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Guided crowd dynamics via modified social force model

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HIGHLIGHTS

- Modification analysis of the social force model is presented.
- Modified social force model is used for guided pedestrian dynamics.
- Some social phenomena like gathering, balance and conflicts are observed.
- Time delay for pedestrians with time-dependent desired velocities is observed.
- Predictive evacuation experiments are carried out using the guided crowd model.

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ABSTRACT

Pedestrian dynamics is of great theoretical significance for strategy design of emergency evacuation. Modification of pedestrian dynamics based on the social force model is presented to better reflect pedestrians' behavioral characteristics in emergency. Specifically, the modified model can be used for guided crowd dynamics in large-scale public places such as subway stations and stadiums. This guided crowd model is validated by explicitly comparing its density–speed and density–flow diagrams with fundamental diagrams. Some social phenomena such as gathering, balance and conflicts are clearly observed in simulation, which further illustrate the effectiveness of the proposed modeling method. Also, time delay for pedestrians with time-dependent desired velocities is observed and explained using the established model in this paper. Furthermore, this guided crowd model is applied to the simulation system of Beijing South Railway Station for predictive evacuation experiments.

1. Introduction

The development of pedestrian dynamics for emergency evacuation is an ongoing research area in traffic science and engineering. A strong interest in this topic since the early 1990s has shown the significance of this issue [1]. Generally, in public places such as subway stations and airports, an evacuation system is an important component of the safety requirements. A good evacuation system could avoid catastrophic consequences in an emergency. Therefore, predictive pedestrian simulation of the evacuation system is essential for infrastructure designs in the planning under certain conditions which take place in different buildings or circumstances.

The dynamic features of pedestrian evacuation such as lane formation, clogging effect, stop and go waves, herding and zipper effect have been observed and successfully regenerated by various pedestrian dynamics models, which mainly fall into two categories: macroscopic level and microscopic level [2]. One of the classical macroscopic model is the fluid dynamics model treating pedestrian dynamics as a fluid with the use of partial differential equation, where the dynamic characteristics

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of the crowd flow are described by average speed, density, location and time. Hughes [3] studied the problem of route choice by using a continuum model based on well-defined observations of pedestrian behavior. Colombo et al. [4] presented a continuum model able to describe features of the possible over-compressions in a crowd and the outflow through a door of a panicking crowd jam. Even though the macroscopic model could describe the overall movement trend of the crowd, detailed behaviors and interactions of the crowd will be overlooked. This is one reason why we do not choose the macroscopic model to study pedestrian dynamics characteristics in this paper.

Unlike macroscopic models, microscopic models are state of the art for computer simulation of pedestrian dynamics which put particular emphasis on the mutual influence of individuals. Hirai and Tarui [5] in the 1970s proposed a mathematical force model which consisted of some forces trying to capture several crowd movement factors like mass psychology and wall configurations. Cellular automata [6] is a discrete dynamic system belonging to a microscopic model with grid-based motion decision. The lattice gas model [7] is a special case of cellular automata based on means of probability and statistics. The social force model [8] is also a microscopic model, but this model is in a continuous space and introduces a desired force to describe the inner drive of pedestrians to escape, especially under the stressful situations. Nomad [9], a generalization of the social force model, incorporates a strategic decision making process unlike the original social force model. The agent-based model [10] which simulates pedestrians with virtual agents establishes the social structures from the "bottom-up", but it usually costs more computation [2]. The game theory model [11] is often adopted to the rational pedestrian evacuation by maximizing each evacuee's utility.

Considering all the above microscopic models' characteristics, we choose to use the social force model as the basic model to study the crowd dynamics. There are several reasons for that. One is that the social force model could qualitatively reproduce some self-organizing phenomena like lane formation and arching [12], which is suitable for describing low density crowd dynamics that can meet our demand. Another reason is that the discrete space model like cellular automata or lattice gas model which makes pedestrians walk at or within a fixed node or grid cannot allow pedestrians to move around in an unrestricted manner that is not in line with reality [13]. The social force model as a continuous space model, however, allows pedestrians to move continuously within a pre-defined place by defining some forces like the desired force. Also, the social force model considers both physical and motivation forces that is believed to be convenient for importing psychological and sociological factors into Ref. [14].

Helbing et al. introduced the vision field by defining a term to the socio-psychological force in the original social force model that could reflect the anisotropic character of pedestrian interaction [15], and they also proposed that the desired speed increased in the course of time to compensate for delays by considering the average speed into the desired direction of motion [16]. In Ref. [16], the desired velocity fluctuated only according to the realization degree of desired velocity itself which reflected the nervousness or impatience. In reality, the desired velocity, however, could also be affected by pedestrians around and the surrounding environment. If pedestrians around have a higher mean speed than that of the current pedestrian or the atmosphere is very tense reflecting from the surrounding environment such as annunciators keep ringing, pedestrians who become nervous will change their motivation or excitement degree accordingly. Therefore, in this paper we are going to do some further modification work directing at the desired velocity to make pedestrians have a sensitive response to surrounding pedestrians and environment, and become more reality.

It is a rather common phenomenon that pedestrians are unfamiliar with the area where they are and insensible of positions of exits, especially when they are too scared to keep sober-minded in emergencies. At present, the role of a guide who rescues them from emergencies is very important for scared people. With the improving awareness of safety, many inspection staff, who may act as guides in an escape, are arranged within a certain range of the large-scale public places to be responsible for safety inspection.

Guided pedestrians usually show special psychological states and complex interactions between each other in emergencies, and the actual observed movement in emergency has obvious nonlinear characteristics [17]. Group dynamics emerges during the escape, showing the characteristics of the group such as gathering, conflicts and balance [18]. Although much research on simulations of pedestrians' movement in emergency has been conducted, little research focuses on the movement of groups, especially groups with guide in the large-scale public places [19]. Generally, modeling a group with guide is essential for the further study of evacuation. It is high time that we should establish a model to reflect the group dynamics aspects.

The rest of this paper is as follows. A modification method of pedestrian dynamics is proposed based on the social force model in Section 2, which considers that the desired velocity is influenced not only by the realization degree of desired velocity itself but also by the surrounding people and the surrounding environment. Section 3 applies the modified pedestrian dynamics model to the guided pedestrian group. Section 4 verifies the crowd dynamics model by comparing its density–speed and density–flow diagrams with fundamental diagrams and studies the effects of the guide for the evacuation crowd, as well as analyzes the effect of desired velocity on the evacuation time through a large number of simulations. In Section 5, evacuation experiments with multiple guides are done based on the simulation system of Beijing South Railway Station.

2. Modification of the social force model

2.1. Social force model

The social force model was proposed by Helbing et al. [12], where the pedestrians are driven by three forces: 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, $\vec{f}_{iw}$.