Simulation of Pedestrian Flow Based on Multi-Agent

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Abstract

Analyzing pedestrian flow characteristics and the interaction mechanism among pedestrians or between pedestrians and environment, we proposed a pedestrian flow simulation model based on the multi-agent technology. In the model, the hierarchical structure of multi agents was designed according to communication relations, and inner structures including network agent, grid agents, pedestrian agents and service interface. Furthermore, a superimposed shortest path algorithm was proposed to cater for the modelling of complex topological network with multiple exits and inner barriers. Pedestrian decision-making rules were established synthetically by considering the distance factor and pedestrian herd mentality factors. A scenario was studied in which pedestrians tried to evacuate from a large room with inner barriers and four exits. The results show that the weight factor of the network edge impacts the crowds shape at exits. In addition, simulation experiments show the trend of evacuation times with respect to the impact factor of pedestrian herd mentality.

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1. Introduction

Traffic behaviors of pedestrian are characterized by randomicity and flexibility, even representing complexity and variability in various scenes. This makes it considerably difficult to gather or extract data on pedestrian behavior. And so, a growing number of researchers use computer simulation to study on pedestrian traffic behavior. Multi agent based model and simulation is one of the most effective ways. Batty et al. (1999) applied agent theories and methods to design a cellular automata model, and developed a simulation system based on...
GIS. Xue (2003) proposed a simulation model for crowd evacuation based on agent technology, where pedestrian psychological factors were taken into account. Cheng et al. (2008) proposed a simulation model of the complex urban pedestrian flow based on multi agent system. Cui et al. (2008) defined a MA-based occupant evacuation model in public facility, where state parameters and experience index were used to imitate pedestrian wisdom. Ha et al. (2012) employed an agent-based system of self-moving particles to investigate the effect of complex building architecture on the crowd motion, and studied how the room door size, the size of the exits and the desired speed affected the evacuation time. And more, an agent-based model encapsulating in pedestrian’s behavioral model effects representing proxemics and group cohesion was designed (Manenti et al., 2012).

However, relevant factors influencing pedestrian behaviors have not been comprehensively studied, and analysis of multi-agent hierarchy has been largely neglected. In this paper, we analyze these issues in-depth, and propose a simulation model of pedestrian flow based on the multi-agent technology.

2. Model

2.1. The hierarchical structure of multi agents

Three types of agents, including network agent, grid agent and pedestrian agent, are used to represent all the roles existing in pedestrian traffic simulation system. In the system, there are exactly one network agent, multiple grid agents and more pedestrian agents.

However, if all agents just heap together disorderly without communication and interaction, it is not a real simulation system. According to the communication relation, all agents in the model are categorized into three layers. Network agent is on the top, and grid agents are in the middle, while pedestrian agents are at bottom. The hierarchical structure of multi agents are shown in Fig.1.

![Fig. 1. The hierarchical structure of multi agents](image)

Network agent, located in the top, monitors the entire state of the simulation environment, periodically obtains data from grid agents, and provides statistics including flow or density. As the exactly one agent in the system which has full knowledge of the simulation environment, it responses queries for shortest path of grid agents and solves the shortest path problems. Grid agents provide state information for network agent, and meanwhile offer service for pedestrian agents. Based on the information provided by grid agents, pedestrian agents make decision and eventually implement the traffic actions. The evacuation process of pedestrians can be seen as an interactive process among pedestrian agents, grid agents and network agent.

According to the Cicortas’s method (Cicortas & Somosi, 2005), network agent and grid agents are designed to normal agents while pedestrian agents are intelligent agents.

2.2. Grid agent
The model is described in a two-dimensional system. It is defined on the square lattice of $L \times W$ grids where $L$ is the length of the evacuation area and $W$ is the width. A grid can either be free or occupied by exactly one pedestrian. The size of a grid corresponds to approximately $0.40\text{m} \times 0.40\text{m}$. This is the typical space occupied by one pedestrian in a dense crowd (Burstedde et al., 2001). In Fig. 2(a), there is a simple rectangle area including a long chair and two exits. Fig. 2(b) represents the scene after discretization of the area: red lines indicate the region boundaries, such as walls; green lines indicate exits, located respectively at left and top; gray grids are barriers, such as chairs. In the model, each grid is defined as a grid agent by

\[ GAgent = \langle \text{Infor}, \text{State}_t, Sdistance, Ph_t, \text{Rule}(Ph), \text{Services} \rangle \]

Where:
1. **Infor**
   - represents the grid basic information, including gridID (an unique key for each grid), geographic coordinates, etc.
2. **State**
   - means the grid state at $t$ time step, including empty, exit, barrier, or occupied by pedestrian.
3. **Sdistance**
   - represents the shortest distance of the grid from the nearest exit. The grid agent initiates query on the shortest path (or its length), and network agent responses to feedback. Shortest path algorithm is shown in section 2.3.
4. **$Ph_t$**
   - is the pheromone value at $t$ time step. Pedestrians have multiple paths to choice to reach the destination, and distance is the most important impact factor in path choice. However, while the information obtained by pedestrians is often incomplete in a relatively closed space or emergency situation, path choice is also impacted largely by pedestrian psychology. Thus, pedestrian behaviors show some special characteristics, such as herd mentality.

The term “pheromone” is defined as a substance released by an organism to the outside that causes a specific behavioral or physiological reaction in a receiving organism of the same species (Nordlund and Lewis, 1976). For example, an ant lays trail pheromones, and others ants will detect the chemical in the trail and follow it. Similarly, when one is not familiar with the surrounding environment, a pedestrian is used to follow others for reasons of travel safety, efficiency, or others to avoid collision with other pedestrians. Unlike ants’ pheromones, pedestrians use virtual pheromones.

5. **Rule ($Ph$)**
   - The pheromone is modified by pedestrians and evolves with time. It has its own dynamics, i.e., spatial diffusion and time decay (Burstedde et al., 2001; Kirchner et al., 2002, 2003; Varas et al., 2007; Zhang et al., 2012).
   a) The pheromone carries a continuous field value $Ph$ between 0 and 1. In addition, the initial value is zero.
b) After a happy pedestrian has completed a certain number of total allowed moves, the value of pheromone of its originating grid is increased. The prescription to alter the pheromone value reads

\[ \Delta Ph = \min((1 - Ph)^\gamma, g, g) \quad g, g \in [0.1], g, g \in [0.1] \]  

(2)

c) The pheromone value \( Ph \) is subject to diffusion and decay. It evolves according to

\[ \frac{\partial Ph}{\partial t} = \alpha(\frac{\partial^2 Ph}{\partial x^2} + \frac{\partial^2 Ph}{\partial y^2}) - \delta Ph \]  

(3)

Here \( \alpha \) is the diffusion constant and \( \delta \) the decay constant. The ranges are restricted to \( \alpha \in [0,0.5] \) and \( \delta \in [0,0.5] \) to ensure that the values do not leave the interval \([0,1]\).

(6) Services

Without reasoning and decision making, grid agent passively responds to network agent or pedestrian agents’ request, including: query of grid state, the shortest distance from exits, the pheromone value, etc.

2.3. Network agent

Network agent is defined as follows:

\[ NAgent=< NetworkTopology, Service> \]  

(4)

As the exactly one agent, network agent is responsible for the maintenance of the road network topology. Fig.3 represents the network topology corresponding to Fig.2(b), where: nodes represents grids; edges between nodes are built based on grid neighborhood of range \( r=1 \); weight of edge is set to 1 or \( \epsilon \) according to directly adjacent or diagonally adjacent among grids; moreover, exits are regarded as special nodes while barrier grids are non-reachable nodes.

Fig. 3. Network topology diagram corresponding to Fig. 2(b)

Besides providing statistics for the system, network agent solves the shortest path and responses to the shortest path query from grid agents. Dijkstra’s algorithm for single-source shortest-path is not applicable to the network possessing non-reachable nodes and multi exits (Guo and Huang, 2008). We propose a superimposed algorithm to cater for the complex topological network. The parameters are explained as follows: \( f_{ij} \) denotes the minimum grids number while pedestrian leaves from a nearest exit when only around four directions are allowed; Similarly, \( e_{ij} \) represents the minimum grids number when eight directions are allowed; \( d_{ij} \) indicates the shortest distance from the grids \((i,j)\) to the nearest exit.

Superimposed algorithm

1. if the type of grid \((i,j)\) is barrier
   then \( f_{ij} \leftarrow 1; e_{ij} \leftarrow 1; \)

2. else if grid \((i,j)\) is not a exit
then \( f_{ij} \leftarrow 0; e_{ij} \leftarrow 0; \}

2 if \( f_{ij} = 0 \) and the grid \((i',j')\) is adjacent to an exit front, back, left or right
then \( f_{ij} \leftarrow 1; A \leftarrow \text{Enqueue}(\text{object}(i',j';f_{ij})); \}

3 while queue A is not NULL
    do{
        \text{object}(i,j,f_{ij}) \leftarrow \text{Dequeue}(\text{A});
        if \( f_{ij} = 0 \) and the grid \((i',j')\) is adjacent to the grid \((i,j)\) front, back, left or right
        then \( f_{ij} \leftarrow f_{ij} + 1; A \leftarrow \text{Enqueue}(\text{object}(i',j';f_{ij})); \}
    }

4 if \( e_{ij} = 0 \) and the grid \((i',j')\) is adjacent of Moore neighborhood to a exit
then \( e_{ij} \leftarrow 1; \text{queue A} \leftarrow \text{Enqueue}(\text{object}(i',j';e_{ij})); \}

5 while queue A is not NULL
    do{
        \text{object}(i,j,e_{ij}) \leftarrow \text{Dequeue}(\text{A});
        if \( e_{ij} = 0 \) and the grid \((i',j')\) is adjacent of Moore neighborhood to the grid \((i,j)\)
        then \( e_{ij} \leftarrow e_{ij} + 1; \text{A} \leftarrow \text{Enqueue}(\text{object}(i',j';e_{ij})); \}
    }

6 for each grid \((i,j)\)
    do{
        \[ d_{ij} = f_{ij} + (1 - e_{ij}) \]
        /* \( \varepsilon \) indicates the weight value of attraction between diagonally adjacent grids */
    }

7 \text{return};

In fact, the value of \( \varepsilon \) impacts the crowds shape at exits, and an appropriate value should be set.

2.4 Pedestrian agent

Pedestrian agents possess the abilities of reasoning and decision-making. The impact factors of decision-making include distance, physical characteristics, mood, herd mentality, and so on. Pedestrian agent is defined as follows:

\[ \text{P} \text{Agent} = \langle \text{Characterization, Mood, Decision rule, Update type, Action} \rangle \] (5)

(1) Characterization

We decide to reduce the characterization of our pedestrians to a small set of essential attributes with \( \text{pedID} \), physical attribute and familiarity degree on exit position.

(2) Mood

Pedestrian can be in one of two moods: happy or unhappy. Happy pedestrians have high ability to judge objectively whereas unhappy pedestrians move in a more random fashion.

Happy pedestrians enter the unhappy mode if several consecutive desired moves could not be carried out due to conflicts(3 in our simulations), while unhappy pedestrians become happy again after a certain number of consecutive allowed desires(4 in our simulations).

(3) Decision rule

\text{Decision rule} represents the rule of decision-making. Pedestrians can change their position along nine directions (keeping at the current position is considered a valid option) into the grids belonging to their Moore neighborhood of range \( r = 1. \) Each possible movement has a value called \( \text{likability} \) that determines how much the move is good. The \( \text{likability} \) of moving to occupied neighboring grids is set to zero. Thus, the \( \text{likability} \) for a jump from the grid \((0,0)\) to an unoccupied neighbor site\((i,j)\) is given by

\[ l_{ij} = -\Delta_d(i,j) \sum j_d + \Delta_p(h)(i,j) \sum j_p \] (6)

Where

\( \Delta_d(i,j) \) is the distance between the current grid and the target grid.

\( \Delta_p(h)(i,j) \) is the pedestrian's preference for the target grid.
\[
\Delta_d(i,j) = d_{ij} - d_{00}, \Delta_p h(i,j) = P_{h_{ij}} - P_{h_{00}}
\]  
(7)

the variables \(d_{ij}\) and \(P_{h_{ij}}\) respectively represent the enhancement of familiar degree on exits and herd mentality.

(4) Update type

The sequential update rules are applied in the model. At each iteration, pedestrians are updated following a random sequence. This choice is made in order to implement our method of collision avoidance based on grid reservation. In the sequential update, a pedestrian, when choosing the destination grid, has to check if this grid has been reserved by another pedestrian with the same time step. If not, the pedestrian will reserve that grid, and move at the end of the iteration. If the grid is already reserved, an alternative destination grid can be chosen.

(5) Action

Actions denote pedestrian traffic behaviors implemented after decision-making, include moving to neighboring grids or keeping the current position.

3. Simulations and results

3.1. Influence of \(\varepsilon\)

We consider a grid of size 240×300 sites with four exits in the middle of four walls. Each exit has three grids. 1000 pedestrians are initially distributed randomly and try to leave the room. Typical recommended values for these parameters \(a, \delta, g_1, g_2, j_{d}, j_{ph}\) are 0.15, 0.005, 0.2, 0.1, 3 and 0.5, respectively. Fig.4 shows the snapshot in the room after 42 time steps of the simulation. It can be seen from three pictures that a varying \(\varepsilon\) parameter can influence the crowds shape in front of the exit. Fig.4(c) shows a typical half-circle way (Helbing and Farkas, 2000) which is consistent with the phenomenon observed in real life.

3.2. Influence of \(j_{ph}\)

The sensitivity parameter \(j_{ph}\) represents the coupling strength to herd mentality. Here we want to focus on the influence of the sensitivity parameter \(j_{ph}\) on the evacuation times. The scenario of simulation is as follows. There are 400 pedestrians who attempt to leave from a square room with 100×100 grids and an exit sized by two grids in the middle of one wall. The representative set of parameters has been used as the 3.2 section except the parameter \(j_{ph}\). In the following experiments, we conduct 20 simulations for each value of the investigated parameter and record the mean.

Fig.5 shows the averaged evacuation times (steps) in dependence of the parameter \(j_{ph}\). We have seen that the evacuation times goes down then up with respect to the parameter \(j_{ph}\). If the \(j_{ph}\) is small, along with its increase, average evacuation times will decrease. This is a collective effect where the herding behavior helps to overcome the insufficient knowledge about the location of the exit. However, when the \(j_{ph}\) is above a certain level, it will
lead to longer evacuation time. With the pheromone value $Ph$ grows, the noise in the system for the pedestrians will be increased. Therefore, for large values of $j_{ph}$ a strong herding behavior would be unfavorable since it tends to ‘confuse’ the pedestrians which already have a good knowledge about the environment. In short, strong or weak herd behavior can lead to the increase in evacuation times.

![Graph showing evacuation times against the sensitivity parameter $j_{ph}$](image)

**Fig.5.** Evacuation times against the sensitivity parameter $j_{ph}$

4. Conclusion

In this paper, pedestrian behaviors are studied and a multi agent based model is proposed. We also implement simulation experiments.

(1) According to the communication relation, three types of agents including network agent, grid agent and pedestrian agent are categorized into three layers. Inner structures of agents besides service interface are defined in detail.

(2) A superimposed shortest path algorithm is developed to cater for complex topological network while possessing multiple exits and inner barriers.

(3) Beside distance (shortest length), the impact factors of pedestrian decision-making also include physical attribute, mood and herd mentality.

(4) The phenomenon of the arching or clogging around the exit is reproduced in simulation experiments if the parameter $c$ is set to an appropriate value.

(5) Finally, we have focused on studying evacuation times in a very simple evacuation scenario. The main purpose was to elucidate the influence of the parameter $j_{ph}$ to facilitate it interpretation.

Future works are aimed at an in-depth analysis about the impact factors of decision-making, such as field of vision, density of the pedestrians, interaction among group members, and so on.

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