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Simulation of evacuation processes using a multi-grid model for pedestrian dynamics

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Abstract

Introducing the force concept of a social force model into the lattice gas (LG) model, a new LG-based discrete model entitled "multi-grid model" is composed. In the new model, finer lattice is used; thus each pedestrian occupies multiple grids instead of one, and the rules of interactions among pedestrians or pedestrians and constructions are built. The interaction forces including extrusion, repulsion and friction are considered as passive factors for evacuation. The strength of the drift, or the intensity of the pedestrians to move toward the exit rapidly, is considered an active factor. A simple situation is studied in which pedestrians try to evacuate from a large room with only one door. The influences of interaction forces and drift on evacuation time are analyzed. The mutual restriction relation of the two factors in the course of evacuating is found.

Keywords: Multi-grid model; Passive factor; Active factor

1. Introduction

In the past several decades, vehicular traffic problems have attracted the attention of researchers, and methods of physics and modern computer science have been successfully used to study the problem [1–3]. Another type of many-body system, i.e. pedestrian flow, which is more difficult to describe in terms of simple models, has been studied in recent years [4–6]. Muramatsu et al. [7] have studied the counterflow of pedestrians within an underpass by using the lattice gas (LG) model of biased-random walkers. It has been found that the dynamic jamming transition occurs at a critical density. Nagatani et al. [8–11] have studied pedestrian flow under different conditions by using the same model and achieved valuable results. With the accumulation of the knowledge of the human behavior during a fire, study in human behavior modeling and evacuation modeling has improved. New methods and models in pedestrian dynamics have been introduced in the field of study [12]. Helbing et al. [13] have studied the dynamical features of escape panic using the social force model that perform features of escape panic such as arching and clogging of pedestrians at the exit. Kirchner et al.

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[14,15] have studied evacuation processes by using the cellular automata model based on the bionics and found that the evacuation time depends on the strength of the herding behavior, with minimal evacuation times for some intermediate values of the coupling constants.

As typical models in evacuation modeling, the LG model [16–19] and the social force model [13] can successfully simulate the most typical phenomena observed in pedestrian dynamics. They have their respective advantages in that the LG model is simple and has a high computational efficiency and the social force model is good at modeling the interactions among pedestrians.

Based on the classic LG model, we develop a new evacuation model entitled multi-grid model that uses finer lattice. In the new model, one pedestrian occupies multiple grids instead of one and overlapping of pedestrians is allowed. The interaction forces among pedestrians or those among pedestrians and constructions can be calculated quantitatively by the number and position of the overlapped grids, together with the model rules. In this paper, the study is focused on the influence of interactions on evacuation time and the mutual restriction relation between interactions and self-driven action. A typical scenario where many pedestrians try to escape from one door is simulated with the multi-grid model and the simulation results are discussed. The proposed model is expected to have some basic characteristics of both the LG model and the social force model.

2. Multi-grid model

Let us consider the simplest parameters of the multi-grid model. In the model, space is represented with a two-dimensional lattice and each pedestrian occupies a foursquare district, the size of which is $40\,\text{cm} \times 40\,\text{cm}$. This is the typical space occupied by a pedestrian in a dense crowd. In the traditional LG model, each pedestrian is assumed to occupy only one grid with the same size as that of the pedestrian. To describe the interaction forces more conveniently and accurately, the multi-grid model uses a smaller grid, the size of which is approximately $13.3\,\text{cm} \times 13.3\,\text{cm}$ or each pedestrian occupies $3\,\text{cm} \times 3\,\text{cm}$ grids. As shown in Fig. 1(a), a black grid denotes the center of the pedestrian which is forbidden to be occupied by another pedestrian, and the red ones can be overlapped by other pedestrians. Considering that the compressibility of a pedestrian is limited, as many as three grids are allowed to be overlapped by other pedestrians. This is the ‘‘conflict rule’’ of the model. Fig. 1(b) is a possible overlapped state of two neighboring pedestrians. A pedestrian moves one grid in each time step with an average velocity of 1 m/s.

In the model, each pedestrian could select one of the eight possible directions with different transition probabilities and move to one of the neighboring grids (see Fig. 2).

We define $P_{i,j}$ as the transition probability that a pedestrian moves to the direction (i, j) and its value is given by

$$P_{i,j} = N\delta_{i,j}I_{i,j}\left(\frac{1-D}{\sum_{(i,j)}\delta_{i,j}} + D_{i,j} + \sum_{P} f_{i,j} + \sum_{W} f_{w}\right). \tag{1}$$

Here $\delta_{i,j}$ denotes the possibility whether the pedestrian can move to the direction (i, j), i.e., $\delta_{i,j} = 1$ if the direction is available and $\delta_{i,j} = 0$ if it is unavailable. The inertia $I_{i,j}$ represents the enhancement of the probability that the pedestrian keeps his previous movement direction. The value of $I_{i,j}$ is greater than 1 in the

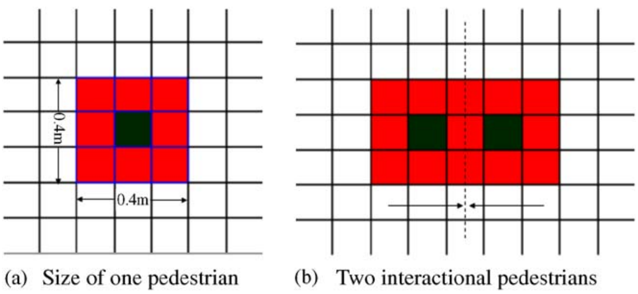

Fig. 1. (a) Size of one pedestrian. (b) Two interactional pedestrians.