DEVELOPMENT OF A SIMULATION METHOD FOR EVACUATION BY WHEELCHAIR USING DISTINCT ELEMENT METHOD

Fusanori MIURA[1], Koichi TAKIMOTO[2] And Masahiro KUBODERA[3]

SUMMARY

The purpose of this study is to develop a simulation method for evacuation by a wheelchair using Distinct Element Method and to evaluate the effectiveness of it. In order to develop it, fundamental experiments were first performed to obtain the parameters such as velocity, acceleration, etc. during evacuation, which govern the evacuation behavior by a wheelchair. In addition to this experiment, a wheelchair with driver was modelled by a Distinct Element. The Distinct Element parameters, such as magnitude of elements, spring constants damping were determined. After developing the simulation, it was tried to simulate evacuation behavior in an actual house. It was found that by using motion governing parameters obtained from fundamental evacuation experiments and introducing a psychological Personal Space, one could simulate evacuation behavior in an actual house with good accuracy.

INTRODUCTION

The 1995 Hanshin-Awaji earthquake in Japan killed more than 5,000 people. Especially, high percentage of casualties was the aged and the disabled. It is very difficult for the aged and the disabled to evacuate quickly from their houses that have complex indoor structures in earthquake disasters because the exercise ability of them is inferior to the person who is not physically handicapped. Many researchers have developed a computational simulation model for evacuation in an emergency. Kiyono et al. applied Distinct Element Method that is a technique for the collapse simulation of the structure to simulate method of evacuation regarding a human body as a Distinct Element [1]. However, their model simulated evacuation of a person who is not physically handicapped.

The study aims to develop a new simulation model for evacuation behavior by a wheelchair using Distinct Element Method. By using proposed simulation model, we can examine the dangerous sections or points in a house or a building for wheelchair users. This paper presents summary of development of the simulation model for evacuation and evaluation of the effectiveness of it

SUMMARY OF SIMULATION MODEL FOR EVACUATION

In this study, simulation model for evacuation behavior by the wheelchair was developed referring to the model of Kiyono's research. The outline of simulation model is explained as follows.

[1] *Symbiotic Environmental Systems Engineering, Yamaguchi University Ube, Japan Email: miura@earth.csse.yamaguchi-u.ac.jp*
[2] *Dept of Computer Science and Systems Eng, Yamaguchi University, Japan Email: takimoto@earth.csse.yamaguchi-u.ac.jp*
[3] *CSK Co., Ltd., Tokyo, Japan*

Modelling of Wheelchair:

Prior to the development of the simulation model, the weight and the size of wheelchairs were measured as shown in Figure 1. The result of measurements is listed in Table 1. Using this result, a wheelchair with driver is modelled by a Distinct Element as shown in Figure 2. It consists of circular elements and a pair of spring and dashpot. These springs represent the elasticity of the wheelchair and Personal Space which is described later. The former is calculated by the strength of wheelchairs and the latter is calculated by fundamental experiments.

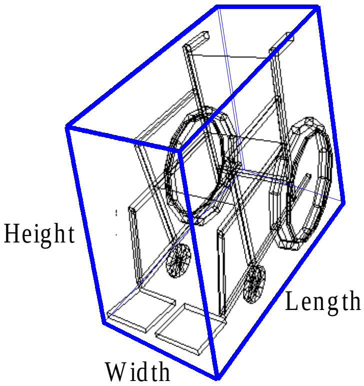
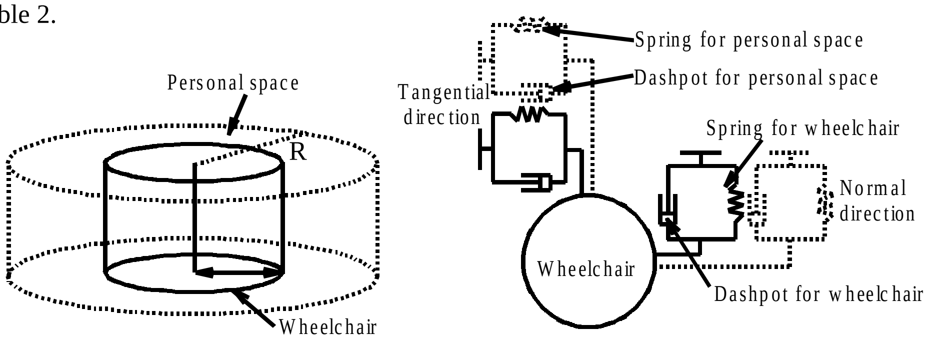


Figure 1: Wheelchair to bb measured

Table 1: Result of the measurement

Length(m)	1.02
Width(m)	0.63
Height(m)	0.94
Volume(m^2)	0.52
Weight(kgf)	19.0
Unit weight (kgf/m^3)	40.2

A new concept of Personal Space with fictitious spring constant and damping factor was introduced in the simulation. Sommer advocated Personal Space that was a kind of psychological border [2]. If Personal Space within which an object such as others or wall enters, the Distinct Element starts to go away from the object. We investigated the radius and spring constant of wheelchair drivers' Personal Space by referring to Tatebe's experiment [3]. As the result, the Distinct Element parameters such as spring constant and damping factor are shown in Table 2.



(a) Wheelchair model **(b) Distinct Element**

Figure 1: Wheelchair model by Distinct Elements

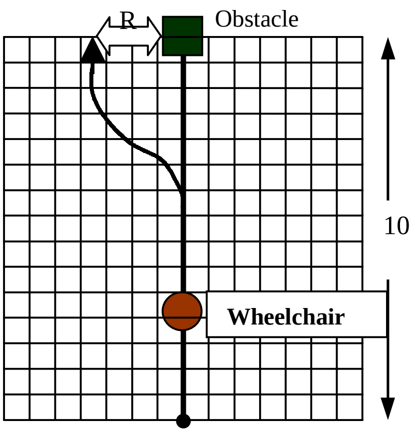


Figure 2: Measurement of Personal Space

Table 2: Result of spring constant and damping factor

Spring constant of wheelchair k_n (N/m) (Normal direction)	20,000
Damping factor of wheelchair c_n (Ns/m) (Normal direction)	1,793.3
Spring constant of wheelchair k_t (N/m) (Tangential direction)	1,000
Damping factor of wheelchair c_t (Ns/m) (Tangential direction)	89.7
Spring constant of personal space $k_{n'}$ (N/m) (Normal direction)	260.1
Damping factor of personal space $c_{n'}$ (Ns/m) (Normal direction)	13.0
Spring constant ofpersonal space $k_{t'}$ (N/m) (Tangential direction)	177.1
Damping factor of personal space $c_{t'}$ (Ns/m) (Tangential direction)	39.5

Determination of Governing Parameters of Motion:

To perform fundamental parametric evacuation experiments by wheelchair, as shown in Figure 3 a simple straight passageway and passageway with right angle corner with different widths were used. The governing parameters of motion were magnitude of velocity and acceleration, length of acceleration and deceleration, location of point where a wheelchair driver changes the direction after entering the corner. They were expressed as a function of the width of the passageway. Parameters were measured and calculated by using an accelerometer and a gyroscope sensor. However, the error occurred for the noise of the sensor in acceleration. Then, the error was corrected by checking with the video. The parameters decided from the experiment are as follows :

(a) Relation between widths of W1, W2 and maximum velocity of a wheelchair

(b) Relation between widths of W1, W2 and deceleration length before a wheelchair turns in a corner

(c) Minimum velocity in a corner

(d) Initial acceleration and acceleration in deceleration distances

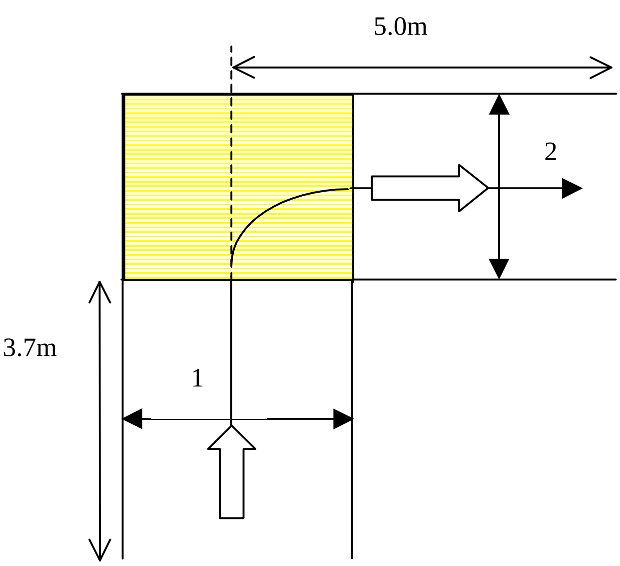


Figure 3: Passageway used in the experiment

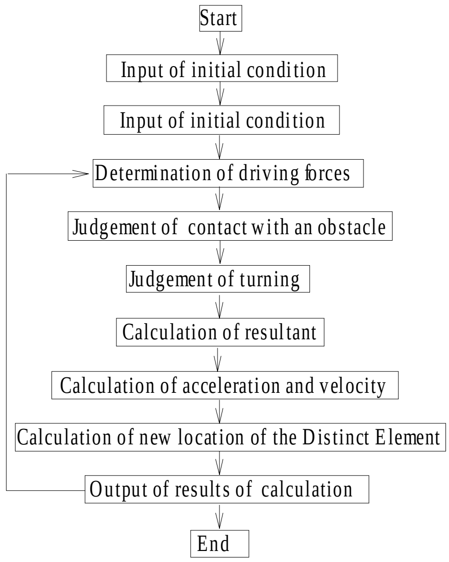


Figure 4: Flow of simulation

Procedure of simulation:

The flow of simulation is explained in Figure 4. Initial conditions such as initial location of a Distinct Element and shape of passageway are as input. After inputting data, driving force is given to the Distinct Element. By using these data, the motion of the wheelchair should be calculated according to equation of motion shown in equations (1) and (2) in each time step. If the Distinct Element turns in a corner of passageway as shown in Figure 3, it decelerates in front of the corner and accelerates again after turning in the corner. Deceleration function and acceleration function that were obtained by the fundamental experiment were then introduced in order to govern motion of the Distinct Element. In addition, we introduced centripetal force shown in equation (3) that was given the Distinct Element from the corner because it was difficult for the Distinct Element to turn repeatedly many corners in an actual house. Furthermore, the restriction was established at the lowest velocity so that the velocity of the Distinct Element may not decrease in order to be able to smoothly turns the corner.

$$m\ddot{\mu} + F \quad 0 \qquad (1)$$

$$F \quad F_1 + F_2 + F_3 + F_4 \qquad (2)$$

$$c\dot{\mu} + k\mu + F_3 + F_4$$

$$F_4 = m\frac{{v_t}^2}{R} \tag{3}$$

Where

m: Mass of the Distinct Element c: Damping factor k: Spring constant

μ : Displacement vector F_1: Force by contacting with other Distinct Element

F_2: Force by contacting with an obstacle F_3: Driving force F_4: Centripetal force in a corner

R: Distance from the corner to the Distinct Element v_t: Velocity of the Distinct Element

EVALUATION OF THE SIMULATION MODEL

Simulation of fundamental evacuation behaviors

By using parameters that was determined by the experiment, fundamental evacuation behavior patterns were first simulated in order to verify the simulation model. Then the same passageway which was used in the fundamental experiment in Figure 3 was simulated. Results of the relation between time to complete evacuation in each pattern are shown in Figure 5. Figure 5 shows that results of the simulation were close to that of observed evacuation behavior. Furthermore, typical locus of observed evacuation behavior and that of the simulation are shown in Figure 6. Figure 6 indicated that both of loci were almost same except for a small part of the curve. Considering these results, good agreement can be obtained with corresponding experiments.

Simulation of evacuation behavior in an actual house

By using the simulation model that we developed, we simulated evacuation behavior in *Ube Welfare-techno-house* that was an actual house. *Ube Welfare-techno-house* is house model that considers facilities for old people and needed-nursing person to live. Four evacuation routes in *Ube Welfare-techno-house* are shown in Figure7. In addition, we also performed evacuation experiments in *Ube Welfare-techno-house* in order to compare the result of the simulation.

The results of locus A that was obtained by the simulation are shown in Figure8. Figure 8(a) and 8(b) show comparison of locus of observed evacuation behavior by the experiment and that of the simulation. From these figures, both loci were different in turning of corners. Furthermore, time to complete evacuation is listed in Table 3. Table 3 shows that both results were also different. The reasons why the simulation were inadequate are as follows:

(1) Parameters that were obtained by the fundamental experiment were not suited to complex indoor structures such as actual houses.

(2) The locus of actual wheelchair drivers was different from that of the simulation as shown in Figure 9 if W1 was wide.

Therefore, the simulation model needs improvement from the viewpoint of motion of wheelchairs in a corner.

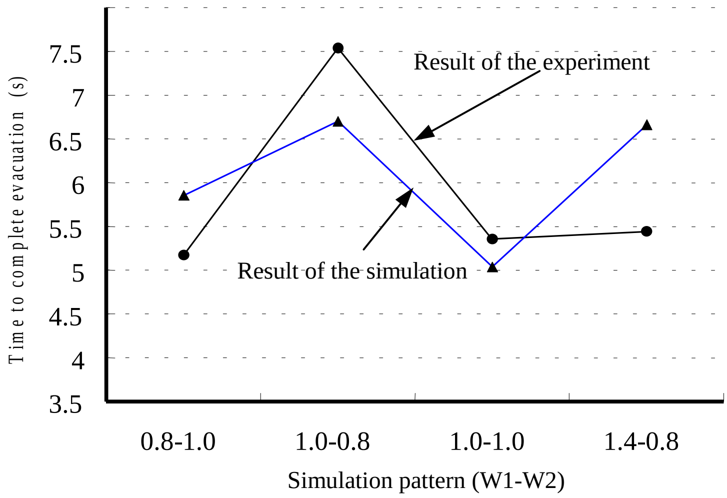
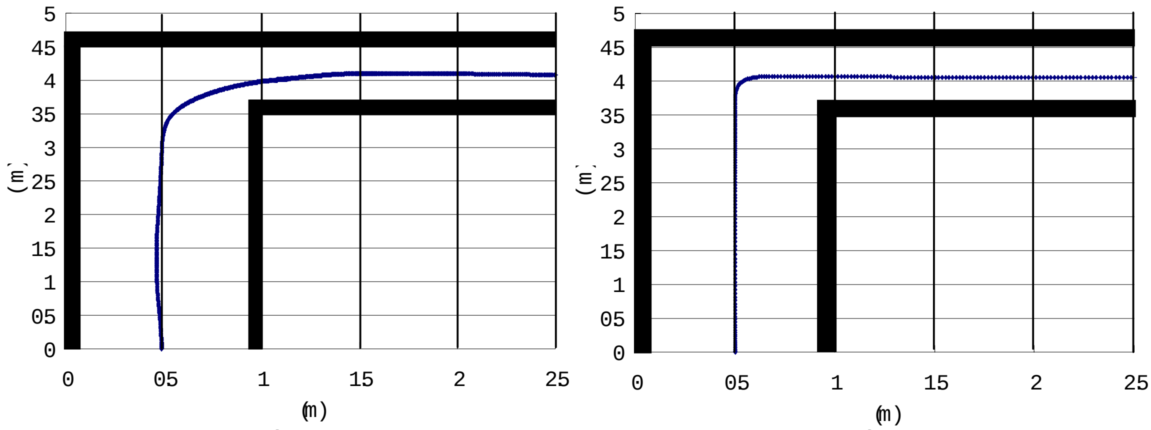


Figure 5: Results of the simulation and the experiment



(a) Result of the experiment **(b) Result of the simulation**

Figure 6: Comparison of locus

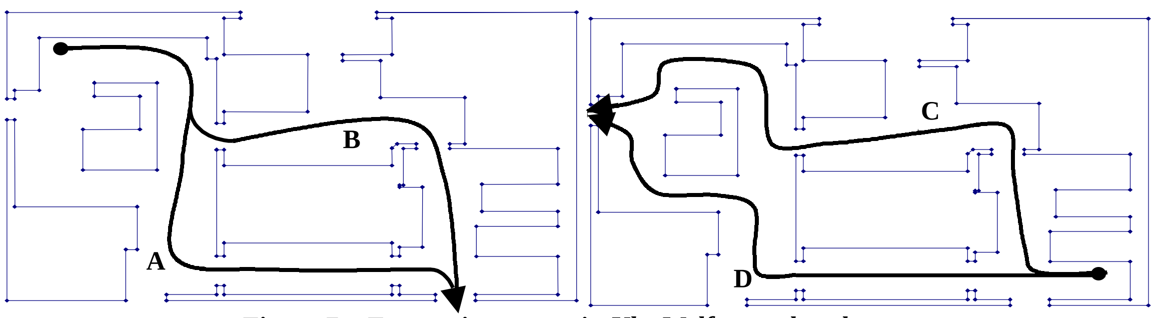
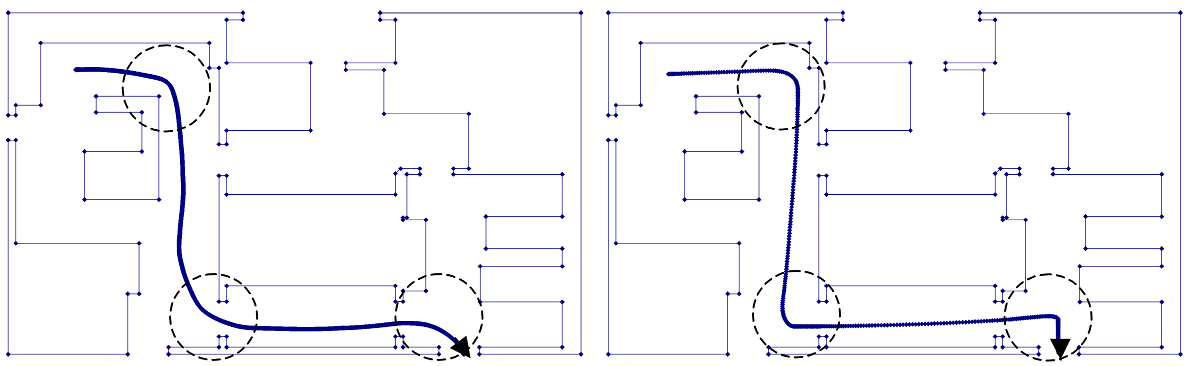


Figure 7: Evacuation routes in *Ube Welfare-techno-house*

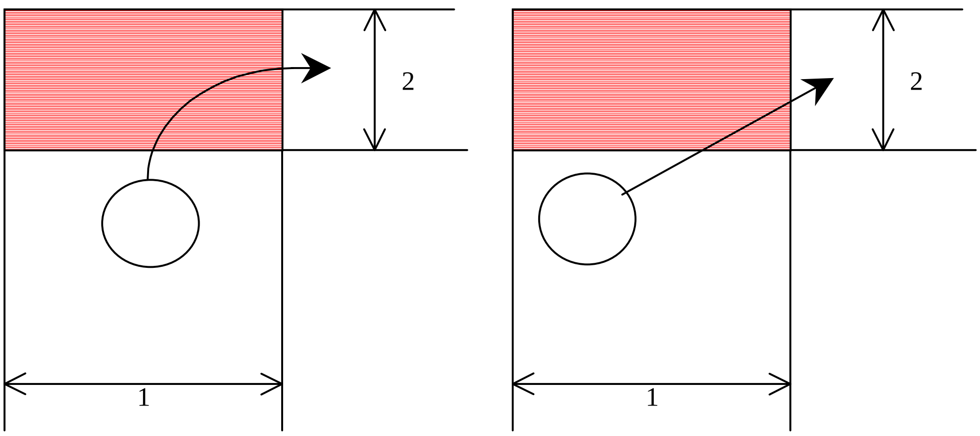


(a) Observed evacuation behavior **(b) Result of the simulation**

Figure 8: Comparison of locus

Table 3: Time to complete evacuation in each evacuation routes

	Evacuation routes			
	A	B	C	D
(a) Average of results of the experiment (sec)	14.87	15.26	19.67	13.82
(b) Standard deviation of results of the experiment	1.15	1.60	1.64	1.87
(c) Results of the simulation (sec)	17.43	18.69	21.70	17.43
(c) –(a) Error	2.56	3.43	2.03	3.61



(a) In case of the simulation **(b) In case of actual wheelchair drivers**

Figure 9: Difference between locus of the simulation and actual wheelchair drivers

CONCLUSION

In this study, the authors developed a simulation model for evacuation behavior by the wheelchair using Distinct Element Method. As a result, it was found that by using motion governing parameters obtained from fundamental evacuation experiments and introducing Personal Space, one could simulate evacuation behavior in an actual house with good accuracy. By using proposed simulation method, dangerous parts or points in a house, a building or an underground shopping center, etc. can be assessed. In addition, the method can give an answer to dissolve the dangerous area and to evaluate quantitatively the effectiveness of it. Finally, it is necessary to improve the motion of wheelchair in turning a corner in the simulation model.

REFERENCES

1. Kiyono, J., Takimoto, K. and Miura, F. (1996), “Simulation of emergency evacuation behaviour during disaster by using Distinct Element Method”, Proc. of JSCE, no.537/I-35, pp.234-235.

2. Sommer, R (1972), “Personal Space: The Behavioral Basis of Design”.

3. Tatebe, K. and Nkajima, H. (1990), “Avoidance behavior against a stationary obstacle under signal walking –A study on pedestrian behavior of avoiding obstacles (I)- ”, Journal of Archit., No118, pp.51-52.