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Necessity of guides in pedestrian emergency evacuation

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HIGHLIGHTS

- The influence of mass behavior on evacuation dynamics is investigated.
- An extended crowd model is proposed for the guided crowd.
- The effect of position of guide on evacuation is studied.
- The effect of the quantity of guides on evacuation is studied.

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ABSTRACT

The role of guide who is in charge of leading pedestrians to evacuate in the case of emergency plays a critical role for the uninformed people. This paper first investigates the influence of mass behavior on evacuation dynamics and mainly focuses on the guided evacuation dynamics. In the extended crowd model proposed in this paper, individualistic behavior, herding behavior and environment influence are all considered for pedestrians who are not informed by the guide. According to the simulation results, herding behavior makes more pedestrians evacuate from the room in the same period of time. Besides, guided crowd demonstrates the same behavior of group dynamics which is characterized by gathering, conflicts and balance. Moreover, simulation results indicate guides with appropriate initial positions and quantity are more conducive to evacuation under a moderate initial density of pedestrians.

1. Introduction

The efficiency of pedestrian evacuation is a key aspect of the safety performance evaluation in public places such as subway stations, airports, and stadiums. Appropriate evacuation measures developed in advance can play important roles in improving the evacuation efficiency when fire, explosion, earthquake and other emergencies occur. In 2008, more than two thousand students and teachers all realized the safe evacuation in 96 s when earthquake occurred in Zaosang middle school, Sichuan Province, China, since emergency evacuation drills were organized in each semester. A large number of facts have proven that the prevention beforehand works much better than a temporary response [1]. Moreover, the poor emergency warning system and unreasonable and temporary evacuation strategy are the root causes of catastrophe. Earthquake tsunami disaster having adverse impacts to more than 10 countries occurred in Indian Ocean in 2004, caused about 30 million deaths, and 14 billion dollars loss because of the poor communication of information. The establishment of

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the predictive evacuation system is therefore very important, and many scholars began to investigate pedestrian dynamics to better understand the evacuation procedure from the 1970s [2].

Generally, pedestrian models to predict pedestrians' behaviors and dynamics in the normal and emergency situations are studied from the macroscopic and microscopic perspectives [3]. Macroscopic pedestrian model considers the pedestrian flow as a whole by using the flow density and velocity to describe its motion [4]. The most remarkable advantage of this model is to save the computation amount and enhance the real-time ability [5]. Fluid dynamics model as a typical macroscopic model treats the flow as the continuous liquid and is described based on the Navier–Stokes equation [6]. However, the macroscopic model neglects the detailed behaviors among pedestrians, and this is one reason why microscopic pedestrian model continues to emerge and has been widely applied in reality. Microscopic pedestrian model considers the interactions among pedestrians such as the cellular automata model [7–10], the social force model [11–13], and the agent based model [7]. Wang et al. [8] proposed a cellular automata model considering the game strategy to study the pedestrian evacuation in a hall. Frank and Dorso [9] studied the room evacuation in the presence of an obstacle based on the social force model and found "clever is not always better" effect. This paper chooses to use the microscopic social force model as the reference model which not only qualitatively represents self-organization behaviors such as lane formation [10] and strip formation [11] but also introduces the physical and psychology forces that make the model more realistic.

During the major events in large public places, we always find some staffs wearing the clothes with bright colors to maintain order. These staffs who are familiar with the building structure may play guides when emergency occurs. Hou et al. [12] investigated the effect of the number and positions of guides on evacuation dynamics in rooms with limited visibility range. However, the walking rules set for pedestrians without following the guide do not consider the mass behavior which are not corresponding to reality. Yang et al. [13] developed the guided crowd model to study the crowd dynamics via modified social force model, but all pedestrians are assumed to have obtained the information from the guide, and they do not give the description for pedestrians who cannot get the information. This paper extends the model proposed by Yang et al. [13] to present the detailed behaviors not only for pedestrians who follow the guide but also for those who cannot be influenced by the guide.

This contribution presents the dynamic behaviors of the guided crowd. It continues with the description of the extended crowd model in Section 2, where the mathematical models for the guide and all pedestrians whether are informed or not are developed. Section 3 gives the scenario setup, effects of mass behaviors in the cases of no guides, evacuation dynamic due to the guide, and the effect of position and quantity of guides on evacuation. After analyzing the simulation results, the key discoveries are reviewed and the future work is looked into in Section 4.

2. An extended crowd model

This section mainly focuses on modeling of the guided crowd in a smoky room, where the normal pedestrians are not familiar with the surroundings except the guides who know exactly where the exit is. Generally, the vision field is limited in a smoky room, the pedestrians who locate in the influence field of the guide may follow the movement of the guide. However, for those who neither belong to the influence area of the guide nor the exit is visible, a random moving direction will be chosen.

2.1. Social force model

The social force model is proposed by Helbing et al. [14], in which pedestrians are driven by the desired force, $\vec{f}_i^{\,0}$; the interaction force between pedestrians i and j, $\vec{f}_{ij}$; and the interaction force between pedestrian i and walls w, $\vec{f}_{iw}$. This model is represented by

$$m_i \frac{\mathrm{d}\vec{v}_i(t)}{\mathrm{d}t} = \vec{f}_i^{\,0} + \sum_{j(\neq i)} \vec{f}_{ij} + \sum_{w} \vec{f}_{iw}, \tag{1}$$

where m_i denotes the mass of pedestrian i, and $\vec{v}_i(t)$ denotes the actual walking velocity at time instant t. $\vec{f}_i^{\,0}$ shows pedestrian's willingness to reach the desired velocity:

$$\vec{f}_i^{\,0} = m_i \frac{v_i^0(t)\,\vec{e}_i^{\,0} - \vec{v}_i(t)}{\tau_i}, \tag{2}$$

where v_i^0 denotes the desired speed, and $\vec{e}_i^{\,0}$ denotes the desired walking direction. τ_i is the adaptation time for adjusting the current velocity to the desired one.

$\vec{f}_{ij}$ presents the pedestrian's psychological tendency to move away from others and the physical force that occurs only when the distance between two pedestrians' centers d_{ij} is less than the sum of these two pedestrians' radii $r_{ij} = r_i + r_j$:

$$\vec{f}_{ij} = A_i \exp\left[\left(r_{ij} - d_{ij}\right)/B_i\right]\vec{n}_{ij} + kg\left(r_{ij} - d_{ij}\right)\vec{n}_{ij} + \kappa g\left(r_{ij} - d_{ij}\right)\Delta v_{ji}^t \vec{t}_{ij}. \tag{3}$$

Here, A_i is the interaction strength and B_i is the magnitude of the repulsive interactions. $\vec{n}_{ij} = (n_{ij}^1, n_{ij}^2) = (\vec{r}_i - \vec{r}_j)/d_{ij}$ is the normalized vector pointing from pedestrian j to i, and $\vec{r}_i$ is the position of pedestrian i. k is the body compression coefficient,