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Formulation of pedestrian movement in microscopic models with continuous space representation

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ABSTRACT

When the microscopic pedestrian models, in which pedestrian space is continuously represented, are used to simulate pedestrian movement in the buildings with internal obstacles, some issues arise and need be dealt with in detail. This paper discusses two of the issues, namely formulating the desired direction of each pedestrian in the buildings and determining the region around each pedestrian, other individuals and obstacles in which affect his or her movement. The methods for computing the desired direction and effect region are proposed, using the algorithms for the potential of pedestrian space. By numerical experiments, the performance results of three proposed formulae for the desired direction are compared, the method for the effect region is tested, and the validity of the method for computing the desired direction as considering the border effect of obstacles is verified. Numerical results indicate that the proposed methods can be used to formulate pedestrian movement, especially in the buildings with internal obstacles, in the microscopic models with continuous space representation.

1. Introduction

Shedding light on the behavior and property of pedestrians in public facilities is critical for maintaining these facilities' level of service and assuring pedestrian safety in these facilities during emergency accidents. Recently, many researchers and authorities have begun to research pedestrian flow problems through mathematical models and computer simulations. These models are generally classified into two categories, i.e., continuum macroscopic models (e.g., Hughes, 2002; Huang et al., 2009; Jiang et al., 2009) and individual-based microscopic models (e.g., Burstedde et al., 2001; Kirchner and Schadschneider, 2002; Huang and Guo, 2008; Asano et al., 2010; Zhao and Gao, 2010; Nagatani, 2010; Guo and Huang, 2010; Helbing and Molnár, 1995; Helbing et al., 2000; Antonini et al., 2006; Guo et al., 2010). The first class of models is usually applied to a large crowd and involves treating the crowd as a whole or a fluid, in the form of partial differential equations formulating the flow conservation law. However, this class of models often oversimplifies and undermines inherent real-world complexity. In the second class of models, each pedestrian is considered as a discrete individual, the position update of each pedestrian is formulated by a continuous or discrete dynamic system, and pedestrian space can be either discretely or continuously represented.

In the microscopic models with discrete space representation (e.g., Burstedde et al., 2001; Kirchner and Schadschneider, 2002; Huang and Guo, 2008; Zhao and Gao, 2010; Nagatani, 2010; Guo and Huang, 2010; Alizadeh, 2011), pedestrian space is discretized into square or hexagon lattice and each individual occupies a certain number of lattice sites and can move into neighboring lattice sites at every update step. Pedestrians perform biased random walk generally and select the neighboring

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lattice sites closer their destinations in route distance with a higher probability than the other neighboring lattice sites. In the microscopic models with continuous space representation (Helbing and Molnár, 1995; Helbing et al., 2000; Antonini et al., 2006; Guo et al., 2010; Guo, 2010), it is generally assumed that each individual selects a desired direction during movement at each update step and his or her movement is effected by surrounding other ones or obstacles in an effect region. The desired direction is a direction, in which each pedestrian will be closer to his or her destination after movement. The effect region around each pedestrian is a region, other ones and obstacles in which will affect his or her movement. Due to the effect of other ones and obstacles in the effect region, his or her actual movement direction may deviate from the desired direction.

In the microscopic models with continuous space representation, when there are no any obstacles in a room, the desired direction and effect region can be obtained easily. The direction from the position to the exit can be as a desired direction and the circular area centering at the position, with a certain radius, can be as an effect region. However, when there are obstacles in a room, it is difficult to formulate the desired direction and effect region.

In this paper, using the distribution of space potential, three formulae for computing the desired direction of pedestrians, especially in the buildings with internal obstacles, in the microscopic models with continuous space representation are proposed and an algorithm for computing the effect region around each pedestrian is developed. By numerical experiments, based on two kinds of algorithms for space potential, the three formulae for computing the desired direction are compared. And the algorithm for computing the effect regions around pedestrians near obstacles is tested. When the formulae for the desired direction are applied to simulate pedestrian evacuation in the building with internal obstacles, the phenomenon that pedestrians stagnate near the corners of obstacles occurs, since the pedestrians' sizes are considered and they occupy a certain space in the microscopic models with continuous space representation. For resolving this limitation, we further develop another algorithm for the desired direction. Simulation results indicate that the algorithm can overcome the limitation. After pedestrians' movement in their desired directions, not only their route distances to destination are decreased, but also they can round nearby obstacles.

2. Method description

2.1. Microscopic pedestrian model

For clarity, the proposed formulae and methods are presented for a specific model. Here, the microscopic pedestrian model proposed in Guo et al. (2010) and Guo (2010) is employed to formulate pedestrian movement. In the model, pedestrian space is continuously represented. The maximum movement distance of pedestrian in each update step is limited and hence the alteration of the update step in a proper range only affects the degree of overlapping among pedestrians and the excluded-volume effect can be guaranteed easily. In addition, the model formulates the irrational and undetermined movement of pedestrians through a logit-based discrete choice principle for selecting their movement directions. We here introduce the model briefly.

In the model, at each update step Δt, the positions of all pedestrians are updated synchronously. Each pedestrian first determines his or her movement direction, and then moves a certain step size in that direction. The possible movements of a pedestrian are shown in Fig. 1. In the figure, the pedestrian n, which is denoted by the gray circle, is moving in the desired direction $\mathbf{e}_n$. The radius of the pedestrian n is r_n. The pedestrian n can move along direction $\mathbf{d}_i^n$ (i = 1, ..., 12) or remain stationary. The angles β_i^n (i = 1, ..., 12) between the twelve directions and the desired direction $\mathbf{e}_n$ are π, $3\pi/4$, $\pi/2$, $3\pi/8$, $\pi/4$, $\pi/8$, 0, $-\pi/8$, $-\pi/4$, $-3\pi/8$, $-\pi/2$, and $-3\pi/4$, respectively. It is assumed that the movement of pedestrian n is affected by the movement of others and by obstacles in the surrounding circular area, the radius of which is R_n.

The effect of pedestrian m on the movement of pedestrian n in the directions toward pedestrian m is illustrated in Fig. 2. If the direction $\mathbf{d}_i^n$ of pedestrian n is in the radial cone between radials l_1 and l_2, which are parallel to segments l_3 and l_4 respectively, then his or her movement in that direction will be affected. The effect of a wall on pedestrian n can be defined in a similar fashion. If the distance between a wall and pedestrian n is less than R_n, then the wall will affect the movement of pedestrian n in the directions toward the wall. As shown in Fig. 3, the movement of pedestrian n in the directions in the

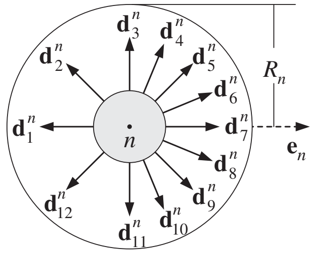

Fig. 1. Possible movements of a pedestrian.