A Pedestrian Dynamics Simulator for Wearable Navigation

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ABSTRACT

There are designated routes that should be taken by a crowd of people during emergency situations. When a disaster happens, some of these routes might not be available because of structural problems caused by the disaster itself. A more important factor is the distribution of congestion of the people spread over the area. The flow speed of people (pedestrians) depends on the density of the area. Therefore, when many pedestrians select the same route, or follow others, they may encounter heavy congestion at various places. Therefore, it is important to assist in the navigation of pedestrians by providing them with useful information. We have designed and developed a pedestrian dynamics simulator to perform navigation system studies, and have validated the system. Moreover, we have performed simulation experiments with a novel wearable navigation device that can guide the evacuation process. In one simulated case, we have verified that the navigation system can handle crowd control when the wearable navigation device is used by over 30% of the crowd.

Index Terms: K.6.1 [Management of Computing and Information Systems]: Project and People Management—Life Cycle; K.7.m [The Computing Profession]: Miscellaneous—Ethics

1 INTRODUCTION

The issue of how to evacuate people efficiently from crowded spaces (e.g., station's platform, concert venue) is an important problem; and a suitable solution can result in saving lives. A emergency situations can happen anywhere, and it is necessary to develop some countermeasures in order to keep people safe in such events. We can categorize the situations of how to shield the general public against danger, as "emergency precautions" and "hazard mitigation". In the former, we could consider how to design buildings, analyze walk flows, allocate emergency sign boards and perform emergency escape drills for efficient escape behavior. A number of researchers have studied this problem [3][5][7], which is called "*Pedestrian Dynamics*" Those researches aim to analyze the characteristic of pedestrian flow for the effective design of human-usable space, or to be used as educational tools to train general public in preparation for disaster. In the disaster, nobody knows what will happen, when and where a congestion occurs, and so on. Furthermore, the dynamics of crowd walking in emergency evacuation is not steady and it has large uncertainty. We should be able to respond to changing the situations in a flexible and dynamic manner.

As wearable technology and ubiquitous technology develop, we can provide some countermeasures against emergency congestion, i.e., evacuation guidance using some types of evacuation methods. We assume that a number of people can use a personal wearable device, such as a mobile phone, UMPC, and Head Mounted Display (HMD), under such situations in order to support the evacuation by a navigation system. These devices are called "Wearable Devices" [6][8]. We have developed the wearable robotics system, entitled the "Parasitic Humanoid (PH)" systems [10]. These novel devices provide some explicit and implicit support and advice for a specific person, who is equipped with one of the devices. Since these navigation systems have a potential to deal with the changing situations, the utilization of the devices can be a novel evacuation measure.

In order to evaluate the effectiveness of the devices, we developed a pedestrian dynamics simulator to perform evacuation experiments in virtual spaces and we validated our simulator as a pedestrian dynamics simulator. We conducted a number of preliminary evacuation simulations and obtained the results of the simulations to show the effectiveness of the devices.

In this paper, we propose the utilization of the wearable devices with the personal navigation function in an emergency and illustrate the results of the evacuation simulations to illustrate the effectiveness of the devices. First, we discuss the potential of the wearable navigation devices as a crowd navigation system in an emergency. Then, we introduce the pedestrian dynamics simulator and show the properties of the simulator. We illustrate the results of the simulation experiments to evaluate the utility of the wearable navigation devices to decrease congestion (i.e., avoid heavy congestion). Finally, we summarize the main contributions of this paper.

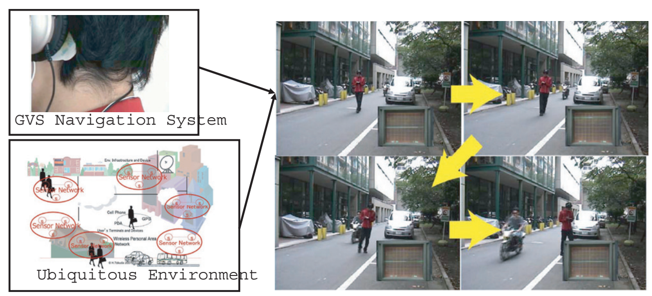

Figure 1: Human Behavior Induction by GVS. By using GVS and the environmental information provided by sensor networks, the wearer of PH can avoid a motorcycle, unconsciously

Figure 2: Prototype Wearable Navigation System using AR Technology. Left: The rapid prototype of the HMD of the PH. Right: The image for the wearer of the PH.

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2 Pedestrian Dynamics Model

2.1 Related Work

There are a number of simulators for simulation of crowd behavior [5][13][18]. Some related work use the particle model or the cellular automaton as an agent model [5]. These approaches are simple for modeling agent actions, and easy to observe crowd behavior. However, it is difficult for these models to describe more complex (and realistic) characteristic properties. Therefore, recent efforts have introduced the multi-agent based model [13][18]. Specifically for disaster evacuation, the RoboCup Rescue Simulator [15][17] and FreeWalk [11] are well-known simulators. RoboCup Rescue aims to promote research and development for disaster risk management, using computer simulations or physical robotic agents. FreeWalk is platform where human participants and autonomous characters can socially interact with one another in virtual city space. The crowd simulation by computers is one of the approaches to construction of a secure and safe society for performing experiments. There are some crowd simulations that include the situation of disaster evacuation [3][17][19]. These simulations aim to design environment in order to realize effective escape behavior. Generally, the method for improving the entire evacuation behavior is effective installation of evacuation directive boards, or participating in an emergency escape drills.

We have developed a simple simulator, and have conducted simulations of situations in order to study the advantages and disadvantages of the proposed devices.

2.2 Wearable Navigation Devices

The target devices provide some explicit [8] and implicit support [9] and advice for a specific person, who is equipped with the devices. We will call these devices ”Wearable Navigation Devices” or ”Wearable Devices”.

The concept of wearable computing has been actively investigated, as the physical sizes of components such as computers, sensors, actuators, etc. are getting smaller, and the wearable VR and wearable robotics have become popular research topics, similar to the popularity of wearable computers [6][8]. The cellular phones with the Global Positioning System (GPS) navigation function are popular now; although, the function does not work inside buildings. Kurata et al. [8] has developed a personal navigation system, which combines the self-contained sensors (accelerometers, gyro sensors and magnetometers), the GPS, and an active Radio Frequency Identification (RFID) tag system for both outdoor and indoor use [8][12].

Our target devices is the wearable robotics device entitled the “Parasitic Humanoid (PH)” system. Maeda et al. developed the wearable robotics system called the PH systems [10]. Although the PH does not have any actuators, the PH can guide the wearer of the PH to walk in desirable course by the galvanic vestibular stimulation (GVS), the wearable moment display, and the Augmented Reality (AR) technology using the HMD with cameras [2][9][1], as shown in Fig.1. The vestibular system is sensitive to GVS intensity changes, and responds by altering the magnitude of the response accordingly.

When GVS is delivered to the mastoid through electrodes during human walking, the wearer of PH responds by deviating towards the anode, as shown in Fig.2. For the motion induction in PH, GVS is available to induce the desirable movement of the direction during human walking. We envision being able to obtain a variety of information, whenever and wherever, desired using these wearable technologies in the ubiquitous societies of near future. In the case of an emergency, the wearable navigation devices directly guide the wearers to follow a safe path. The availability of our wearable navigation devices make a difference between the existing crowd simulations and our simulation at the point of being able to manage individual behavior, rather than the unspecific population behavior.

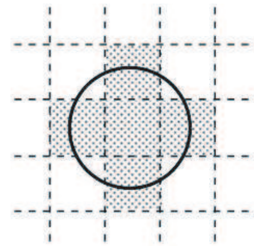


Figure 3: Agent Behavior Decision Model. The circle shows agent’s body, and the cells occupied by only one agent. The agent selects its own direction of movement from five cells (forward, back, left, right, stay here). These cells are smaller than the agents’ scale. Then, the agent moves with no constraint except that if the target cell is closed or is a wall.

2.3 The Simulation Model

Our target simulation is called “Pedestrian Dynamics Simulation” or “Crowd Simulation”. Some researcher model this simulation as cellular automaton model [4] and multi-agent model [13][18]. We should chose our own model to fit the purposes of our experiments. The cellular automate model is based on discrete spatial representations. A pedestrian is expressed as a particle, and the cell is the same as the particle size. Each cell is defined as the potential fields that can use the reference value as the local effect of obstacles or moving pedestrians. The second model, the multi-agent model, focuses on the simulation of a pedestrian’s action as an entity, and the interactions among agents. This model is able to deal with individual cognitive capabilities.

In our simulations, some agents obtain a guidance provided by the wearable navigation system and the other obtain no guidance. Since the device is a personal device, we selected the multi-agent model for our simulations. The social force model proposed and developed by Helbing et al.[5] is the representative model, which describes the interaction between the agents. The direction and speed of a pedestrian is assumed to be computed by the combination of the virtual forces between the agents. The description of the behavior of the agents is based on the social force model in our simulations.

2.3.1 The Environment Model

We describe the simulated world as a typical grid world (similar to a cell-based), where the pedestrian is described as a particle. Each cell is smaller than an agents’ scale. Our goals are to model the complex interaction between agents in crowded space, and to reduce the amount of required calculations. As the size of the cell decreases, the computational requirements increases. We set the cell size to about 0.1m x 0.1m, with human width of 0.5m. Our simulation breaks the time into discrete steps, where in each step, an agent decides its own behavior. The simulator performs collision detection.

2.3.2 The Agent Model

The pedestrian dynamics simulation aims to reproduce complex behavior patterns using interactions among pedestrians. And our proposed device targets personal user, hence we modeled pedestrians using the multi-agent model, and implemented the multi-agent simulator for simulating pedestrian dynamics. We used the boid model [16] for crowd behavior. The model is regarded as a kind of the social force model.

We developed our simulator based on C. Parker’s pseudocode of Boids [14]. Let $x(t)$ be the 2D position vector of an agent i at time t. According to the pseudocode, $x(t)$ is updated as follows:

$$v(t) = v(t-1) + a(t) \tag{1}$$

$$x(t+1) \quad = \quad x(t)+v(t) \tag{2}$$

$v(t)$ is the velocity of the agent and $a(t)$ is the acceleration of the agent. Let $F(t)$ be the real and virtual force affects the agent. We assume the following equation is established.

$$a(t) = F(t) \tag{3}$$

$F(t)$ consists of the following three forces:

$$F(t) = F_{drag}(t) + F_{goal}(t) + F_{boids}(t) \tag{4}$$

$F_{drag}(t)$ is the drag force affecting the agent, which is proportional to $v(t)$. $F_{goal}(t)$ is the force driving the agent to follow the path to the goal. $F_{boids}(t)$ is the social force, which describing the flocking behavior of the agents based on Reynolds' Boids model. The force consists of three simple steering behaviors which describe how an individual boid maneuvers, based on the positions and velocities of its nearby flock-mates: *Separation ($F^S(t)$)* steer to avoid crowding local flock-mates, *Alignment($F^A(t)$)* steer towards the average heading of local flock-mates, *Cohesion($F^C(t)$)* steer to move toward the average position of local flock-mates.

The agent i receives the social force F_{boids}, as follows:

$$F_{boids}(t) = F^S(t) + F^A(t) + F^C(t) \tag{5}$$

An agent i decides its own direction of movement in the grid with roulette selection based on F_i. At each moment, a selection probability calculates a component of the resultant force between boid model and target direction. When the selection probability of each direction is lower than any threshold value, the agent increases a probability to stay there. The property of wearable navigation device is expressed as an internal parameter of agents.

3 Simulator Properties

In this section, we check the basic properties of the simulator described in 2.

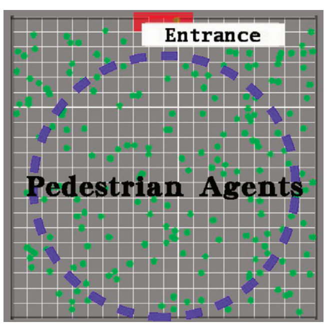


Figure 4: Pedestrians evacuating from a room with one door: Distribution of pedestrians, who can see the door.

3.1 Volume Effect

Since the simulator integrates excluded volume effect [5], it can represent an arch-like blocking (bridging) at an exit. The phenomenon is important for pedestrian simulation. We checked the volume effect of the pedestrian flow.

The room size is 10m x 10m and the exit size is 1m as shown in Fig.4. N pedestrians attempting to leave a one-door square room. Pedestrians are initially placed randomly in the room. As the pedestrians move toward the exit, the arching behavior near the exit can be observed as shown in Fig.5.

The calculation results of the proposed model reflects the volume effect of the social force model.

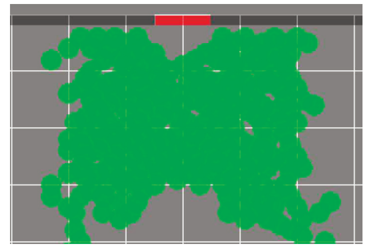


Figure 5: Arching and clogging at exit are observed: People stack near exit, because physical interactions in jams can build up in high density.

3.2 The relationship with crowd flow and entrance width

Since the speed of crowd flow decreases with an increase in density around the exit, the evacuation time decreases as the exit width increases. We checked the characteristics by the evacuation simulations. In the simulations, the number of the pedestrians N changes from 10 to 300 and the entrance width W changes from 1 m to 3 m. Fig.6 shows that the average time changes according to both N and W. The average time increases as W decreases. The narrow entrance, which width is 1 m suddenly rises the average time when more than 70 pedestrians in the room. The arching phenomenon can explain the rapid rise of the average time. The simulator qualitatively emulated the volume effect, which causes this result. The validity of the simulator was partially confirmed by this result.

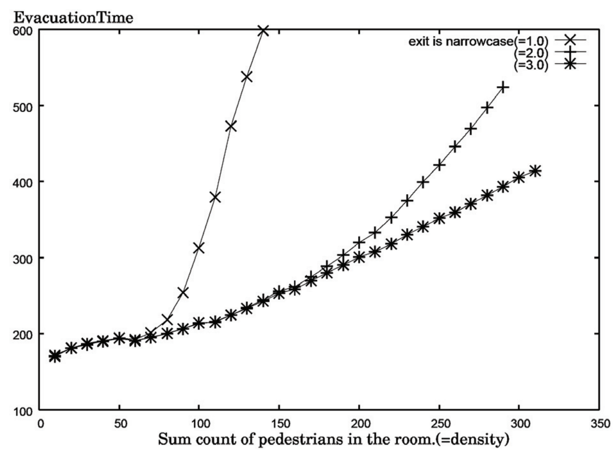


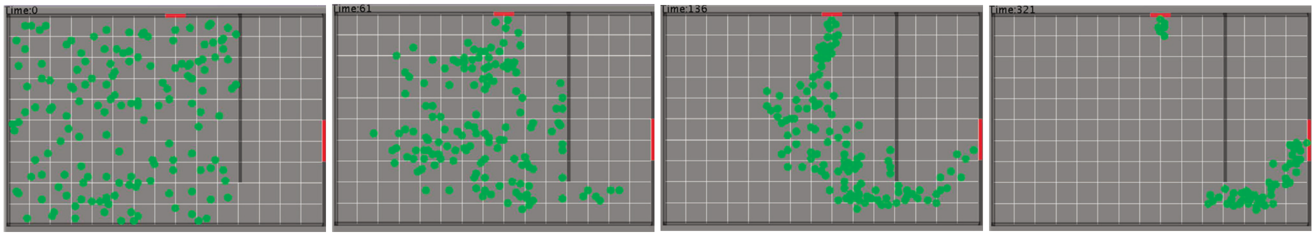
Figure 6: The average time of evacuation depending on entrance width: There are entrances, which are two types of width W. the narrow(W = 1.0) and the wide (W = 2.0, 3.0). The narrow line increased exponentially earlier than the wide line.

4 Preliminary Evacuation Simulations

In order to evaluate the effectiveness of the wearable navigation devices for personal navigation, two preliminary simulations were conducted in this paper.

4.1 Effect of Exit Selection

The first simulation aims to evaluate the effect of instruction in the evacuation. The experimental environment is shown in Fig.7. Usually, there are some designated escape routes at any place (buildings, parks, etc.). There are two exit, Exit A and Exit B in the room. All pedestrians in the room can find Exit A, which is narrow, and some pedestrians can see Exit B, which is wide. Exit A has a



a) initial state | b) 61 simulation steps | c) 136 simulation steps | d) 321 simulation steps

Figure 8: Screen-shoots of evacuation simulation

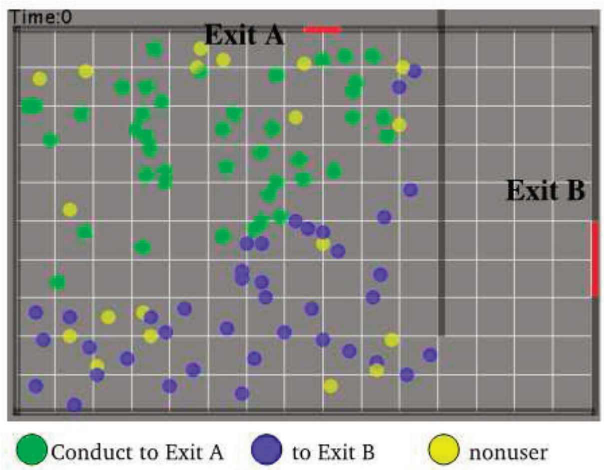


Figure 7: Simulation Field: Field size is 10m x 15m. This situation has two possible escapes: Exit A and B. Exit A is narrow, but is known by all pedestrians. Exit B is wide, but not all pedestrians may know its existence.

tendency to be clogged. All pedestrians receive an instruction that shows an escape pathway. The escape pathway, which is given to one pedestrian approximates the shortest pathway from him/her to one exit. The pedestrian who has shorter escape pathway to Exit B has a tendency to be instructed to move to Exit B. In the simulations, we changed the ratio of the pedestrians, who is instructed to use Exit B. Let α be the ratio. Fig.8 shows the screenshot of one evacuation trial.

All the following experimental results are the average of 1000 trials. 50 initial status of the pedestrians were generated randomly. 20 simulation trials are conducted from each initial status of the pedestrians.

Fig.9 shows the change of the average time of evacuation according to α. The vertical bar of the graph represents the simulation steps corresponding to the time of evacuation. It can be seen that there is an optimal point of efficient evacuation time around $\alpha = 0.5$. Fig.10 shows the ratio of escape completion until a certainly time (= 1500 simulation steps). The clogging happens with large α as well as small α. However, the clogging with large α is relatively small since Exit B is wider than Exit A. Therefore, the escape pathway to Exit B is a tolerant pathway. When N is smaller than 250 and α satisfies $0.4 < \alpha < 0.7$, the ratio of the successful evacuation nearly equals 1. Almost all the pedestrian successfully escape from the room in the emergency. The best value of α exists between 0.5 and 0.6.

4.2 Effectiveness of Wearable Navigation Devices

It is not realistic to assume that all people would have their own wearable navigation devices in case of an emergency. Therefore, we conducted the second simulation to investigate the relationship between the average time of evacuation and the percentage of the pedestrians, who have the wearable navigation devices.

Initially, N pedestrians are distributed randomly. All pedestrians try to leave a room. There are two groups of agent: (1) first type of pedestrians, who have the devices and (2) second type of pedestrians, who have no wearable navigation device. The first type of the pedestrians have support from the navigation system. They will leave the room through the instructed pathways. The other pedestrians, who have no wearable device will leave the room through the nearest door or follow other pedestrians as described in 2.3.2.

As the ratio of the wearable navigation device users increases, the wearable device users who are instructed to move to Exit B increases. Green circles in Fig.7 represent one group of the wearable device users, who are instructed to move to Exit A. Blue circles in Fig.7 represent the other group of the wearable device users, who are instructed to move to Exit B. Yellow circles in Fig.7 represent the other pedestrians, who have no wearble device. Snapshots of one simulation traial is shown in Fig.11.

Fig.12, and Fig.13 show the result of simulation experiment, where the horizontal axis is the ratio of the pedestrians, who use the wearable devices. In Fig.12, the vertical axis is the average time of evacuation. The vertical is the ratio of escapes completed in Fig.13. All the experimental results are the average of 1000 trials as described in the previous section. The average time of evacuation decreases according to increase of the users of the wearable navigation devices. And the ratio of escapes complete is 100% when the percentage of the users is over 30%. When 30% of pedestrians use the navigation system, the secure evacuation is realized in the simulation case.

These results indicate that the wearable navigation devices are effective, when certain percentage of pedestrians use the devices. It should be noted that the devices are effective even when the devices is used by some pedestrians, not all the pedestrians. The nature of the boid model, which encourages pedestrians to flock caused the result.

5 Conclusion

We proposed and developed wearable navigation systems for management of crowd behavior (crowd control) in case of an emergency. In order to perform navigation system studies, we have designed and developed a pedestrian dynamics simulator. In this paper, the simulator is illustrated. By using the simulator, the effectiveness of the wearable devices are evaluated. In one simulated case, the evacuation is successful when the wearable device is used by over 30% of the crowd. We verified that the wearable navigation devices has a potential to handle the crowd control.

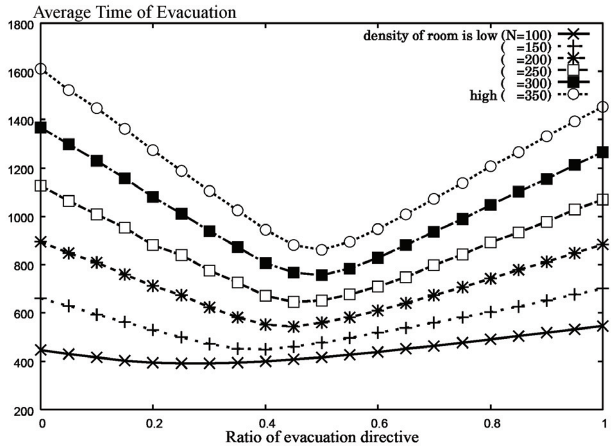


Figure 9: The average time of evacuation: Each line is different density of agents $N = \{100, 150, 200, 250, 300, 350\}$. The x-axis is the ratio of pedestrians α, who leave via Exit B. The y-axis is the average time of evacuation of all pedestrians. When α is around 0.5, all pedestrians escape efficiently.

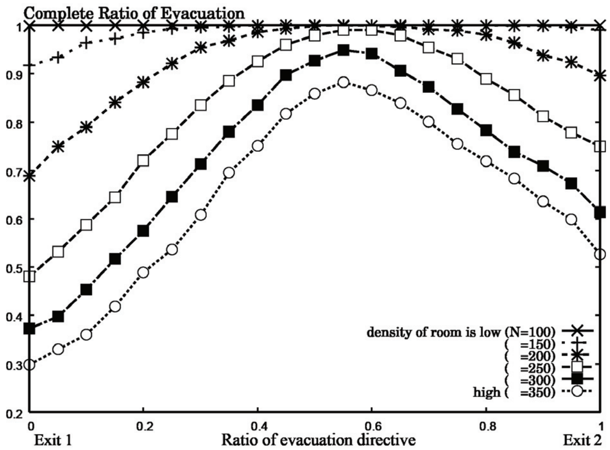
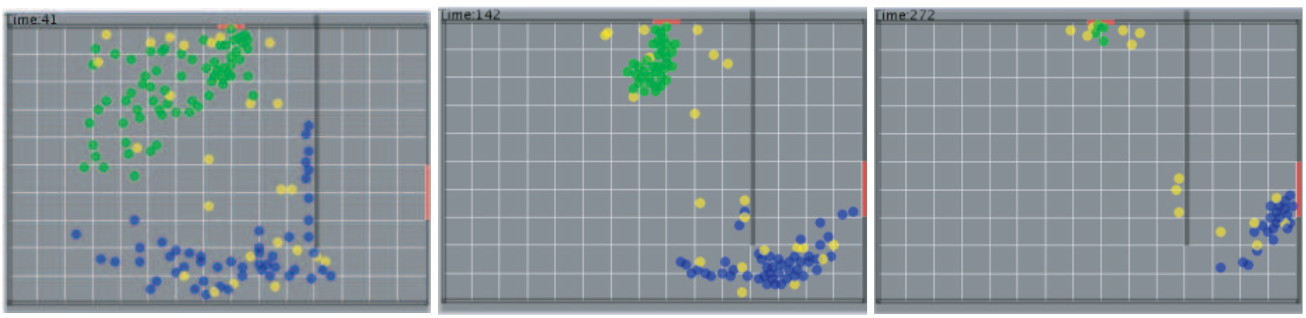


Figure 10: The ratio of escape completion: Each line is different density of agents $N = \{100, 150, 200, 250, 300, 350\}$. The x-axis is the ratio of pedestrians α, who leave via Exit B. The y-axis is the ratio of pedestrians who complete the evacuation by certain counts(= 2000 steps).



a) after simulation started

b) Pedestrians via separate exit

c) before simulation finish

Figure 11: Screen-shots of the pedestrian dynamic simulation

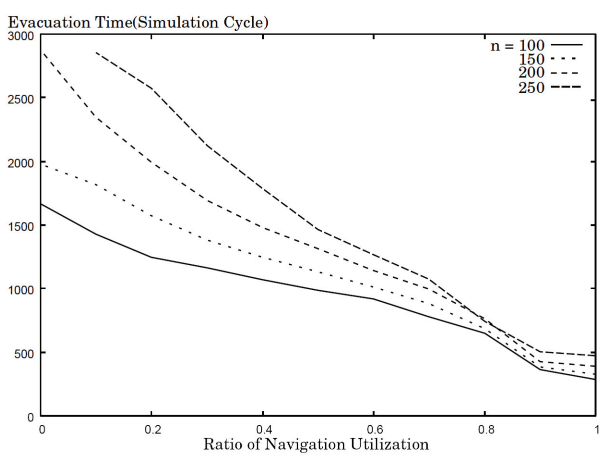


Figure 12: The average time of evacuation. Each line is different density of agents $N = \{100, 150, 200, 250\}$. The x-axis is the ratio of navigation utilization. When all pedestrians are provided the support from navigation system, the average time of evacuation decreases.

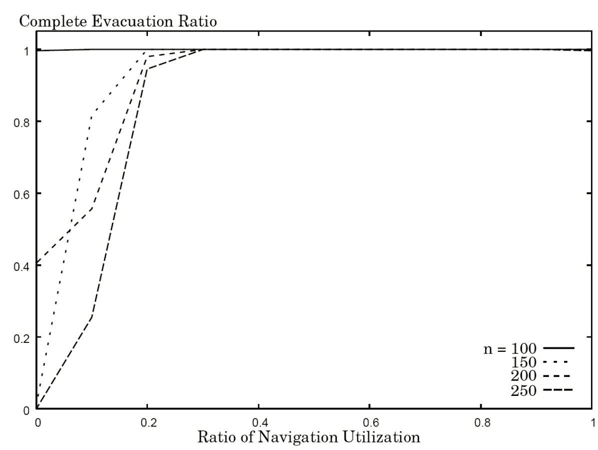


Figure 13: The ratio of complete evacuation. Each line is different density of agents $N = \{100, 150, 200, 250\}$. The x-axis is the ratio of navigation utilization. When N is 100, all pedestrians finish the escape action completely. In Other conditions, when the system utilization is over 30%, all pedestrians may finish escape action completely.

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