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Simulation of space acquisition process of pedestrians using Proxemic Floor Field Model

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ABSTRACT

We propose the Proxemic Floor Field Model as an extension of the Floor Field Model, which is one of the successful models describing pedestrian dynamics. Proxemic Floor Field is the Floor Field which corresponds to the effect of repulsion force between others. By introducing the Proxemic Floor Field and threshold, we investigate the process that pedestrian enters a certain area. The results of simulations are evaluated by simple approximate analyses and newly introduced indices. The difference in pedestrian behavior due to the disposition of the entrance is also confirmed, namely, the entrance in the corner of the area leads to the long entrance time because of the obstruction by pedestrians settling on the boundary cells.

1. Introduction

Study on pedestrian dynamics has attracted many physicists over the past few years [1–3]. We can see many collective phenomena induced from the complexity of the system of pedestrian flow. In order to describe these phenomena, some models have been suggested and have achieved success in some situations. Helbing et al. designed the *social force model* [4–6], which represents pedestrian movement using differential equations. Interaction between pedestrians is demonstrated by introducing "social force" — which acts between others. Using this model, we can reproduce phenomena such as arching at an exit, lane formation in counter flow, and oscillations of flow directions at narrow doors where pedestrians are crowding in both sides.

Cellular Automaton (CA) based models are also often used for their simplicity. In CA based models such as the *lattice gas model* [7] and *floor field model* [8], time and space are discretized and simple update rules are introduced. These characteristics of CA based models are suited for numerical simulations.

The floor field model is one of the major CA based models that describe the pedestrian dynamics stochastically on latticed cells. In Ref. [8], two types of *Floor Field (FF)* which control hopping probability are introduced. One is the *Static Floor Field (SFF)* which controls the "destination of pedestrians". The other is the *Dynamic Floor Field (DFF)* which describes the characteristic that pedestrians tend to follow their predecessor. In addition, other studies introduced the effects of wall [9], force [10] and collisions [11] among pedestrians, etc., and many valuable results have been obtained.

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Although CA based models have been studied extensively for describing the evacuation process [8,12,13] and counter flow [7,14,8] etc., few studies have been done for the *proxemic* problem. *Proxemics* is the term introduced by Hall [15] referring to the study of set measurable distances between people as they interact. Hall proposed four types of distance range: Intimate distance, Personal distance, Social distance, and Public distance. Hall also summarized the effects of proxemics as *"Like gravity, the influence of two bodies on each other is inversely proportional not only to the square of their distance but possibly even the cube of the distance between them."* This repulsive force has been introduced into a few CA based models [16].

In this paper, the characteristics of the proxemic behavior are integrated into the floor field model. We just introduced the *Proxemic Floor Field (PFF)*, which describes the proxemic behavior of pedestrians, and the *threshold*, which describes the "motivation to move" dependent on the crowdedness of the neighborhood of each pedestrian. By using this model, we investigate *inflow process*, in which the proxemic effect is predominant. Inflow process is the situation where pedestrians enter a certain area and acquire their own space; this can be observed on elevators, trains, attractions in theme parks, and many other places. This process is universally seen in the situations where pedestrians temporarily stay in a limited area. The study of this process can be applied to the design of buildings, infrastructures, and so on. In such situations, after entering the area, pedestrians look for the location where they can keep their own space and are not intruded upon by other pedestrians. This movement is driven by the repulsion force between others. After they successfully acquire the location, they stops walking. We also have to consider the attractiveness of locations. For example, the space in front of the exit in the train carriage is valuable for passengers in a hurry who do not want to be obstructed during boarding, passengers who carry bulky items, and so on. On the other hand, the place may be uncomfortable for passengers not in a hurry because many passengers intrude their space every time the train arrives at the stations.

Though there are some CA based models which consider the "force" of pedestrians [10,17–19], they mainly focus on the local effect related to physical contact and thus they are not suited for simulating the non-local repulsion dominant in the inflow process. Moreover, in the *social distance model* [16] dealing with the long range effect of social force, proxemic force does not affect walking pedestrians, so this model cannot simulate inflow process either. Thus, the Proxemic Floor Field model is a new model capable of simulating inflow process. Furthermore, it should be noted that, although they seem to be just an opposite processes, the inflow dynamics are more complicated than the evacuation ones because the destination is not clear in the inflow process; therefore we have to set the driving force on each pedestrian. This is why the inflow process has been less studied, compared to evacuation process. Of course, this model can also be used for other situations, which adds the effect of proxemic force to previous CA based models.

We evaluated simulation results of the time required for all the pedestrians to enter the room by mean field analyses and confirmed the difference due to the disposition of the entrance. We focus on not only the inflow process, but also the *steady state*; the state in which every pedestrian has stopped. We evaluated the steady state by introducing a couple of new indices to represent the disposition of the pedestrians.

2. Model

In this section we summarize the update rules of Proxemic Floor Field Model. The space is discretized into cells which can either be empty or occupied by one pedestrian. Each pedestrian can move to one of the unoccupied next-neighbor cells (or stay on the present cell) at each discrete time step $t \longrightarrow t+1$ depending on Floor Fields and threshold as explained below.

In the simulation of the inflow process, the Static Floor Field S represents the attractiveness/unattractiveness of each cell for pedestrians. We can control the pedestrian's behavior such as "stay on a comfortable place (local maximum/minimum of S)", "approach the destination (gradient of S)", or "never stay on an uncomfortable place (local minimum/maximum of S)", by setting the appropriate Static Floor Field. It should be noted that this Static Floor Field is often set as the value dependent on the distance from the exit in the context of the evacuation process. The Dynamic Floor Field D represents the characteristic that pedestrians tend to follow their predecessors. This tendency is observed in crowded or emergency situations. This is implemented by virtual pheromone, which has its own dynamics of diffusion and decay controlled by the parameters α and δ. Each pedestrian drops a boson on the present cell as he/she walks, and this boson decays or diffuses with probability α and δ respectively in each time step. The Dynamic Floor Field D is the number of bosons remaining on the cell at each time step. These two types of Floor Fields have been historically used as fundamental and essential components of the Floor Field Model.

As explained below, transition probabilities of Floor Field Model are modified by following components newly introduced in this paper.

2.1. Proxemic Floor Field

Proxemic Floor Field represents the effect of repulsion which acts between others according to their distance. As mentioned in Ref. [15], repulsion for small distance is much greater than that for large distance. In this paper we define the Proxemic Floor Field P_{ij}^k generated by each pedestrian k as (1), and P_{ij} is gained by taking sum of each P_{ij}^k for all the pedestrians. Here, r_{ij}^k is the distance between k-th pedestrian and cell$-(i,j)$. This distance is defined to be 1 for the neighboring cells and