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On the Modeling and Simulation of the Walking Behavior

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Abstracts : We propose a mathematical model which describes the walking behavior of a person and to analyze the effect of the personality on the dynamics of the crowd. The fundamental assumption is that the human behavior is not a random process but a deterministic process with several basic mechanisms and each fundamental mechanism is common and only the parameter is different from person to person. The proposed model is based on the servomechanism which drives a person along the planned path from point to point.

This model has been applied to simulate the walks of people in a crowd and the simulated results have a good coincidence with actual measurement.

Key word : modeling, simulation, walking behavior, movement, individuality, servomechanism

1 INTRODUCTION

The model which describes human behavior is useful for the plan of building and the prediction of movement during rush hour or of evacuation, and fire. There have been many psychological and qualitative studies to clarify the mechanisms of human behaviors based on the field data[9]. And recently some mathematical models have been proposed from the engineering fields. There are several types of the mathematical models for the movement of the person. The one is network type[1], which counts the number of people in networked architectural space. This model is good to examine flow of people. The other is mesh type[2][3], which employs meshed space for describing human density on meshed space. This model is good to examine scattered people on space. However almost all of these models are stochastic and the individuality of each person has been ignored[4][5][6][7].

The final purpose of this study is to derive a dynamical model which describes the movement of a person and analyze the effect of the personality on the dynamics of the crowd.

In this paper as a starting point of the study, we apply the proposed model to simulate the walking behavior of people in a crowd and compare simulated results with actual measurement. This model is applied to simulate the passing behavior of people, who are different in speed, on straight way and corner.

2 MODELING

We make some assumptions to describe mathematically the walking behavior.
(1) Person plans a path to one's destination and walks along the path.
(2) If there are obstacles in walking space, one assigns the evaluated values to them by using their positions and velocities.
(3) If an obstacle, which is given the highest evaluation, disturbs movement, one intends to avoid it by changing present path.
(4) If visibility is bad, one intends to track a walker ahead of him.

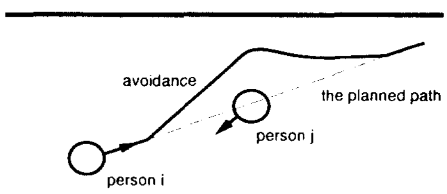

Figure 1: Modeling of the walking behavior

2.1 Dynamical Model of the Walking Behavior

Dynamical model [7], which describes the movement of person i, is given by

$$m_i \ddot{x}_i + \nu_i \dot{x}_i = u_i \qquad (1)$$

where

x_i	position
m_i	weight
$\ddot{x}_i$	accelerated velocity
$\dot{x}_i$	velocity
ν_i	coefficient of friction
u_i	moving force

2.2 Walking Behavior

Assume that a person decides the path to one's destination and moves toward the point on the path. We describes the walking behavior by using savomechanism, which drives a person along the planned path from point to point.

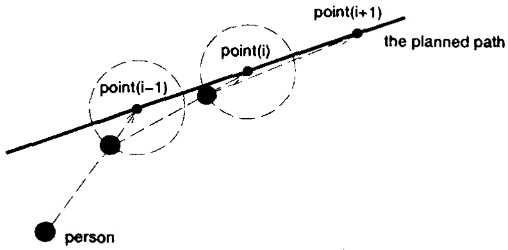

Figure 2: Walking behavior based on servomechanism

If there are people and obstacles in walking space, a person assigns the evaluated values to them by using their positions and velocities. This values is calculated by the following equation.

$$evaluated\ values = \frac{1}{|l_{ij}|} \times \cos\theta_{ij} \qquad (2)$$

where

$$l_{ij} = \begin{cases} l_{ij} & l_{ij} \leq l_i \\ 0 & \text{else} \end{cases}$$

l_{ij} is the vector in the direction from person i to obstacle. If distance l_{ij} from person i to obstacle is within l_i, he can see it.
θ_{ij} is the angle between velocity vector v_i and l_{ij}.

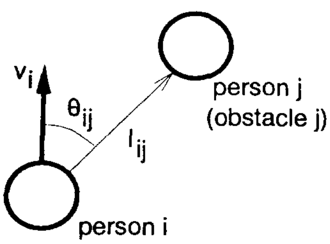

Figure 3: Calculation of the evaluated values.

If every values given to the obstacles or people is 0, person i moves along the initial planed path.

2.3 Tracking Behavior

If the velocity vector of a person j, who is given the most highest evaluation, is almost coincide with that of a person i, person i intends to track person j walking ahead of him. Because of the poor information ahead, he tracks the walker ahead of him for safety.

2.4 Avoiding Behavior

If an obstacle, which is given the highest evaluation, disturbs movement, person i intends to avoid it so that he is not collision with it. Assume that there is avoiding area. When person i is left-hand side of avoiding area, he veers to the left to avoid person j. When on the right, he veers to the right.

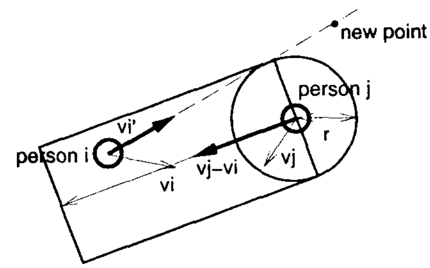

Figure 4: Avoiding person j

The rectangular area shown in the Figure 4 characterizes the avoiding area for the other persons and the length of sides are determined by the radius r and the length of vector $v_i - v_j$.

2.5 State Equation

To describe the walking behavior, equation (1) is transformed to the following state equation.

$$\begin{bmatrix} \ddot{x}_i \\ \dot{x}_i \end{bmatrix} = \begin{bmatrix} -\frac{\nu_i}{m_i} & 0 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \dot{x}_i \\ x_i \end{bmatrix} + \begin{bmatrix} \frac{1}{m_i} \\ 0 \end{bmatrix} u_i \qquad (3)$$

$$y = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{x}_i \\ x_i \end{bmatrix} \qquad (4)$$

2.6 Modeling of Walking Behavior

We replace the model, which describes the walking behavior, with savo system. As shown Figure 5, this model is given by

$$\begin{bmatrix} \ddot{x}_i \\ \dot{x}_i \\ \dot{z}_1 \end{bmatrix} = \begin{bmatrix} -\frac{\nu_i}{m_i} & 0 & 0 \\ 1 & 0 & 0 \\ 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} \dot{x}_i \\ x_i \\ z_1 \end{bmatrix} + \begin{bmatrix} \frac{1}{m_i} \\ 0 \\ 0 \end{bmatrix} u_i \qquad (5)$$

$$u_i = -\begin{bmatrix} \mathbf{f}, -k_1 \end{bmatrix} \begin{bmatrix} \dot{x}_i \\ x_i \\ z_1 \end{bmatrix} \qquad (6)$$

$$\dot{\bar{x}} = (\bar{A} - \bar{b}\bar{f})\bar{x} + gr, y = \bar{c}\bar{x} \qquad (7)$$

$$\bar{c} = \begin{bmatrix} 0 & 1 & 0 \end{bmatrix}, g = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$\bar{A} - \bar{b}\bar{f} = \begin{bmatrix} -\frac{f_1 + \nu_i}{m_i} & -\frac{f_2}{m_i} & \frac{k_1}{m_i} \\ 1 & 0 & 0 \\ 0 & -1 & 0 \end{bmatrix}$$

The pole of system are given by the roots of following equation :

$$s^3 + \frac{f_1 + \nu_i}{m_i} s^2 + \frac{f_2}{m_i} s + \frac{k_1}{m_i} = 0 \qquad (8)$$

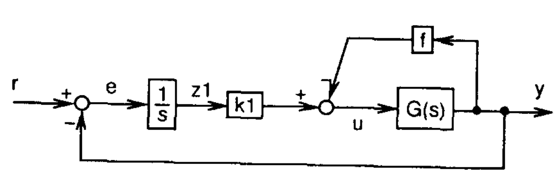

Figure 5: Block diagram of the servo system

3 SIMULATION

3.1 Comparison with Actual Measurement

The following simulations were carried out in order to demonstrate the derived model. Actual measurement was recorded on videotape with a camera mounted on a tall building. It is compared with the simulation result shown Figure 6 to 9.

- ● Simulation result (person)
- ··· Simulation result (locus of person)
- o Actual measurement

3.1.1 Person 1, Person 2, Person 3

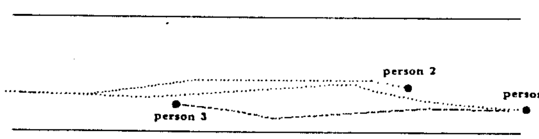

Figure 6: Simulation results for the walking behavior of three persons

We compare simulation of each person with actual measurement.

3.1.2 Person 1 (Ahead of Person 2, Opposite of Person 3)

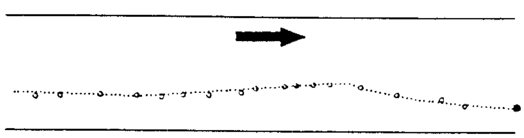

Figure 7: Simulation result of person 1

3.1.3 Person 2 (Behind Person 1, Opposite of Person 3)

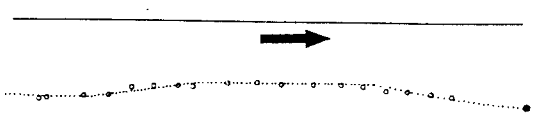

Figure 8: Simulation result of person 2

3.1.4 Person 3 (Opposite of Person 1 and Person 2)

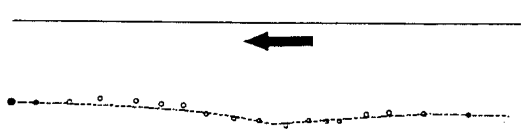

Figure 9: Simulation result of person 3

3.2 Other Simulation

The following simulations were carried out in order to test the proposed model. If slow walker disturbs the movement of fast walker, the fast pass the slow. Passing behavior are simulated on straight way and corner when there is difference in speed between two people.

3.2.1 Passing Behavior on Straight Way

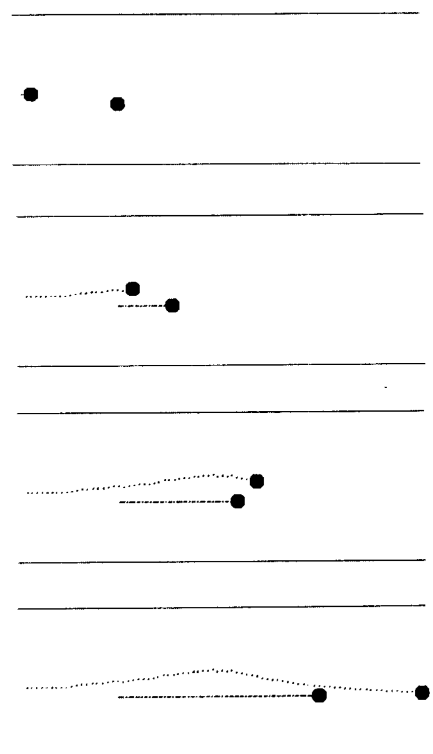

Figure 10: Passing behavior at different speed

3.2.2 Decision of the Path at Corner

When a person arrives at corner, one has to turn in the direction of one's destination. Assume that person decides the path to arrive and leave at corner. If person intends to go to corner, one makes the circle. Center of the circle is corner and radius of it is L as shown Figure 11. The path to arrive at corner is the tangent line drown from one's position to the circle. If person turns left at the corner, the path to leave the corner is the tangent line drawn from the left to the circle. Person is derived along these paths from point to point.

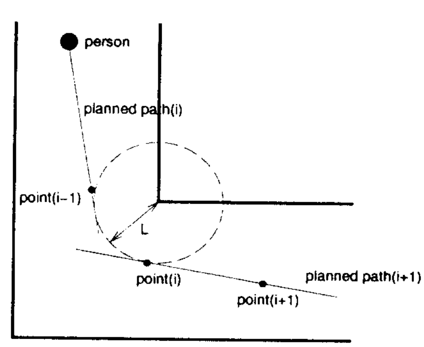

Figure 11: Decision of the path at corner

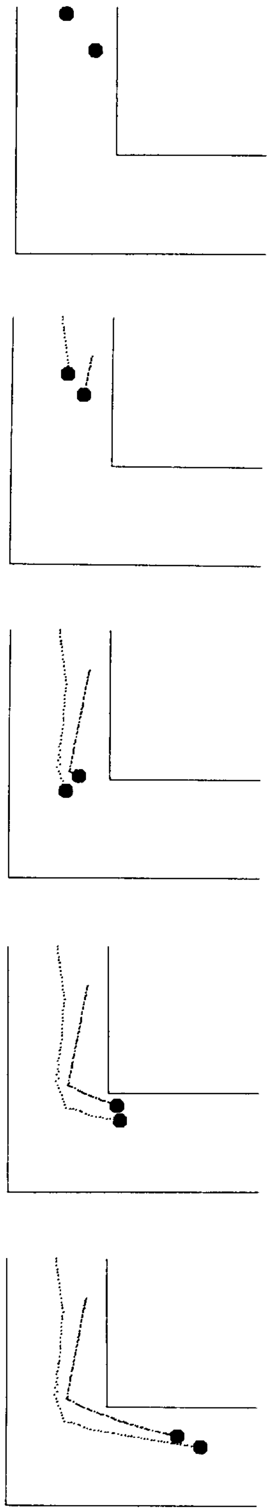

Figure 12: Passing behavior on corner

4 CONCLUSION

In this paper, we proposed the dynamical model which describes the walking behavior of a person and compared simulation result with actual measurement. The fundamental mechanism of the walking behavior is common and only the parameter, which characterize individuality, is different from person to person. By tuning these parameters, simulation of each person was good coincident to actual measurement.

Moreover, this model was applied to simulate the passing behavior of two people who are different in speed. This simulation was good coincident to the behavior which we often see.

Only the proposed model is not enough to simulate movement of individual in a crowd and does not enable us to analyze the effect of the personality on the dynamics of the crowd. If some assumptions are added to the proposed model and this model is expanded, the model will be able to simulate human behavior in a complex architecture or city and enable us to analyze the human behavior in panic.

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