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Agitated behavior and elastic characteristics of pedestrians in an alternative floor field model for pedestrian dynamics

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ABSTRACT

An alternative floor field (FF) model is proposed by incorporating the agitated behavior and elastic characteristics of pedestrians. The agitated behavior which is regarded as an important factor to pedestrian dynamics is depicted by introducing a parameter to revise the transition probability of pedestrians to move to the neighboring cells. To characterize elasticity of pedestrians, it is assumed that a cell can hold more than one pedestrians in crowd condition, while it can hold only one pedestrian in normal condition. In addition, a method to deal with conflicts is employed by considering the effects of agitated behavior and desired velocity. Numerical simulations are carried out to investigate pedestrian evacuation from a room. The results show, that as the value of agitated parameter increases, the evacuation time decreases to the minimum value and then increases gradually. Also, the faster-is-slower effect which is obtained by some other simulation models can be reproduced by the proposed model. Finally, the influence of exit width and the corresponding mechanism on evacuation process is investigated which is expected to be helpful to the exit design of public rooms.

1. Introduction

Most traffic and transport systems can be regarded as self-driven many-particle systems, for instance, intracellular transport, highway traffic, and pedestrian dynamics [1–3]. Pedestrian flow is a complex system consisting of many particles with different properties and various interactions. Recently, it has attracted considerable attention [4] and some interesting phenomena have been found, such as arching, clogging and faster-is-slower [4,5]. Pedestrian dynamics is important in analysis and design of transportation facilities, walkways, traffic intersections, markets, and other public buildings. Therefore, it is necessary to understand the characteristics of pedestrian flow in various scenarios. These pedestrian problems including various self-organization phenomena and evacuation design have been investigated not only in physics but also in engineering, and various models are proposed to reproduce the phenomena [6–12].

The pedestrian models can be classified into two classes, that is macroscopic [6,7] and microscopic [8–35]. The macroscopic models depict the relationships among flow, density and speed, and can be reduced to a partial differential equation system. In a word, they depict pedestrians with fluid-like properties, and the different behaviors of individuals cannot be distinguished.

The microscopic models can be further classified into continuous [8–13] and discrete ones [14–35]. In the continuous models, the behavioral changes are induced by the combined force translated from the desired destination and the

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interactions among pedestrians and obstacles. The social force model developed by Helbing et al. [8,9] is a typical example which is able to reproduce many observed characteristics of pedestrian flow. The discrete models are mainly the lattice gas models [14–22] and cellular automaton (CA) models [23–35]. The conventional CA models take into account only the interactions between the nearest neighbors, and so they cannot depict the phenomena related to the long-ranged interaction. The floor field (FF) model [30–35] is a new class of CA model. In this model, the static and dynamic floor field are introduced to translate a long-ranged spatial interaction into a local interaction, where the static field represents the tendency to the destination and the dynamic field represents the behavior of following preceding pedestrians. As a result, most characteristics of pedestrian flow dynamics can be reproduced by this model, particularly the various collective effects observed empirically.

Some researches of simulating pedestrian evacuation have been conducted with the FF model and its extended models [30–35]. However, to our knowledge the agitated behavior and elastic characteristics of pedestrians have not been considered in those models. In reality, pedestrians usually keep appropriate distances to other pedestrians or obstacles for comfortableness. However, different from vehicle traffic, collision and pressing between pedestrians are normal in crowded pedestrian flow. Particularly in some emergency situations, crowd and jams would appear, and fatalities would take place as pedestrians are crushed or trampled.

Since fatalities induced by crowd generally occur in emergency situations, the behavior characteristics and properties of pedestrians should therefore be investigated. In this paper, a new FF model is proposed by incorporating the agitated behavior and elastic characteristics of pedestrians. By introducing a new parameter, the sensitivity of agitated behavior is represented. Also, to depict the elastic characteristics of pedestrians, a cell can hold more than one pedestrians in crowd, while it can hold only one pedestrian in normal. In addition, a method to deal with conflicts is proposed by considering the effects of agitated behavior and desired velocity. Numerical simulations of pedestrian evacuation from a room with one exit are performed. It is found interestingly that evacuation time decreases firstly and increases then with the increase value of agitated sensitivity. It is also found that the arch-like clogging and faster-is-slower phenomenon can be reproduced. The evacuation time varies with pedestrian density is investigated to test the stability of the model. Also, the influence of exit width on evacuation time and the corresponding mechanism is investigated.

2. Model

In the proposed model, space, velocity and time are all discrete. Particularly, different from the classical CA models, each cell can hold M pedestrians at most, and so a cell can either be empty or occupied by $1, 2, \ldots, M$ pedestrians. Then, the density of a cell is defined as n_m/M, where n_m is the number of pedestrians in the cell. In the following simulations, the size of each cell is approximately 50×50 cm^2, and M is selected as 2 correspondingly. The desired velocity is $V_{\max}$ which is the same for all pedestrians. Generally, there are two methods for the modeling of different desired velocities $V_{\max}$. Firstly, it can be done by changing the value of the update time step. Secondly, it can be done by dividing each time step into $V_{\max}$ substeps. Compared with the first method, the model can easily be extended to deal with the heterogeneous pedestrians by using the second method. Therefore, similar to Weng et al. [25], the second method is used in the proposed model. That is, at each time step, $V_{\max}$ sub-steps are performed. And for each sub-step, pedestrians move only one cell to one of its neighboring cells or remain unmoved according to certain transition probabilities which are mainly determined by the static and dynamic floor fields.

The static floor field S is initialized at the beginning of the model run and does not change with time. It is used to specify the surrounding geometry and the attractive strength of such regions as emergency exit and shop windows. Therefore, the static floor field depends on pedestrians according to their destinations. Nevertheless, in evacuation scenarios with only one exit, it is the same for all pedestrians. And it depicts the shortest distance to the exit. The field value is a discrete gradient which decreases as being apart from the exit, and it is calculated by the method proposed by Huang et al. [35] in this paper. According to their method, the shortest distance from cell (i, j) to the exit is calculated by two ways, that is, $e_{i,j}$ (movement in all eight directions is permitted) and $f_{i,j}$ (movement to the diagonal directions is prohibited). In fact, the most feasible distance is the weighted sum of them, i.e., $d_{i,j} = \varepsilon f_{i,j} + (1 - \varepsilon)e_{i,j}$, where $0 \le \varepsilon \le 1$ (according to Huang et al. [35], the value of ε should be within the range [0.4, 0.6], so that the arch-like clogging could be reproduced). Then, the static floor field value for cell (i, i) is given by

$$S_{i,j} = d_{\max} - d_{i,j}, \tag{1}$$

where $d_{\max} = \max_{(i,j)}\{d_{i,j}\}$. In summary, the static field value is given by the hypothesis that pedestrians intend to move to a neighboring cell that is closer to the exit in the most feasible direction [35].

The dynamic floor field D which is regarded as a "bosonic" field represents a virtual trace left by the pedestrians and their dynamics. Generally, it is used to depict the long-ranged attractive interaction between individuals based on the following principle. The floor field of occupied cells is increased when a pedestrian leaves a virtual trace. Since the transition probability is proportional to the dynamic floor field it becomes more attractive to follow in the footsteps of other pedestrians. The dynamic field value $D_{i,j}$ of cell (i, j) is the number of bosons corresponding to the exit. Initially, cells contain no bosons. When a pedestrian moves to one of its neighboring cells, a boson is produced at the departure cell. Simultaneity, the bosons have their own dynamics, that is, diffusion and decay. In each time step, each boson decays with probability $\delta(0 \le \delta \le 1)$ and other bosons without decaying diffuse with the probability $\alpha(0 \le \alpha \le 1)$.