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Block-based floor field model for pedestrian's walking through corner

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HIGHLIGHTS

- A concept of block division is proposed according to the flow characteristics in different scenarios.
- A calculation method is proposed to obtain an accurate solution of static floor field in CA model.
- Pedestrian flow simulations are implemented in L-type and T-type scenarios with corners.
- This method can well reproduce the moving behavior around corner.
- The evacuation time can be reduced due to full utilization of the scenarios.

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ABSTRACT

Floor field model, characterized by discretization in both time and space, is very popular in pedestrian modeling. In this paper, the pedestrian's moving behavior of walking through corner is described by a block-based floor field model. In this method, a complicated scenario with corners is divided into different types of blocks, the static floor field of each block is separately calculated, and a boundary rule is incorporated into the model to deal with the connected adjacent blocks. Two typical scenarios, L-type scenario and T-type scenario, are used to investigate the performance of the proposed model. The simulation results showed that the proposed model could well reproduce the empirical pedestrian's moving behavior through corner, i.e., pedestrian may transfer to the far corner instead of queuing up at the near corner when congestion happens. Pedestrians are more uniformly distributed in the whole evacuation process and the total evacuation time could be reduced due to the full utilization of scenarios for both channel and corner.
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1. Introduction

Pedestrian dynamics has been vigorously studied in traffic science, engineering and physics fields over recent decades. Understanding pedestrian flow characteristics beforehand is of great importance in designing and improving the layout of many public buildings, such as waiting rooms, meeting rooms and stadiums. In order to investigate pedestrian dynamics, many microscopic models have been developed, such as social force model [1–3] and cellular automata (CA) model [4–21]. CA model is a common spatial–discrete model, and it has been fully studied by the method of simulation. In addition, some pedestrian evacuation experiments have been conducted to verify these models [8,22–26].

The floor field (FF) model is a well-established CA model for describing the pedestrian dynamics, and it has received growing interests from researchers for its simplicity and extensibility in reproducing characteristics of pedestrian dynamics [5–18,20,21]. In the model, the floor field can be separated into two categories: the static floor field (SFF) and the dynamic

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floor field (DFF). The SFF describes the shortest distance from the current cell to all exit cells, and the value of SFF is time-independent. Therefore, the SFF is always linked with a destination as it is a map of distance to destination. The DFF reflects the virtual trace left by moving pedestrians. During an evacuation, the DFF of each cell may decay or diffuse to other neighbor cells with some certain probability, which indicates the pedestrians' collective behavior. Compared with DFF, the SFF plays a more dominant role in the FF model [20]. A higher-precision value of SFF could make the FF model more accurate and comprehensive. Therefore we only focus on the discussion of the SFF in this paper.

There are several approaches of calculating the distance based SFF [4–21,27–30], i.e. Manhattan metric, Chessboard metric, Euclidean distance, and Dijkstra metric. Kretz et al. [19] gave an overview of existing methods of calculating SFF, and compared these approaches with numerical experiments. Nishinari et al. [11] proposed a new approach to calculate the SFF through the combination of Dijkstra's algorithm and visibility graph. Huang and Guo [12] calculated the SFF by the most feasible distance from the lattice to an exit. Wei et al. [20] presented a method of building SFF for the scenario with wide exit by putting forward an idea of "virtual reference point". Kimmel et al. [27] extended the Fast Marching Method to triangular domains and computed geodesic distances and minimal geodesic paths on manifolds as an application. Zhang et al. [13] established a discrete cost potential field, which considered the costs of travel time and discomfort. A similar intension existed in Ref. [28], which established a new theory of pedestrian behavior under uncertainty based on the concept of utility maximization.

The existing FF models can provide believable results for simple or small scale structure. However, for some complex scenarios, especially the scenario with corner, these models would lead to some illogical phenomena, such as the highly insufficient utilization of outer corner regions or irrational distribution of pedestrians. These unrealistic behaviors are mainly due to simply define the shortest distance from the current cell to the exit cells as the SFF, while neglecting the impact of local irregular structure on pedestrian dynamics [31,32]. To reproduce more realistic pedestrian dynamics through corner, several extension works have been done based on FF model by introducing additional field, e.g., dynamic distance field [31], flood fill dynamic potential field [33], wall interactions and inertia effects [32], local view field [34], perceived potential field and aggregated force field [35], etc. Some other models with continuous time and space have also been developed to simulate the empirical pedestrian dynamics around corner [36–41].

In this paper, an extended FF model is established to reproduce some empirical moving behavior around corner, and enhance our knowledge on pedestrian dynamics through passageway contain irregular structures. In our model, a scenario with corner is divided into different types of blocks and the SFF is calculated separately within each block. Additionally, a boundary rule is introduced to connect adjacent blocks. The definition of SFF within each block is based on pedestrian's moving behavior in the corresponding region. Simulations are carried out to verify the proposed model.

The remainder of this paper is organized as follows. In Section 2, a block based FF model is proposed, and the method of calculating SFF is given. Then, the simulation results and numerical analysis are fully discussed in Section 3. Finally, in Section 4, we conclude the paper and point out the future research.

2. Block-based FF model for scenario with corner

2.1. FF model

In the existing FF models, the evacuation scenario is represented by a series of cells with the same size. Each cell can be either empty or occupied by pedestrians or obstacles. In each time step, a pedestrian at (i_0, j_0) will move to one empty of its neighboring cells, or remain unmoved. The Von-Neumann neighbor is adopted in this paper, which implies that each pedestrian can move to one of four next-neighboring cells or stay at the present cell within each time step. Fig. 1 shows pedestrian's moving directions and corresponding transition probabilities. The pedestrian's moving direction is determined by two types of floor fields: SFF and DFF. SFF is initialized using some distance metrics for all cells, it is geometry specific and reflects the distance from the cell to exit. The SFF of exit cell is the smallest and set as 0, and as the cell far away from the exit, the SFF increases. It is time-independent and is not influenced by the presence of pedestrians, so it can be used to specify regions of space which are more attractive, e.g. an emergency exit or shop windows [4,5]. DFF is time-dependent and represents a virtual trace left by moving pedestrians, which is used to model a long-ranged attractive interaction between the pedestrians. Similar to the chemotaxis [4,5] that are used by insects for communication, the DFF has its own dynamics, i.e., diffusion and decay, which leads to broadening, dilution, and finally vanishing of the footprints [7].

The transition probability $P_{i,j}$ for a jump to the neighboring cell (i, j) is given by the following expression:

$$P_{i,j} = \exp(-K_s S(i,j) + K_d D(i,j))(1 - o_{i,j})/N \quad (1)$$

where $1/N$ is a normalization factor to ensure that $\Sigma_{(i,j)} P_{i,j} = 1$. $S(i, j)$ and $D(i, j)$ are the SFF and DFF of cell (i, j), respectively. $o_{i,j}$ represents whether the neighboring cell (i, j) is occupied by a pedestrian, wall or obstacle, so $o_{i,j} = 1$ for an occupied cell and $o_{i,j} = 0$ for an empty cell. K_s and K_d are two non-negative sensitivity parameters for scaling SFF and DFF, respectively. SFF and DFF modify the transition probability in such a way that a motion into the direction of smaller SFF and larger DFF is preferred. Note that when all neighboring cells are occupied by others or obstacles, the pedestrian will stay at the cell (i_0, j_0).

In this paper, the parallel update method is adopted, that is to say, the positions of all pedestrians are updated simultaneously. Due to the use of parallel dynamics, it may happen that $M (M > 1)$ pedestrians try to move to the same target cell at the

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