第4章 Avoiding walking pedestrians using anticipation effect

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Abstract

Logistics consists of various activities including transportation of goods by trucks and warehouse operations. In this paper, we focus on storing and picking behavior of workers at a warehouse. There are usually many workers in a warehouse who are picking at the same time. Then sometimes there are collisions among them at a narrow corridor. This reduces the efficiency of operation since picking time significantly increases. Such collisions also occur in a public place where there are crossings of pedestrians, such as train stations and stadiums. In this paper, we propose an anticipation floor field (AFF) as an extension of the floor field (FF) model, which is one of the successful models in describing pedestrian dynamics. AFF focuses on long-range interaction between pedestrians, which has not been taken into account in the FF model based on local rules. It is found that the strength of anticipation significantly affects pedestrian dynamics, and there is an optimal strength of anticipation to avoid collisions and realize the smoothest counterflow at a corridor.

1. Introduction

Study on motion of crowd attracts many physicists because of its complex nature and wide applications to reality [1]. Here we are interested in collisions between pedestrians which can be seen in storing and picking behavior of workers at a narrow corridor in a warehouse. This reduces the efficiency of operation since picking time significantly increases. In order to consider a solution for such collisions, we study modeling of pedestrians by using a mathematical model. There are two types of pedestrian models, macroscopic or fluid model [2, 3] and microscopic model. We focus on the latter since they are able to describe details of interaction of particles easily even in complex situations. In the latter model, cellular automaton (CA) is often used. Time and space are discrete in CA, thus it fits to numerical simulations. The lattice gas model [4] is a model using CA and has been recently studied actively.

The floor field (FF) CA model or the FF model [5] is one of the major models based on CA, and it describes the pedestrian dynamics by moving pedestrians stochastically on latticed cells. Researches with the FF model have been done actively in recent years. Although there are many researches using the FF model, anticipation effect has not been studied up to now in the FF model. Anticipation and avoidance of collisions, one of the long-range interactions, is important in pedestrian dynamics, because everyone consciously or unconsciously anticipates motion of others and avoid collisions when they are walking. Heavy jamming and confusion would occur if no one should anticipate, especially under crowded situations. In this paper, we show the importance of anticipation for avoiding collisions.

This paper is constituted as following: Sec. 2 is devoted to a review of the FF model. Then, we introduce anticipation FF in Sec. 3 and present details of our simulations in Sec. 4. We summarize our research in Sec. 5.

2. Floor Field Model

In the FF model, pedestrians are expressed as particles which move on two-dimensional squared cells. Each cell is possible to be occupied at most one particle at the same time. This means that the excluded volume effect, which is induced by the short-range repulsive interaction, is contained as a basic rule in the model. Each pedestrian moves to its Neumann neighborhood cells (for simplicity) or stay at the present cell according to the transition probabilities $p_{ij}$ at each time step $t \rightarrow t + 1$, i.e., each pedestrian has five choices to go and five transition probabilities (Fig. 1).
The transition probabilities are determined by information buried in target cells (Fig. 1) of each pedestrian. We can set multiple information by introducing multiple identical fields, which is called the FFs. What is important is that these information implemented by FFs are arbitrary, hence the FF model is easy to extend for various factors of walking. Concrete way to set transition probabilities by FFs are shown in Sec. 2.2.

2.1. The dynamic floor field and the static floor field

Among various FFs, which effect $p_{ij}$, two FFs have historically come to be used as fundamental and essential ones: the dynamic FF and the static FF. The dynamic FF corresponds to the characteristics that pedestrians tend to follow the predecessor. This tendency is observed especially in crowded area since it enables fewer collisions with others. It is also reported that pedestrians in an emergency situation tend to follow their predecessors [6]. This is implemented by virtual pheromone, which increases the transition probability to the cell and attracts other pedestrians. When a pedestrian moves to their target cell, pheromone is generated at the cell where he/she was standing, i.e., the value of pheromone $D_{ij}$ is added by one. Pheromone has its own dynamics of diffusion and decay [5], therefore it is called “dynamic” FF. The static FF is an introduction of the fact that pedestrians walk toward their destination. The static FF holds the shortest distance to the destination or exit by some metric, which is described as $S_{ij}$, and the smaller $S_{ij}$ leads to the higher transition probability. Since $S_{ij}$ does not change, it is called “static” FF.

2.2. Update rules and transition probabilities

Here we will explain the case of parallel update rule. At first, the static FF is calculated. Note that $D_{ij} = 0$ at $t = 0$. Procedures at $t \rightarrow t + 1$ is the following.

1. All $D_{ij}$ decays, then diffuses (See [7] for details).
2. Transition probabilities are calculated for each pedestrian as

$$p_{ij} = N \xi_{ij} \exp(-k_{s} S_{ij}) \exp(k_{d} D_{ij})(1 - \phi n_{ij}) \tag{1}$$

where

$N$: the normalization

$k_{s}$: the sensitivity parameter for the static FF, which weights $S_{ij}$

$k_{d}$: the sensitivity parameter for the dynamic FF, which weights $D_{ij}$

$\xi_{ij} \in [0, 1]$: the obstacle parameter; $\xi_{ij} = 0$ only if the cell $(i, j)$ is a wall cell or obstacle cell or does not exist, otherwise $\xi_{ij} = 1$.

$n_{ij} \in [0, 1]$: the occupancy parameter; $n_{ij} = 1$ if there is a pedestrian at cell $(i, j)$, otherwise $n_{ij} = 0$.

$\phi \in [0, 1]$: the parameter which weights $n_{ij}$
Figure 2: Schematic view of the reserved cells, which are the cells surrounded by bold solid lines. Number in each cell denotes the static FF. The pedestrian depicted by the black circle is expected to move toward the direction to which the static FF decreases. Since the anticipation range \( d_A = 4 \), four right cells of the particle are the reserved cells.

The values of the sensitivity parameters are same for all pedestrians for simplicity in this paper. \( \phi \) is usually set as 1.

3. Each pedestrian decides which cell to proceed based on the transition probabilities determined in the previous step.

4. (A) If there is an other pedestrian at the chosen cell at the time step \( t \), the pedestrian who is trying to proceed to the cell cannot move.

   (B) If two or more pedestrians try to move to one vacant cell, one pedestrian chosen randomly is allowed to move to the cell and the rest cannot move.

   (C) If neither of previous two cases does not happen, pedestrians can go to the desired cell.

5. Whenever a pedestrian move to its adjacent cell in the step 4, \( D \) at its origin cell is added by one.

Extensions of the FF model is basically presented in the step 2 by adding additional FF and modifying the equation (1), while the friction parameter [8] is an extension in the step 4 (B). Anticipation FF presented in this paper is classified as the first extension.

3. Anticipation Floor Field

We consider the anticipation as “the ability of avoiding collisions with other people considering their future walking way” in this paper. Then, anticipation is divided into two steps:

   (a) recognizing the area that is expected to be occupied by the other pedestrians in the future, which we call future walking way

   (b) changing direction or speeding down/up the walking speed referring to the area obtained in the step (a) to avoid collisions

In the following, we explain how to introduce these two steps into the FF model.

3.1. Cells expected to be occupied in the future: Reserved Cells

In the FF model, the step (a) correspond to deciding the cells which are expected to be occupied by each pedestrian in the future. We determine those cells using the static FF since pedestrians are mostly expected to move toward the destination or exit in the shortest way: we assume that pedestrians walk along to the gradient of the static FF. Here, we define the reserved cells as the nearest \( d_A \) cells of the future walking way, where \( d_A \) is a non-negative integer parameter and represents the range of anticipation. In Fig. 2, simple example of the reserved cells are shown.
3.2. Anticipation floor field and modified transition probability

In the FF model, the step (b) corresponds to the change of transition probability using reserved cells. To modify the transition probability, we newly introduce the anticipation FF.

The anticipation FF is described as nonnegative integer $A_{ij}^{(a)}$, where $a \in \{1, 2, 3, 4\}$ corresponds to four directions, i.e., 1 corresponds to right, 2 to up, 3 to left, 4 to down (Fig. 5 (a)). Therefore, the anticipation FF has four values for one set of $(i, j)$. These values are basically set as zero, while some of them can be added through the procedures in the following.

We use the reserved cells to add the anticipation FF. If the cells is the reserved cell, value of an anticipation FF in the cell is added by one, and the direction to be added is determined by the direction from which a particle is expected to enter in the future. In Fig. 3 (b), the black-filled particle is expected to move from left to right, thus the value of the right directional anticipation FF is added to its reserved cells, and similarly the value of down directional anticipation FF is added by the white-filled particle. If a cell is a reserved cell for two or more particles, the value is identically added (see the cell filled with dark gray or the cell filled with diagonal stripes in Fig. 3 (b)).

Next, we define the value $E_{ij}$ for calculating the modified transition probability as

$$E_{ij} = \sum_{m'} A_{ij}^{(m')}$$

where $m'$ corresponds to the direction of a pedestrian at cell (0, 0). Note that $E_{ij}$ is not universal and calculated for each pedestrian, while $A_{ij}^{(m)}$ is a universal field for all pedestrians. $E_{ij}$ is given by summing up the value of the all directional anticipation FF at the cell $(i, j)$ except the direction of the pedestrian at cell (0, 0) (Fig. 4). There are two reasons why we disregard the anticipation FF of the same direction as the pedestrian, one is that he/she cannot see people who walk behind him/her, and the other is that he/she is not affected by the anticipation FF derived from himself/herself. Hence, the value $E_{ij}$ for a pedestrian indicates the subjective impression that the cell $(i, j)$ is occupied in the future.

Then, our modified transition probability is given as

$$p_{ij} = \frac{N_{ij} \exp(-k_{i}E_{ij}) \exp(-k_{s}S_{ij}) \exp(k_{d}D_{ij})}{1 + \phi N_{ij}}$$

where $k_{s}$ is the sensitivity parameter of anticipation and $E_{ij}$ represents the effect of anticipation. By introducing this new definition, transition probability to the cell of larger $E_{ij}$ is decreased compared to conventional definition because $\exp(-k_{s}E_{ij})$ is multiplied. In this way, the characteristic of avoiding conflict is realized.

3.3. Update rules

To conduct the procedures described in Sec. 3.1 and 3.2 for every pedestrian at each time step, a new step is added to the update rules shown in Sec. 2.2, which is

A. Values of the all directional anticipation FF in the simulated area are reset as zero. This means the equation below.

$$A_{ij}^{(1)} = A_{ij}^{(2)} = A_{ij}^{(3)} = A_{ij}^{(4)} = 0$$

B. The reserved cells are determined for every pedestrian, and the anticipation FF is added.

C. $E_{ij}$ is calculated for each pedestrian.

The transition probability in the step 3 is also replaced by the equation (3).

4. Simulations

4.1. Procedure

Let us conduct simulations of the counter flow in a corridor using our model. The length of the corridor is 100 cells and the width is 20 cells as shown in Fig. 5. Three FFs, i.e., the anticipation FF, the static FF, and the dynamic FF is used in the simulations. Boundary condition is open since it is natural that the corridor has finite length. Since there are two kinds of groups, walking from right to left and from left to right, the static floor field $S$ and the dynamic
Figure 3: (a) Relation between the value of \( n \) in \( A_{i,j}^{(n)} \) and the direction. (b) An example of the anticipation FF. For clarity, black filled particle and gray filled particle are determined to go right, and white filled one to go down in this figure (actually, we used two static FFs for this simulation). The direction of an arrow is the direction of the anticipation FF and the number is its value. The cells filled with diagonal stripes are reserved cells of both black filled particle and gray filled particle, hence \( A^{(2)} \) in those cells equals to two. In the same way, since the gray filled cell is the reserved cell of both black filled particle and white filled particle, \( A^{(1)} \) and \( A^{(0)} \) equal to 1 respectively.

Figure 4: Schematic view of \( A_{i,j}^{(2)} \) (left) and \( E_{i,j} \) (right) for right directed pedestrian at the center cell, which is shown as circled right directional arrow. The value of up, down, and left directional anticipation FF is summed up.

Floor field \( D \) have two values respectively, while the anticipation floor field \( A^{(n)} \) is not distinguished for two groups and \( A^{(1)} \), \( A^{(2)} \), \( A^{(3)} \), and \( A^{(4)} \) have one value respectively. New pedestrians appear in the both left and right edge cells with the entrance probability \( \alpha \) at each time step. \( \alpha \) is applied for every left and right edge cell. If a pedestrian is already exists in the cell, it is impossible for new pedestrian to enter into the cell. After entering, they move toward the opposite side of the corridor by referring to the static FF derived from the opposite edge cells. Note that the static FF is homogeneous in the direction of width. When pedestrians reach the end of corridor, they disappear. We have simulated 32,500 steps for one trial. Snap shot of the simulation is given in Fig. 6.

4.2. Measured values

At first, we define several words described in the following. If two pedestrians use the same static FF for deciding the transition probabilities, they are defined as the “fellow pedestrian” of each other. In the same way, if two pedestrians use different static FF, they are defined as “counter pedestrian” of each other. The “update rules” correspond to the procedures in Sec. 2.2. The “nearest cell” is the cell that holds the smallest value of the static FF among Neumann neighborhood cells. In these simulations, the nearest cell is limited to the right cell or the left cell. The “backward cell” is counter directional cell of the nearest cell. The “side cell” is defined as the up or down cell, which indicates
the vertical directional cell to the traveling direction. “Conflict” is defined as going into the 4 (A) and 4 (B) in the update rules.

We measured the values listed below. Since the corridor is empty at the beginning of the simulation, measurements are restricted to pedestrians that enter into the corridor after 250 steps, which is enough for the first pedestrians of both directions to reach the opposite edge. Measurements are also restricted to pedestrians who have passed the corridor by the end of one trial. Average values over all measurement objective pedestrians are calculated for each trial. We conducted 20 times simulations for $k_A = 0, 1, 2, 3, 4, 5$. The average values over 20 times trial are shown in Sec. 4.3.

1) Travel time steps: $T$

Travel time step is defined as the number of steps from entrance until exit. We describe it as $T$.

2) Time loss by vacant cell: $L_v$

$L_v$ is number of moving to the present cell or the side cells when there is no pedestrian at the nearest cell. It is counted from entrance until exit.

2-2) Time loss by adjacent counter pedestrian: $L_c$

$L_c$ is number of (a) moving to the present cell or the side cell when there is a counter pedestrian at the nearest cell and (b) remaining at the present cell due to conflict with a counter pedestrian. It is counted from entrance until exit.

2-3) Time loss by adjacent fellow pedestrian: $L_f$

$L_f$ is number of (a) moving to the present cell or the side cell when there is a fellow pedestrian at the nearest cell and (b) moving to the present cell due to conflict with a fellow pedestrian. It is counted from entrance until exit.

2-4) Time devoted to move forward or backward: $T_{fb}$

$T_{fb}$ is number of moving to the nearest cell or the backward cell.

Actually, $T$ is summation of $L_v$, $L_c$, $L_f$, and $T_{fb}$. Therefore, change of $T$ is attributed to change of the four measured values.
4.3. Results

In Fig. 7, typical relations of each measured value and \( k_A \) are presented. \( T \) at \( k_A = 0 \) is smaller than that at \( k_A = 0 \) as shown in Fig. 7 (a). This result implies that anticipation leads smoother flow because the state at \( k_A = 0 \) corresponds the state where pedestrians do not anticipate at all. More remarkably, \( T \) does not monotonically decrease and achieves minimum. In other words, excessive anticipation does not give the optimal flow. The reason of this result is explained by measured values \( L_c \), \( L_a \), and \( L_f \).

\( L_c \), which is depicted as blue circle in Fig. 7 (c), increases monotonically as \( k_A \) becomes large. This is because avoidance increases due to the anticipation PP when \( k_A \) increases. The nearest cell and the present cell are more likely to be avoided when they are the reserved cell of counter pedestrian. Increase of \( T \) at large \( k_A \) is mainly caused by increase of \( L_c \) (See Fig. 7 (b)).

\( L_a \), which is depicted with red square in Fig. 7 (d), decreases monotonically as \( k_A \) increases, and it is convex downward. Since we have introduced the anticipation PP to make pedestrians avoid counter pedestrians in advance, this result implies that the anticipation PP is validly introduced. It is clear that the decrease of \( T \) at small \( k_A \) value is mainly due to decrease of \( L_c \).

\( L_f \), which is depicted with green triangle in Fig. 7 (e), achieves minimum against increase in \( k_A \). Note that the percentage of \( L_f \) is less than 4% (Fig. 7 (b)), and it is likely to be effected by \( L_a \), \( L_c \), and \( T_{ph} \). When \( k_A \) increases at the range where \( k_A \) is small, flow becomes smoother, so that the density in the corridor decreases. Therefore, chance of contacting with fellow pedestrian also decreases as \( k_A \) increases. At the range where \( k_A \) is large, pedestrians frequently try to avoid counter pedestrians without paying attention to fellow pedestrians. This is why \( L_a \) decreases.

\( T_{ph} \), is almost constant versus the change of \( k_A \). In other words, the step to move to vertical direction (left or right) is invariant. Hence, change of \( T \) is mainly due to other three values.

Now let us look back above discussions. When anticipation is weak, the flow is in the most disordered state, and many conflicts occur. As the anticipation becomes strong, the travel time steps decreases mainly because the reduction of interaction with adjacent counter pedestrian. However, further increase of anticipation results in the increase of the travel time steps since pedestrian anticipates and avoids the counter pedestrian actively more than necessary.

5. Conclusions

In this paper, we have considered the effect of anticipation of pedestrians, which has not been researched so far, by newly introducing the anticipation floor field. It modifies the transition probability of pedestrians to the more realistic ones, and pedestrians in our model succeed to avoid collision with others in advance. We have performed both simulation and experiment of counter flow, which reveal validity of our model and the surprising characteristics of pedestrian dynamics. When the effect of the anticipation is weak, traveling time to pass through the corridor is large since pedestrians cannot avoid collisions with others. While when the effect of the anticipation is excessively strong, traveling time becomes large again due to the unnecessary evasive action. Therefore, the minimal travel time is attained, i.e., there is an optimal degree of anticipation to realize maximum flow.

References

Figure 7: Change of the measured values versus $k_A$ at $\alpha = 0.033$, $d_A = 3$, $k_3 = 3$, $k_D = 2$, and $\phi = 1$. 