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Simulation model of bi-directional pedestrian considering potential effect ahead and behind

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HIGHLIGHTS

- Potential field is defined to depict the guide, contain and press effects.
- Preventative steering behavior and congestion unlock phenomenon are observed.
- Coefficient β controls competition ability, and k reflects affected range.
- Larger β accelerates lane formation by forcing fewer leaders to side step.
- Larger k depicts behavior of pedestrians with high awareness of potential effect.

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ABSTRACT

This paper presents a simulation model for bi-directional pedestrian behavior. Guide effect and press effect performed by pedestrians with same direction, and contain effect performed by opposite pedestrians were considered as potential effects. Potential field was defined to simulate the complex interactions, which provided an effective and integrated approach to depict the immediate effects imposed by individuals ahead and behind, with different directions. The number of following pedestrians was regarded as a factor for lane change decision. Experiments ran for the model validation and coefficient performance verification. Preventative steering behavior and congestion unlock phenomenon were observed in the simulation. Velocity–density and flow rate–density curves with different coefficients show the effectiveness of the presented model to capture self-organization phenomenon in counter flow. Coefficient performance reveals the flexibility and controllability of the model to apply on various circumstances.

1. Introduction

Bi-directional pedestrian flow has been a popular topic for decades due to its complexity and regularity. Investigation and empirical study provide a basic approach to understand bi-directional pedestrian behavior. Lam WHK (1997–2005) made series of studies on bi-directional pedestrian behavior in certain traffic facilities in Hong Kong [1,2]. Bi-directional flow distributions (or flow ratios) were found to have significant impacts on both the at-capacity walking speeds and the maximum flow rates of the selected walkways [3], and also impacts on LOS boundaries for signalized crosswalks [4]. Daamen and Hoogendoorn [5] studied bi-directional pedestrian behavior by organizing volunteer pedestrians to perform specific walking tasks in a controlled experimental setup. Guo [6] presented an empirical evidence for the look-ahead behavior of pedestrians in bi-directional flows by scenario experiments.

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On the other hand, simulation modeling is one of the effective methods to study bi-directional pedestrian behavior. Social force model presented by Helbing and Molnar [7] moved bi-directional flows as social forces. Interesting phenomena of self-organization were observed and proposed. Muramatsu, Irie and Nagatani [8] presented a lattice gas model with biased random walkers to mimic the pedestrian counter flow. Series of studies were done including Pattern formation and jamming transition [9] in pedestrian counter flow, simulation for counter flow of people going on all fours [10], and sidle effect [11] on counter flow.

Blue and Adler [12] present a use of CA microsimulation for modeling bi-directional pedestrian flows, termed CA-Ped. Simulation results demonstrate the ability of CA method to capture fundamental properties of pedestrian movements using a small set of fairly simple rules. Thus, various studies based on CA model occur with plenty of findings. Li [13] examined possibility of exchange position between face-to-face pedestrians by a CA model. Takashi Nagatani [14] presented a deterministic cellular automaton (CA) model for facing traffic of pedestrians on a wide passage. Jamming and freezing transitions were studied. Another deterministic CA model for facing pedestrian traffic at rush hour [15] was proposed to clarify pedestrian behavior under the traffic rule. Yue [16] used Dynamic Parameters Model (CA-based) to study bi-directional flow. It is found that direction split and pedestrians' walking habit affect the value of critical density point and the figures of velocity_density and volume_density curves. Certain patterns of pedestrian behavior were also studied by CA model, such as back stepping [17], team-moving [18], Partition line [19], right preference, conforming and space priority [20].

Floor Field Model (FF model) presented by Burstedde [21], one of the variants of CA model is also a successful model in describing pedestrian dynamics. The floor field model simulates individual intelligence with a virtual floor field, which makes it possible to reveal dynamic interaction between pedestrians. Extended FF models and similar concepts were also applied to the simulation of pedestrian friction effects and clogging [22], movement of crowds [23], and evacuation [24,25]. Yushi Suma [26] propose the anticipation floor field as an extension of the floor field model. The AFF focuses on non-local interaction between bi-directional pedestrians to improve collision avoidance. FF model proves the ability of simulated field on cells to model potential interaction among pedestrians. The author presented a potential field model [27] to provide an approach to model pedestrian interactions simply and flexibly. Circumstance potential field and interaction potential field were defined to model the desire to get to targets and interactive effects among pedestrians. The difference of potential field model compared to FF model is the integrated description of potential effect performed by individuals in different groups (such as opposite pedestrians in counter flow).

Among the numerous research topics of bi-directional pedestrian behavior, lane changing has been highly focused. Blue and Adler [12] did a dedicated analysis of lane changing, claiming it as an important factor in understanding pedestrian flow. The essence of lane changing behavior can be regarded as a leader–follower relationship and collision avoidance decision. Observations of crowd movement in the "Jamarat" system [28] reveal that effect of pedestrians going in the same direction is the major effect compared to the opposite ones, especially under a crowd circumstance. Empirical study [6] reveals that movement of pedestrians is most affected by other pedestrians moving in the same direction about 1 m ahead. However, besides individuals ahead, following ones also affect pedestrian's decision. The author (2008) studied alighting and boarding behavior of passengers in Beijing metro stations [29]. It was found that potential pressures related to the size of groups of alighting and boarding passengers affect the priority of the two groups with opposite directions. According to daily experience, pedestrians tend to change lanes when opposite flow is powerful, usually means larger number of individuals. Moreover, when pedestrians stop and stay for a while, potential pressure from behind will also affect the walking decision. Therefore, lane changing decision should be modeled considering effect from individuals in both directions, ahead and behind.

The study in this paper is an attempt to model bi-directional pedestrian behavior considering potential effect from individuals ahead and behind. Potential fields were defined to trigger pedestrians' movement. Each pedestrian generates and updates the potential field value according to its movement and status. Potential effect on individuals behind with same direction triggers following behavior. Potential effects on individuals ahead with both directions trigger lane changing behavior by comparing potential field value with opposite groups.

The study in the paper is novel for several reasons. First, guide effect from pedestrians ahead with same direction, contain effect from opposite pedestrians ahead and press effect from pedestrians behind caused by waiting and queuing are considered for modeling bi-directional walking behavior. Second, potential field generated and updated by individuals during movement is defined to depict potential effects, which provide an integrated and efficient approach to simulate complex interaction. Third, the number of following pedestrians reflecting locally unequal power of opposite pedestrian groups is considered and studied for lane changing decision. Fourth, preventative steering behavior and congestion unlock phenomenon are observed in the simulation, reflecting intelligent decision of the pedestrians. The presented model is flexible to simulate variety of pedestrian behavior under different situations by adjusting the coefficients.

2. Pedestrian bi-directional walking behavior characteristic

Pedestrians make decision during movement according to their desire to get to the target and the interaction with other pedestrians. For bi-directional pedestrians, the desire to get to their targets basically means to keep moving towards their direction. However, pedestrians must be influenced by the others during movement. Some of the interaction with others is helpful for getting the targets, while some may be impeditive. Fig. 1 shows three major potential effects during bi-directional walking. The first one is guide effect applied by pedestrians ahead with same direction (Fig. 1(a)). Guide effect may trigger