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Crowd evacuation simulation using active route choice model based on human characteristics

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ABSTRACT

Modern buildings have become larger in scale and function, and the complexity has also increased considerably. For these reasons, there are more difficulties in evacuation and rescue when an emergency occurs, so effective evacuation methods and risk should be predicted and applied to building design, safety training, and education. We have developed an active route choice model based on human body organs and characteristics that detects risks and route conditions, communicates with neighboring occupants, determines the bottleneck point, and selects evacuation routes according to each occupant's personal characteristics. In this study, we introduce the implementation process and characteristics of the active route choice model, and by applying the model to the occupants, we compared the evacuation times according to the route condition, number of occupants, and corridor width in a virtual environment. We believe that realistic and valid results can be obtained by applying the active route choice model in crowd evacuation simulation.

1. Introduction

Most buildings and structures have increased in size and complexity because of industrialization, specialization, and diversification of functions. This phenomenon is expected to accelerate [1]. As buildings change, the risk of disasters, such as an unexpectedly large fire or earthquake, increases, and the evacuation time is delayed as evacuation routes become complicated. Especially, large structures, such as passenger ships, subways, schools, and hospitals, that accommodate many people are more difficult to evacuate safely, and large-scale casualties are a concern when a disaster occurs. Because of these problems and the increased interest in safety in recent years, performance-based design based on engineering tools and research is being implemented to achieve safety performance from prescriptive design, only implemented as a regulation in guidelines and standards. Performance-based design methods include analysis of the evacuation and safety of occupants using evacuation simulations to plan and design buildings or to remove and minimize risk factors for existing buildings. Simulation methods can describe various disaster situations that are impossible in theory or experimental methods, and there is considerable potential for improvement in accuracy. However, simulations based on human body organs and characteristics are still lacking. In this research, we developed an active route choice model that reflects human characteristics and senses to develop a more accurate and realistic crowd evacuation simulation. The active route choice model based on an agent-based method uses human behavior algorithms and aspects of human sensory organs, implemented through computer graphics techniques, to decide the route of each occupant for evacuation by recognizing risk factors and the current route conditions. Applying the active route choice model to the occupants, we compared the evacuation times according to the route condition, the number of occupants, and the corridor width in a virtual environment. If the implementation process and results of this study are

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applied to other buildings and structures, it should be possible to design a building with high reliability in terms of safety by confirming the evacuation performance and by correcting and supplementing the bottleneck point. In addition, it should be possible to minimize casualties in the event of a real disaster by knowing in advance the optimum measures about the accident scenarios.

2. Related works

Most analyses of evacuation in an emergency in 1970s focused on fires in buildings and structures, and this work developed to apply and combine the crowd simulation technology that started in the field of computer graphics in the 1980s [14]. Depending on how the person expresses the movable area and the characteristic, crowd simulation can be divided into flow-based, cellular automata, agent-based, and activity-based simulation [12]. The flow-based method is similar to the continuum equation of fluid mechanics. It defines and connects each point to a node and analyzes the time taken to travel between the points. The flow-based method assumes that all occupants have the same characteristics, so that it is possible to calculate quickly and simply. However, there is a limitation in terms of reflecting the occupant's position and individual characteristics. The cellular automata method represents a movable region as cells in a grid structure. It is possible to calculate relatively quickly and obtain more accurate results compared with the flow-based method. The agent-based method can reflect the characteristics of each occupant and accurately indicate the position in a movable coordinate system. The disadvantage is that the calculation amount is large, and the calculation time is long. In recent crowd simulations, an activity-based method for expressing behavior in specific situations was added to existing methods. Basically, an evacuation simulation analyzes and defines human behavior in an emergency and then converts it into a computer algorithm. For this purpose, existing evacuation simulation research is based on the cohesion, separation, and alignment of flock behavior to describe human walking speed, collision avoidance, and crowd behavior and to focus on finding the shortest evacuation route. In recent years, evacuation simulation research has attempted to search for the shortest-time route, the optimal route, and the safety route to reflect human characteristics more accurately and obtain more realistic and valid results. As an example of real-time route search, in [6], the occupant selected another route only if changing the route enabled one to reach the target point faster than by using the current route. Pereira et al. [9] studied the bottleneck phenomenon when the moving speed of the occupant is 0 and when the probabilistically determined occupants selected different routes. Liu et al. [7] developed a dynamic obstacle method. The dynamic obstacle method removes the hazardous route so that all occupants using that route select a different route. Providing an example of non-real-time route search, Han et al. [3] provided the optimal route to each occupant by repeatedly calculating the distance and length of the route, the degree of the bottleneck caused by the occupant, and the size of the exit about all routes before the simulation started. Wong et al. [17] simulated the optimal route by using crowd distribution, exit locations, and corridor widths as variables. Much research has been carried out to obtain the optimal path and reflect human characteristics. However, there are still many limitations and physical contradictions in reflecting human characteristics in the calculation process and algorithm. The limitations of existing research are that it assumes that the dangerous or impassable routes are recognized by the occupant before the simulation starts. Through this, the optimal route is given to occupants, and all occupants in the simulation automatically detect the path condition by removing the dangerous or impassable routes without a confirmation process for the occupants. In detecting bottlenecks and selecting other routes, a specific space chose the occupants stochastically, and selected occupants were forced to choose other routes instead of changing the routes judged by the occupants themselves. In addition, the arrival times of occupants when maintaining the current route were compared with arrival times when changing the route. The route was only changed when the time to reach the arrival point was less than the time to keep the current route. These methods are examples of contradictions to reality, and it is impossible to describe situations in which occupants must change their route when a route is unavailable because of a fire or an earthquake. In this research, we have developed the active route choice model for crowd evacuation simulation. It minimizes the physical contradiction by reflecting the human characteristics based on the human senses of the occupant. Table 1 compares the main features of this research and previous research.

Here, we implemented an evacuation simulation by applying the active route choice model using the UNITY platform [15] and C# programming language. UNITY is a game development platform that has high visualization quality and freedom to express various physical characteristics and disaster situations. It is impossible to test an emergency situation on a real scale. Therefore, in most cases,

Table 1
Technical comparison of previous works with this research.

		KEMLOH [6]	Pereira [9]	Han [3]	Liu [7]	This research
Base		Cellular automata	Cellular automata	Cellular automata	Agent-based	Agent-based
Route		Quickest route	Alternative route	Optimized route	Alternative route	Alternative route
Real-time		○	○	×	○	○
Method		Cost benefit comparison	Select randomly	Route set comparison	Dynamic obstacle	Active route choice model
Perception	Human organs	×	×	×	×	Perception
	Simulation	$\|\vec{v}(t)\|\leq v_{min}$	$\|\vec{v}(t)\| = 0$	Comparison results	Unmovable	Ray-casting & Characteristic coefficient
Route change moment		Algorithm satisfaction	Probability distribution	Before simulation	Deletion of calculated path	Detection & sharing information
Decision maker		Bottleneck node	Bottleneck node	Navigation field	Navigation field	Individual agent
Range of application		Selected agent	Selected agent	Global (all agents)	Global (all agents)	Perceived agent