] School of Applied Science, Taiyuan University of Science and Technology, Taiyuan, 030024, China
[b] College of Physical Science and Technology, Guangxi Normal University, Guilin 541004, China

HIGHLIGHTS

- An extended cost potential CA model describing the restriction of visual field is presented.
- A visibility function is introduced to describe visual effect.
- The extended cost function is related to three factors: density, behavior variation and visual effect.
- Evacuation time relies on visual radius and initial density.
- A moderate tension degree can improve the evacuation efficiency at low density.

ARTICLE INFO

Article history:
Received 5 May 2018
Received in revised form 4 September 2018
Available online xxxx

Keywords:
Pedestrian evacuation
Visibility function
Cost potential field
Psychological tension
Cellular automaton model

ABSTRACT

Pedestrian dynamics with affected visual field under emergency situation is a difficult point in the simulation of pedestrian flow. In this paper, an extended cost potential field cellular automaton model is proposed to investigate the motion of pedestrians through obscure room lack of visibility (due to smoke, darkness, etc.). A novel visibility function is introduced to describe visual effect caused by poor vision, which will lead to the increasing cost of discomfort. The numerical simulations are performed to explore the effects of factors, such as psychology tension, visual radius and pedestrian density on pedestrian evacuation. It was found that evacuation time relies on visual radius and initial density. The evacuation time under affected visual field increases with the decrease of visual radius. At low density, a moderate tension degree can improve the evacuation efficiency. These findings will be helpful in pedestrian control and management under an emergency.

1. Introduction

Pedestrian dynamics is the basis of the management of pedestrian evacuations and the design of pedestrian facilities, which contributes to the reasonable design of walking facilities and evacuation rules. Understanding pedestrian flow characteristics beforehand is extremely important in emergency management to improve evacuation procedures and relevant regulations [1,2]. The dynamic properties of pedestrian crowds, including various self-organization phenomena, have been observed and successfully reproduced by various physical methods. Generally, pedestrian flow models can be mainly classified into two categories: macroscopic [3–8] and microscopic [9–31]. Microscopic models include social force model [9–13], lattice gas model [14–19] and cellular automata model [20–30]. Because the concept of cellular automata

* Corresponding author.
E-mail address: khphy@gxnu.edu.cn (H. Kuang).

https://doi.org/10.1016/j.physa.2018.09.145

model is simple and it is easy to simulate in computer, based on the characteristics of individual pedestrian and system surroundings, the original CA models are combined, extended, or improved to approximate pedestrian dynamics, especially in the evacuation from a room [23–28].

In most simulations of pedestrian evacuation related to the above research, the room is supposed to be under favorable sight conditions. However, the visible scope of pedestrians is often affected by fire/smog, electricity outage, panicked mood, etc. Under the condition with adverse sight, due to a decrease in sight scope, pedestrians show movement behaviors different from those with favorable sight. These behaviors are critical in reflecting the characteristics of the pedestrian evacuation process under adverse sight conditions. However, evacuation exercise under adverse sight may be difficult than normal pedestrian flow because of the danger and possible crowd disaster caused by incidents. To explore macroscopic feature and jamming formation mechanism without visibility, various modeling approaches to study evacuation behavior have been proposed.

Mantovani et al. investigated the effect of red and green indicator on the virtual library scene under poor visibility [32]. Nagai et al. simulated the movement of students with multiple exits and discussed the evacuation process in the dark room [33]. Nagatani et al. modeled the pedestrian evacuation process in a single exit dark room with considering the biased random walk of pedestrian [34]. Yuan et al. studied the effect of smoke on pedestrian evacuation [35]. Emilio et al. studied the motion of pedestrians through obscure corridors where the lack of visibility hides the precise position of the exits [36]. Frank et al. modeled the effects of low visibility by considering three pedestrians behavioral patterns (i.e., individualistic, herding-like and the "following the wall") during the evacuation of pedestrian from a single exit room [37]. Song et al. investigated the effect of visible domain for evacuation signs on the pedestrian flow and found that how to set evacuation signs has a significant effect on the evacuation [38]. Cao et al. proposed a multi-grid evacuation model without visibility through evacuation characteristics of the blind [39].

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 [40]. 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. [20]). 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 [41]. Recently, the authors have extended this model to simulate the behavior variation of pedestrian flow from nervous emotion in a room and counter flow, respectively [42,43]. In real life, the lack of understanding the information surrounding the room for the pedestrians can influence the selection of movement, which will inevitably cause the increase of discomfort.

Compared with the previous studies about pedestrian flow under adverse conditions, the different psychological tensions and the induced corresponding behavior variations under emergency have not been perfectly considered up to now. This is insufficient to describe a more general pedestrian flow, where pedestrians might have been influenced by the internal behavior variations due to psychological tension and the external environment. How do these factors affect the pedestrian dynamics in the evacuation? This is an interesting but still open problem. Motivated by the above reasons, in this paper, we use an extended cost potential field CA model combined with abnormal nervousness to simulate pedestrian flow under poor vision. This model enables analysis of the effect of different level of tension, visibility radius and pedestrian density on pedestrian movement under an absence of visual field. The paper is organized as follows. Section 2 describes the new cost potential field CA model integrated with a visibility functions. Section 3 gives simulation results and corresponding discussion, followed by conclusions in the final section.

2. Model

We consider a room divided into $L \times L$ finite two-dimensional grids. The black border denotes 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 approximately regarded as $0.4 \times 0.4\ \mathrm{m}^2$, where L and W are the width of the room and the exit, respectively. As shown in Fig. 1, the whole system is divided into two regions: region A indicates exit-visible area and region B represents exit-invisible area. The sets Ω, Ω_1 and Ω_2 are used to represent the whole system area, region A and region B, respectively. The semicircle near the exit represents that the exit position can be seen and its radius is set R. Exit logo is the exit position and is represented by set Γ. The solid circle denotes the pedestrian. Here it is assumed that the visual radius of each pedestrian is equal and its size is R, e.g., a red solid circle denotes a pedestrian located in the center whose visual radius is R (see Fig. 1).

2.1. Quantitative description of behavior variation

As we know, human psychological characteristics under the emergency situation will inevitably lead to the "rational" or "irrational" behavior. Here the parameter $\eta(0 \le \eta \le 1)$ is introduced to describe the influence of nervousness μ on behavior variation and it is defined as follows [42]:

$$\eta(t) = \begin{cases} 0 & 0 \le \mu \le 0.05 \\ k_1\mu + a_1 & 0.05 < \mu \le 0.6 \\ \exp(k_2\mu) + a_2 & 0.6 < \mu \le 1 \end{cases} \tag{1}$$