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Microscopic events under high-density condition in uni-directional pedestrian flow experiment

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HIGHLIGHTS

- The pedestrian flow experiment under periodic boundary condition is filmed by UAV.
- Two interesting events are observed in the video data and quantitatively measured.
- First critical density about pedestrians' movement is found in time series data.
- Second critical density about pedestrians' comfortableness is found in averaged data.
- The bridge between pedestrian dynamics and individual behaviors is built.

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ABSTRACT

In order to investigate the pedestrian behaviors under high-density condition, we organize one experiment with 278 pedestrians, and the global density as high as 9 ped/(mˆ2) is reached. The experiment is filmed by one unmanned aerial vehicle (UAV). In the experimental video, we find many interesting microscopic events. They can be categorized into two types: the interactions with the boundaries (Type A) and the absentmindedness (Type B). Among them, "the staffs arrange the stools" (Event A1) and "the pedestrians play with mobile phones" (Event B1) can be measured and evaluated. We find the time series data of Event A1 and B1 have strong relationship with the evolution of pedestrian flow. The results in hyper-congested state and that in over-congested state are qualitatively different, and the critical density is about 8 ped/(mˆ2). At the same time, the averaged results of both Event A1 and B1 qualitatively change at about 6 ped/(mˆ2), which is the critical density between over-congested state and congested state. Why different pedestrian flow data have different maximum densities also can be explained by this critical value. Therefore, the bridge between pedestrian dynamics and individual pedestrian's behaviors is built in this study.

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1. Introduction

The study of pedestrian movement has many different aspects, from the pedestrian dynamics and modeling, to the analysis of individual pedestrian's behavior. Different approaches are used in this interdisciplinary field, and many different results are introduced in recent years [1,2].

From the perspective of pedestrian dynamics, one of the important topics is the critical phenomena between different states. The most common situation is the transition from free moving state to congested state. It can be found in various situations, including counter flow [3,4], two-dimensional flow [5], the flow at crossings [6] and the flow at T-junctions [7], etc. Sometimes the pedestrian flow is divided into several states by density intervals, and the various transitions between them may be complex [8–11]. Some new phenomenon at very high densities is also revealed and discussed. For example, in the study of Helbing et al. [12], the transition from the stop-and-go waves to "crowd turbulence" is observed in the high-density data of Hajj pilgrimage, in which the flows drop drastically with medium densities and nearly keep constant with high densities. This is explained via a transition between anisotropic and isotropic features of pedestrian flow [13].

In recent years, In order to investigate the mechanism of pedestrian flow in a controllable way, some pedestrian flow experiments have been conducted at different places [7,10,14–21]. Many of them are recorded by cameras, and the video data may become good resource for the study of pedestrians' behaviors. However, the densities in these experiments are usually low. In the experiments under periodic boundary conditions, the maximum density of pedestrian flow is usually between 4∼6 m^{-2}. With such a configuration it is impossible to investigate the complex phenomena under high-density condition.

Therefore, recently we organized a high density experiment with 278 participants, and the extreme situation in which $\rho = 9$ m^{-2} is realized. This experiment is filmed by one unmanned aerial vehicle (UAV), and the evolution of pedestrian flow can be observed clearly. At the same time, we find many interesting events in the video data. Among them, the results of two events named "staff arrange the stools" (Event A1) and "pedestrians play with mobile phones" (Event B1) can be measured in different ways. We find these results, including the time series data and the averaged values at given densities, can well coincide with the evolution of uni-directional pedestrian flow. At the same time, two critical densities are found, which can well coincide with the critical values in the fundamental diagram. These findings can be considered as the bridge between the two fields of pedestrian dynamics and individual pedestrian's behaviors.

This paper is organized as follows. In Section 2 the basic configuration of this experiment is shown, and the fundamental diagram of uni-directional flow in the experiment is presented for comparisons. In Section 3, the microscopic events found in this experiment are classified, and the Event A1 and B1 are particularly introduced. In Sections 4 and 5, two important critical densities in the experiment are introduced, and the relationship between the measured results of two events and the pedestrian dynamics is discussed. The conclusion is given in Section 6.

2. The basic configuration of the experiment and the fundamental diagram

We organized the pedestrian flow experiment on Dec. 3th, 2016, in the Jiulonghu Campus of Southeast University of China. 278 students are recruited to take part in the experiment which lasts for about 2.5 h. Their ages are all between 18∼25, and the sexual ratio is about 50:50. The experiment is organized on a large square, and plastic stools are used to form the boundaries, as shown in Fig. 1. The radius of the inner circle is 2m, and that of the outer circle is 3.5 m. So the area of the ring road is about 26 m^2. We use one UAV to film the whole experiment. It hovers over the center of the two circles, and the height is about 11.8 m.

For the periodic boundary condition, the predetermined global density (ρ_P) in each run is fixed. For example, when $\rho_P = 6$ m^{-2} there should be 156 pedestrians on the ring road. For higher densities ($\rho_P = 5\sim 9$ m^{-2}), we make two independent runs. For lower densities ($\rho = 1\sim 4$ m^{-2}), we only make one run. Thus there are 14 runs in the experiment, and the order is: 9-8-7-6-5-9-8-7-6-5 -4-3-2-1 . For convenience, in the following sections we will name all the runs as "ρ_P-order of run", e.g., "8-2" means $\rho_P = 8$ m^{-2} and the run is the second run.

In the first runs of 5 high densities, the initial moving direction of all the pedestrians is anti-clockwise, and in the other 9 runs it is clockwise.[1] Firstly we do the experiment for the uni-directional flow, and ask all the participants to move forward. The simple instruction for them is just: "*walk as usual*". When they reach a "steady state" after some time, we make them stop and start a new run. We also conduct the experiment for the bi-directional flow, and this is the reason why pedestrians wear different caps. But it is out of the scope of this paper, since the experimental properties of bi-directional flow are different and complex: the lane formation process emerges and plays an important role. Note that in some runs, the actual numbers of pedestrians are not the same as we designed. Since we do not have enough time to count them, the pedestrian numbers in some runs are not enough, as shown in Table 1.

In order to compare with the results shown in the following sections, we briefly introduce the fundamental diagram of uni-directional flow in the experiment. In Fig. 2, each data point corresponds to one experimental run. Here the flow rate is averaged over four equidistant locations. At each location, the flow rate is defined as $Q/(WT)$. Here T is the duration time of one run. Q is the number of pedestrians that have crossed the location during this run, and W is the system width (1.5 m).

[1] But the differences between two moving directions seem not obvious in all the results.