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Traffic Flow in Heterogeneous Pedestrian Crowds

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***Abstract*—**In this paper, we study the effects of heterogeneous velocity on pedestrian crowds. An ageing population complicates the behaviour of crowds in both microscopic and macroscopic ways. A crowd comprising pedestrians of different ages can be regarded as a heterogeneous crowd, in the sense that each pedestrian's walking speed is different. To observe how heterogeneity affects a pedestrian's behaviour, we conducted an experiment in which the subjects were told to walk at different speeds: slowly, normally and fast. Through this experiment, contrary to previous research wherein a pedestrian's walking speed was attributed to local densities, we have found that walking speed is affected not merely by the local density but also by the walking speeds of the people around each pedestrian. Moreover, we have quantitatively demonstrated that other people's velocities are more important factors than the local density in deciding a pedestrian's velocity. Therefore, we must consider the pattern of pedestrians when examining a heterogeneous crowd more closely.

***Keywords*:** Heterogeneity, Self-organisation, Experiment, Walking speed

1. Introduction

Increasing urban populations have led to traffic jams on pedestrian walkways. To mitigate this, numerous studies have attempted to understand the behaviour of pedestrian crowds. In such studies, a fundamental flow diagram is often used to determine the relationship between density and traffic flow [1]. However, in these studies, groups of pedestrians are usually regarded as homogeneous in terms of walking speed and effective size, and relatively few studies have considered the heterogeneity in pedestrian walking speeds [2 - 3]. Pedestrian crowds on urban sidewalks differ in age, body size, temperament and other factors, which affects their walking pace in an urban environment. These differences are expected to affect the macroscopic behaviour of a pedestrian crowd; however, the details of the interactions between heterogeneously grouped pedestrians are not well understood.

One study which focused on age differences concluded that heterogeneous flow is more likely to cause traffic jams owing to pedestrian interactions [3]. However, this study tested pedestrians with enough space for only one lane of traffic, and hence allowed only one-dimensional movement, which is unrealistic for most sidewalks. Accordingly, obtaining more realistic experimental data is necessary.

2. Experimental Method

To obtain more realistic data by observing two-dimensional (2D) movements, such as bypassing behaviour or lane formation, in groups of pedestrians moving at different velocities, we conducted an experiment on the circular course shown in Fig.1. This course was sufficiently wide for 2D behaviour to occur. All subjects were male university students.

In our experiment, the pedestrians were divided into two groups. The group with red caps in Fig.1 were asked to walk either slower or faster than the other group, who wore yellow caps and were asked to walk at their normal speed. The number of red-cap (slow or fast) pedestrians was always equal to that of yellow-cap (normal) pedestrians. Experiments were also conducted with homogeneous crowds for reference.

We varied the global density and the crowd composition, where the global density is the mean density of the whole experimental field. The global density was increased from 0.1 to 1.5 $/m^2$ in increments of 0.2 $/m^2$ by changing the number of pedestrians. The crowd composition was studied for two cases; we tested a group of normally walking pedestrians mixed with slow pedestrians (slow mix), and a group of normally walking pedestrians mixed with fast pedestrians (fast mix). In every trial, the pedestrians were instructed to walk for approximately 60 s.

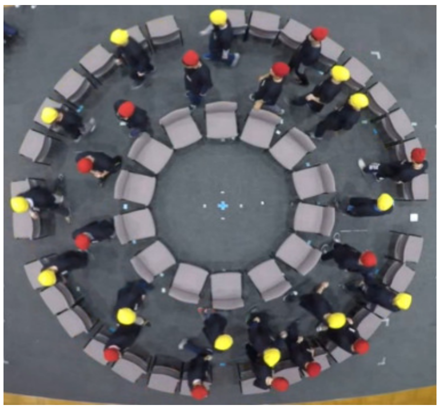


Fig. 1. Overview photograph of the experiment.

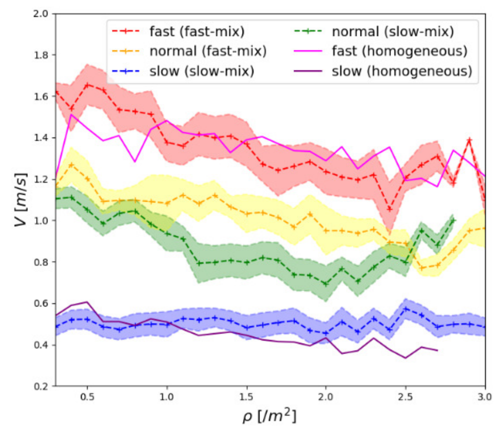


Fig. 2. Fundamental diagram (mean with sd).

3. Results

To analyse this experiment, we prepared a fundamental diagram, which plots the average velocity for each type of pedestrian against the local density obtained by calculating the area of the Voronoi cell for each pedestrian (Fig. 2). Dotted lines with error bars represent the average velocity in a heterogeneous crowd, whereas solid lines represent the average velocity in a homogeneous crowd.

Figure 2 shows that the average velocity of normal pedestrians grouped with fast pedestrians, represented by the yellow dotted line, is always higher than that of normal pedestrians grouped with slower pedestrians, represented by the green dotted line. This indicates that even though pedestrians were instructed to walk at their normal speed, their walking speed is affected by the speed of other people walking with them. This observation holds true for pedestrians walking at slower or faster speeds, especially when the local density exceeds 1.0 $/m^2$. For example, the velocity of slower pedestrians in a heterogeneous crowd (blue dotted line) is higher than that of the same group of pedestrians in a homogeneous crowd (purple solid line), especially at higher densities. These results demonstrate that a pedestrian’s walking speed is affected by other people’s walking speeds, as well as by the local density.

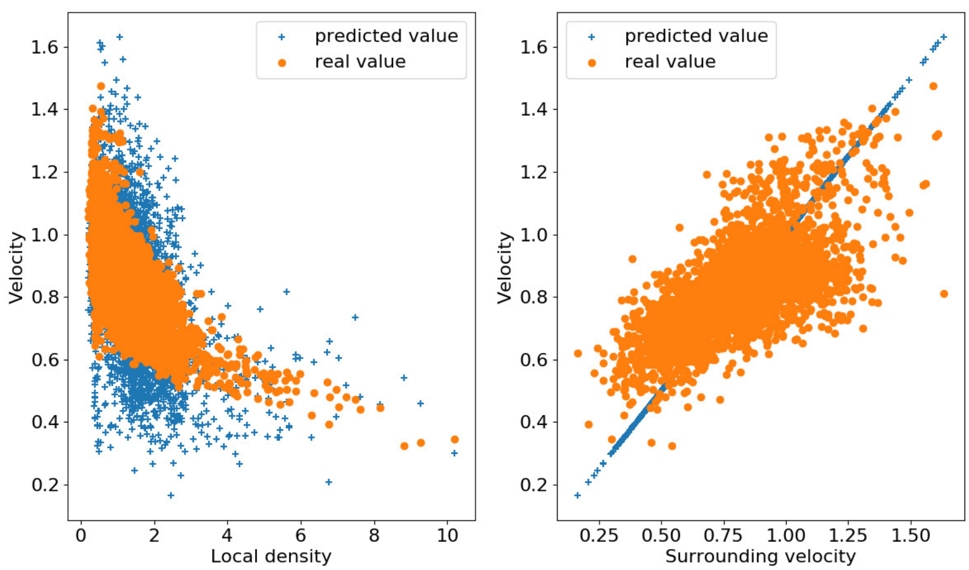
3.1 Effect of local velocity

As mentioned above, we find that other people’s walking velocity is an important factor in determining the speed of a pedestrian. To examine this observation closely, we introduced a new parameter: ‘surrounding velocity’. This parameter is a value, assigned to each pedestrian, and is calculated as a simple mean of the velocities of other pedestrians who are within a specified range from the given pedestrian (defined as the ‘region of interest’). For example, if there are n pedestrians around a given pedestrian, the surrounding velocity of that pedestrian is calculated according to (1), where v_i is another pedestrian’s velocity in the region of interest. Using this surrounding velocity, we conducted multiple regression analysis to investigate which factors (local density or surrounding velocity) affect a pedestrian’s walking velocity more significantly in a heterogeneous crowd. All factors are normalized in conducting this analysis.

$$v_{sur.} = \frac{1}{n}\sum_{i=1}^{n} v_i \tag{1}$$

Figure 3 shows the results of the multiple regression analyses. Orange dots represent the real (measured) values, whereas blue dots represent the values predicted from the regression analysis.

Figure 3 indicates that the local density does not determine the velocity of a pedestrian, especially for densities lower than 3.0 m^{-2}. Moreover, the partial regression coefficients from the multiple regression analysis are −0.15 for the local density and 0.59 for the surrounding velocity, respectively. This result demonstrates quantitatively that the surrounding velocity is more significant in determining the walking velocity in heterogeneous crowds. However, the coefficient of determination is 0.455. Therefore, it can be said that these two parameters are not enough for fully explaining the cause of walking velocities.



(a) (b)

Fig. 3. Results of the multiple regression analyses. (a) Relationship between velocity and local density. (b) Relationship between velocity and surrounding velocity.

4. Conclusion

Based on the abovementioned results, we conclude that other people's walking speed is more significant in determining a pedestrian's walking speed than the local density, especially in a heterogeneous crowd. Therefore, this point should be considered in creating simulation models for pedestrian flow.

5. Acknowledgement

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References

[1] A. Seyfried, B. Steffen, W. Klinsch, M. Boltes, 'The fundamental diagram of pedestrian movement revisited', *J. Stat. Mech. Theor. Exp.*, vol. 2005, no. 10, pp. 41-53, 2005

[2] W. G. Weng, T. Chen, H. Y. Yuan, W. C. Fan, 'Cellular automaton simulation of pedestrian counter flow with different walk velocities', *Phys. Rev. E*, vol. 74, no. 3, p. 036102, 2006

[3] S. Cao, J. Zhang, D. Salden, J. Ma, C. Shi, R. Zhang, 'Pedestrian dynamics in single-file movement of crowd with different age compositions', *Phys. Rev. E*, vol. 94, no. 1, p. 012312, 2016