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Subconscious Effect on Pedestrian Counter Flow *

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We propose an extended lattice gas model with different maximum velocities to simulate pedestrian counter flow by considering the subconscious behaviour of walkers. Four types of walkers including faster right walkers, slower right walkers, faster left walkers and slower left walkers are involved in the simulation. The simulation results show that our model can capture some essential features of pedestrian counter flows, such as the lane formation, segregation effect and phase separation at higher densities. We also find that the subconscious effect can reduce the occurrence of jam cluster evidently compared with the case of un-subconscious effect. At large maximum velocity, the critical density corresponding to the maximum flow rate of the fundamental diagram is in good agreement with the empirical results.

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Recently, pedestrian flow has attracted considerable attention in the field of physical science.[1−7] As a typical pedestrian flow phenomenon, the counter flow in different situations has also been studied extensively. Muramatsu *et al.*[8] found that the jamming transition occurs in the pedestrian counter flow within a channel when the density is higher than a threshold. Takimoto *et al.*[9] investigated the effect of the partition line on the pedestrian counter flow. It was shown that the partition line has a significant effect on the counter flow. Fukamachi and Nagatani[10] simulated the pedestrian counter flow sidling through the crowd. Yu and Song[11,12] modelled the pedestrian counter flow in a channel with considering the surrounding environment and the traffic rule breaking behaviour. The counter flow in different scenarios such as in T-shaped channel,[13] the effects of following the front pedestrians in the same direction,[14] back stepping,[15] and exchanging position between face-to-face pedestrians,[16] with different velocities,[17−20] different sizes of slender particles,[21−23] have also been investigated.

The lattice gas model has been extensively used to simulate pedestrian flow. However, up to date, in almost all the existing lattice gas models, it has been supposed that the maximum velocity of all pedestrians is $V_{\max} = 1$. This is not in agreement with the real situation, where different pedestrians might have different walking speeds. In addition, pedestrians generally have some subconscious behaviour that they are accustomed to exceeding the preceding walkers in the same direction from the left-hand side, avoiding colliding with others in the opposite direction from the right-hand side and walking along a certain side of the road, e.g., the right-hand side in China or the left-hand side in Japan. How do these factors affect the pedestrian dynamics? This is an interesting but open problem.

In this Letter, we present an extended lattice gas model to investigate the pedestrian counter flow with different moving velocities and subconscious behaviour. The simulation results show that the subconscious behaviour and mixed maximum velocities has an important effect on the pedestrian dynamics.

The model is defined on the square lattice of $W \times L$ sites where W is the width of the channel and L is the length of the channel. There are four classes of pedestrians: walkers with faster or slower velocity going to the right and walkers with faster or slower velocity to the left. Each site contains only a single walker and each walker moves with no backward step. When the walker arrives at the wall of channel, they are reflected by the wall and never go out through the wall. The periodic boundary conditions are used herein.

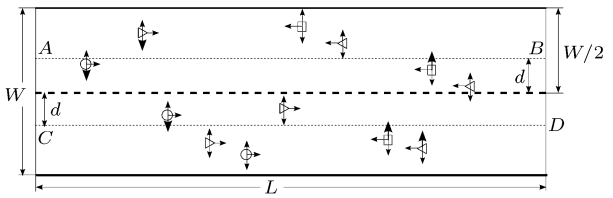


Fig. 1. Sketch of the pedestrian counter flow.

We extend the lattice gas model of pedestrian flow to take into account the different maximum velocities and the subconscious behaviour of walkers in a channel. Figure 1 shows the sketch of the pedestrian

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counter flow. The top and bottom sides of the channel are walls. The faster (slower) walkers going to the right and to the left are indicated, respectively, by right triangles (circles) and left triangles (squares). Arrows indicate the possible moving directions of the four groups. The bold arrows indicate the moving directions of walkers' subconscious behaviour, i.e., the different kinds of pedestrians would subconsciously cross the different partition lines, e.g., the faster (slower) right walkers may walk toward the right-hand side and cross the central partition line (or partition line CD) of the channel. In this study we assume that the walkers have the tendency to walk toward the right-hand side. The parameter d represents the distance between the partition line and the central one, which reflects the fact that the slower walkers prefer to move along the right-hand side of the walkway. Similarly, the faster (slower) left walkers have the same situations.

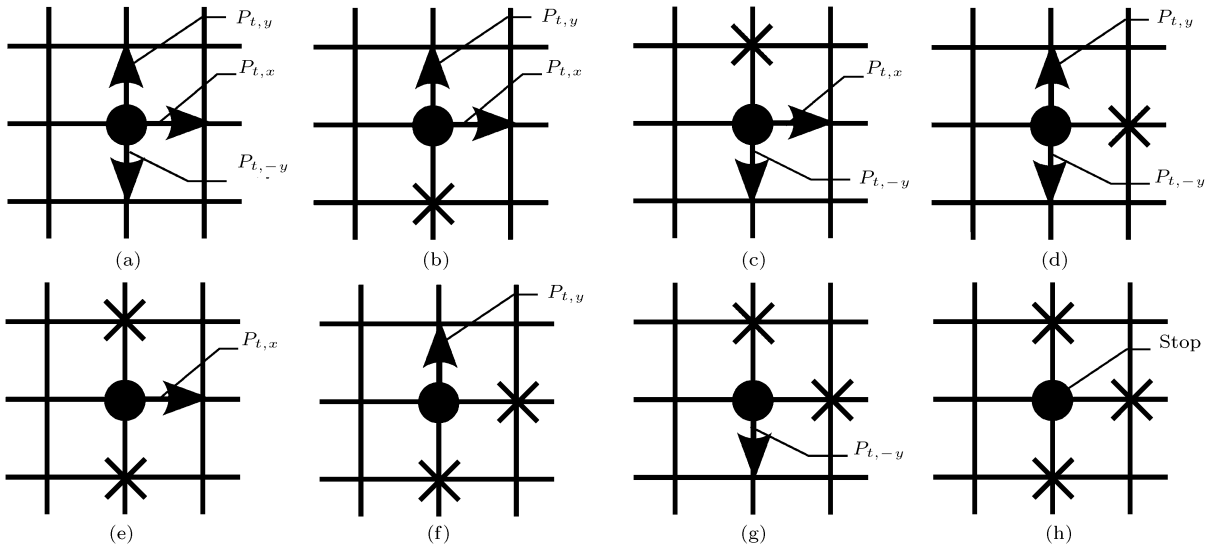


Fig. 2. All the possible configurations of the faster and slower walkers going to the right on the square lattice

Figure 2 presents all the possible configurations of the faster and slower walkers going to the right. The full circle indicates the right walker. The cross point indicates the site occupied by the other walkers or the wall. The transition probabilities $P_{t,x}$, $P_{t,y}$, $P_{t,-y}$ of the right walker corresponding to each configuration are given by the following: $P_{t,x} = D_1 + (1 - D_1)/3$, $P_{t,y} = (1 - D_2)(1 - D_1)/3$ and $P_{t,-y} = (1 + D_2)(1 - D_1)/3$ for the configuration (a); $P_{t,x} = D_1 + (1 + D_2)(1 - D_1)/2$, $P_{t,y} = (1 - D_2)(1 - D_1)/2$ and $P_{t,-y} = 0$ for the configuration (b); $P_{t,x} = D_1 + (1 - D_2)(1 - D_1)/2$, $P_{t,y} = 0$ and $P_{t,-y} = (1 + D_2)(1 - D_1)/2$ for the configuration (c); $P_{t,x} = 0$, $P_{t,y} = (1 - D_2)/2$ and $P_{t,-y} = (1 + D_2)/2$ for the configuration (d); $P_{t,x} = 1$, $P_{t,y} = 0$ and $P_{t,-y} = 0$ for the configuration (e); $P_{t,x} = 0$, $P_{t,y} = 1$ and $P_{t,-y} = 0$ for the configuration (f); $P_{t,x} = 0$, $P_{t,y} = 0$ and $P_{t,-y} = 1$ for the configuration (g); $P_{t,x} = P_{t,y} = P_{t,-y} = 0$ for the configuration (h), where D_1 indicates the strength of the drift pointing to the exit (right or left), and D_2 represents the strength of the preferential direction of subconscious behaviour.

The different kinds of walkers have different subconscious behaviours under the different situations. The values of D_2 are set as follows: (1) When the walkers are situated out of the partition lines (CD for the slower walkers and central partition line for the faster walkers), they have the priority to move on the right-hand side of the walkway, and in this case, $D_2 \neq 0$, otherwise, $D_2 = 0$. (2) When the walkers are situated on the inner side of the partition lines, the faster walkers would be accustomed to exceeding the preceding slower walkers in the same direction from the left-hand side, and in such a case, $D_2 \neq 0$ and the transition probability $P_{t,y}$ is replaced with $P_{t,-y}$ for the configuration (d), otherwise, $D_2 = 0$. (3) When the walkers encounter the opposite walkers, they often walk from the right-hand side so as to avoid collisions for the configuration (d), and in this case, $D_2 \neq 0$, otherwise $D_2 = 0$. For a left walking walker, a similar treatment can be followed for the possible configurations in the same way.

We introduce a new idea for simulating pedestrian movement with different maximum velocities. In order to avoid the ping-pong behaviour of pedestrians (for example, a pedestrian move quickly left and then move quickly right back in one time step), we only consider the walkers move quickly forward. Therefore, the walkers will move forward for $x(n)$ cells in one update time step if the transition probability $P_{t,x}$ is met, where $x(n) = \min(V_{\max}(n), \mathrm{gap}(n))$, $V_{\max}(n)$

denotes the maximum velocity of the nth walker, and gap n denotes the number of front empty cells of the nth walker.

We carry out the computer simulation for the above model. The total number of every kinds of walkers $\rho_{fr}LW$, $\rho_{sr}LW$, $\rho_{fl}LW$ and $\rho_{sl}LW$ are distributed randomly within the channel, where ρ_{fr}, ρ_{sr}, ρ_{fl} and ρ_{sl} are respectively the initial densities for the faster right walker, the slower right walker, the faster left walker and the slower left walker. The total density is $\rho = \rho_{fr}+\rho_{sr}+\rho_{fl}+\rho_{sl}$. $V_{\max,fr}$, $V_{\max,sr}$, $V_{\max,fl}$ and $V_{\max,sl}$ are the maximum velocities for different kinds of walkers, respectively. For simplicity, only $\rho_{fr} = \rho_{sr} = \rho_{fl} = \rho_{sl}$, $V_{\max,fr} = V_{\max,fl} = V_{\max,1}$ and $V_{\max,sr} = V_{\max,sl} = V_{\max,2}$ is considered in this study. All the walkers are numbered randomly from 1 to N ($N = \rho LW$), where N is the number of walkers existing within the channel. Following the above rule, all the numbered walkers are in order updated. After all the walkers are updated, if the right (left) walkers arrive at the right (left) boundary, the walkers are returned to the left (right) boundaries. After the abovementioned procedure is carried out, one time step is completed. The above procedure is repeated. In the simulations, the parameters are $W = 20$, $L = 100$, $d = 5$, $V_{\max,1} = 3$, $V_{\max,2} = 1$, $D_1 = 0.6$ and $D_2 = 0.9$ unless otherwise mentioned.

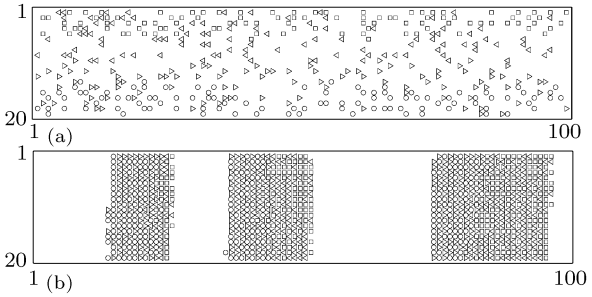


Fig. 3. Pedestrian patterns obtained at $t = 1000$. (a) The freely moving phase obtained at density $\rho = 0.2$. (b) The perfectly stopped phase obtained at $\rho = 0.5$.

The mean velocity in one update time step is defined as the sum of the velocity of walkers moving forward divided by the total number of walkers existing in the system. The mean flow is defined as the sum of the number of the right walkers moving through the right boundary and that of the left ones moving through the left boundary in one update time step. For each simulation, 10000 time steps are carried out, and the value of the mean velocity and mean flow are computed according to the last 2000 time steps averaged over 10 different random initial pedestrian distributions, although in all of our simulations it takes no more than 1000 time steps to reach the steady states.

Firstly, we study the patterns of pedestrian counter flow in the channel. Figure 3 shows the patterns at $t = 1000$ time step. (a) The freely moving phase obtained at density $\rho = 0.2$ and (b) the perfectly stopped phase obtained at $\rho = 0.50$. At low density $\rho = 0.2$ (see Fig. 3(a)), walkers intend to move along the right-hand side of road with the same maximum velocity, which is consistent with the empirically confirmed development of dynamically varying lanes.[19] In addition, we also find that in the region near central partition line, the faster walkers exceed the slower walkers from the left-hand side and then form a narrow-sparse walkway. This segregation effect of lane formation is the result of the initial distribution as well as the walkers' subconscious behaviour and interactions. Walkers moving in a mixed crowd or moving against the stream will have frequent and strong interactions. In each interaction, the encountering pedestrians move a little aside according to subconscious behaviour in order to pass over each other. In such a case, on the one hand, walkers have the tendency to move along the right-hand side, which leads to separate oppositely moving walkers; and on the other hand, they have the tendency to exceed the preceding walkers from the left-hand side, which makes different walkers with the different maximum velocities in the same direction separate. Moreover, once the pedestrians move in uniform lanes, the interaction among them will be weak. The simulation results further validate that in low density, there are always four lanes of walkers with different walking directions and velocities. Figure 3(b) shows that the jam cluster occurs at higher density $\rho = 0.5$ than the jamming transition point. The jam cluster does not move and is stationary within the channel. In such a case, the walkers' subconscious behaviour and different maximum velocities have no effect on the jam cluster.

Secondly, in order to gain a deeper insight into the subconscious effect, we investigate the fundamental diagram under different values of D_2 and the ratio of walkers' number of the difference walking direction against D_2. Figure 4 shows the plot of the mean velocity and the mean flow against density at $D_2 = 0.0$, 0.3, 0.6, 0.9, 1.0. When $D_2 = 0.0$, the subconscious behaviour is not considered and our model reduces to the original model in Ref. [8]. From Fig. 4, we can clearly see that at low density, the mean velocity (the mean flow) decreases (increases) linearly with the increase of the density. In comparison with that of $D_2 = 0$, the mean velocity for $D_2 > 0$ decreases slower, and correspondingly the mean flow increases faster. Moreover, the plots of mean velocity and mean flow for $D_2 > 0$ nearly keep the same under the critical density. When the density is larger than the critical density, the mean velocity and the mean flow decreases abruptly and becomes zeros, in such a case, the sub-consciousness has no obvious influence on the mean velocity and flow except for the critical density which increases gradually

with the increase of D_2. The corresponding critical density is $\rho = 0.27$, 0.32, 0.34, 0.36, 0.38, respectively. All these reflect that the walkers' subconsciousness could effectively decrease the occurrence of jam cluster.

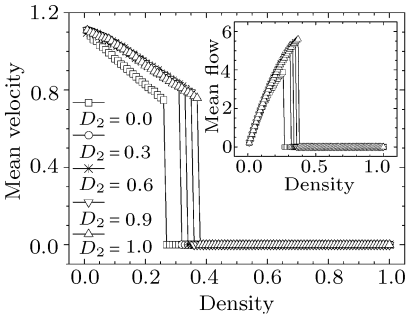


Fig. 4. Mean velocity and mean flow against density at $D_2 = 0.0$, 0.3, 0.6, 0.9, 1.0.

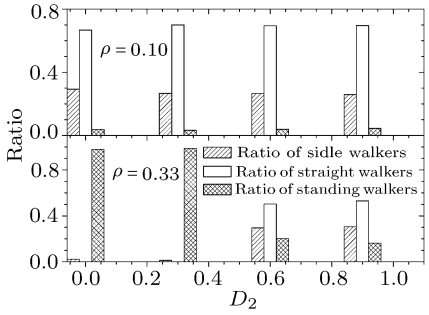


Fig. 5. Ratio of walkers' number in the different walking directions against D_2, at $\rho = 0.1$ and $\rho = 0.33$.

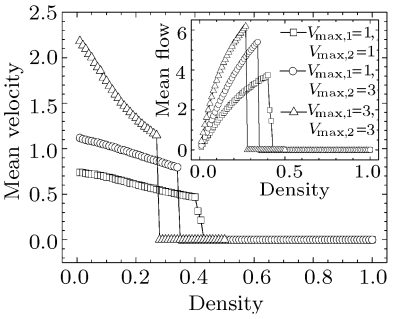


Fig. 6. Mean velocity and the mean flow against the density for different mixed maximum velocities at $V_{\max,1} = V_{\max,2} = 1$; $V_{\max,1} = 3$, $V_{\max,2} = 1$ and $V_{\max,1} = V_{\max,2} = 3$.

In Fig. 5, we give the plot of the ratio of walkers with the difference walking directions against D_2 at a fixed density. One can see that (1) when $\rho = 0.1$, the walkers are all in the free flow and the ratio of walkers of moving forward is at most, in this case, and the strength of D_2 has no obvious effect on the pedestrians' movement after the system attains its stable state; (2) when $\rho = 0.33$, the ratio of the straight walkers becomes zeros for $D_2 = 0$, 0.3. This indicates that the jam cluster appears. However, with the further increase of D_2, there are some people who can move forward. All these results are consistent with the above analysis.

Finally, we investigate the effect of the different maximum velocities on the mean velocity and the mean flow. In Fig. 6, we give the fundamental diagram for different maximum velocities $V_{\max,1} = V_{\max,2} = 1$; $V_{\max,1} = 3$, $V_{\max,2} = 1$ and $V_{\max,1} = V_{\max,2} = 3$. One can see that when the mixed velocity is high, the mean velocity and flow is enhanced compared with that of the low mixed velocity, whereas the critical density decreases and the jam occurs more easily. Note that in the case of larger $V_{\max}$, the critical density corresponding to the maximum flow rate in the fundamental diagram is in good agreement with empirical results.[17]

In summary, we have proposed an extended lattice gas model with different maximum velocities to simulate pedestrian counter flow by considering the human subconscious behaviour, which can lead to appropriate responses to some complicated situations. The simulation results demonstrate that the new model can reproduce some characteristics of pedestrian counter flows, such as the lane formation, segregation effect and phase separation at higher densities. Particularly, with the increase of the strength of D_2, the critical density increases. All these show, to some extent, that the subconscious behaviour could decrease the occurrence of jam cluster. Furthermore, in the case of larger mixed $V_{\max}$, the critical density corresponding to the maximum flow rate in the fundamental diagram is in good agreement with empirical results. We hope our primitive results herein can be useful to make decisions in the design of pedestrian facilities. In our future work, the presented model will be extended to investigate more general situations, e.g., the cases under open boundary conditions, etc.

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