Physica A 392 (2013) 215–220

Contents lists available at SciVerse ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

The escape of pedestrians with view radius

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ARTICLE INFO

Article history:
Received 14 May 2011
Received in revised form 13 January 2012
Available online 10 August 2012

Keywords:
Escape
View radius
Pedestrian

ABSTRACT

In this brief letter, we modify the classic social force model of Helbing which is applied to simulate how a pedestrian gets outside a hall full of smoke. As the Vicsek model does, the view radius is introduced to describe the range the pedestrian can see. The relation between the evacuation time and the view radius is studied with different numbers of pedestrians. The results show that the shorter the view radius is, the more time walkers will spend escaping, and even fail to escape. And the relation between the number of remaining walkers and the view radius shows non-monotonicity, if the number of pedestrians is larger than 600. And lastly, we propose to enlarge the width of the exit or to add two small exits in the corners, which may decrease the evacuation time greatly and obviously reduce the number of remaining walkers.

1. Introduction

Pedestrian flow which is a kind of many-body system with strong interaction has attracted a lot of scientists for many years. In this field, several models have been proposed to describe pedestrian flow. In the 1970's, Henderson pointed out that pedestrian flow is very similar to fluid and gas [1] so that hydromechanics has been applied to the research of crowd behavior [2,3]. In 1995, Helbing et al. proposed a social force model to research crowd flow, which has been studied widely to describe a pedestrian in a passage or outside a hall [4–6]. In 1999, Muramatsu et al. studied the counter flow of pedestrians within an underpass by using the lattice–gas model of biased random walkers [7–10]. These three models mentioned above have been studied deeply and applied widely to different situations to explain the complexity of pedestrian flow. In resent decades, the research of pedestrian flow mainly focuses on two respects. On one hand, more and more new models have been proposed [11–13], such as the centrifugal force model [14], and old ones [15–18] are improved in theory. And on the other hand, some researchers have focused a lot of attention on the empirical observations of pedestrians [19,20] these years, so that these models are applied widely to solve the realistic problems [21,22]. In light of the development of pedestrian flow, the problem how a pedestrian escapes from a hall has still been attracting scientists [5,10,14,23–25] since the last decade. Meanwhile, in another field, the collective behaviors of groups have also been studied by scientists since 1995 when Vicsek et al. proposed their model to exhibit a complex cooperative behavior successfully [26].

In this paper, we mainly study how a crowd gets outside a hall with our model which is simplified slightly and based on the classic social force model. And it is considered that a pedestrian flow is similar to collective behavior partly so that the view radius is introduced into our model. Furthermore, we propose the methods to decrease the evacuation time and to reduce the number of the remaining walkers who fail to escape from the hall.

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0378-4371/$ – see front matter
doi:10.1016/j.physa.2012.07.053

2. Modeling

Our simulations of crowd dynamics are based on the modified social force model, which is slightly different from the original one. We assume a mixture of socio-psychological and physical force influencing the behavior in a crowd. Each walker of mass m likes to move with a certain desired special speed v^0 in a certain direction $\mathbf{e}_i$, and tends to adapt correspondingly its actual velocity $\mathbf{v}_i$ within a certain characteristic time τ. Simultaneously, walker i tries to keep a distance from another walker j and a wall W. In mathematical terms, the change of velocity in time t is given by the equations:

$$\frac{\mathrm{d}\mathbf{r}_i}{\mathrm{d}t} = \mathbf{v}_i$$
$$m\frac{\mathrm{d}\mathbf{v}_i}{\mathrm{d}t} = m\frac{v^0\mathbf{e}_i - \mathbf{v}_i}{\tau} + \mathbf{F}_i.$$

We describe the psychological tendency of two walkers i and j to be away from each other by a repulsive interaction force $A\exp[(D - d_{ij})/B]\mathbf{n}_{ij}$. Here both A and B are constants, d_{ij} is the distance of walker i from walker j and $\mathbf{n}_{ij} = (\mathbf{r}_i - \mathbf{r}_j)/d_{ij}$ is a normalized vector pointing from walker j to walker i. If their distance is smaller than D, which denotes the diameter of the walker, the pedestrians will touch each other. In this case, it is assumed that an additional force is inspired by granular interaction, which is important for us to understand the particular effect in panicking crowds: a "body force" $k\Theta(D - d_{ij})\mathbf{n}_{ij}$ counteracting body compression. Thus, we have that the perpendicular force between two walkers is

$$\mathbf{F}^1_{ij} = \{A\exp[(D - d_{ij})/B] + k\Theta(D - d_{ij})\}\mathbf{n}_{ij}$$

where the function $\Theta(x)$ is zero, if the pedestrians do not touch each other; otherwise it is equal to 1.

The interaction between a pedestrian and a wall is treated analogously, if d_{iW} means the distance to wall W and $\mathbf{n}_{iW}$ denotes the direction perpendicular to it. The corresponding interaction force with the wall reads

$$\mathbf{F}^2_{iW} = \{A\exp[(r - d_{iW})/B] + k\Theta(r - d_{iW})\}\mathbf{n}_{iW}.$$

In the social force model, the interaction between walker i and walker j (or wall W) includes friction. Yet, here we simplify it and redefine the action on walker i in our model. It reads $\mathbf{F}^3_i = -\mu\mathbf{v}_i$.

As the Vicsek model does, we introduce view radius into our model. Here, it is assumed that the view radius may represent the range the pedestrian can see in a smoky hall. If the view radius is large enough, it means the pedestrian knows the way to get outside clearly. If the view radius is very small, it will make most walkers fail to see the exit and have to move as their neighbors do. Thus, the equation ought to describe the motion of both the pedestrian who can see the exit and the ones who fail to see it. The equation of motion is

$$\frac{\mathrm{d}\mathbf{r}_i}{\mathrm{d}t} = \mathbf{v}_i$$
$$m\frac{\mathrm{d}\mathbf{v}_i}{\mathrm{d}t} = m\frac{v^0\mathbf{e}_i - \mathbf{v}_i}{\tau} + \sum_{j\in\Omega}\mathbf{F}^1_{ij} + \sum_{W\in\Omega}\mathbf{F}^2_{iW} + \mathbf{F}^3_i.$$

Here $\mathbf{e}_i$ is defined as: $\mathbf{e}_i = \frac{\mathbf{r}_0 - \mathbf{r}_i}{|\mathbf{r}_0 - \mathbf{r}_i|}$, if the walker i can see the exit. It is the direction pointing to the exit, and $\mathbf{r}_0$ is the middle position of the exit. If walker i fails to see the exit, $\mathbf{e}_i$ is defined as: $\mathbf{e}_i = \frac{\sum_{j\in\Omega}\mathbf{v}_j + \mathbf{v}_i}{|\sum_{j\in\Omega}\mathbf{v}_j + \mathbf{v}_i|}$, which is the direction of average velocity of its neighbors and itself. And Ω is the range that walker i can see.

The model parameters are specified as follows: The mass of each pedestrian m is 80 kg. The desired speed v^0 is 1 m/s. The acceleration time τ is 0.5 s. With $A = 2000$ N and $B = 0.08$ m, one can reflect the distance kept at normal desired velocity. The parameter $k = 12\,000$ kg/s^2 and $\mu = 200$ Ns/m determine the obstruction effect in case of physical interactions. The length of time step $\mathrm{d}t = 0.01$ s. And the pedestrian diameter $D(=2r)$ is 0.6 m, where r is the radius of each walker's body.

3. Simulation

Now we may carry out the computer simulation. Initially, all the walkers are distributed randomly in the hall without touching each other. Their initial velocities are 1 m/s in a direction pointing to the exit. These walkers are numbered randomly from 1 to N, where N is the number of walkers existing within the system. The system is bounded by the hall $L \times L$, and the exit w. L is the length of the hall and w is the width of the exit, where L is 30 m and w is 1.4 m. And the exit is located at the middle of the right boundary. The pedestrians move according to the rule mentioned above. If the walkers go out of the system, they will be removed from the system. Additionally in the simulation, we consider that a walker fails to leave the hall, if it spends more than 10^5 time steps moving in the hall.

Fig. 1 shows the relation between the evacuation time and the view radius in case of the different numbers of pedestrians. Via careful simulation, it is found that the evacuation time decreases when the view radius increases. If the view radius is large enough ($R \geq 5$ m), it is discovered that the evacuation time is nearly a constant. It hardly decreases with a further increase of view radius. It means that all the walkers get outside the exit directly without difficulty. The walkers close to