Physica A 417 (2015) 358–366

Contents lists available at ScienceDirect

Physica A

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

# Modification of the dynamic floor field model by the heterogeneous bosons

Wei Guo [a], Xiaolu Wang [a], Mengting Liu [b], Yuan Cheng [b,*], Xiaoping Zheng [c,**]

[a] College of Information Science and Technology, Beijing University of Chemical Technology, Beijing 100029, People's Republic of China

[b] College of Mechanical and Electrical Engineering, Beijing University of Chemical Technology, Beijing 100029, People's Republic of China

[c] Department of Automation, Tsinghua University, Beijing 100084, People's Republic of China

## HIGHLIGHTS

- The reason of bosons confusion is the homogeneity of the bosons.
- A modified dynamic floor field model based on the heterogeneous bosons is proposed.
- Transformation mechanism of bosons determines the characteristics of a crowd system.

## ARTICLE INFO

*Article history:*
Received 26 January 2014
Received in revised form 8 August 2014
Available online 19 September 2014

*Keywords:*
Dynamic floor field
Pedestrian dynamics
Modified model
Evacuation

## ABSTRACT

In the dynamic floor field model, the bosons are homogeneous. This causes a problem that the pedestrians are confused by their own traces. The model has been modified by the heterogeneous bosons. Compared with the dynamic floor field model based on the homogeneous bosons, the modified model exhibits realistic pedestrian behaviors, and the effect of modification on the model parameters is analyzed in subsequent numerical simulations. By sensitivity analysis for the model parameters, it is found that the characteristic of a crowd system, which is represented by the correspondence between the following behavior and the evacuation time, is determined by the decay of the bosons; it is also found that diffusion of the bosons can describe the uncertainty of information transformation which is related to the evacuation time. In addition, an interesting phenomenon implies that for the pedestrians who are unfamiliar with the structure to find the exit, the accurate information from the persons around them is more beneficial than that from the distant ones.


## 1. Introduction

The dynamic floor field is typically used to model long-range interactions between the pedestrians, e.g. following people walking some distance ahead. In the discrete case, the field is compared to a bosonic field, i.e., the bosons dropped by the moving pedestrians create the virtual traces. Thus the pedestrians could get information about the exit location by following these traces. In simulations, however, it is found that the bosons indiscriminately affect the pedestrians who dropped them. This can cause the models not to exhibit realistic pedestrian behaviors. Therefore, it is necessary for evacuation simulation to modify the dynamic floor field.

* Corresponding author.
** Corresponding author. Tel.: +86 10 62781475.
*E-mail addresses:* yuancheng@mail.buct.edu.cn (Y. Cheng), asean@mail.tsinghua.edu.cn (X. Zheng).

http://dx.doi.org/10.1016/j.physa.2014.08.072
0378-4371/

The dynamic floor field is an important part of the floor field model. Since the bosons attract all the pedestrians including who dropped them, the pedestrians could be confused by their own traces and are likely to take a detour. Burstedde et al. [1] proposed to leave the bosons which were dropped at the last time step out of computing the transition probability in order to alleviate the confusion. This improvement can be called One Step Correction Model (OSCM). However, the situation that the bosons do not decay after more than one time step was not considered in OSCM. This causes that the confusion would occur later during the evacuation. Kirchner et al. [2] continued to adopt OSCM without explaining the details about the bosons, removing the matrix of preference and analyzing the characteristics of the model parameters. Based on the Kirchner's model, there are many researches employing the dynamic floor field for evacuation modeling, e.g. researches on friction [3] and pushing force between the pedestrians [4–6], one pedestrian occupying multiple cells [7], exit choice [8,9], local view floor field [10], inhomogeneous exit attraction [11] and choice between stairway and escalator [12]. All these researches do not take into account the bosons confusion. In some cases where following behavior is not necessary to be considered, e.g. model test [13], pedestrian behavior analysis at the exit [14–16] and evacuation in one-exit room without obstacles [17–21], the floor field model without dynamic floor field can be adopted. Nevertheless, some researchers suggested that the dynamic floor field, which induces the individuals in front to move backwards, is not capable to describe pedestrian following behavior in the scene with obstacles [22] or simulate pedestrian counter flow on a crosswalk [23]. It is a violation of the purpose of the dynamic floor field. Inspired by the dynamic floor field a communication field was presented in Ref. [24]. According to the bosons dynamics, the transformation mechanism of the escape information in the evacuation was introduced. This illustrates that the dynamic floor field can further describe the information exchanges between the pedestrians. Therefore, the dynamic floor field model has a broad prospect in evacuation research, but the bosons confusion problem needs to be solved.

In the present work, a modified model with heterogeneous bosons is proposed in an effort to resolve the bosons confusion problem. To show the validity of modification in theory, we apply this model in a typical scenario where people escape from a room with one single exit, analyze the impacts of dynamic floor field parameters on the evacuation time and compare the results with those by other floor field models.

## 2. Analysis of the bosons confusion in OSCM

Kirchner's model consists of static floor field $S$ and dynamic floor field $D$. Pedestrians select their destinations according to $S$, move to unoccupied neighbor cells and then drop one boson in the cell they came from. All bosons constitute $D$. In each time step, each single boson decays with probability $\delta$ at first. And if not vanish, it diffuses with probability $\alpha$ to one of its neighbor cells which are not occupied by obstacles. The order of diffusion and decay does not affect the transition probabilities [25]. The dynamic floor field discussed here is a velocity density-dependent field, which means that only the moving pedestrians drop bosons.

Fig. 1 shows graphical representations of the relative location of a single boson changing with the host pedestrian. The pedestrian walked into the right cell from the middle cell at $t = 1$, dropping a boson (the orange dot) in the previous cell. At $t = 2$ the boson was not updated because its lifetime was not larger than one step. This boson would confuse the pedestrian through computing the transition probability. For this problem, Ref. [1] proposed OSCM, which takes no account of the boson dropped at $t = 1$. If this boson will not vanish at $t = 3$, it is likely to appear in pedestrian's neighbor cells again (the cases are shown in orange box) and confuses the pedestrian. In this case OSCM fails to eliminate the confusion.

To compute the confusion probability at $t = 3$ in OSCM, all possible cases of updating the pedestrian locations at $t = 2$ are expressed in $A_1 \sim A_5$, where the pedestrian is not confused in OSCM, and all possible cases of updating the boson locations at $t = 3$ are expressed in columns $B_1 \sim B_6$ (see Fig. 1). The probabilities of cases $A_1 \sim A_5$ are given by $P(A_i)$, ($i = 1, 2, 3, 4, 5$), and the probabilities of cases are given by $P(B_1) = (1-\alpha)(1-\delta)$, $P(B_2) = P(B_3) = P(B_4) = P(B_5) = (1-\delta)\alpha/4$ and $P(B_6) = \delta$. Therefore, the probability $P$ that the pedestrian is confused at $t = 3$ in OSCM is determined by diffusion parameter $\alpha$, decay parameter $\delta$ and the transition probabilities $P(A_i)$:

$$P = \begin{bmatrix} P(A_1) & P(A_2) & P(A_3) & P(A_4) & P(A_5) \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 \end{bmatrix} \begin{bmatrix} P(B_1) \\ P(B_2) \\ P(B_3) \\ P(B_4) \\ P(B_5) \\ P(B_6) \end{bmatrix}$$

$$= (1-\delta)\left[\left(1-\frac{3}{4}\alpha\right)P(A_1) + P(A_2) + \frac{\alpha}{2}P(A_3) + \frac{\alpha}{4}P(A_4) + \frac{\alpha}{2}P(A_5)\right]. \quad (1)$$

To get $P = 0$, it is necessary that $\delta = 1$ or $\left(1-\frac{3}{4}\alpha\right)P(A_1) + P(A_2) + \frac{\alpha}{2}P(A_3) + \frac{\alpha}{4}P(A_4) + \frac{\alpha}{2}P(A_5) = 0$. Due to $\sum P(A_i) = 1$ and $0 \le P(A_i) \le 1$, if $\alpha = 0$ and $P(A_1) = P(A_2) = 0$, then $P = 0$. It means that if the boson does not diffuse, the pedestrian would not be confused just in the cases of moving forward or turning around. The coefficient of $P(A_2)$, independent of $\alpha$, identically equals to one, which indicates that the pedestrian must be confused in the case of moving backwards. The coefficient of $P(A_1)$ decreasing with $\alpha$ increasing implies that the pedestrian could keep still to dodge the confusion for large $\alpha$. $P(A_3)$ and $P(A_5)$ have the same coefficient and thus the same effect on $P$. That the coefficient of $P(A_4)$ is not larger than any other coefficients states clearly that it is always best for the pedestrian to move forward.