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Uni- and bi-directional pedestrian flow in the view-limited condition: Experiments and modeling

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ABSTRACT

In this paper, the impact of vision on the uni- and bi-directional flow has been investigated via experiment and modeling. In the experiments, pedestrians are asked to walk clockwise/anti-clockwise in a ring-shaped corridor under view-limited condition and normal view condition. As expected, the flow rate under the view-limited condition decreases comparing with that under the normal view condition, no matter in uni- or bi-directional flow. In bidirectional flow, pedestrians segregate into two opposite moving streams very quickly under the normal view condition, and clockwise/anti-clockwise walking pedestrians are always in the inner/outer ring due to right-walking preference. In the first set of experiment, spontaneous lane formation has not occurred under the view-limited condition. Pedestrian flow does not evolve into stationary state. Local congestion occurs and dissipates from time to time. However, in the later sets of experiments, spontaneous lane formation has re-occurred. This is because participants learned from the experience and adapted right-walking preference to avoid collision. To model the flow dynamics, an improved force-based model has been proposed. The driving force has been modified. The right-walking preference has been taken into account. The fact that pedestrians cannot judge the moving direction accurately under limited-view condition has been considered. Simulation results are in good agreement with the experimental ones.

1. Introduction

In recent years, the study of pedestrian flow has drawn wide attention in the field of physical science and engineering (Helbing, 2001; Daamen and Hoogendoorn, 2003; May et al., 2014; Zangenehpour et al., 2015). Understanding the behavior of pedestrians is significantly important for the design of urban infrastructures, traffic management, and ensuring the safety of people during emergency or evacuation processes.

Many empirical and experimental studies have been conducted to investigate the characteristics of pedestrian flow. The complicated pedestrian behaviors can generate a number of interesting self-organization phenomena, such as “fast is slow” effect, turbulent movement in the dense crowds, the lane formation in bidirectional flow, and oscillations at bottlenecks (Helbing et al., 2000a, 2002; Seer et al., 2014). A large number of models (Hughes, 2002; Helbing and Molnár, 1995; Muramatsu et al., 1999; Guo and Huang, 2012; Duives et al., 2013; Jian et al., 2014; Wang et al., 2014; Hsu and Chu, 2014; Hoogendoorn et al., 2014; Hanseler et al., 2014) have been developed to simulate the observed characteristics.

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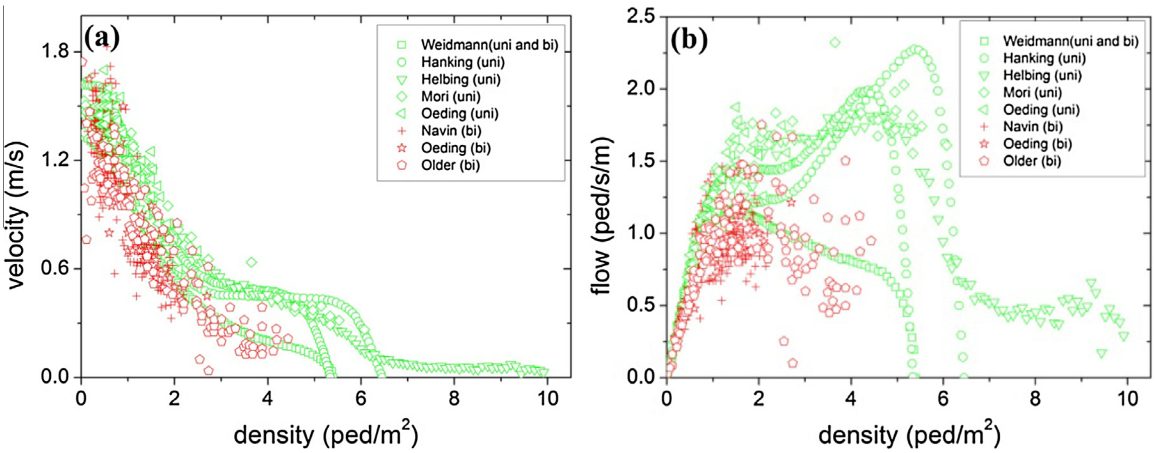

Fig. 1. (a) Velocity-density relations and (b) flow-density relations of uni- and bi-directional pedestrian flow from some previous studies. The data are from www.asim.uni-wuppertal.de/en/database.html.

The fundamental diagram, which describes the relationship between speed, density and flow, is a representation of pedestrian traffic (Seyfried et al., 2005; Chattaraj et al., 2009; Suma et al., 2012; Yanagisawa et al., 2012; Flötteröd and Lämmel, 2015). Fig. 1 presents some fundamental diagrams reported in previous studies. One can see that the density-velocity relationships basically follow the identical tendency in the low density regime, no matter in the uni- or bi-directional condition. However, when the density exceeds about 2 ped/m^2, the flow rate exhibits significant difference in different studies. Nevertheless, Predtechenskii and Milinskii (1978) and Weidmann (1993) claimed that the fundamental diagrams of uni- and bi-directional flow have only slight difference. In contrast, Navin and Wheeler (1969) reported that the flow decline depends on directional imbalances. Cheung and Lam (1997) studied the bi-directional flow in Hong Kong Mass Transit Railway, and observed that the flow and speed of the minority stream reduce with enhancement of majority stream. Lam et al. (2002, 2003) studied bi-directional flows in in- and outdoor walkways. They found that bidirectional flow is mainly the same as unidirectional flow, unless the densities of opposite directions have big difference. Helbing et al. (2005) and Kretz et al. (2006) conducted bidirectional experiments with multi densities and flow compositions, and showed that the bidirectional flow is larger than the unidirectional one at the same density. Zhang et al. (2012) found no large differences among density-flow relationship in experiments of various forms of ordering, but the flow in unidirectional stream is larger than that in bidirectional stream at high densities. The diversity of the findings demonstrates that the fundamental diagram should depend on many factors, which vary across the studies. Among these factors, one can expect that the view range should have significant impact. In the above mentioned works, the data were all collected under normal view condition. An experimental study on quantitative effect of view range is lacked.

Lane formation, which terms the effect that pedestrians in a crowd segregate spontaneously according to their desired walking direction, is a kind of functional self organization in bi-directional flow (Navin and Wheeler, 1969; Helbing et al., 2000b; Schadschneider et al., 2003; Zhang and Seyfried, 2014). Isobe et al. (2004a) performed an experiment in a channel with open boundaries. To avoid collision with others, the walkers prefer to follow the front ones in the same direction, which leads to formation of lanes. However, when the walkers go through the opposite ones, the lanes disappear. Kretz et al. (2006) launched an experiment in a corridor, and confirmed the lane formation with asymmetry between left and right hand. In experiments forming only two lanes, left-hand traffic does not appear even once. Moussaïd et al. (2012) studied the bidirectional flow phenomenon in the experiments, finding that the traffic segregation exhibits structural instabilities characterized by the alternation of organized and disorganized states. In the experiments of Zhang et al. (2012), different instructions to participants result in different lane configurations. When participants are required to use the left/right exit at the end of corridor, lane formation is found, but lanes are changing in space and time. Without any instruction, stable lanes form immediately after the experiment starts.

To simulate the lane formation phenomenon, many models have been developed (Helbing and Molnár, 1995; Muramatsu et al., 1999) and several mechanisms have been proposed, such as right-walking preference (Muramatsu et al., 1999), following behavior (Wang et al., 2012), anticipation (Suma et al., 2012).

Nevertheless, the above mentioned studies were all carried out under the normal view condition. Actually, view limited condition exists for pedestrian flows. For example, illumination in the outdoor passage might be weak in the night, or is absent in the indoor or underground passage due to e.g., power outage.[1] Under the view limited condition, pedestrian flow

[1] If power outage happens when pedestrians are in the passage, the pedestrians might be in panic. However, if pedestrians know that there is power outage and the passage is in darkness before they enter the passage, there will be no panic. Our study concerns on the non-panic situation. Pedestrians can use the cell phones to produce a small field of vision in darkness.