Emergence of motion synchronization in pedestrian crowds

Yi Ma*[1], Meng Shi[2], Eric Wai Ming Lee[3], and Richard Kwok Kit Yuen[3]

[1]Institute for Disaster Management and Reconstruction, Sichuan University, Chengdu 610065, China
[2]School of Computer Science, South-central Minzu University, Wuhan 430074, China
[3]Department of Architecture and Civil Engineering, City University of Hong Kong

Abstract This study investigates when, how and why motion synchronization spontaneously emerges in pedestrian crowds through a pedestrian flow experiment that directly track the foot motion of pedestrians. We show that synchronization is most likely to emerge at the onset of jamming. We demonstrate that synchronization is essentially caused by insufficient interpersonal safety distance; it actually serves as a motion strategy that helps pedestrians avoid interpersonal collisions and maintain maximal collective movement efficiency under insufficient safety distance.

Keywords Pedestrian flow, synchronization, self-organized phenomenon

In pedestrian crowds, it is often observed that pedestrian individuals spontaneously synchronize their movements in the absence of external stimuli. However, it is unclear why this synchronization phenomenon spontaneously emerges in pedestrian crowds.

To address this question, we conducted a quasi-one-dimensional pedestrian flow experiment in a corridor with a length of 25.2 m and a width of 2.40 m. We performed 40 runs of experiments using different crowd sizes in the corridor, including using 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, and 120 participants. In the experiment, we tracked and recorded the pedestrians' foot motion, then extracted the pedestrians' foot motion trajectories and footsteps from the recorded video clips.

Based on the experiment, we first investigated the probability of the synchronization at different pedestrian densities. Specifically, we calculated the proportion of synchronized steps for each pedestrian and linked it with pedestrian density (see Fig. 1(a)). The results show that when the density is approximately 1.80 persons/m^2, the proportion of pedestrian synchronized steps is the highest, suggesting that synchronization is most likely to spontaneously emerge at 1.80 persons/m^2. We found from the fundamental diagram obtained from the experiment that this critical density is exactly the jamming density (see Fig. 1(b)). This also means that the movement synchronization of pedestrians is most likely to emerge at the onset of jamming, similar to the occurrence of the synchronization of pedestrians in a one-dimensional single-file crowd environment [1].

For the detected synchronized pedestrian steps in the experiments, we also recorded the relative position of synchronized pedestrian and neighbor, and the directional angle of synchronized neighbor (i.e., the angle between the direction of the synchronized neighbor and the desired moving direction of the pedestrian) at the starting frame of each of these synchronized step samples. Figs. 1(c) and (d) show the relative positions and the distribution of the directional angles of synchronized neighbors over the collected synchronized step samples, respectively. From Fig. 1(d), we can see that the number of occurrences of a 0° directional angle is obviously larger than that of 90° and 270° directional angles. This result indicates that synchronization with neighbors in front is more likely to spontaneously occur than synchronization with neighbors on the left or right.

Why are pedestrians most likely to spontaneously synchronize their movements at the jamming density? To answer this question, we calculated the difference between the step length in each natural step and the interpersonal distance at the starting moment of pedestrian step, then linked this difference with the density at the starting moment of the step. The resulting relation diagram is shown in Fig. 1(e). The result shows that the difference is the minimal (only 0.22 m) at 1.80 persons/m^2 (i.e., at the jamming density). That is, if a pedestrian makes a step, the buffer distance between the adjacent neighbors and the body center of the pedestrian will only be 0.22 m. This means that if the neighbors stop suddenly, the

*Email of the corresponding author: yima23-c@my.cityu.edu.hk

body of the pedestrian will likely collide with the body of a neighbor, given that humans have a certain body thickness. However, if the pedestrian chooses to synchronize his or her stepping motion with the adjacent neighbors, the pedestrian will not only avoid potential collisions with the adjacent neighbors but also realize a stepping motion. This twofold benefit induces the pedestrian to synchronize with the adjacent neighbors. This is the reason why pedestrians are most likely to spontaneously synchronize their movements at the jamming density.

Our findings provide new insights into pedestrian flow dynamics.

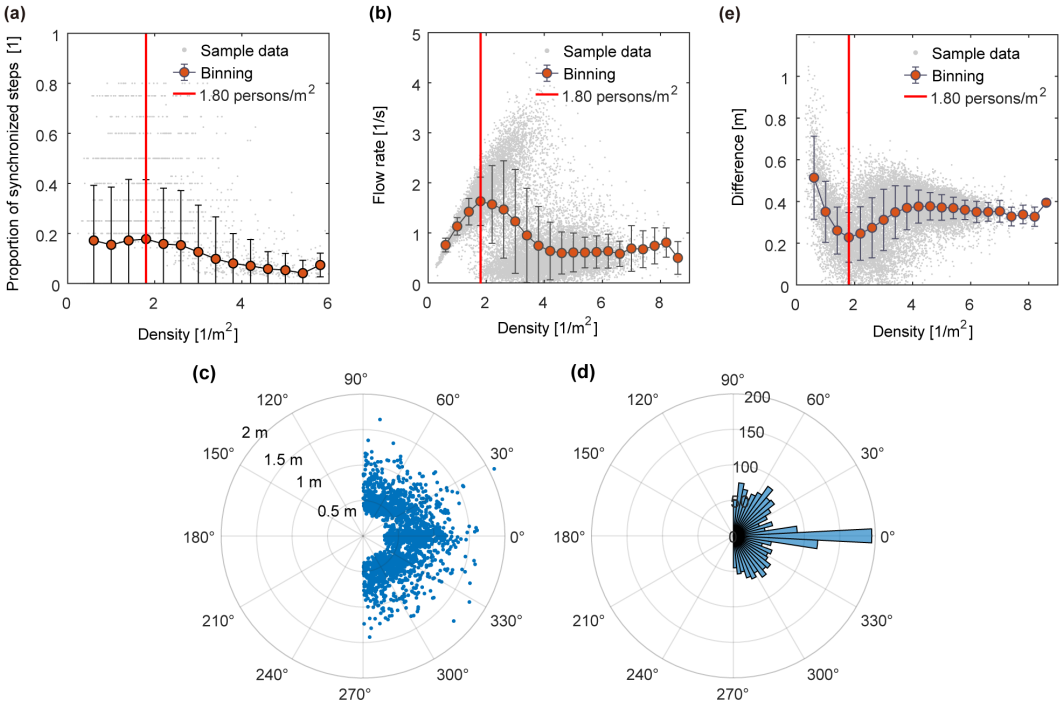

Figure 1: The experimental results. (a) Relation between the proportion of synchronized steps and pedestrian density. (b) Fundamental diagram. (c) and (d) are the relative positions and the distribution of the directional angles of synchronized neighbors over the collected synchronized step samples. (e) Relation between the distance difference and pedestrian density.

Reference

[1] Ma, Y., Lee, E. W. M., Shi M., Yuen R. K. K., *Emergence of motion synchronization in pedestrian crowds*, Nat. Hum. Behaviour **5**, 447-457, 2021.