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Development of Simulation System for the Disaster Evacuation Based on Multi-Agent Model Using GIS

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Abstract: This paper presents a simulation system for the disaster evacuation based on multi-agent model considering geographical information. This system consists of three parts, the modeling for the land and buildings using GIS data, the analysis of disaster evacuation using multi-agent model, and the visualization for the numerical results using the virtual reality technique. By introducing the numerical solver of the natural disaster to the present system, it is possible to evaluate not only the damage of structure but also the damage of human being. Furthermore, it is possible to investigate the appropriate evacuation route by the simulation. The Dijkstra algorithm is used to obtain shortest route to the refuge. In addition, the visualization using virtual reality technique is curried out to understand the feeling of refugee. The present system is applied to the evacuation analysis by the flood flow in urban area and is shown to be a useful tool to investigate the damage by natural disasters.

Key words: multi-agent model; GIS; virtual reality; evacuation analysis; flood flow

Introduction

A number of natural disasters, such as earthquake, storm surge, Tsunami wave and the flood, etc, occur annually in various parts of the world. In order to estimate the extent of a disaster quantitatively, it is necessary to estimate the behavior of natural phenomena which cause the natural disaster. There have been presented a number of numerical methods to evaluate the damage by the natural disaster since the numerical simulation is one of the safe and cheap ways to investigate the damage by disaster. Recently, the numerical evacuation analysis is becoming popular to estimate the extent of the damage of human being[1-3]. In the evacuation analysis, it is very important to evaluate the evacuation behavior of the human being in the time during the disaster accurately. The evacuation behavior is strongly related to the circumstance, age, and sex of the refugees. The multi-agent model[4] is one of the techniques which can evaluate the evacuation behavior accurately.

This paper presents a simulation system for the disaster evacuation based on multi-agent model considering geographical information. This system consists of three parts, the modeling for the land and buildings using geographical information system (GIS) data, the analysis of disaster evacuation using multi-agent model, and the visualization for the numerical results using the virtual reality technique. By introducing the numerical solver of the natural disaster to the present system, it is possible to evaluate not only the damage of structure but also the damage of human being. Furthermore, it is possible to investigate the appropriate evacuation route by the simulation. The Dijkstra algorithm[5] is used to obtain shortest route to the refuge. In addition, the visualization using virtual reality technique is curried out to understand the feeling of refugee.

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2 Disaster Evacuation Simulation

2.1 Outline of disaster evacuation simulation

The simulation software based on multi-agent model is developed using the multi-agent simulator “artisoc” based on VBA and GUI. Figure 1 shows the screen of evacuation simulator. The user can change the data and parameter using the panel on screen. The main parameters are follows: the refuge cognitive ratio *K*, walking speed $V/(\mathrm{m\cdot s^{-1}})$, and the time to start the evacuation action *t*/min.

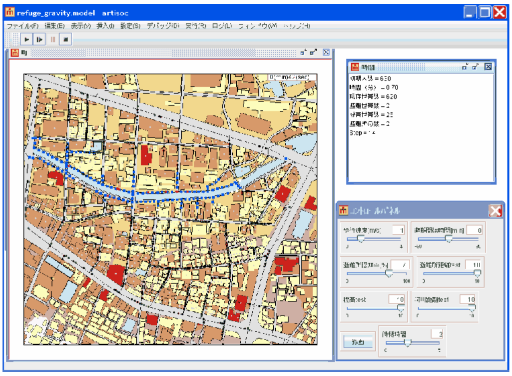


Fig. 1 Screen of evacuation simulator

2.2 Data origination of evacuation simulation

The input data for evacuation simulation are prepared by the process shown in Fig. 2.

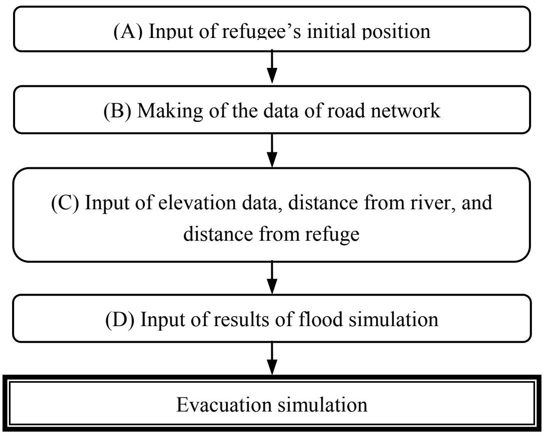


Fig. 2 Data preparation for evacuation simulation

(1) Input of refugee’s initial position (Flow A)

It is assumed that the refugees evacuate from inside the building and the initial positions of refugees are set to the center of gravity of the building as shown in Fig. 3. The dot marks denote the initial position of refugee. The unit of refugee is assumed as home-wise in this paper.

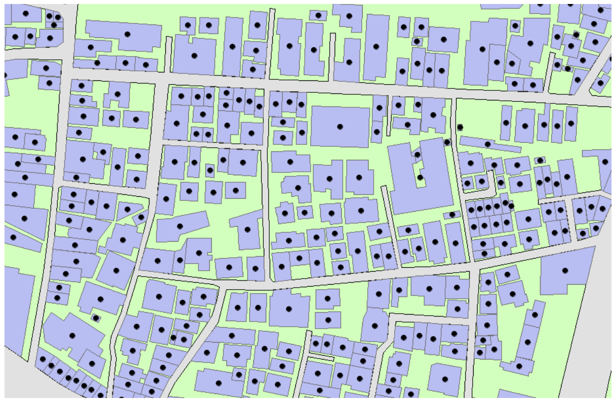


Fig. 3 Center of gravity point of building

(2) Making the data of road network (Flow B)

It is assumed that the refugee move on the centerline of road. Therefore, it is necessary to make the data of road network which consists of the road centerlines and the connecting points of road centerline.

In order to make the data of road network, the data of center lines and connecting nodes which are referred as intersection points are extracted from the GIS digital map 2500 (Geographical Survey Institute) and the maple 2500 (Shobun-sha). In the digital map, the road centerlines are included as polyline, and the intersection nodes included the edge point of polyline. Figure 4 shows the road netrork for the studied area. The road data from the center of gravity of the building to the nearest road point are also added.

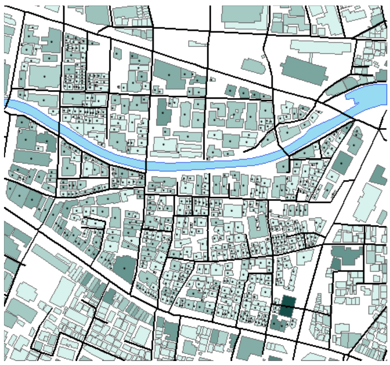


Fig. 4 Road network

Using the data of centerlines and interaction nodes, the road network which is used for the evacuation route is prepared. Figure 5 shows the example data. In this figure, the number without a square bracket denotes the intersection node number and the number with a square bracket denote the road centerline number. Table 1 shows the network data for the example. In this table, node IP is the intersection node number, NIP is the number of intersection points, p_1-p_4 denote the intersection point associated with node IP.

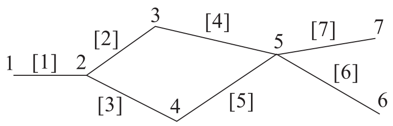


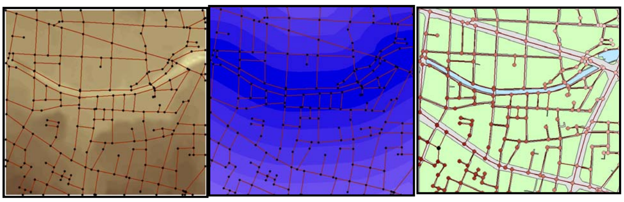
Fig. 5 Example of the road network

Table 1 Data structure for example

IP	NID	p_1	p_2	p_3	p_4	p_5	…
1	1	2					
2	3	1	3	4			
3	2	2	5				
4	2	2	5				
5	4	3	4	6	7		
6	1	5					
7	1	4					

(3) Input data for elevation, distance from river and refuge (Flow C)

For the evacuation analysis, the data for elevation, distance from river and refuge are needed at every intersection node. The elevation data is prepared by the interpolation using the digital elevation map (Geographical Survey Institute). The distance from river is computed by using the analytical function of ArcGIS from the polygon data of the river in maple 2500. The distance from refuge is obtained by the computation of distance between intersection nodes and refuge points along the road. The shortest route is obtained by the Dijkstra algorithm[5]. Figure 6 shows the distribution of three variables.



Elevation Distance from river Distance from refuge

Fig. 6 GIS data for intersection nodes

(4) Input data for flood simulation result (Flow D)

The new nodes are generated on the road center line at constant intervals. Before the evacuation analysis, the unsteady water depth and velocity are evaluated and stored at every node using the flood simulation data. As the flood simulation is performed by triangular mesh, the water depth and velocity are evaluated by the linear interpolation using the area coordinate of triangular mesh.

The refugee's action status can be classified into three patterns as shown in Table 2 according to the water depth and flow velocity. Figure 7 shows the relationship between flood status and refugee's status. In this figure, the region *A* denotes the status that the refugee can evacuate safely (Class 2 in Table 2) but the evacuation speed is reduced by half, and region *B* denotes the status that the refugee can not evacuate safely (Class 3 in Table 2) and evacuation speed is assumed to be zero.

Table 2 Categories of refugee's status according to flood status

Class	Flood status	Refugee's status
1	Water depth is 0 (m)	No influence ($Ve = V$)
2	Region *A* in Fig. 7	Speed reduced by half ($Ve = V/2$)
3	Region *B* in Fig. 7	Victim ($Ve = 0$)

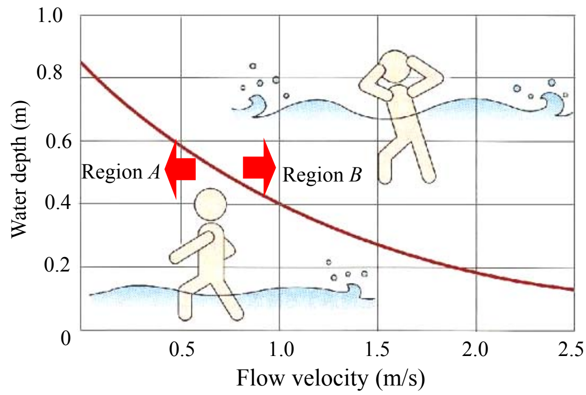


Fig. 7 Relationship between flood and refugee's status[6]

3 Evacuation Simulation

The judgment of refugee's route performs when the refugee arrives at the intersection node, and refugee compares the data of the neighbor intersection nodes on elevation, distance from river and refuge. For the evacuation model, the gravity model is employed as

$$S = \frac{a}{s^{\alpha}} - \frac{b}{r^{\beta}} - \frac{c}{z^{\gamma}}$$

where S is the distance from refuge, m; r is the distance from river flooded, m; z is the elevation of intersection node, m; α, β, and γ are the weighting coefficient for three important factors, respectively. The evacuation route is decided to the direction of intersection node which has the highest value of S.

4 Visualization and Animation

The results of evacuation analysis are shown by the 3-D CG image and animation using the virtual reality technique. In order to prepare the 3D CG and animation, it is necessary to use the following three different data; 3D CAD data for land and buildings, the unsteady refugee data (position of refugee), and flood data (water depth and velocity) are prepared.

The 3D CG image is made by POV-Ray[7] by using those data (Fig. 8). Two animations are made in this example: one is the bird view animation to be able to observe the behavior of the refugee and the appearance of the flood, the other is the animation from the eye-view point of refugee to understand the feeling of refugee.

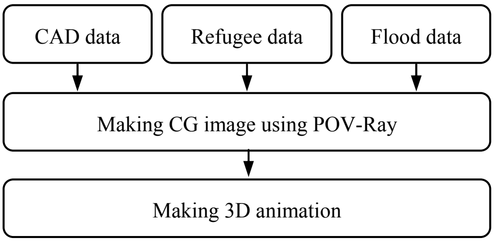


Fig. 8 Procedure of making to 3D animation

(1) Conversion of CAD data

The CAD data for landform and building is shown in Fig. 9. The file format is changed to that for POV-Ray using PoseRay, which is the data exchange software (Fig. 10). The texture can be set to the layer-wise of CAD data.

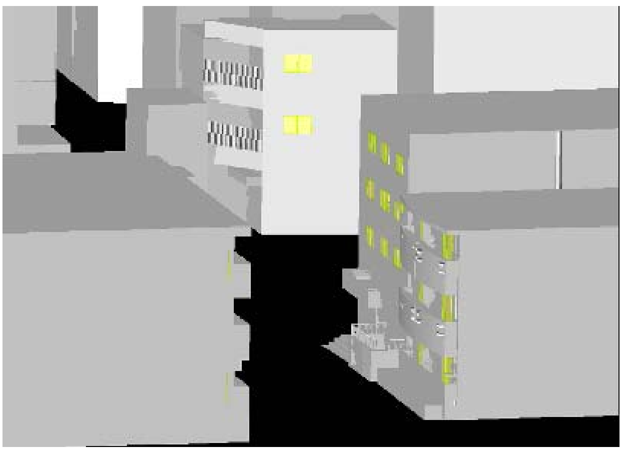


Fig. 9 CAD data of structure

(2) Conversion of refugee data

The position of refugee can be obtained by the evacuation simulation. The file data is also changed to that for POV-Ray.

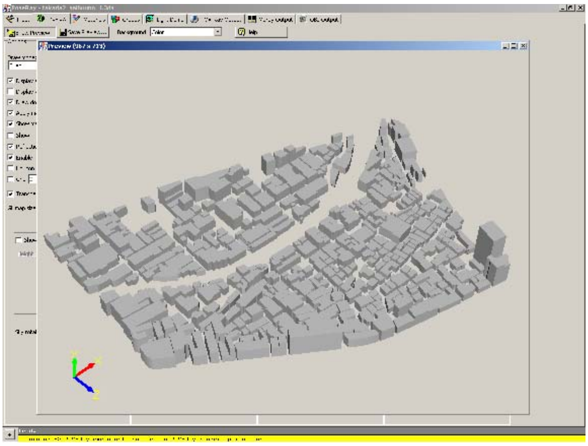


Fig. 10 PoseRay

(3) Conversion of flood data

The numerical simulation is performed by the triangular finite element mesh. The file format of the mesh data and the computed results (nodal water depth and velocity) at each time levels are changed to the format for POV-Ray.

(4) Making of CG image and animation

The CG image is made by POV-Ray using the three different data (CAD, refugee, flood) at each time level. The animation is made by using the CG image.

5 Application Example

5.1 Simulation condition

The present method is applied to the evacuation simulation by flood disaster in urban area. Figure 11 shows the simulation area (570 m×530 m) which is around Takadanobaba in Shinjuku Ward, Tokyo. Figure 12 shows the satellite image of the simulation area. The flood simulation is performed by the stabilized finite element simulation based on SUPG method[8]. The shallow water equation is employed for the governing equation.

For the evacuation simulation condition, the walking speed V is 1 m/s, the refuge cognitive ratio K is 100%, and the number refugee are 630 houses. The parameter in the route selection model is assumed as; α, β, $\gamma = 1$, a, b, $c = 10\,000$. The time to start the evacuation action t is assumed from -3 min to 3 min at interval 1 min. The negative sign means that the evacuation action starts before occurring flood at this area.

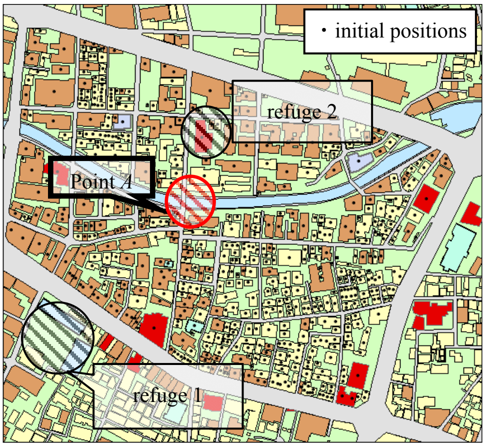


Fig. 11 Simulation area

Fig. 12 Satellite image

5.2 Simulation results

The simulation results are shown in Figs. 13 and 14. Figure 13 shows the number of victims versus the time to start evacuation action. From this figure, it can be seen that the number of victims are increased in accordance with the time delay to start the evacuation action.

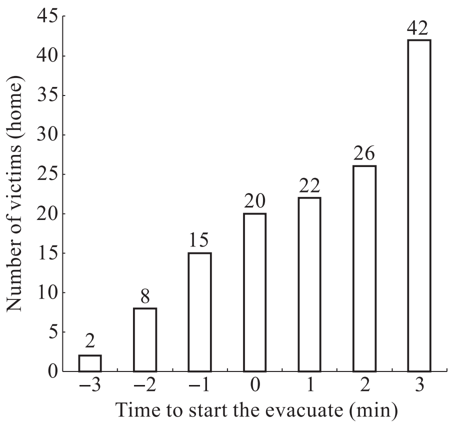


Fig. 13 Simulation results

Figure 14 shows time history of the number of victims in case of the time to start evacuation action is assumed to be 0 min. From this figure, it can be seen that the water depth and velocity increased within first 1-2 min and the victims are increased during this period. In addition, a number of victims are occurred around the bridge of the northwest (Point *A* in Fig.11) from the evacuation simulation, because the evacuation route is limited around the bridge.

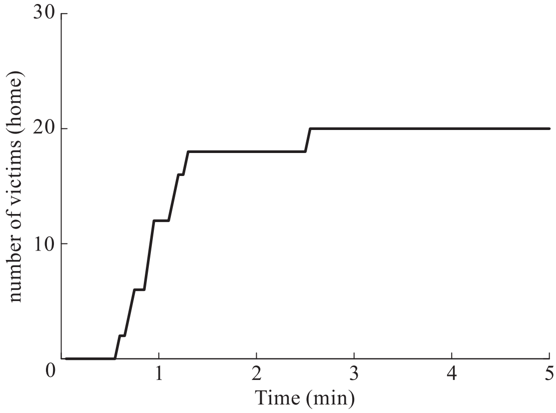


Fig. 14 Time history of number of victims ($T = 0$ min)

5.3 3D visualization

The computed results are shown by 3D animation using the CG image created by POV-Ray. Figure 15 shows the bird view for the evacuation analysis. In this animation, the refugee can be expressed by a sphere. Figures 16 and 17 show the eye-view from a refugee before and after the occurrence of flood. It can be seen that the user can understand the feeling of refugee from the eye-view animation of refugee.

Fig. 15 Bird view

Fig. 16 Eye-view from refugee (Before flood)

Fig. 17 Eye-view from refugee (After flood)

6 Conclusions

This paper has been presented the simulation method for the disaster evacuation based on multi-agent model considering geographical information. The following conclusions have been obtained.

(1) The input data related to geographical information has been prepared accurately by using the several GIS data. The user can input the other input data needed for evacuation simulation by using GUI easily.

(2) The evacuation model based on gravity model has been employed. It is possible to evaluate not only the damage of structure but also the damage of human being.

(3) By using the visualization based on virtual technique, the high quality CG image has been created. From this, the user can understand the feeling of refugee.

The verification and modification of the evacuation model are left for the future work.

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