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Simulation of pedestrian counter flow through bottlenecks by using an agent-based model

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ABSTRACT

Considerable research has been conducted on the topic of unidirectional evacuations from exits. However, few studies aim at simulating counter flow through a bottleneck with complex conflict. This paper proposes an agent-based model to investigate bidirectional flow evacuation. Pedestrian speed is determined by the speed of the leading agent and the surrounding agents. The moving direction of pedestrian originates from four forces, namely, gradient force, repulsive force, resistance force, and random force. These four forces dominate the main stream of the pedestrian moving trajectory, the interaction between pedestrians and their local environment, the resistance or disinclination to movement, and the random variations and chaotic nature of pedestrian dynamics. The novelty of this research is in the agent-based model that combines the agent and forces while providing insights for the simulation of the pedestrian dynamic on the cognitive level. The experiment results show that the behavior that arises from this model is consistent with the observations from Guangzhou Metro and that this model could help capture the essence of pedestrian behavior near egresses.

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1. Introduction

Pedestrian flow has attracted increasing attention in research. Bohannon reviewed crowds and the science of evacuation [1]. Based on the concept of utility maximization, Hoogendoorn put forward a theory of pedestrian behavior under uncertainty [2]. Henderson introduced Navier–Stokes equations to mimic pedestrian behavior [3]. An improved fluid-dynamics model was proposed to study the movement of pedestrians [4–6]. The application of fluid-dynamics models to pedestrian movement remains challenging, given that a fluid particle does not have a preferred direction of motion and cannot make decisions [7]. The social force (SF) model, a self-driven multi-particle model originally proposed by Helbing and improved by Lakoba [8–10], has been successfully used in simulating escape panic [11], crowd turbulence, and room evacuation [12]. However, complex rules make the SF model computationally intensive [13]. In addition, the SF model is unsuitable for tackling complex geometries [14], given that it ignores the contributions of individuals who make local decisions based on personal strategies [15].

With simple transition rules and discrete space–time, the lattice gas (LG) model [16–24], cellular automata (CA) model, and multi-grid CA model play a dominant role in recent investigations of pedestrian dynamics [25–38]. To guide pedestrians to the right direction, the floor field is married to the CA model to mimic pedestrian behavior [39–43]. However, a problem

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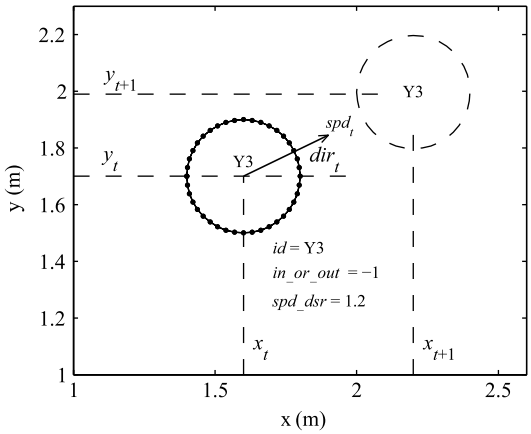

Fig. 1. Features of the agent. From $t \to t+1$, agent Y3 walked from location (x_t, y_t) to (x_{t+1}, y_{t+1}). For clarity, the figure exaggerates the distance covered by agent Y3 within one time step 0.1 s, and the neighbor agents are not shown.

with the LG and CA models is that the force is entirely excluded by the crowded pedestrian models, and the discrete space is the cell size, 40 or 50 cm. Thus, pedestrian movement is restricted to a multiple of cell sizes in each time step. Although the multi-grid CA model struggles to improve precision with small grids, the increasing complexity of modeling dwarfs its application. The agent-based (AB) model offers an innovative perspective to pedestrian dynamics. Antonini presented a discrete choice model based on an agent for pedestrian dynamics [44]. Henein proposed an agent-based model to evacuate crowds incorporating pushing forces and injuries [45]. As previously mentioned, unidirectional evacuation has been studied intensively. However, few published studies have satisfactorily modeled the evacuations of counter flow through a bottleneck with complex conflicts. This paper proposes an AB model to investigate bidirectional flow evacuation. This model integrates the agent and other forces. Each pedestrian is represented by an intelligent agent with self-determination. The forces accepted by the agent are gradient force, repulsive force, resistance force, and random force. This model can capture the macro-level pattern of combined activities of each agent, while investigating pedestrian behavior at the micro-size level. For testing the proposed model, a scenario is presented to simulate the boarding and alighting in the metro station during peak hours. Swarms of passengers, weaving pedestrian flows and complex evacuation spaces are characteristics of the application.

This paper is organized as follows: In Section 2, the AB pedestrian model is introduced. In Section 3, we present a scenario with experiments and observations, result analysis, and discussion. Finally, a brief summary is given in Section 4.

2. AB model

AB pedestrian models are interesting for their complex dynamic behavior, the interactions between the pedestrian and the environment, and the synthesis characteristics of individuals and collective behavior. An intelligent agent has the overall features of the pedestrian. At time t, the features of a given pedestrian agent are defined as

$$Agent_id, t = [id, in_or_out, spd_dsr, x_t, y_t, spd_t, dir_t] \tag{1}$$

where id, in_or_out, and spd_dsr respectively denote the unique identifier, general intention, and desired speed; x_t andy_t represent the location; and spd_t and dir_t respectively describe the speed and walking direction (Fig. 1). The static features are id, in_or_out, and spd_dsr, whereas the others are dynamic. The static features are initialized and constant after the agent's birth, whereas x_t, y_t, spd_t, and dir_t vary dynamically. Given $Agent_{id,t}$, the essence of the AB model is to define the transition rule of dynamic features of the agent at each discrete time step $t \to t+1$. Hence, the AB model can be expressed as

$$Agent_{id,t+1} = f(Agent_{id,t}, N), \tag{2}$$

where $Agent_{id,t+1}$ is the feature of Agent id at the instant of time $t+1$; N denotes the environment, the layout of neighbor agents, and the evacuation space; and f is an iterative transition function that defines the change of features from t to $t+1$. Generally, f includes updated strategies on the location, speed, and direction of the agent. The transition rule of the agent's location is given by

$$\begin{cases} x_{t+1} = x_t + spd_t \times \cos(dir_t) \times step \\ y_{t+1} = y_t + spd_t \times \sin(dir_t) \times step \end{cases} \tag{3}$$

where $step$ is the time interval, (x_t, y_t) is given by the precedent iteration, and dir_t and spd_t respectively denote the walking direction and speed. In this model, the driving force is the sum of forces received by the agent, including gradient force, repulsive force, resistance force, and random force. Generally, these forces are from pedestrian agents' psychology, not from classical mechanics. The motion of the agents is a self-driven non-equilibrium system. Thus, describing pedestrian

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