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Influence of the exits' configuration on evacuation process in a room without obstacle

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HIGHLIGHTS

- The improved floor field can be used to describe the distance to the exit and the distribution of pedestrians.
- The evacuation time (T) is a function of the exit width (Dw) in negative power.
- Mean flow rates and the using efficiency of each exit cell are compared.
- Phase diagrams for three different situations are given.

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ABSTRACT

The floor field model is the most popular cellular automata (CA) model which is used to simulate the pedestrian's behaviors. In the floor field model, the interaction between pedestrians is expressed by the dynamical field. In this paper, we proposed an improved and simple method to calculate the floor field. In our method, the pedestrians are treated as the movable obstacles which will increase the value of the floor field. The additional value is interpreted as the blocking effect of proceeding pedestrians. And then, the influence of the exits' configuration on evacuation process in a room without obstacle is simulated. The evacuation time for different widths and positions of the exits is investigated.

In the case of single exit, there is a power law relationship between the evacuation time (T) and the exit width (Dw) with a negative exponent when $Dw \leq 6$. Mean flow rates and the using efficiency of each exit cell obtained by our model are higher than other models. The simulation results indicate that pedestrians do not choose the shortest path but a faster path in our model. For the case of two exits, the relationships between the location of the exits and evacuation time are discussed. When the total width of two exits is small (i.e. $Dw = 2$), the main factor affecting the total evacuation time T is the exits' capacity. If the total width of two exits is large (i.e. $Dw = 12$), the moving distance of pedestrians to exits is the main factor affecting the evacuation time, and the corresponding phase diagrams are given.

1. Introduction

Recently, pedestrian flow has been studied by many scholars who are of physics, mechanics, mathematics, architecture and computer fields [1–4], especially evacuation dynamics. One of the reasons is enormous loss of property in the escape

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process, even lives. Another reason is numerous interesting self-organization phenomena of pedestrian flow, such as lane formation [5], arching [6], the "faster-is-slower" effect [6], oscillations [5], "freezing-by-heating" effect [7] and herding behavior [8].

In counter flow, a kind of spontaneous symmetry breaking occurs and lanes are formed where people move in the same direction. In this way, strong interactions (i.e. frictional effects) with oncoming pedestrians are reduced and a higher walking speed is possible. At bottlenecks, bidirectional flows with moderate density are often characterized by oscillatory changes in the flow direction, the frictional effects and delays in oppositely moving pedestrians are reduced. The arching can be found at locations with high density where the inflow exceeds capacity, and the interactions between pedestrians are intense. In the herding behavior, the individual gives up his or her personal opinion, imitates and follows one another. For the individual who is unfamiliar with the facility, following other pedestrians can lead to better performance. If the followed pedestrians make a bad choice, that may also worsen jams. In the "faster-is-slower" effect, a higher desired velocity leads to a slower movement of a large crowd. In the "freezing-by-heating" effect, increasing the fluctuations can lead to a more ordered state. However, it is still unclear how the latter two effects occur in real emergency situations since there is not any supportive evidence with the exception of a biological experiment [9] so far.

Until now, a lot of models have been proposed to simulate the pedestrian flow, for example, cellular automata model [3, 4,10–22], lattice gas model [23], the space-continuous force-based model [24], social force model [1,5,6], centrifugal force model [25,26], fluid-dynamic model [27–30] and optimal velocity model [31–33]. In those models, the CA model would be more appropriate to describe pedestrian flow because of its simplicity, flexibility and efficiency. Furthermore, it is difficult to describe directly each pedestrian by solving coupled differential equations, especially if the number of pedestrians is large.

Based on the Biham–Middleton–Levine model [34] for city traffic, a CA model has been proposed by Fukui and Ishibashi [10,11]. In their work, they focus on the jamming transition as the density of pedestrians is increased. Burstedde et al. [12] and Kirchner et al. [13] proposed a two-dimensional CA model respectively. The long-range interactions between pedestrians are explored by using floor field with an idea similar to chemotaxis [35]. In order to describe real evacuation process, a floor field model with friction effect has been taken into account [15]. Fang et al. [14] proposed a new CA model by considering the custom of pedestrians (for example, the pedestrian prefers to walk on the right-hand side of the road) and the back stepping. It is found that the critical density increases with the probability of back stepping when the system size is same. Zhao et al. [19] proposed a CA model to investigate the exit dynamics of occupant evacuation by considering the widths, positions and separations of exits in a large room without obstacle. Song et al. [17] proposed a CA model with forces essentials (CAFE). The interactions between pedestrians in evacuation are classified into three types: attraction, repulsion and friction. Based on the CAFE model, an improved model [18] has been constructed and the arching, clogging and faster-is-slower behaviors, as well as the evacuation time, are compared with those of the social force model [6]. The real-coded cellular automata (RCA) model [21] has been presented by Yamamoto et al. A two-dimensional CA random model [22] is applied to occupant evacuation considering the influence of human psychology and behavior. It is shown that the exit's width must be bigger than a certain critical value. The optimal value of the exit separation f is independent of the exit's width d, but is related to the total width of the building D: $f \approx 0.3D$. A symmetrical layout of the exits should be applied and bad random factors will occur and lead to a prolonged and fluctuated evacuation time when the value of f is too small. A two-dimensional CA model is used to simulate the process of evacuation of pedestrians in a room with fixed obstacles by Varas et al. [20].

In a CA model, the space is divided into rectangular cells and each cell is assigned a value which modified the transition rates to neighboring lattices in every time step. The set of these cells with their values is called floor field in CA model. In general, there are two kinds of floor fields: static and dynamic floor fields. The static floor field S does not evolve with time and is not changed, depending on the position of the door. In order to calculate the value of static floor field, there are several methods such as the Euclidean distance, the Manhattan distance and the Dijkstra distance. The Euclidean method is suitable for the room without obstacle, but the Manhattan and Dijkstra methods are used for the room with obstacle. In comparison to Manhattan method, pedestrians' movements are more realistic with the Dijkstra method. However a static floor field with Dijkstra method may consume a considerable time in large environments. Varas et al. [20] and Huang et al. [36] introduced a method which works as well as the Dijkstra method but is easier and faster to compute respectively. Schultz et al. [37] have proposed a direction field by using the floor fill algorithm and this method could be used to calculate the directions based on the shortest distance but not the shortest time. Kretz et al. [38] have given an overview over existing and approximate methods to calculate a potential field, analytical investigations for their exactness, and tests of their computation speed. Hartmann [39] has introduced a navigation field by solving the Eikonal equation and the navigation field corresponds to the shortest distance to the target. In his work, the virtual pedestrian moves along the path which is minimum deviation from the shortest path.

The dynamic floor field D is modified by the presence of pedestrians and has its own dynamics, i.e., diffusion and decay, depending on human psychology and behavior, distribution of pedestrians and some other factors.

In most of the introduced models, the transition rates to neighboring cells of pedestrians are modified only by the static floor field or by both of the static floor field and the dynamic floor field. When a large group of pedestrians leave from a room, especially in an emergency, most pedestrians do not follow the shortest path, but try to minimize the travel time based on the observed environment and are routed dynamically. An event-driven way finding algorithm for pedestrians has been proposed [40], in which pedestrians observed the environment (identified the jam situation) and took their decisions of route choice by using an appropriate cost benefit analysis function based on the obtained data. In addition, the business

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