Physics Letters A 381 (2017) 1837–1844

Contents lists available at ScienceDirect

Physics Letters A

www.elsevier.com/locate/pla

Dual effects of guide-based guidance on pedestrian evacuation

Yi Ma*, Eric Wai Ming Lee, Meng Shi

Department of Architecture and Civil Engineering, City University of Hong Kong, Kowloon, Hong Kong

ARTICLE INFO

Article history:
Received 9 February 2017
Received in revised form 29 March 2017
Accepted 30 March 2017
Available online 1 April 2017
Communicated by C.R. Doering

Keywords:
Pedestrian evacuation
Guidance
Visibility
Social force model

ABSTRACT

This study investigates the effects of guide-based guidance on the pedestrian evacuation under limited visibility via the simulations based on an extended social force model. The results show that the effects of guides on the pedestrian evacuation under limited visibility are dual, and related to the neighbor density within the visual field. On the one hand, in many cases, the effects of guides are positive, particularly when the neighbor density within the visual field is moderate; in this case, a few guides can already assist the evacuation effectively and efficiently. However, when the neighbor density within the visual field is particularly small or large, the effects of guides may be adverse and make the evacuation time longer. Our results not only provide a new insight into the effects of guides on the pedestrian evacuation under limited visibility, but also give some practical suggestions as to how to assign guides to assist the evacuation under different evacuation conditions.

1. Introduction

Guidance is a very important rescue strategy for the pedestrian evacuation under emergency. With the guidance, evacuation efficiency can be usually improved. Up to now, the studies into pedestrian evacuation guidance can be roughly categorized into two levels: macroscopic network level and microscopic local level. The macroscopic pedestrian evacuation guidance studies represent evacuations as optimization models on road networks. Guidance strategies, including the road design on evacuation networks [1], the location of intersections, signal controls and turning restrictions [2–5], lane control [6] and route guidance information [7] were addressed through solving these optimization models.

In recent decades, as various microscopic pedestrian evacuation simulation models such as the social force model [8,9], the cellular automaton model [10–12], the lattice gas model [13,14], the agent-based model [15] and Vicsek model [16,17] arise, an increasing number of pedestrian evacuation studies on microscopic local level, including, evacuations in buildings with simple geometry, such as classroom, single-exit/multi-exit room [18,19], the whole building, part of the building, such as corridor, bottleneck, and exit [20–23] have been conducted because the pedestrian evacuation studies on microscopic local level are more helpful than that on macroscopic network level for understanding the detail of evacuation and the complex behavioral characteristics of evacuees.

In many cases, the evacuation in buildings may be affected by many adverse environmental conditions, such as, insufficient lighting, blackout, and smoke. Under adverse environmental conditions, a usual counter-measure to assist the evacuation is guidance. For the pedestrian evacuation guidance studies, some focused on the design of guidance facilities, such as the location of emergency evacuation signs [24], flashing emergency lights [25], and acoustic warning systems [26].

Another type of usual guidance strategy is to assign the experienced or trained evacuation guides. For example, in daily life we can usually see some staffs wearing the clothes with bright colors to maintain order in large public places. These staffs who are familiar with the building layout may also take charge of the guidance when emergency occurs. To date, many studies about the pedestrian evacuation guidance by assigning guides have been conducted. Pelechano and Badler [27] developed a two-level model to simulate leadership behavior during the evacuation in a maze-like building. The high level model was used for path-finding and the low level model was used to control local motion. Yuan and Tan [28] investigated the effects of trained guides on the evacuation dynamics in a single-exit room. They found that the guides can efficiently accelerate the evacuation, especially in conditions of low visibility. Hou et al. [29] extended this study into the multi-exit rooms. Interestingly, they found that guides may make the evacuation slower in the multi-exit rooms unless they are distributed at the room's center and each guide heads to a different exit. Yang et al. [30] revealed that the positioning as well as the quantity of guides is also important during the evacuation. Cao et al. [31] found that guides should be distributed randomly within the evac-

---

* Corresponding author.
E-mail address: yima23-c@my.cityu.edu.hk (Y. Ma).

http://dx.doi.org/10.1016/j.physleta.2017.03.050
0375-9601/

uation area. They also found that the evacuation guidance is more effective when the speed of guides is about 75% of the herding pedestrians' speed. Wang et al. [32] presented an extended evacuation field model for simulating the pedestrian evacuation under the guidance of evacuation assistants. They found that there is an optimal number of evacuation assistants for achieving satisfactory evacuation efficiency. They also showed that this number will decrease when the number of evacuees increases. Wang et al. [33] also investigated the effectiveness of evacuation assistant with different sensing radius in a T-shaped channel scenario. They found that the guidance effect of the evacuation assistant will be insufficient, optimum, or excessive when the sensing radius changes from very limited to enough large.

These related studies enriched the understanding into the effects of guides on the pedestrian evacuation. However, the effectiveness of the guidance under different assignments of guides has not been fully understood. Furthermore, it has been revealed that guides may make the evacuation slower in case of improper distribution [29]. Also, Ma et al. [34] mentioned that guides may be negative for the pedestrian evacuation when the visibility range of the room and the crowd size are very large. Is there any other adverse guidance result? It is important and necessary to understand these problems for making guide resources use to assist the evacuation more effectively and efficiently. Thus in this study, the effects of guidance under different assignments of guides are investigated and analyzed from positive and adverse perspectives. The main objective of this study is to understand the effects of guides on the pedestrian evacuation more fully, so as to provide some practical suggestions as to how to assign guides to assist the evacuation under different evacuation conditions.

2. Model and method

2.1. Basic model

We extend the social force model [8] to simulate the guided pedestrian evacuation under limited visibility, given that it is continual. The movement trajectory of pedestrians in the simulation is smoother than that simulated by the discrete models. This advantage can be advantageous to better observe and analyze evacuation dynamics through the movement trajectory of pedestrians.

In the social force model, pedestrian i in the crowd is represented as a circle of body radius r_i and mass m_i. The movement of the pedestrian i is subject to the following mechanic equation:

$$m_i \frac{\mathrm{d}\mathbf{v}_i(t)}{\mathrm{d}t} = m_i \frac{v_i^0 \mathbf{e}_i^0 - \mathbf{v}_i(t)}{\tau} + \sum_{j(\neq i)} \mathbf{f}_{ij}(t) + \sum_{W} \mathbf{f}_{iw}(t) \tag{1}$$

where, v_i^0 and $\mathbf{e}_i^0$ represent the desired speed and direction respectively. $\mathbf{v}_i$ represents its actual velocity. τ is the characteristic time used for adjusting its actual velocity $v_i^0\mathbf{e}_i^0$ to the desired velocity $\mathbf{v}_i$. $\mathbf{f}_{ij}$ represents the interaction force between the pedestrian i and any of other pedestrian j, which is calculated by:

$$\mathbf{f}_{ij} = A_i \exp\big[(r_{ij} - d_{ij})/B_i\big]\mathbf{n}_{ij} + kg(r_{ij} - d_{ij})\mathbf{n}_{ij} + \kappa g(r_{ij} - d_{ij})\Delta v_{ji}^t \mathbf{t}_{ij} \tag{2}$$

where, $A_i \exp[(r_{ij} - d_{ij})/B_i]\mathbf{n}_{ij}$ represents the psychological repulsion between the pedestrian i and j. A_i and B_i are constants. r_{ij} and d_{ij} represent the sum of the body radii of the pedestrian i and j and the distance of the centers of mass between the pedestrian i and j. $\mathbf{n}_{ij} = (n_{ij}^1, n_{ij}^2) = (\mathbf{r}_i - \mathbf{r}_j)/d_{ij}$ is the normalized vector pointing from the pedestrian j to i. The terms $kg(r_{ij} - d_{ij})\mathbf{n}_{ij}$ and $\kappa g(r_{ij} - d_{ij})\Delta v_{ji}^t \mathbf{t}_{ij}$ are respectively referred to as "body force" and "sliding friction force". They will arise when the pedestrian i and j touch each other (i.e., $d_{ij} < r_{ij}$). The function $g(x)$ equals x only when $d_{ij} < r_{ij}$; otherwise it equals zero. k and κ are large constants. $\mathbf{t}_{ij} = (-n_{ij}^2, n_{ij}^1)$ denotes the tangential direction $\Delta v_{ij}^t = (\mathbf{v}_j - \mathbf{v}_i)$. $\mathbf{t}_{ij}$ represents the tangential velocity difference.

Similarly, if d_{iw} corresponds to the distance between the pedestrian i and the obstacle, such as walls, $\mathbf{n}_{iw}$ corresponds to the direction perpendicular to the obstacle, and $\mathbf{t}_{iw}$ corresponds to the tangential direction. The interaction force $\mathbf{f}_{iw}$ between the pedestrian i and the obstacle can be given by

$$\mathbf{f}_{iw} = A_i \exp\big[(r_i - d_{iw})/B_i\big]\mathbf{n}_{iw} + kg(r_i - d_{iw})\mathbf{n}_{iw} + \kappa g(r_i - d_{iw})(\mathbf{v}_i.\mathbf{t}_{iw})\mathbf{t}_{iw} \tag{3}$$

Finally, the position of pedestrian $\mathbf{r}_i(t)$ can be updated by

$$\frac{\mathrm{d}\mathbf{r}_i}{\mathrm{d}t} = \mathbf{v}_i(t) \tag{4}$$

2.2. Assumptions and rules

We assume that the visibility in the evacuation context is limited by adverse environmental conditions, such as blackout or smoky conditions. In this case, pedestrians can only see the objects within the visual field of radius η. Thus, in the model, pedestrians only interact with the neighbors, obstacles and escape exits within the visual field.

To guide the crowd, guides knowing the location of the escape exit are beforehand assigned into the crowd. That is, pedestrians in the crowd are divided into two types: evacuation guides and disoriented pedestrians.

Because the guides are able to perceive the location of the escape exit by their memory and experience, normally, they will tend to move toward the escape exit during the evacuation. The desired direction of them can be therefore given by:

$$\mathbf{e}_i^0(t) = \mathrm{Norm}\big[\mathbf{r}_i(t) - \mathbf{r}_e\big] \tag{5}$$

where, $\mathrm{Norm}[\mathrm{x}] = \mathrm{x}/||\mathrm{x}||$ means normalization of a vector x. $\mathbf{r}_i(t)$ and $\mathbf{r}_e$ represents the position of guide i and escape exit, respectively.

During the evacuation, the disoriented pedestrian may confront following four situations:

(i) Pedestrian can fortunately see the escape exit within the visual field near the escape exit. In this case, the desired direction of pedestrian i can be also calculated by Equation (5), if $\mathbf{r}_i(t)$ represents the position of pedestrian i.

(ii) Pedestrian cannot see anything within the visual field, including, escape exit, guide, and other disoriented pedestrian. In this case, we assume that pedestrian will move randomly for simplicity. Such assumption was also adopted by Ref. [29].

(iii) Pedestrian can only see other disoriented pedestrians. In this case, a collective behavior can not be neglected is "follow the crowd" [35,36]. It propels people to move toward and align with the crowd within the visual field. Correspondingly, the desired direction can be given by:

$$\mathbf{e}_i^0(t) = \mathrm{Norm}\big[\omega \mathbf{e}_i^\beta(t) + (1 - \omega)\mathbf{e}_i^\alpha(t)\big] \tag{6}$$

where, $\mathbf{e}_i^\beta(t)$ and $\mathbf{e}_i^\alpha(t)$ is the average direction of neighbors and the direction of the center of neighbors. They are respectively calculated by:

$$\mathbf{e}_i^\beta(t) = \mathrm{Norm}\Big[\sum \mathbf{v}_j(t)/||\mathbf{v}_j(t)||\Big] \tag{7}$$

$$\mathbf{e}_i^a(t) = \mathrm{Norm}\Big[\sum \mathbf{r}_j(t)/n - \mathbf{r}_i(t)\Big] \tag{8}$$