Simulation of Human Behavior in Different Densities as a Part of Crowd Control Systems

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Abstract. This paper presents a novel approach to the crowd behavior modeling and simulation in different densities used as a decision support tool in crowd control systems. Non-invasive examination of movement and behavior of people in different densities and situations may lead to the detection and prevention of crisis situations involving crowds especially at high densities. In order to get approximated model of human acting we use microscopic approach for pedestrian representation. In model each person in crowd is described as an agent with individual attributes, behavior rules and own proxemics space. Representation of environment uses a combination of two approaches: coarse network model and fine network model simultaneously. The model and simulator can be used as a part of systems for supporting and controlling pedestrian movement, evacuations, demonstrations or situations where high congestion of people can be critical.

Keywords: Crowd modeling · Crowd control system · Crowd simulation · Pedestrian movement model

1 Introduction

Public spaces should be safe for moving pedestrians. Typically, security is provided by the physical objects in accordance with accepted safety standards. As shown by numerous disasters involving crowds [1], sometimes it is not enough to prevent injury or even loss of life. Awareness of the threat posed by a large gathering of people in a small area makes it necessary to look for better solutions to this problem. One of them is the use of computer simulation of pedestrian movement in a virtual environment to analyze possible threats. On the basis of the work of many crowd researchers [2,3,4,5] of the crowd there are many known phenomena of movement of the crowd such as: lane formation, stop-and-go waves or oscillations at bottlenecks. Many of the characteristics associated with the movement of the crowd has been well described and have become a tool for testing the adequacy of the new tools. In the field of crowd modeling there are many sophisticated models [6] that can reproduce real human behavior in many scenarios. The next step is to use these models in real crowd control systems to have a tool for non-invasive testing physical or non-physical methods for making pedestrian movement safer. In this paper model for decision support in area of managing crowd movement is presented.

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2 Crowd Behavior Model

The main purpose of the model is to reproduce real human behavior during movement in different densities. Pedestrians act different in different congestion of people around them. With that information it is necessary to take into account the fact that pedestrians change behavior with density changes. In our model the space is based on hybrid representation using fine and coarse network models simultaneously. Each pedestrian is represented by an agent with its individual characteristics. For different behavior simulation rule based system was used. To obtain behavior changes based on actual density around pedestrians we take into consideration concept of personal distances described by E. Hall [7].

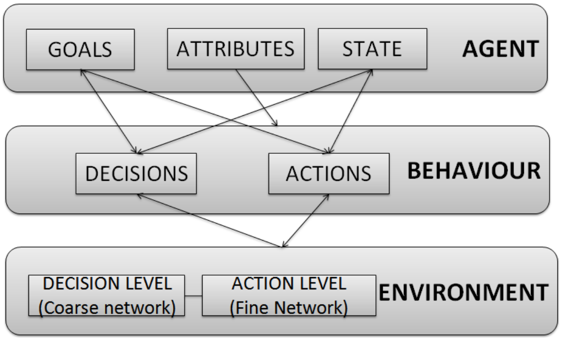


Fig. 1. Base elements of crowd behavior model

2.1 Space Representation

We use hybrid space representation to reproduce natural human perception of surroundings. People, when they want to go somewhere they do not see all the way to the target as a single trajectory. At a higher level, they see important points: front door, staircase, bus stop, pedestrian crossing. That level in our model is represented by a coarse network E^C and will be named as **decision level**,

$$E^C = \langle G, f^C \rangle \tag{1}$$

where: $G = \langle W, U \rangle$ is a graph, W is a set of nodes where each represents a logical space such as single room (e.g. corridor, staircase), U is a set of edges where each represents physical possibility to move between nodes and f^C is a set of functions related to graph G. In our model we use some modification of a classical graph representation of a space. We split the space near each exit from a rooms space and set it as a single node. We do that to have a way to describe each exit with function of pass cost. In real situations people often chose less crowded exits to walk.

Second level in our space representation is a **action level**. On that level we describe space as a fine network E^F,

$$E^F = \langle X, Y, C, C^S, C^D, f^F \rangle \tag{2}$$

Where: $X, Y \in \boldsymbol{N}_+$ is space size as number of cells horizontal and vertical, $C = \{\langle x, y\rangle \in \boldsymbol{N}_+^2 : x \leq X, y \leq Y\}$ is a grid of square cells, $C^S \in 2^N$ is a set of possible cell states (in basic approach we use three states: unavailable space, free space for pedestrian, space occupied by pedestrian), $C^D = \{\langle x, y\rangle \in \{-1,0,1\}^2 \backslash \langle 0,0\rangle\}$ is a set of possible moving directions for pedestrians and f^F is a set of functions related to elements of E^F.

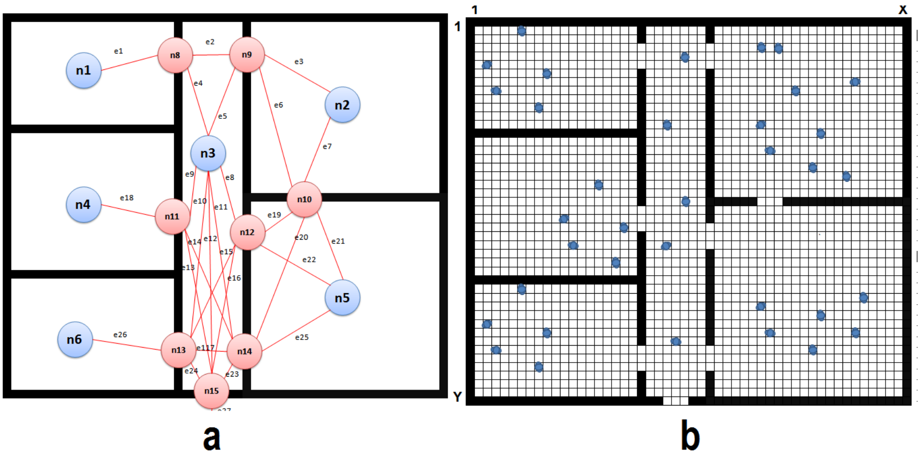


Fig. 2. Space representation on decision level (a) and action level (b)

Hybrid space representation E in our model use described 2 levels: decision and action simultaneously and is described as:

$$E = \langle E^C, E^F, E^O, f^E\rangle \tag{3}$$

where: E^O is a set of phenomena and interactive objects and f^E is a set of functions related to elements E^C, E^F, E^O.

2.2 Pedestrian Model

In this model each pedestrian is an individual and heterogeneous agent. In simulation the model from the viewpoint of pedestrians can be treated as an multi-agent system where agents (pedestrians) interact with each other while moving to desired locations. Model of single pedestrian can be described as

$$P = \langle P^A, P^S, P^G, B\rangle \tag{4}$$

where: P^A is a list of agent attributes, P^S is a state vector of agent, P^G is ordered list of agent goals and B is model of agent behavior. In basic approach the main attributes of agent are: energy, preferred velocity, preferred personal distances, interaction time, knowledge of the environment – these attributes have impact on how, when and where the agent will move in the space. In each moment P^S describes current state of an agent: position, velocity and energy. The goals of each agent can be different, the ordered list P^G can be changed during simulation many times according to situation around agent.

Using approach with multi-agent systems to simulate crowd movement is well known. One of the first who proposed this conception was Raynolds[9] and later this method became one of the fundaments of crowd models [11,13,16,17]. In our model we use this approach with extended pedestrian model to reproduce individual and different behavior and role in crowd. One of the our assumptions that can be achieved using agent system is to reproduce sophisticated pedestrian phenomena (e. g. supervised children and family evacuation, leadership in crowd or riot movement).

2.3 Pedestrian Behavior Model

Agents acts individually, but their actions depends where other agents are and what they do. The basic algorithm of agent action is shown in Fig. 3

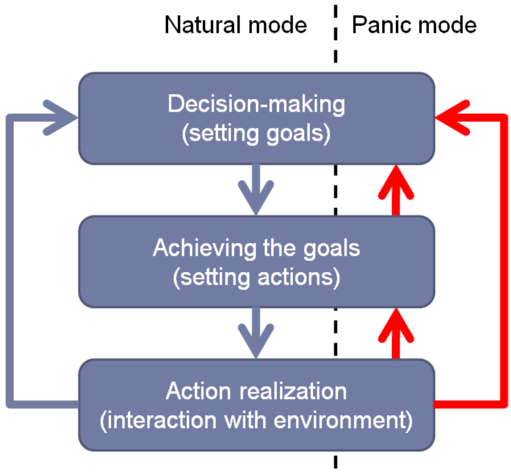


Fig. 3. Basic algorithm of agent behavior

Agent can act in two modes. The normal mode is chosen when agent is safe. That means there is no risk for him to lose extra energy, health or life. In this mode his behavior is based on basic goals such as: go to specific place or follow a leader. In panic mode agent can act differently. Panic is a situation when agent are in stress caused by a specific threat (e.g. fire, smoke, running agents, crowded place). In this mode the basic goal of agent can be changed to respect "instinct" of escape from threat.

Agent behavior in model is rule based. For each simulation we can change the rule sets to achieve desired pedestrian acting. The basic rules are focused on reproduction of real human movement including: obstacle avoiding, choosing "best" routes, avoiding other agents, forming lanes, changing velocity in specific situations. Some of the rules are based on social forces described by D. Helbing [8]. The open character of creating rules for agents gives the possibility for creating agents with specific roles in crowd movement (e.g. during simulation of evacuation from building in fire there is sometime a need to simulate and chose best routes for movement of firefighters who usually goes in the opposite direction then crowd). Another advantage of model is possibility to defining group behaviors. Using simple rule sets described by Reynolds [9] we can reproduce realistic group movement.

Behavior rules are dependent on congestion of agents. This is author interpretation of proxemics, a phenomena related with personal distances between pedestrians. The idea of personal distances are known to crowd researchers where one of the firsts who described it in crowd modeling were Fruin[3], Helbing[8] and Raynolds[9]. As shown in some later works [14,15] still this idea can be used with new interpretation. In our model we use proxemic spaces to reproduce phenomena of unequal distribution of pedestrian density (e.g. on mass events we can notice empty and overcrowded places) by possibility of defining a sets of different personal spaces to each pedestrians and change them in different scenarios. We use cellular automata to check and change defined in model proxemic spaces. Changing proxemic space alters behavior rules of agent. The personal distances are strictly related with fundamental diagrams which represents the relationship between density and velocity of pedestrians. These relationship is one of the major rule in presented model. The basic proxemics spaces (with corresponding cells available for pedestrian in set C) defined by author is showed on Fig. 4.

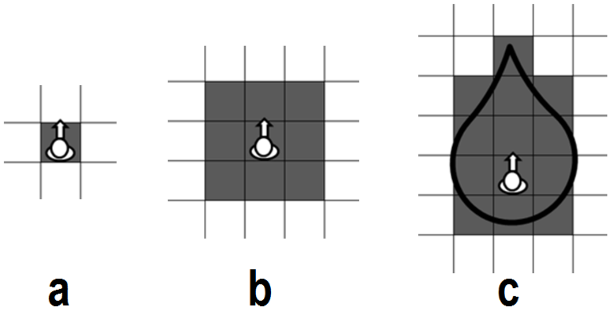


Fig. 4. Basic proxemics spaces for pedestrian: intimate distance (a), social distance (b), public distance (c)

Pedestrian behavior model can be described as

$$B = \langle B^G, B^A, B^P, B^D, B^S, B^R, B^{GR}, B^{IR}, f^B \rangle \tag{5}$$

where: B^G is a set of defined goals, B^A is a set of defined actions, B^P is a set of defined personal distances, B^D is a set of defined density levels, B^S is a set of stress levels, B^R is a set of defined behavior rules, B^{GR} is a set of global behavior rules, B^{IR} is a set of individual behavior rules and f^B is a set of functions related to elements $B^G, B^A, B^P, B^D, B^S, B^R, B^{GR}, B^{IR}$.

2.4 Methods and Algorithms

In presented solution we use large set of methods and algorithms to be able to reproduce human behavior. Pedestrian behavior and movement on decision and action level are achieved using additionally:

- graph algorithms [10] for finding shortest paths with time-dependent cost function for nodes
- potential fields method for finding best trajectories between nodes
- attraction masks for computing actual moving direction of agents
- calibration phase to reproduce dependencies from fundamental diagrams
- discreet simulation method in two modes: with event and with steps

One of the most frequently used goals by each agent is reaching specific nodes. In real situations people knows the best route for them. Typically it will be the shortest one, but not always. Exception of this rule can be unfamiliarity of the environment. In that situation sometimes people takes a longer known to them way. In model each agent has own knowledge of network and nodes on decision level. Choosing a way to desired node is based on shortest path algorithm with functions: $f_{UC}^{E}: U \rightarrow \boldsymbol{N}$ determining static cost moving between nodes, $f_{NMC}^{E}: W, t \rightarrow \boldsymbol{N}$ determining dynamic, changing in time cost of crossing single node (this function is strictly related with pedestrian congestion in node).

On action level pedestrian move from cell to cell (between two adjacent nodes) is determined by using potential fields method and attraction masks which represent dynamic changes in agent surrounding. In potential fields method each cell has computed a potential which reflects real distance from target. The trajectory is determined in two steps: first a desired direction probability mask is computed by seeking free cell with smaller potential, the second step is to calculate real move direction.

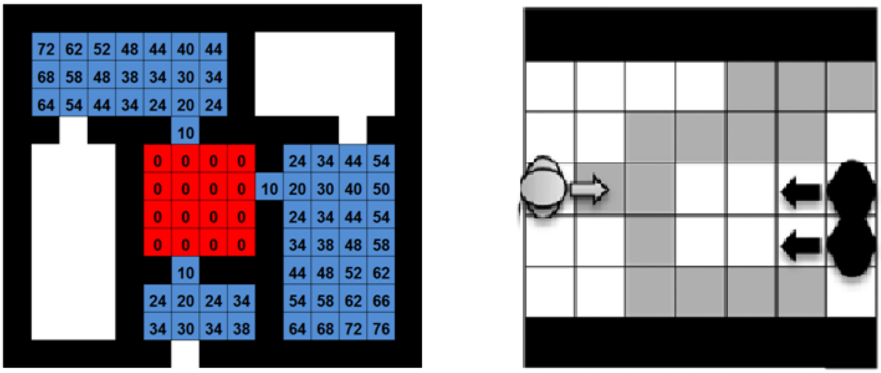
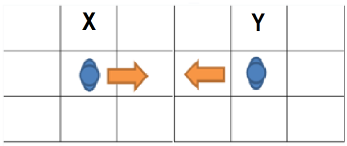


Fig. 5. Conception of potential fields method and changing cells attraction

The second step is needed to avoid collision between pedestrians. In real situations if pedestrians are walking against themselves one of them or both will change direction before collision. In model we applied a attraction masks for each agent. These masks change probability of choosing cells surrounding other agent.



0,01	0,05	0,1
0	0,03	0,6
0,01	0,05	0,1

a

0,01	0,05	0,125
0,01	0,02	-0,4
0,01	0,05	0,125

b

0,02	0,1	0,225
0,01	0,05	0,2
0,02	0,1	0,225

c

Fig. 6. Probability mask for determining best direction: individual probability for agent X (a), changing cell attraction mask for agent X from agent Y (b), result direction probability mask for agent X (c)

3 Experiments and Possible Applications

Stage preceding the execution of simulation experiments and collecting the desired output characteristics is a calibration step. This step is necessary to obtain the desired adequacy of the model. The calibration process involves appropriate selection of input variables such as .: average speed of movement of persons, the average space occupied by a person, the strength of interpersonal interaction, response times, or the probability of interaction between individuals competing for space. The output characteristics from one of calibration processes are presented on Fig. 7.

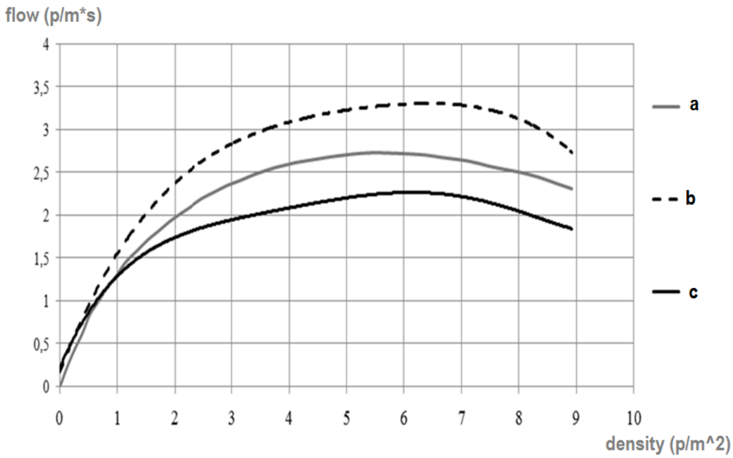


Fig. 7. Fundamental diagram and output characteristics from calibration process: fundamental diagram [4] (a), output data for probability of pedestrians interaction set to 0.3 (b), output data for probability of pedestrians interaction set to 0.4 (c)

Presented model can be successfully used to simulate the evacuation process. To simulate evacuation process one base rule is create: *reach nearest safe area*. For experiment basic input data included: average velocity 1,2 m/s, space occupied by each pedestrian 0,25m x 0,25m, reaction time 10s. In experiment we use university building with 3 lecture rooms (areas 1-3), one corridor (intersection area) and one exit to safe area. The simulation results of evacuation experiment are shown in Fig. 8.

Successful experiments of evacuation process was a first step to start using model as a support tool in developing and testing conception of dynamic signage system for evacuation process in complex buildings[12, 13].

In addition to providing numerical output data from experiments, implemented simulator is capable to give real time preview of simulation process. This feature is important for training workshops where experts can see moving crowd on a screen and interactively react in simulated emergencies. 2D preview of a simulation evacuation process from 2 floors building is presented on Fig. 9.

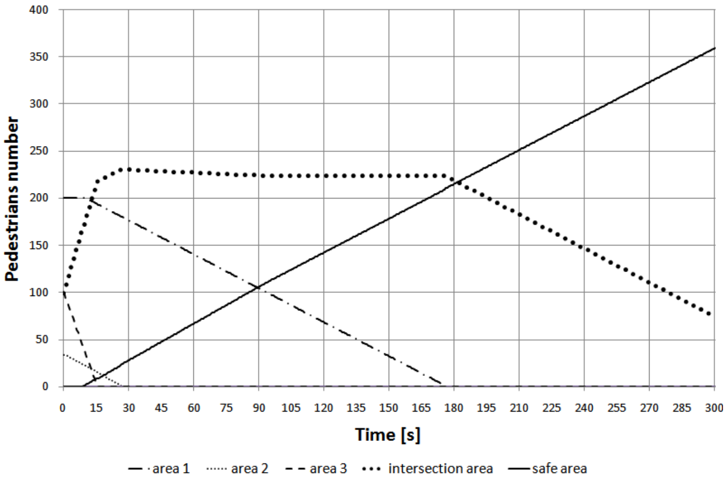


Fig. 8. Pedestrians in different areas during evacuation process, experiment results

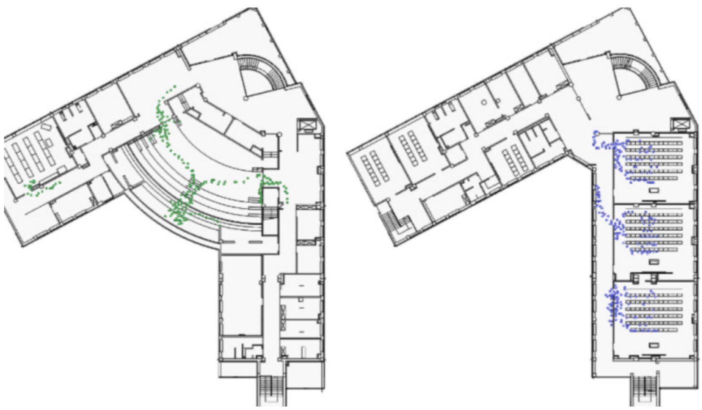


Fig. 9. 2D visualization of simulation process, 2 floors of a building

4 Crowd Control Systems

Systems for managing pedestrian movement should be well prepared. Today all around the world we have directives and rules how make public and gathering places for large number of peoples to be safe. The main problem in most of this situations is that all these methods are static and not prepared for unusual scenario. We can find elements of today's crowd control system at mass events, in every buildings with evacuation plans with evacuation route signs. But signs and crowd control barriers are not enough. Especially when situation changes to different than expected. For example a good static evacuation plans can be deadly when part of a route are destroyed or dangerous to walk in.

The next step in making pedestrian movement safer is to support static methods with analytical systems which are able in reasonable time find a threat and help to prevent it. In real situations when in one area gathers a large number of pedestrians the dynamic crowd control is the only way to prevent deaths (e.g. crowd control system at Jamarat Bridge [11]).

Proper system for crowd control should be prepared to work in several areas:

- monitoring and detection – this is very important thing to know positions and numbers of pedestrians in each areas,
- adequate model of the environment and pedestrian behavior
- cooperation with other supporting models
- effective and dynamic information system
- trained staff to support crowd controlling

Presented in this paper crowd behavior model can be an important part of crowd control system. Microscopic representation of pedestrians, open and rule based behavior modeling and high resolution of space representation are advantages that allow to use model to simulate pedestrian movement in different densities and scenarios (e.g. evacuations, supervised evacuations in schools, tunneling movement during mass events, controlling demonstrations and even preventing riots). Using hybrid space model with presented approaches gives possibility to simulate crowd situations from beginning when density is still low and single pedestrians can cause a dangerous event. This model can be a real improvement as a decision support tool in crowd controlling especially in detection of undesirable situations before they happen (e.g. monitoring and making ahead simulations during real events can show that without intervention critical situation may occur) and verification of efficacy and safety of potential reacting methods during real situations.

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