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Experimental study on relaxation time in direction changing movement

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HIGHLIGHTS

- In this paper, we investigate the direction changing characteristics of pedestrians by controlled experiments.
- Supported by the quantitative analysis of the experimental data, we show the existing social force model is too simple on the assumption of self-driven force and some quantitative results based on existing hypothesis need to be modified.
- Furthermore, we find pedestrians are insensitive to tiny angular difference in freely walking and define two parameters, d_s and θ_s to describe this characteristic.

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ABSTRACT

Controlled experiments were conducted to clarify the movement characteristics of pedestrians in direction changing processes. We track pedestrians' trajectories and map them into real space coordinates by the direct linear transformation method. In the acceleration process, the relaxation time and free moving speed in our experiments respectively equal 0.659 s and 1.540 m/s, which are consistent with those for Chinese participants in other experiments. Meanwhile, the values of relaxation time in the direction changing process are calculated by a derived equation from the concept of the social force model. It is observed that the relaxation time is not an invariable parameter, and tends to increase with an increase in the angular difference. Furthermore, results show that pedestrians are insensitive to a tiny angular difference between instantaneous velocity and desired velocity. These experimental results presented in this work can be applied in model development and validation.

1. Introduction

Since the pedestrian is an indispensable component in traffic system, the researches of pedestrian dynamics provide important reference to facility designers and city conductors. Up to now, the relativities of macroscopic factors in crowd movement such as flow rate, local density, crowd speed, have been widely studied [1–5]. Those empirical results provide general characteristics in pedestrian movement. Considering the pedestrian flow is composed of separate individuals, microscopic movement simulation is a rather promising way to predict pedestrian behavior pattern under different

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Table 1
Participants' information.

Participant No.	Height (m)	Age	Gender	Participant No.	Height (m)	Age	Gender
1	1.58	24	Female	7	1.68	25	Male
2	1.62	21	Female	8	1.70	23	Male
3	1.60	25	Female	9	1.72	26	Male
4	1.58	26	Female	10	1.73	22	Male
5	1.68	25	Male	11	1.73	25	Male
6	1.67	25	Female				

circumstances. Many microscopic mathematical models (such as lattice-gas model, CA model, optimal velocity model, social-force model and so on) have been developed to reveal the influence of the local interaction among the pedestrians to the large-scale collective behavior [6–15]. In order to determine the reliability and validity of pedestrian dynamics models, observation and controlled experiment are essential. Checking whether the model reproduces particular self-organized patterns is one of principal methods in model validation [16,17]. The self-organized phenomena such as lane formation in bi-directional flows and stripe formation in intersecting flow have been widely observed and applied in establishing the validity of prediction of models [10,18]. Due to development of digital image processing, it is possible for us to extract the trajectories of pedestrians and investigate detailed moving characteristics which can be applied in model calibration. Meanwhile, the studies of pedestrian kinematics provide a more micro perspective to pedestrian dynamics. For instance, Patla et al. [19] found that pedestrians could not alter the direction of locomotion at the end of the stance phase just before the next step. Hase and Stein [20] proposed there are two turning strategies during human walking: step turn (turning to the opposite side of the stance limb) and spin turn (turning towards the stance limb). And they further compared the stability and found pedestrian preference between two turning strategies [19,21]. Olivier et al. [22] focused on the stepping strategy while turning. They pointed out pedestrians would apply spin turn more frequently in the gentle turn.

In particular, the social force model which was first proposed by Helbing and Molnar [23] has been successful in qualitatively describing observed phenomena in many respects [24–29]. The basic concept of the social force model suggests the interaction among pedestrians and environment manifests as influence to their acceleration, just like physical forces acting on objects. Another critical assumption of this model is that the forces are calculated according to the superposition principle. The self-driven force is an important component of the social force model. It drives a walker towards his/her destination. In previous simulation, the self-driven force is supposed to be linearly related with difference between instantaneous velocity and desired velocity. Different from the interactions between pedestrians and obstacles which have been deeply discussed and improved, the driven force is still used as original hypothesis in subsequent research. There is some validation of the underlying assumptions that primarily focuses on linear acceleration [30,31] however, the validation in two-dimensional pedestrian movement is still rate. Furthermore, Fredrik et al. [32] pointed out that the values of fitted relaxation time from linear acceleration lead to significant drifting in simulation. Seer et al. [33] estimated model parameter values for three different social force models and they noticed parameters estimated for each pedestrian separately show large standard deviations. Their work also weakens the claim that the social force model can reproduce human behavior at a trajectory level for each single pedestrian.

Therefore, it is necessary to study the original hypothesis in simpler scenes to clarify whether the assumption of self-driven force is generally applicable under all conditions. In this paper, we investigate the direction changing characteristics of pedestrians by controlled experiments. Then the proposed assumption in force models from experimental results is tested.

2. Experiment setup

In order to clarify movement mechanism in direction changing procedure of pedestrians, controlled experiments were conducted in April, 2015. To eliminate the influence of the other factors, we set the experiment scene without obstacles such as walls and deliberated the guide words given to the participants. The experiment scene was composed of a passageway with a length of 6 m, a width of 0.6 m and a 6 m × 6 m area. The details of the scene are shown in Fig. 1(a). One snap shot of the video scene is shown in Fig. 1(b). In total, 5 females and 6 males who gave informed consent to the experimental procedure took part in the experiments. They are in the age of 21–26 and with a mean height of 166.8 cm, as shown in Table 1. The participants were asked to wear red hats for the convenience of detecting and tracking.

In the beginning of each experiment procedure, the participants waited in one end of the passageway and then walked straightly after hearing the signal. Once passing through the other end of passageway, they were asked to move towards and walk through one selected destination without slowing down. The destinations were represented by 6 landmarks which have diameters of 0.2 m. Each experiment scene was repeated 4–6 times, we collected 4–6 trajectories of each participant to each destination.

3. Data extraction

Moving behaviors of the pedestrians were observed and recorded by 2 video cameras which have resolution of 1920 × 1080 pixels and frame rate of 25 fps. These cameras were located on the top of a nearby building. The positions of the red

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