退出可能な出口位置を知る人数の割合と避難挙動の関係

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概要

部屋の形状や避難者が持つ情報は、避難の挙動に関して重要な要素である。しかし、退出不可能な出口が存在し、避難者の一部が退出可能な出口位置を知っている状況下での研究はあまりない。本稿では、このような状況でも有用な拡張フロアフィールドモデルを提案し、実験によってその妥当性を評価した。

Relation between evacuation behavior and the ratio of evacuees who know the open exit position

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Abstract

The configuration of a room and the evacuee information are important factors that determine evacuation performance. There are little research on the evacuation of a room with blocked and open exits and a part of evacuees are unaware about the position of open exit. In this paper, we proposed an extended floor field model that accounts for these types of conditions and validated the model by experiments.

1 Introduction

The evacuation performance in emergency situations is important for the design of buildings. Thus, many studies have been done on evacuation under various situations [1, 2, 3, 4]. However, there is little research on more realistic situations such as a room with blocked and open exits and a part of evacuees are unaware about the position of open exit. Our research attempts to address this situation by proposing an extended floor field model [5] that judgment mark concept into the model to better account for blocked exits and uninformed evacuees in evacuation scenarios.

2 Model

2.1 Basic floor field model

The floor field model is based on a cellular automaton model [6]. A cell is characterized by “floor field”. The floor field typically includes a static floor field and a dynamic floor field. These are used to calculate the transition probability $p_{i,j}$ of an evacuee at a cell $(0,0)$ to cell (i,j). $p_{i,j}$ is given by Eqs. (1) and (2).

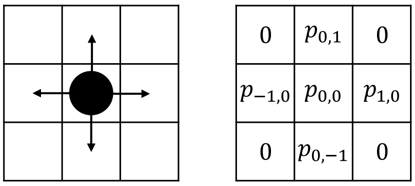


Fig.1: Possible transition and transition probability.

$$p_{i,j} = \begin{cases} N\xi_{i,j} f_{i,j} & (i,j) \neq (0,0), \\ N\xi_{i,j}\left(\dfrac{\Delta x}{v\tau} - 1\right) \displaystyle\sum_{(i,j)\neq(0,0)} f_{i,j} & (i,j) = (0,0), \end{cases} \tag{1}$$

$$f_{i,j} = \exp(-k_{\mathrm{S}} S_{i,j} + k_{\mathrm{D}} D_{i,j}), \tag{2}$$

where N is the normalization factor to ensure that $\sum p_{i,j} = 1$. $\xi_{i,j}$ is the obstacle value that returns 0 for forbidden transitions and 1 for others. $f_{i,j}$ is the weight of probability of moving to cell (i,j). Δx is the length of one side of a cell. v is the average velocity of evacuees. τ is the time length of a time step. k_{S} is the strength of the static floor field. $S_{i,j}$ is the static floor field as a function of the distance from the cell (i,j) to evacuee's destination. k_{D} is the strength of the dynamic floor field. $D_{i,j}$ is the dynamic floor field at cell (i,j). Dynamic floor filed has its characteristic dynamics, i.e. diffusion and decay as shown in Eq. (3).

$$\begin{aligned} D_{i,j}^{t+1} = (1-\alpha)(1-\delta)D_{i,j}^{t} + \frac{\alpha(1-\delta)}{4}(D_{i+1,j}^{t} \\ + D_{i,j+1}^{t} + D_{i-1,j}^{t} + D_{i,j-1}^{t}), \end{aligned} \tag{3}$$

where $D_{i,j}^{t}$ is the amount of dynamic floor field on cell (i,j) at time t. Diffusion and decay are characterized by two parameters $\alpha \in [0,1]$ and $\delta \in [0,1]$.

2.2 Informed evacuees (IEs) and uninformed evacuees(UEs)

In real evacuations, exits that are normally opened may be blocked and evacuees may not know the position of the open exits. Therefore, the exit information is often different depending on the evacuees. In this study, we divided evacuees into two groups: informed evacuees (IEs) who know the position of the open exits and uninformed evacuees (UEs) who do not know it.

2.3 Judgment mark J

To describe evacuation that involve a room with blocked exits, we introduce judgment mark J into the floor field model. J is dropped by all evacuees and diffuses and decays in the dynamics as that of D as shown in Eq. (3) [5]. There are two differences, namely variety and amount, between J and D.

2.3.1 Variety of J

The variety of J is equal to the number of exits, including the blocked exits. For example, in a room with four exits, four types of J are dropped by evacuees. In addition, evacuees can drop multiple types of J at the same time step.

2.3.2 Amount of J

The amount of J dropped by an evacuee at one time step changes depending on evacuee's location and exit information. In the case of the evacuation of a room with n exits that include one open exit l, J dropped by IEs and UEs are defined as follows.

1. If IEs move to neighboring cells from their present cell in the next time step,
    (a) IEs always drop $J_l = c$ ($c \in (1, \infty]$) at the present cell.
    (b) IEs drop $J_m = -c$ at the present cell if blocked blocked exit m ($m \neq l$) is visible from the present position of the IEs.
2. If IEs remain in the same cell in the next time step, the amount of J dropped by IEs is $\frac{1}{c}$ of the case 1.

1. If UEs move to neighboring cells from their present cell in the next time step,
    (a) UEs whose target exit is exit m always drop $J_m = c$ at the present cell.
    (b) UEs who have not arrived at exit m but infer exit m is blocked drop $J_m = -c$ at the present cell if exit m is visible from the present position.

(c) UEs who have arrived at blocked exit m drop $J_m = -cE$ $(E \in (1, \infty])$ at the present cell if exit m is visible from the present position.

2. If UEs remain in the same cell in the next time step, the amount of J dropped by UEs is $\frac{1}{c}$ of the case 3.

In the above conditions, an exit is "visible" from an evacuee means that there are no obstacles on the straight line connecting the exit and the evacuee.

2.3.3 Target exit and the inference of blocked exits

During evacuation, all evacuees have their target exit. Since IEs know the position of open exit, their target is always the open exit; however, UEs' target exit and their inference about blocked exits are subject to change. In our model, UEs choose their target exit and infer blocked exits in every time step by referencing J at their present cell. For instance, in a simulation of a room with n exits, n types of J exist in every cell. Each UE refers these n types of J dropped at his/her cell. Each UE decides to aim at exit m, when J_m is the largest one among all J, and infers exit m is blocked when $J_m < 0$.

In our simulations, the initial target exit of UEs is their nearest exit.

2.4 Extended floor field model

By incorporating J into the floor field model, we are able to describe the evacuation of a room with n exits, including one open exit. We suppose the exit l is open. The transition probability, $p_{i,j}$, is given by Eqs. (1) and (4);

$$f_{i,j} = \exp\left\{ \left(\sum_{m=1}^{n} -k_{\mathrm{S}}^{m} S_{i,j}^{m} \right) + k_{\mathrm{D}} D_{i,j} \right\}, \quad (4)$$

where k_{S}^{m} is the strength of the static floor field to exit m, and $S_{i,j}^{m}$ is the static floor field as a function of the distance between cell (i, j) and exit m.

The target exit of IEs is exit l. IEs never follow other evacuees because they know the location of open exit. Therefore, we set $k_{\mathrm{S}}^{m} = 0$ when $m \neq l$ and $k_{\mathrm{S}}^{m} = 10$ when $m = l$ and $k_{\mathrm{D}} = 0$ for IEs.

UEs may follow others and change their target exit. In particular, UEs tend to stop and observe others during the initial stage of evacuation. Therefore, we introduce the time delay T_{delay} of UEs' initial movement and the threshold J_{th} of judgment mark and set parameters as follows. When $t \leq T_{\mathrm{delay}}$, we set $k_{\mathrm{S}}^{m} = 10$ and $k_{\mathrm{D}} = 1.0$ if J_m satisfies $J_m \geq J_{m'} + J_{\mathrm{th}}$ for all m' $(1 \leq m' \leq n,\ m' \neq m)$, and $k_{\mathrm{S}}^{m} = k_{\mathrm{D}} = 0$ otherwise. When $t > T_{\mathrm{delay}}$, we set $k_{\mathrm{S}}^{m} = 10$ when exit m is the target exit of the evacuee and set $k_{\mathrm{S}}^{m} = 0$ otherwise. We set $k_{\mathrm{D}} = 1.0$ when $t > T_{\mathrm{delay}}$.

3 Simulations and experiments

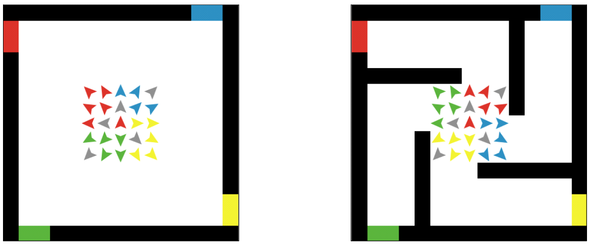
Using our extended model, we carried out simulations of evacuation from two types of room as shown in Fig. 2. Both room have one open and three blocked exits and 25 evacuees were initially located at the center of the room. In these simulations, we changed the ratio r of IEs to total evacuees.

Furthermore, we conducted evacuation experiments that essentially duplicated simulation conditions. The experiments were performed in the dark (the illumination was less than 0.01 lux) in order to prevent evacuees from finding the location of open exit without moving around the room.

4 Results and discussions

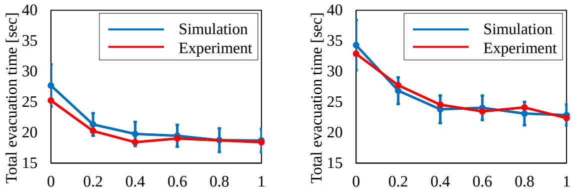
Fig. 3 shows the relation between r and total evacuation time in the square and the swastika rooms. Our model reproduced the experimental results as shown in Fig. 3.

Hereinafter we describe how J_{th} affects the total evacuation time at $r = 0.2$ as an example. Fig. 4 shows that total evacuation time decreases as J_{th} increases for $0 \leq J_{\mathrm{th}} \leq 4$ and increases for $4 \leq J_{\mathrm{th}}$. This result suggests that the optimal J_{th}, which achieves the minimum total evacuation time, is around $J_{\mathrm{th}} = 4$ in the both rooms. When J_{th} is small, UEs may get away from the open exit be-



(a) Square room (b) Swastika room

Fig.2: Configuration of rooms which consist of 15×15 cells. The colored cells represent both open and blocked exits. Gray arrows are IEs and other the other colored arrows are UEs. UEs' color indicates their nearest exit. In simulations we chose $\Delta x = 0.5$ m, $v = 1.0$ m/sec, and $\tau = 0.1$ sec.



(a) Square room (b) Swastika room

Fig.3: Simulation and experimental results of total evacuation time as a function of r. The parameter set adopted in our simulation is as follows: (a) $c = 50$, $E = 50$, $T_{\mathrm{delay}} = 2.9$ sec, $J_{\mathrm{th}} = 25$, $\alpha = 0.4$, and $\delta = 0.06$ (b) $c = 30$, $E = 500$, $T_{\mathrm{delay}} = 3.5$ sec, $J_{\mathrm{th}} = 12$, $\alpha = 0.4$, and $\delta = 0.1$.

cause they start to move promptly without exit information. In contrast, when J_{th} is large, the motion of UEs delay because they observe others at their initial position for a long time. Therefore, there is an optimal J_{th}, which achieves the minimum total evacuation time. In our simulation, J_{th} qualitatively means the carefulness of UEs to move toward their target exit from their initial position. Thus, we can conclude there is the optimal carefulness for UEs to head for their target exit at the beginning of evacuation.

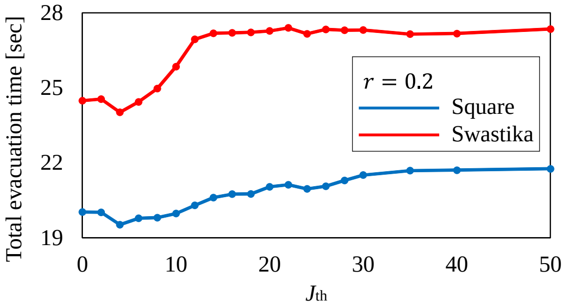


Fig.4: Simulation results of total evacuation time as a function of J_{th} for $r = 0.2$. The parameter set except J_{th} is the same as Fig. 3.

5 Conclusions

We proposed an extended floor field model by introducing judgment mark J in order to apply evacuation from a room with blocked and open exits. The model was validated by experiments. It was found that our model can reproduce the experimental results at least two types of room. Moreover, it was found that there is the optimal carefulness for UEs to head for their target exit from their initial position in both rooms.

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