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Effect of psychological tension on pedestrian counter flow via an extended cost potential field cellular automaton model

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HIGHLIGHTS

- The extended cost potential CA model describing psychological tension of pedestrian counter flow is presented.
- An extremely nervous state can destroy the occurrence of lane formation.
- A larger asymmetrical ratio will decrease the formation of jamming phase.
- A moderate level of psychological tension will delay the occurrence of jamming phase.

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ABSTRACT

Psychology tells us that the different level of tension may lead to different behavior variation for individuals. In this paper, an extended cost potential field cellular automaton is proposed to simulate pedestrian counter flow under an emergency by considering behavior variation of pedestrian induced by psychological tension. A quantitative formula is introduced to describe behavioral changes caused by psychological tension, which also leads to the increasing cost of discomfort. The numerical simulations are performed under the periodic boundary condition and show that the presented model can capture some essential features of pedestrian counter flow, such as lane formation and segregation phenomenon for normal condition. Furthermore, an interesting feature is found that when pedestrians are in an extremely nervous state, a stable lane formation will be broken by a disordered mixture flow. The psychological nervousness under an emergency is not always negative to moving efficiency and a moderate level of tension will delay the occurrence of jamming phase. In addition, a larger asymmetrical ratio of left walkers to right walkers will improve the critical density related to the jamming phase and retard the occurrence of completely jammed phase. These findings will be helpful in pedestrian control and management under an emergency.

1. Introduction

Recently, more and more attention has been paid to traffic flow, pedestrian and vehicle modeling has become one of the most exciting fields in traffic science and engineering [1–8]. The dynamic properties of pedestrian crowds, including collective behaviors and various self-organization phenomena, have been observed and successfully reproduced by various

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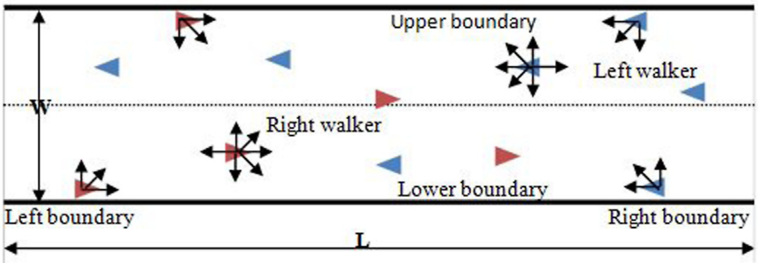

Fig. 1. Schematic illustration of the pedestrian counter-flow in a channel. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

physical methods [9–11]. Understanding the origin of these self-organization phenomena, especially the pedestrian flow in rush hour and panic escape is of great importance in designing a safe and efficient transportation environment.

The typical pedestrian flows have been simulated with various models, such as the social force model [10–14], the hydrodynamic models [15–18], cellular automaton models [19–27] and lattice gas models [28–39]. Since the lattice gas models and the cellular automaton models are conceptually simpler and can be easily implemented on computers for numerical investigations, they have found wider applications. As a typical pedestrian flow phenomenon, the counter flow in different situations has also been studied extensively. Muramatsu et al. found that the jamming transition occurs in the pedestrian counter flow within a channel when the density is higher than a threshold [28]. Takimoto et al. investigated the effect of the partition line on the pedestrian counter flow. It was shown that the partition line has a significant effect on the counter flow [29]. Fukamachi and Nagatani simulated the pedestrian counter flow sidling through the crowd [30]. Yu and Song modeled the pedestrian counter flow in a channel with considering the surrounding environment [32] and the traffic rule breaking behavior [33]. The counter flow in different scenarios such as in T-shaped channel [34], the effects of following the front pedestrians in the same direction [35], with different velocities [24,36], right-moving preference [26] and variable step size [37], human subconscious behavior [38], active slowing down and lane changing [40] and emotion propagation [39,41] have also been investigated.

These majorities of above mentioned models can generally reproduce dynamic characteristics of pedestrian counter flow under normal situation. However, the emotion plays an important role in the decision-making of individuals in some emergency situations, and the contagion of emotion may induce either normal or abnormal consolidated crowd behavior [41]. In fact, according to the intensity level of the emotion, there are three levels of fear: normal, stress and fear (or panic) [39] and different kind of tension will induce different behavior variation. Up to now, there is still no precise accepted definition of panic although in the media usually aspects like selfish, asocial or even completely irrational behavior and contagion that affects large groups are associated with this concept (see Refs. [42,43]). So, in this paper, we use "fear" not "panic" to describe pedestrians' psychological characteristics when they confront an emergency [44].

Compared with the previous studies about pedestrian counter flow, psychological tension and the induced corresponding behavior variation under emergency have not been perfectly considered up to now. This is insufficient to describe a more general counter flow, where pedestrians might have been influenced by different magnitude of behavior variations due to psychological tension in the process of evacuation. How do these factors affect the pedestrian dynamics in the counter flow? This is an interesting but still open problem. Motivated by the above reasons, in this paper, we use an extended cost potential field CA model combined with abnormal nervousness to simulate pedestrian counter flow under emergency situations. This model enables analysis of the effect of different level of tension and ratio of left and right walkers on pedestrian movement under a crowded condition. The paper is organized as follows. Section 2 describes the new cost potential field CA model integrated with behavior variation from nervousness. Section 3 gives simulation results and corresponding discussion, followed by conclusions in the final section.

2. Model

The model is described in a two-dimensional system. It is defined on the square lattice of $L \times W$ grids where L is the length of the channel and W is the width of the channel. A grid can either be empty or occupied by exactly one person. The size of a cell corresponds to approximately $0.4 \times 0.4\ \mathrm{m}^2$. This is the typical space occupied by a person in a dense crowd [19]. Fig. 1 shows the schematic illustration of the pedestrian counter flow in a channel. The top and bottom of the channel are walls. No walker may go out through the walls, and will be reflected when it arrives at a wall. The dotted line is the central partition line, through which walkers can pass. Two types of walkers are taken into account: walkers going towards the right and the left are indicated by red triangle and blue triangle, respectively. Arrows indicate the possible moving directions of the two groups.

The Moore neighborhood [19] is adopted and each occupied cell has eight neighboring cells, corresponding to nine probabilities for the pedestrian in the occupied cell to update his or her position (see Fig. 2).