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An extended floor field model based on regular hexagonal cells for pedestrian simulation

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HIGHLIGHTS

- Our model adopts regular hexagonal cells instead of square ones.
- A psychological repulsive force is proposed instead of classical dynamic field.
- Our model successfully reproduces some self-organization phenomenon.
- A linear relationship between pedestrian density and the repulsive force is found.
- A new conception of velocity level is put forward to modify the model.

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ABSTRACT

Recently the floor field (FF) model has been widely used to simulate pedestrian dynamics. This paper presents an extended FF model based on regular hexagonal cells to simulate pedestrian dynamics in a corridor scenario. In this model, the elements in FF model are redefined. Scenarios are discretized into regular hexagonal cells rather than squared ones. Pedestrian repulsion is adopted instead of dynamic floor field. Velocity level is proposed to describe pedestrian movements. Simulations in a corridor scenario are conducted, and the basic property of the new model is discussed deeply, including the parametric effects on flow and wait distribution of pedestrian. The fundamental diagrams of pedestrian dynamics are used to verify the model.

1. Introduction

Walking is playing an important role in daily life. With the rapid development of the society, more and more people get together in many public places, leading a serious hidden danger to the public security, which has drawn much attention. Nowadays, microscopic simulation of pedestrian dynamics has been widely used in intelligent transportation. Many researchers have adopted a lot of excellent models of people to simulate pedestrian dynamics in many kinds of facilities including the emergency situations.

Generally, these models are split into two groups: continuous model represented by the social force (SF) model [1–4] and discrete model delegated by the cellular automata (CA) model [5–12]. The SF model belongs to the force-based approaches, having an accurate description of pedestrian dynamics. The movement of pedestrian is considered as the effect of social force [1]. The CA model is discrete in space, time and state variables. Pedestrians are regarded as agents within these space cells [8]. The CA model is also widely applied in many simulation softwares for its simple rules and high efficiency.

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One of the widespread CA models is floor field (FF) model [5]. After that, lots of extended FF models are proposed in different aspects. Kirchner et al. [13] found the irrationality for all pedestrians share the same velocity. Weng et al. [14] and Guo et al. [15] adopted smaller cells to simulate pedestrian evacuation and successfully reproduce more unorganized movements. Yang et al. [16] and Yue et al. [17] focused on the right-moving preference while Xu et al. [18] and Yanagisawa et al. [19] paid attention to the turning effect. Fang et al. [20] considered the slow-to-start effect in pedestrian movement, and observed stop-and-go waves and phase separation in pedestrian flow. Schadschneider et al. [21] calibrated the floor field model in single-file motion. Nowak et al. [22] studied lane formation, jamming, and other features in pedestrian counterflow by quantitative analysis. Zeng et al. [23] and Leng et al. [24] studied the psychological feature of pedestrians in unfamiliar and complex scenarios and proposed a local view model for simulating the pedestrian choice of temporary goals.

Most of FF models [25–29] adopt the shape of a square cell. However, there are some obvious defects in square cell structure: it is difficult to handle pedestrians when walking in an oblique direction. For the four-directions models, the diagonal walk need two steps and to go through a right angle, leading a very mechanized pedestrian movement; for the eight-directions models, the displacements between diagonal walking and straight walking are different, resulting in different velocities of pedestrian, a number of other control methods must be taken to balance the moving speed of the pedestrian.

In this paper, an extended FF model based on the regular hexagon cell structure is proposed. The regular hexagon structure is everywhere in the nature, such as snowflakes, bee nests and so on. Maniccam [30] firstly used hexagonal lattice to simulate pedestrian dynamics and found the critical density of hexagonal model is higher than square model. However, in his work pedestrians never go straight, so we rotate the cells 90° to fix that. Hartmann [31] proposed an approach for adaptive path finding using the hexagon structure, but he did not consider the interaction between pedestrians. Guo et al. [32] described the collection, spillback, and dissipation by network based on hexagonal cells. However, their work was based on a mesoscopic scope and the maximum capacity of each cell was 16 pedestrians. So their model would not reflect the interaction between pedestrian exquisitely.

This paper focuses on pedestrian dynamic features in corridor simulated by hexagonal-cells FF model, and reveals the relationship among density, velocity and flow via fundamental diagrams. There is an obvious advantage in describing the behavior of pedestrian dynamics using regular hexagonal cell model. For example, in corridors and other long straight channel facilities, pedestrians are basically classified into two directions of movement patterns. Due to the competition of space resources, pedestrians usually step forward. Even if the space in front has been occupied by others, they would like to detour via their lateral front direction, rather than a translation motion. Hexagonal cell structure provides an effective support for this movement. The simulation using this new model is also conducted and the parameters are detailed discussed. The fundamental diagrams of density, flow and velocity compared to practical experiments [33–35] prove that this model is practical.

2. Model

The model redefines the discretization of the basic elements, especially the shape and size of cells, and considers the effect from the exits, wall and the pedestrian around.

2.1. Discretization

Regular hexagonal cell model is different from the classical floor field model in discretization of the basic elements. The following sections expound the differences in three aspects: space, time and the speed of pedestrians.

2.1.1. Discretization of space

In this model, the pedestrian space is discretized into regular hexagonal cells. One pedestrian will occupy approximately one hexagonal cell and the pedestrian can move to one of the six neighboring cells (if the target cell is empty), stay in the current cell (when all the six cells are occupied) or even go back with a certain probability when updating. The basic discretization of space is shown in Fig. 1(a). Since regular hexagon is not isotropy in orthogonal directions, this model may inconvenient to describe the scenes such as crossroads. The basic size of the hexagonal cell is set as shown in Fig. 1(b): side length $l = 0.2$ m, the max length of the cell is 0.4 m, and the two neighboring cells are approximately 0.346 m away from each center.

2.1.2. Discretization of time

Weng et al. [36] worked on pedestrian movement with different walk velocities and pointed out that different walk velocities can be simulated through update at different time-step intervals. However, in their settings of parameters, pedestrian can only have two kinds of velocity: 1.0 m/s, 1.5 m/s. They considered that each pedestrian has a fixed velocity. In our consideration, pedestrians may have more velocity level and they can change their velocity according to the circumstance.

In our model, time is discretized into the basic time slices and each second contains 24 basic time slices. The location of pedestrian will be updated within one basic time slice. The setting of basic time slice can scatter the update time of pedestrian, reducing the conflict caused by synchronous update of pedestrian position. At the same time, this setting of basic time slice can contribute to the description of different pedestrian velocity. The pedestrian velocity is controlled by changing his/her refresh rate.