Physica A 427 (2015) 34–39

Contents lists available at ScienceDirect

Physica A

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

Effective strategies of collective evacuation from an enclosed space

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HIGHLIGHTS

- One exit in the corner is the best choice.
- Multi exits will hinder evacuation.
- Increasing the intensity of exit sign takes only effect in some extent.

ARTICLE INFO

Article history:
Received 26 April 2014
Received in revised form 18 October 2014
Available online 9 February 2015

Keywords:
Evacuation
Self-propelled particles
Collective motion
Emergency exit

ABSTRACT

On the basis of fundamental principles of the Vicsek model and the leader–follower model, we develop an extended evacuation model of self-propelled particles system considering movable exits, and then propose effective strategies of self-organization evacuating from an enclosed space. It is found that placing exits in the corner is an effective strategy for evacuation via simulations. Furthermore, increasing the intensity of exit sign takes only effect in some extent. In addition, multi exits will make the evacuation more slowly. In general, one corner exit is the best choice for collective evacuation. Our results provide new insights into designing a safe passage in some enclosed places, such as the cinema and conference halls.

1. Introduction

Collective motion, which can be extensively found in macroscopic and microscopic scales, is a common phenomenon in nature [1]. The movement of social animals, such as fish schools, and bird flocks [2–5], and even the motion of microorganisms like bacterial colonies [6–11], can belong to examples of biological systems showing collective behavior. In these systems, biological groups can be viewed as a complex intelligent behavior with the combination of each agent's limited cognitive abilities and social interactions within neighboring individuals during movement. With the growing interest in collective behavior and raising development of computer, researches on collective motion have been broadly investigated in reality [12–17].

Over these years, the research of crowd evacuation in emergency [16,17] has greatly been enhanced more deeply. At the same time, further progresses on collective evacuation have been achieved among biology, physics as well as computer science, and even some other inter-disciplines. The social force model [18–20] is mainly utilized to research crowd evacuation phenomenon in an enclosed space. So far, researches in this field have proposed the social force evacuation model with the leadership effect [18], the escape of pedestrians model with view radius [21], and some other models aiming at solving the realistic problems [22,23]. They have found that the smaller the view radius was, the more evacuation time groups would spend. Furthermore, the distance between each leader and the corresponding exit is better close to half the length of

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http://dx.doi.org/10.1016/j.physa.2015.01.080
0378-4371/

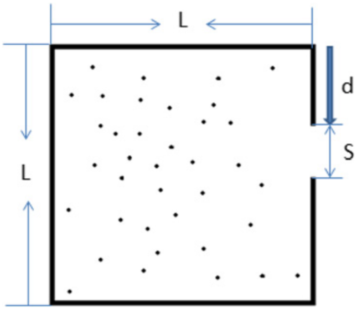

Fig. 1. (Color online) Schematic diagram of our model. L is the size of system. S is the width of the exit, and d is the distance between the corner and the exit.

boundary. As well, it is beneficial to group evacuation enlarging the width of exits. However, they all located exits in fixed positions in previous studies, such as the center of the special boundary. In reality, various positions of exits are likely to have different effects on the evacuation.

In our paper, we have proposed an extended self-propelled particle model to investigate evacuation behavior in order to reduce the avoidable loss in case of emergency on the basis of existing models [24–26,18,21]. Instead of fixed exits, we add movable exits in the boundary, and point at the exits via a preferred direction in our model. Boundary conditions are the reflective boundary conditions. We investigate the dependence of the evacuation on several parameters, such as the number of group, system size, positions of exits, width of exits, and weighing factor of the preferred direction. Some effective strategies are presented to speed up the evacuation of self-propelled particles from an enclosed space.

2. Model and methods

Fig. 1 illustrates the schematic diagram of our model. L is the size of the system. S is the width of the exit, and d is the distance between the corner and the exit. N particles move with the fixed velocity magnitude in an $L \times L$ square space with reflective boundary conditions. The exit sign is placed in the middle of exit. Velocity directions of individuals are determined by the social interaction of group members within an interaction radius r [24,27]. Initially ($t = 0$), the location $\vec{x}$ and moving direction $\vec{\theta}$ of each particle are distributed randomly in space. $\vec{\theta} = cos\theta \vec{i} + sin\theta \vec{j}$, where θ is taken randomly in $[-\pi, \pi)$, $\vec{i}$ and $\vec{j}$ are the unit vectors. At the next step, the position of a particle is updated according to the following equation [24],

$$\vec{x}_i(t+1) = \vec{x}_i(t) + \vec{v}_i(t)\Delta t \tag{1}$$

and the moving direction of the individual can be modified as follows [26],

$$\vec{\theta}_i(t+1) = \frac{\langle \vec{\theta}_i \rangle_r + \omega \vec{g}_i}{|\langle \vec{\theta}_i(t) \rangle_r + \omega \vec{g}_i|}, \tag{2}$$

where $\langle \vec{\theta}_i(t) \rangle_r$ represents the mean direction vector of all the particles j within an interaction radius r of the particle i, which is as follows [27,28],

$$\langle \vec{\theta}_i(t) \rangle_r = \Sigma \vec{\theta}_j(t) / |\Sigma \vec{\theta}_j(t)|. \tag{3}$$

And ω is the weighting factor, and $\vec{g}_i$ represents the preferred direction, which is defined as [26]

$$\vec{g}_i(t) = \frac{\vec{x}_i(t) - \vec{x}_{sign}(t)}{|\vec{x}_i(t) - \vec{x}_{sign}(t)|}, \tag{4}$$

where x_{sign} is the position of the exit sign. As ω is close to 1, the direction of particles is more heavily influenced by the preferred direction $\vec{g}_i$, whereas ω is close to zero, which indicates no preferred direction. When reaching a wall, self-propelled particles move under reflective boundary conditions.

All simulations were carried out with these parameters as follows. The constant velocity magnitude of each particle is fixed as $v = 0.03$, and the interaction radius is fixed as $r = 2.4$. We change the number of group N, system size L, the position d, width of the exit S and the weighing factor of preferred direction ω to investigate the collective evacuation. Our results were gained by averaging over 10,000 independent runs.