Evaluation of Behavior of Evacuees on a Floor in a Disaster Situation Using Multi-agent Simulation and Mixed Reality Game: Effectiveness of the Field of Vision and Priority of Referred Objects

Keita Sugiura and Masahiro Arakawa

The Field of Systems Management, Graduate School of Engineering, Nagoya Institute of Technology, Nagoya, Aichi 466-855, Japan

Abstract: In this study, we develop a mixed reality game system to investigate characteristics of judgments of individual players in an evacuation process. The characteristics of judgments of the players that are inferred from the performance of the game are then incorporated into a multi-agent simulation as rules. The behavior of evacuees is evaluated in approximations of real situations, by using the agent simulation including different judgments of evacuees. Using the results of the simulation, effective methods are discussed for achieving the escape of the evacuees within a short time.

Key words: Multi-agent simulation, mixed reality game system, emergency exit sign, behavior of evacuees, field of vision.

1. Introduction

The prediction of evacuee behavior during disasters plays a useful role in the design of urban structures, such as department stores, schools, and office buildings. However, because it is difficult to investigate the behavior of evacuees in damaged structures using actual structures during real disasters, computer simulations are used to design structures such that the damage to structures and evacuees can be reduced, as well as to predict the effects of disaster situations [1-2].

Multi-agent simulation is ordinarily employed to investigate the distinctive behavior of evacuees and populations, including theoretical decision making in complex situations. In past studies, simulations have been adopted to model the behavior of evacuees in situations such as customers moving in shops [3-4], evacuees escaping from a building [5-6], and passengers moving in a rail station including

platforms [7].

Regarding the behavior of evacuees in buildings, researchers have studied the behavior of a population given different layouts, the influence of the initial distribution of evacuees, and the influence of different layouts. In these previous studies, agent simulations include typical rules relating to typical behaviors of evacuees. However, because evacuees who have different judgments regarding movement are present in actual disaster situations, it is difficult to use simulations that only include typical rules for the judgment to predict the behavior of evacuees in real situations.

In this study, we develop a mixed reality game system to investigate the characteristics of judgments of individual players in an evacuation process. Then, the characteristics of judgments of players that are inferred by performing the game are incorporated into the simulation as rules. The behavior of evacuees is evaluated in approximations of real situations, by using the agent simulation including different judgments of evacuees. By considering the simulation

Corresponding author: Keita Sugiura, doctoral student, research fields: multi-agent simulation, simulation and optimization algorithm.

results, effective methods are discussed for achieving the escape of many evacuees within a short time.

2. Mixed Reality Game System

We develop a mixed reality game system, to investigate the characteristics of distinctive judgments of evacuees in an evacuation process. The “Unity (Unity3D: Unity Technologies)” game creation system is used to develop the system. In this game system, the movement of evacuees, simulated by agent simulation, is shown, and the layout of passageways and facilities can be dynamically changed on the floor. In addition, players are displayed in the game as game players, and a player’s running path is saved in the system. The game system is composed of two subsystems: one (a) to control the game and render the behavior of the evacuees obtained by the multi-agent simulation, and the other (b) to store a player’s path, and to present the layout while players play the game for comparisons with simulated agents. The subsystems are developed using C#. Fig. 1 presents a sample display from the mixed reality game system, including the resulting behavior of evacuees obtained by the agent-simulation.

3. Multi-agent Simulation

We develop the multi-agent simulation software used in this study using Java. The software is hereafter referred to as the “Agent Simulator”. The Agent Simulator is comprised of “Agents” and a “Field”. An “Agent” is an object with the property of an individual

evacuee. A “Field” is an object with the property of a field in which agents can move. The characteristics of these objects are as follows.

3.1 Agent

Every agent includes the following characteristics:

- (1) The initial locations and the number of agents can be arbitrarily decided.
- (2) An agent collects information regarding the field environment, and decides which direction to move in.
- (3) Initially, an agent does not know the exit locations. It moves towards a target within its field of vision.

An agent moves toward targets in the following order of priority: (1) the nearest exit, (2) emergency exit signs, (3) the nearest agent. When none of these targets is located within the agent’s field of vision, the agent continues to move in its original direction (4). Fig. 2 depicts a schematic diagram of the objects regarded as targets. In this study, there is one case in which the second and third priorities are exchanged, in order to change the characteristics of the judgments of agents. Here, the emergency exit sign denotes a sign that indicates the nearest exit using an arrow.

The speed and initial positions of the agents are randomly pre-determined. In this model, the agents are positioned in an aisle. Two agents are prohibited from overlapping each other, and must be located at two adjacent grid cells on the floor.

Fig. 1 A sample display from the mixed reality game system including the resultant behavior of evacuees obtained by the agent-simulation.

Fig. 2 Original target priority of agents.

Therefore, the distance maintained between different agents is greater than the predetermined cell size on the floor. When an agent meets an obstacle, it moves along the shape of the obstacle with the shortest length.

3.2 Field

Fig. 3 depicts a sample layout of a floor used in an agent simulation. The floor is the field object in the simulation, and agents can move on it. Black blocks denote walls, and white blocks denote aisles in which the agents can move. The field object maintains the positions and dynamic variable data for walls,

exits, and emergency exit signs as properties of the floor.

Grid cells are generated on the field object. Positions and dynamic variable data for walls, exits, and emergency exit signs are also available in the corresponding grid cells as properties of the floor. An agent retrieves the grid cell properties in its field of vision, and evaluates the locations and situations of these objects (such as exits, walls, and signs). When an agent meets an obstacle, it passes alongside the obstacle after a uniformly distributed random number determines its route. The floor layout is drawn based on the floor of an actual department store.

3.3 Simulation Conditions

In the simulator, an agent's speed and field of vision can be determined. In this study, a single time step in the simulation corresponds to 0.1 sec in real-time. We collect the object information from each agent's field of vision at each time step. Table 1 lists the parameters used in the simulation for the agent speed and field of vision radius.

Fig. 3 Floor layout for agent simulation.

Table 1 Basic parameter for agent simulation.

Agent speed	1.0 m/sec
Agent field of vision radius	20 m
Field area	50×71 m ²
Grid size in field passageway	1 m/grid

4. Investigation of Behavior of Evacuees Using a Mixed Reality Game

In order to investigate the complex and distinctive behavior of evacuees, we create game trials under the following conditions.

We predetermine the ratio of agents that move in the opposite direction of the simulated agent movement. Players play the mixed reality game, including this predetermined ratio.

Here, a multi-agent simulation is performed under the condition that the predetermined ratio of agents who move in the opposite direction is included in advance. The paths of all agents are collected for use in the mixed reality game. We use an eye-mark recorder device to investigate the viewpoints of players in the game. This “View Tracker” device is produced by Ditect Co., Ltd. Fig. 4 illustrates the layout of devices.

There are seven subjects, aged between 21 and 23 years old. The subjects playing the game in this experiment are different from the subjects mentioned in the previous section. We chose different subjects because the previous subjects memorized the route and exit locations. Table 2 lists the experiment patterns. Fig. 5 shows the initial locations of players, under the conditions of different ratios for agents moving in the opposite direction. Emergency exit signs are located in the fields of view of the players at their initial positions in all patterns. Different ratios of agents moving in the opposite direction are determined for the different patterns. In addition, players are located at different initial positions in different patterns, in order to avoid memorizing the routes to exits. Each player plays the game three times for each pattern.

Fig. 4 Layout of devices for the experiment on a mixed reality game.

Table 2 Experiment patterns of mixed reality game.

Patterns	The ratio of agents who move in the opposite direction to original agents
A	10:0 (All agents move to the opposite direction)
B	8:2 (The opposite direction: the positive direction)
C	5:5 (The opposite direction: the positive direction)

Fig. 5 Initial positions of players on different patterns.

Pattern A includes the condition that all agents move in the opposite direction of the agents originally obtained by the simulation. Pattern B includes the condition that 80% of all agents move in the opposite direction of the original agents. Pattern C includes the condition that half of the agents move in the opposite direction of the original agents. Fig. 6 presents the ratio of players who referred different objects at start of game. Fig. 7 shows the number of players who arrived at different exits when they referred to an

Fig. 6 The ratio of players who target different objects at start of game.

Fig. 7 The number of players who arrive at different exits when they refer to an emergency exit sign.

emergency exit sign. Here, players cannot arrive at the exit within a predetermined time in some games.

In Pattern C, almost all players referred an emergency exit sign when they began to move. In Pattern B, half of the players followed agents when they began to move. However, although all of the agents move in the opposite direction, almost all players referred the emergency exit signs when they began to move in Pattern A. We suppose that players referred to the sign because it is located at a corner of the floor, and they recognized an exit located near the corner. In addition, in this case the players arrived at the second nearest exit, although they referred the emergency exit signs. The reason for this is that they miss the nearest exit while focusing on the second nearest exit, which is located in the direction of their movement.

We suppose that the objects players choose to refer

to are effected not only by the ratio of agents moving in the opposite direction, but also the floor layout. The following distinctive player characteristics are obtained from the experimental data, including video:

(1) Many players focus on a narrow area in the direction of movement. Therefore, the players were unable to notice the nearest exit, located at the side of the passageway.

(2) There are cases in which players stop to look for new targets, as they cannot easily locate exits at corners, although the signs do indicate exits.

(3) There are cases when players return to a passageway because they cannot locate exits, and follow agents who move in the opposite direction.

(4) There are cases of players being unaffected by agents when there are a small number of agents near the player. In this case, players mainly target emergency exit signs.

5. Multi-agent Simulation Including Agents with Different Characteristics of Judgement

In the previous chapter, the experimental results indicated that some players move in reference to the nearest evacuees on the floor, and otherwise they look at emergency exit signs. Furthermore, these players require a longer time to escape than those who refer emergency exit signs, and they may not be able to escape at all. We perform a multi-agent simulation, including agents who have different priorities for the order in which they choose objects to follow, in order to evaluate the behavior of a population of agents with different characteristics of movement. Fig. 3 illustrates the floor layout used in this experiment.

Table 3 presents the simulation conditions, in terms of the different fields of vision of the agents. The total number of agents is 100. In this simulation, the second-highest priority object for all agents to refer to

is the emergency exit sign. The third-highest priority object for all agents is the nearest agent. In Table 3, 90°, 180°, and 360° indicate that the fields of vision extend by 45°, 90°, and 180°, respectively, to the left and right hand sides from the direction of movement of every agent.

Figs. 8 and 9 present the number of agents successfully completing the evacuation under the conditions presented in Table 3. Fig. 8 shows that the number of agents completing the evacuation decreases when field of vision of the agents represents a narrow angle. This tendency is easily predicted. However, the number of agents completing the evacuation within 300 sec is lower with field of vision of 360° than with a field of vision of 180°. The visualization of the simulation shows that when agents have 360° field of vision, many move towards the nearest signs, and then stop after coming into conflict with other agents. Fig. 9

Table 3 Conditions of simulation for actual floor layout with regards to different fields of vision. (The second-highest priority object for all agents to follow is emergency exit signs. The third-highest priority object for all agents is the nearest agent.)

Condition	Field of vision	The number of agents	Field of vision	The number of agents
1	90°	100		
2	180°	100		
3	360°	100		
4	180°	75	90°	25
5	180°	50	90°	50
6	180°	25	90°	75

Fig. 8 The number of agents completing the evacuation under different conditions for their fields of vision.

Fig. 9 The number of agents completing the evacuation under different conditions regarding the ratios of agents with different fields of vision.

Table 4 Conditions of simulation for the actual floor layout with regards to different highest priority objects to refer to. (The field of vision for all agents is 180°.)

Condition	The number of agents referring different object as the second priority object	
	Emergency exit sign	The nearest agent
2	100	0
7	75	25
8	50	50
9	25	75
10	0	100

Fig. 10 The number of agents completing the evacuation under different conditions regarding the ratios of agents referring to different objects with the second-highest priority.

shows the number of agents that complete the evacuation for the various ratios of agents with different fields of vision. The results indicate that the

number of agents completing the evacuation decreases as the number of agents with a narrow field of vision increases.

Table 4 lists the simulation conditions in terms of the various ratios of agents that refer to different objects as their second priority. Here, the field of vision of all agents is 180°. Fig. 10 indicates that the number of agents completing the evacuation decreases when the number of agents treating emergency exit signs as a higher priority object becomes smaller. However, comparing the results for Conditions 9 and 10 in Fig. 10 also shows that having a small number of agents referring to emergency exit signs with a higher priority helps to increase the number of agents completing the evacuation.

6. Characteristics of Behavior of Evacuees Obtained from the Simulation

From the previous chapters, we can analyze the characteristics of the behavior of evacuees as follows:

(1) Many evacuees move in reference to exit signs. However, some evacuees refer instead to the nearest evacuee, although exit signs are located within their field of vision.

(2) Evacuees can effectively move towards exits by following exit signs. Evacuees move in reference to the nearest evacuees when no exit sign is located in their field of vision. Therefore, when the number of evacuees that move according to exit signs is increased, other evacuees who refer to their nearest evacuees can escape within a short time.

(3) In the real world, the field of vision of evacuees is ordinarily narrow. When evacuees are moving, their field of vision tends to become narrower. Therefore, evacuees take a long time to arrive at the exit when exits and exit signs are outside of their field of vision, although the exits and exit signs may be located near to the evacuees.

(4) The time required to arrive at an exit depends on the situation in front of an evacuee at the time that they start. When an exit sign is located near to an evacuee but outside of their field of vision, they move in reference to the nearest evacuee. Therefore, they require a long time to arrive at the exit.

From these characteristics, we suggest that the following methods should be recommended to evacuees to achieve an effective escape of many evacuees within a short time:

(1) Each evacuee should move in reference to an emergency exit sign.

(2) Each evacuee should be conscious of their left and right sides while they are moving, to enlarge their field of vision.

(3) The number of evacuees using methods (1) and (2) should be increased.

On the other hand, when a floor layout is designed or a disaster situation is simulated, these results show that a multi-agent simulation including various conditions relating to the judgments of agents is useful for evaluating the approximate real behavior of evacuees.

7. Conclusion

In this study, we have developed a mixed reality game system and a multi-agent simulation. The multi-agent simulation is performed to evaluate the general behavior of evacuees, using as many rules for movements as possible. Players played the mixed reality game, including the simulation data, to evaluate the complex decision making of the players. The developed game system was employed as a case study, including an actual floor layout and emergency exit sign.

In addition, a multi-agent simulation was performed to evaluate the behavior of evacuees under an approximated real situation, by including agents under different conditions for their priorities regarding reference objects and fields of vision. The simulation results demonstrate that the number of agents completing the evacuation is influenced by their priorities regarding reference objects and their fields of vision. Guided by the results, we have proposed significant recommendations for evacuees in order to complete an evacuation within a short time.

In a future study, we will develop the game system

to investigate the complex and dynamic characteristics of evacuees in extensive areas, such as cities and urban areas. In addition, a multi-agent simulation will be developed to evaluate the behavior of evacuees, including agents with individual and complex characteristics, to investigate movements within these extensive areas.

Acknowledgements

Shingo Muramatsu and Mizuki Ohashi, who were students in the Nagoya Institute of Technology, supported the performance of the experiment. This study is supported by a 2013 Research Grant of the HAYAO NAKAYAMA Foundation for Science & Technology and Culture.

References

- [1] Ohata, D. Takai, N., and Kagami, H. 2007. "Spatial Evaluation of Tsunami Refuge Facilities in the Central Kushiro City: Simulation of Evacuation Behavior from Tsunami Utilizing Multi Agent System Part 2." *J. Archit. Plann., AIJ* 74 (612): 87-91 (in Japanese).
- [2] Watanabe, K., and Kondo, A. 2009. "Development of Tsunami Evacuation Simulation Model to Support Community Planning for Tsunami Disaster Mitigation." *J. Archit. Plann., AIJ* 74 (637): 627-34 (in Japanese).
- [3] Masuda, H., Kikuchi, S., and Arai, T. 2009. "Performance Analysis of Retail Store Layout Using Agent-Based Simulation." *Journal of Japan Industrial Management Association* 60: 128-44.
- [4] Kishimoto, A., Takahashi, T., Takahashi, M., Yamada, T., Tsuda, K., and Terano, T. 2009. *An Agent Simulator for Analyzing Consumer Behaviors and Sales Promotion in a Retail Store*. IEICE Technical Report, AI2008-79, 87-92 (in Japanese).
- [5] Pelechano, N., and Badler, N. I. 2006. "Modeling Crowd and Trained Leader Behavior during Building Evacuation." *Computer Graphics and Applications, IEEE* 26 (6): 80-6.
- [6] Ohi, F., and Onogi, M. 2008. "A Simulation of Evacuation Dynamics of Pedestrians in Case of Emergency by a 2-Dimensional Cellular Automaton Method." *Transactions of the Operations Research Society of Japan* 51: 94-111 (in Japanese).
- [7] Nishinari, K., Kirchner, A., Namazi, A., and Schadschneider, A. 2004. "Extended Floor Field CA Model for Evacuation Dynamics (<Special Section>Cellular Automata)." *IEICE Transactions on Information and Systems* E87-D (3): 726-32.