Study on a Pedestrian Simulation Model of Natural Movement

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Abstract

The purpose of this study is to construct a pedestrian simulation model of natural movement by applying rules that influence pedestrian route selection from previous experimental studies. Based on wall vector field, the multi agent-based simulation model which evolves through the relationship between vision-driven agents and configuration of environment was programmed by NetLogo. It considered visual field angle, visual distance, visual noise (looking around), moving speed, attractive factor, and other agents. The results of the simulation in several environments including a real architectural space such as the Tate Gallery produced better movement patterns than a previous model (Turner's EVA model) both locally and globally. Since the simulation model included variables related to visual factors which affect natural movement, it could help towards understanding the relationship between visibility and movement, its effects on spatial usage, and the affordance of configuration in a built environment for natural movement.

Keywords: natural movement; pedestrian simulation; agent-based model; wall vector field

1. Introduction

Movement such as walking is a basic mode of human behavior and occurs as a result of multi-layered desires. Thus it is a field that should be studied in order to understand human behaviors; however, the factors generating movement have various layers, so it is not easy to reveal its mechanism.

Previous studies on movement were mostly qualitative (Thiel, 1997) or one on the common characteristics of pedestrian groups (Fruin, 1971). Recently, with advances in digital technology, modeling and simulating movements from more detailed perspectives have been carried out. Yet the mechanism of movement has not been clearly investigated and there is a limit to processing a simulation considering all of the various factors that influence movement.

Gibson (1979) indicated the complementary relationship between visual perception and movement in which humans perceive a space through movement and the perceived space in turn affects movement. From Gibson's ecological perception theory, Turner (2001) pointed out that most simulation models of movement are ones which give no consideration to an agent's vision and then encode natural movement as an agent-based system.

The two different patterns of movement as a movement simulation model could be considered; a natural movement and a navigational movement. Natural movement could be suggested as the simple product through an agent's vision and the spatial affordances of the built environment. Navigational movement is the pattern of movement in which agents have a spatial memory and the system should set origin-destination (O-D) pairs. Therefore natural movement has the following meanings. Firstly, natural movement could help us to understand the basic mechanism of movement which is generated by vision-driven agents as a lower hierarchy of movement behavior. The concept of Maslow's hierarchy of needs might be mentioned as a reason why an analysis of natural movement is meaningful. This is because movement that meets higher factors only cannot be made while lower factors are not met. And another reason is that natural movement has relevance to the affordance, because its pattern evolves through the agent's perception of the built environment. That is to say that one could understand how the perceived environment would affect or afford the agent's natural movement patterns from a simulation.

Thus, it is necessary to study the fundamental and influential factors of natural movement and develop simulation techniques based on the findings. This study aims to model the hypotheses of most fundamental

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spatial factors among those affecting natural movement based on previous experimental studies, to develop a basic simulation program and examine the validity of the model.

2. Literature Review
2.1 Natural movement theory and EVA model

![Fig. 1. Hierarchy of Individual Behavior (Therakomen, 2001, p.20, Re-Quote)](image)

'Natural movement' is a concept proposed by Hillier et al. (1993) who discussed the relationship between configuration and movement in an urban grid, and examined it through space syntax analysis. Following this, Turner & Penn (2002) proposed an agent natural movement model from a more microscopic perspective through an ecological approach based on Gibson's 'natural vision' theory. Natural vision refers to the behavior of visual perception that occurs when one usually moves and looks around, while natural movement concerns the behavior of movement occurring through interaction with environmental information perceived by this natural vision. They redefined the natural movement theory as human movement that is generated by configuration. Thus, natural movement could be a behavior beyond the level of reaction like obstacle avoidance and one at the level of motivation taken selectively in one's path from an external stimulus according to the hierarchy of individual behavior as shown in Fig.1.

Turner & Penn considered a visible surface as a space in which one can move and thus, encoded an agent's natural movement through the Markov process where he or she takes a random point in the visible region as a goal of movement. Also, in order to reduce the process for computing the visibility information of an agent in real time, a program which calculates the partial isovist at every grid point in advance was made and thus called the Exosomatic Visual Architecture (EVA) model. In the EVA model, an agent selects a target point within the visible region, moves for a certain distance (three steps) and then selects another target. If the agent comes across an obstacle, he or she turns 90° to the right or left and selects another target. He implemented this model as a natural movement simulation model in the visual analysis program, Depthmap.

However, since the EVA model is one that agents select and move to a random point in the visible region for every certain distance (time), it shows irregular movement patterns such as zigzag unlike the actual movement from a microscopic perspective. Also, since the visual information comes from the agent, the possibility of reflecting the changes of visual factors of agents and visual information of the environment in real time is limited.

2.2 Experimental studies of natural movement

Turner (2002) used movement data in a built environment such as an exhibition space — the Tate Gallery — where a path exploration is not driven by a specific destination and could be thought of as a natural movement, in order to compare the EVA model with actual data related to natural movement. However, for the movement data of such space, it is difficult to control the variables of other attractive factors, except for configuration factors which could be related to natural movement and to obtain microscopic movement patterns accurately. Thus, Lee (2011) carried out a natural movement experiment on subjects in a virtual environment to overcome the limitation of controlling variables and collecting such actual natural movement data.

In this experimental research, three types of environment consisting of 31 x 31 cells as shown in Table 1 were proposed, which was presented to subjects as a 3D space with a visual field angle close to about 90° on the monitor. The subjects, who were unaware of its entire spatial structure perceived only this display, and selected the next point to move and iterated at the speed of 1 cell/step. A total number of 35 persons participated in the experiment and each moved 300 steps. Their movement trajectory and the cumulative value of occupation in every cell were stored, and through comparison with a Visual Graphic Analysis (VGA) and Turner's EVA model simulation value, spatial factors affecting natural movement were hypothesized.

As a result of an examination of the subjects’ movement pattern through this experiment, it was suggested that natural movement does not simply depend on a 'movable space' but can be made by 'physical substances constituting the visible space and their relationship' and natural movement could be generated especially by the distances and relationships between a subject and substances. However, in this research, hypotheses were only raised through the experiment and there is the limitation that they have not been verified. Therefore, this study attempts to model these hypotheses and compare simulation results with the actual experiment results to examine the validity of the hypotheses and the simulation model.

3. Simulation Model
3.1 Natural movement model using wall vector field

When considering Gibson's concept of 'affordance', an empty space itself could not support a pedestrian's movement. As a result the basic elements of an architectural space such as floor or wall could be
Turner’s EVA model discussed above could be seen as one approaching from the perspective that the only floor within the visibility range limited by the walls is the element that supports natural movement. However, it could be seen that here one already perceived the walls before perceiving the floor and rather one tended to perceive the movable space by the walls. Actually our movement follows boundaries like walls or fences rather than the floor itself. Continuous boundaries or perceived substances such as these would guide one’s movement continuously. However, the microscopic movement pattern of agents in Turner’s EVA model is very irregular. This is because it is a model in which agents randomly select a point on the movable space, that is, the floor, with the result that a movement pattern similar to the path in the EVA model (Fig.2., b) could be achieved. Thus, like the hypotheses raised by the natural movement experiment research mentioned above, this simulation model showed that an agent's natural movement is affected by the substance of the wall.

Fig.2. Natural Movement Model by Wall Vector Field

Fig.3. Agent Decision Process of Natural Movement Simulation Model
Furthermore, when one perceives the walls, one does not perceive them as the same objects but instead obtains the information of configuration by the distance and direction to the wall, so in this model the distance and the direction between an agent and the wall was considered. Therefore it could be concluded that their continuous variation to the walls guides an agent's natural movement. In addition, when the distance from the walls was taken into account, one's movement might be attracted by a distant wall rather than by walls nearby. One always looks to the front and is more interested in the change of a wall which newly unfolds, than by those already experienced and close-by. Applying this rule to the model could naturally help avoid obstacles of walls and at the same time generate a natural movement at corners as shown in Fig.2.

Thus, the next orientation selection \( (\vec{a}_{(t+1)}) \) of an agent who makes a natural movement in their current orientation \( (\vec{a}_{(t)}) \) could be thought to be guided by the field of vectors \( (\vec{w} \cdot \vec{d}) \) formed by the walls within the visible range, where \( |\vec{w}| \) could be the distance between the agent and the wall, which could be expressed as follows:

\[
\vec{a}_{(t+1)} \approx \vec{a}_{(t)} + \int a \times \vec{w}(t) \cdot d\vec{w} \tag{1}
\]

However, to apply this rule to agent-based models, since the vector values of walls \( (\vec{w}) \) according to an agent's position and visible range change continuously, there is a limitation in applying vector values in advance as in Turner's EVA model. Therefore, this simulation model was programmed to calculate the agent's partial isovist and the vector values of walls in real time. In this case, despite the need for many operation processes, there is the advantage of performing a more dynamic analysis; e.g. by reacting to moving elements (another agent or automobiles, etc.) or changing the environment, etc.

An agent with an orientation, visual field angle and visible distance, looking around (noise frequency and noise angle) and moving speed decides his or her next direction of movement by the vector field of walls after exploring the partial isovist and physical boundary (wall) at a certain position, like the process in Fig.2. and Fig.3. At this time, in order to exclude the possibility that a certain direction might restrict an agent's movement, the model has a noise like looking around so that he or she can make various path selections similar to the actual movement behavior. Also the following rules were applied: Agents should take the direction with a long visible distance when in a position with a very small visual field (at a corner of a room or in a dead-end space) in order to return or turn. If there is an obstacle ahead, agents should take a random angle within the range of 30° to the right or left until there is no obstacle. And since the model proposed in this study is a natural movement model using wall vector field, it is suggested that it be called a 'Wall Vector Field Model' to distinguish it from the EVA model.

3.2 Programming
The above-mentioned model process with agent-based model programming language NetLogo was programmed. Since the NetLogo environment consists of unit cells, it is difficult to implement the above discussed vector field model accurately. Although a relatively similar model could be built if the cells were divided into a very small unit, the operation time might be increased. Thus, this study carried out simulations with a unit cell, the size of which is similar to a normal step of about 50-100cm and the unit module of a wall can also be represented at the same level. This is because it was considered that an architectural plane generally consists of a rectangular system and walls are usually arranged continuously. Therefore these cells might represent configurations even if the space and wall are divided at regular intervals. For this reason, there would be a minimal affect on the simulation results.

Also in a simulation program, the agent's visual field angle and visible distance can be controlled and multi-agents can move individually at the same time. The agent's movement trajectory and the cumulative value of its occupation on the unit cells, etc. were stored at the same time in order to compare them with other data.

4. Simulation Results
4.1 Simulation in test space
4.1.1 Visual field and noise
Fig.4. shows the result of a simulation carried out in a virtual test space (31 x 31 cells). The test space is a vertical symmetry designed for an agent to repetitively move in spaces such as rooms or hallways. In the natural movement model proposed in this study, the agent moves by the wall vector field in the visible

![Fig.4. Simulation Result in Test Space](image-url)
region, so it is important to set up the visual field of the agent.

a) is the case in which the visual distance is shorter and the visual field angle is narrower than in a usual situation. This case can be thought of as a very dark place or one in which people look at a certain object as in an exhibition hall. When the movement trajectory of an agent in the result of the simulation was examined, there was a little irregular movement pattern in the hallway, and in the room, and he or she moved very close to the wall. This is because the visual field was limited, so the agent explored and decided the next route depending on the wall close to him or her. Actually, when the visual field angle is narrow in the case of a fire, an evacuator tries to explore their path depending on the near wall (Jeon & Hong, 2009), and this is similar to the case of an exhibition hall where visitors usually view exhibits along a wall.

The simulation result b) has a general visual field angle but a relatively small angle range for looking around, that is, noise value. If the agent enters a certain position, it might be very difficult for him or her to select their next path since their selection is only made based on the wall vector field and there is no chance to explore another space. If the noise is close to 0, the agent chooses a fixed route according to the figure of the given space, and in reality there is a difference from the pattern with a variety of movement trajectories.

The simulation result c) reflects a general noise with a general visual field angle. Actually, the human eye is not still but looks around at a very fast speed, and one even rotates one's head and trunk to take in visual information from a wider range. The simulation result shows the trajectory reflecting this noise. Like the actual movement in a hallway, it represents some regular movement patterns but in a room, more varied trajectories: i.e. behavior like looking around the interior. Also another reason why the noise rule is important in this model is that it allows the agent to avoid his or her path selection from being fixed by the configuration of the space. If the entrance of a room or narrow space is arranged based on the hallway space, it is difficult for an agent who looks to the front only to understand the interior of these spaces, so it is difficult to get out of the hallway space, which is called the 'corridor problem'. However, around the space, if the agent's noise is large enough and he or she explores the interior space, it could be possible for them to make the decision of selecting the interior direction and not the forward one. Similarly, unpredicted movement could be obtained not only in such a space but also in other spaces.

4.1.2 Moving speed

Fig.6. shows the different movement patterns according to an agent's moving speed. Moving speed means how much unit cell space per step an agent gains and as the moving speed becomes faster, the development of the space the agent explores changes more rapidly. Therefore a more irregular pattern takes place than with a slow moving speed. In the case of a fast moving speed as in c), it is difficult to avoid obstacles and rapid rotation occurs around them. In contrast, if the moving speed is slow, the change of wall vector field is small, so overall, one could obtain a regular movement pattern. This simulation result could be seen to reflect patterns similar to actual movement by the difference of speed such as walking and running.

![Fig.6. Simulation Results by the Difference of Moving Speed](image)

4.1.3 Attractive factor

Fig.7. Simulation Results by Attractive Factor (Visual Field Angle: 90°, Noise< 30°, Moving Speed: 1c/s)

a) Intensity of Attraction Factor: none

b) Intensity of Attraction Factor: 5

c) Intensity of Attraction Factor: 10

![Fig.7. Simulation Results by Attractive Factor](image)
Fig. 7. shows the result of a simulation carried out to obtain attractive factors \((a)\) at a certain position in a hallway: an environment where there are objects such as exhibits or signs. This reflects a phenomenon in which the attractive factor appears in the visual field, an agent is drawn to the attractive factor and the greater the intensity of the attractive factor or the area, the more movement is drawn to it. However, if the attractive factor is scattered in several places in the visual field or is arranged symmetrically to the agent’s orientation, the intensities of the attractive factors are counterbalanced, and the phenomenon of attraction decreases because the current model cannot selectively detect them.

4.1.4 Multi-Agent

In this model, an agent considers other agents as visual obstacles, so its visual field is limited by them. If there is an agent in a 1.5 cell ahead (in this model, greater than the diagonal distance of the cell to exclude the possibility of inclusion of himself or herself), the agent is asked to stop after one step. Thus, as a result of a simulation where a multi-agent moves in the same environment, their movement trajectory becomes very irregular in order to avoid other agents, while when there are few agents, his or her movement pattern is relatively regular. Fig. 8. shows the movement trajectory of a certain agent in an environment with multi-agents.

The various simulation variables examined in this section were for reflecting factors which should be considered for representation of natural movement; however, these require more research in the future. Nevertheless, these results show that the model proposed in this study could involve more various factors in the future.

4.2 Comparison with experimental research

This section attempts to compare the simulation results carried out in three types of environment, the same as the models of previous experimental studies on natural movement mentioned in a literature review.

| Table 1. Comparison of Experiment Result with Simulation Result (Partial Quote of Experiment Result of Lee (2011)) |
|---|---|---|---|
| Type | Experiment Result of Virtual Space by Subjects | EVA model (Depthmap Simulation Result) | Wall Vector Field model (NetLogo Simulation Result) |
| Analysis Environment | 35 x 35 cells | Global Steps: 3,000 | Visual Field Angle: 90°, Noise < 45° |
| | No. of Subjects: 35 persons | Release Rate: 1 | Visual Distance: 35 cells |
| | Moving Distance: 300 steps | Agent Steps: 3,000 | No. of Agents: 35 agents |
| Subject's Trajectory | CDO on the condition of Not Occlusion Driven | Agent's Trajectory | Cumulative Distribution of Occupation (CDO) |
| CDO on the condition of Any Occlusions | | | |
| A-type | R = 1.0000 | R = -0.0091 | R = 0.4132 |
| B-type | R = 1.0000 | R = 0.4182 | R = 0.3540 | R = 0.5108 |
| C-type | R = 1.0000 | R = 0.1870 | R = 0.3168 | R = 0.3382 |
Thus, in the simulation model, such visual field angle, moving speed and total number of steps was applied and the accumulated results for 35 simulations were used.

Each result of the experiment by actual subjects and an agent-based simulation by the EVA model and wall vector field model are as shown in Table 1. The number of subjects in the experimental research was relatively few and the same result could not be obtained in every simulation; however, most of all, unlike the comparison by gate-counting value at specific positions, it would be improper to compare quantitatively the cumulative values of the agents' occupation with actual subjects at every unit cell. However, for each type, the wall vector field model showed a more similar movement pattern to the experiment results and obtained better correlation in occupation distribution than the EVA model in Depthmap.

4.3 Comparison with movement pattern in actual space

In 1995, Hillier (1996) collected various data on visitors to the Tate Gallery in the U.K. This report contained the flow and density of the number of visitors to each space in a certain time period. This section compared the simulation result in an environment similar to the Tate Gallery with the actually measured data.

The simulation was as follows: in an environment consisting of 200 x 200 cells, 100 agents with a visual distance of 50m (cell), visual field angle of 90°, and noise <45° enter the entrance (at the bottom of Fig.9.) at a moving speed of 1m (cell)/step and move a total of 1,000 steps. Fig.9.-b) shows the result of the movement trajectory of the simulation which shows a pattern similar to Fig.9.-a) as an actual trajectory of visitors for each space in the Tate Gallery for five minutes three times throughout the day. The visitors and agents entering from the entrance mainly used the central hallway to enter each space, and due to the noise in the agent simulation, it looks as if they explore the space like the actual movement pattern. However, overall, it tends to converge to a global pattern.

Using the cumulative value of the agent's occupation at each unit cell obtained from this simulation, its correlation with the gate counting value of the actual visitors in the Tate Gallery for an hour were analyzed. Although the actual data were measured for a certain time period, they show more movement at the entrance. It is thought that in the actual exhibition.
hall, the location of the entrance has a great affect on movement. However, the agents in the simulation make a natural movement based on the rules only, without having knowledge of the entire spatial structure. Thus, with this in consideration the agent is asked to enter the space from the entrance, and in some cases, the moving distance of 1,000 steps is one in which an agent could come back to the entrance after exploring other spaces. The gate-counting data of a total of 67 gates were used for analysis and the correlation coefficient between the actual observation data and the simulation data was R=0.7678, which was similar to the correlation coefficient of Turner's research (2002) (R=0.72).

Most of all, the difference from Turner's EVA model is as shown in Fig.11.; since the agent's path selection was generated by the wall vector field each time, the microscopic pattern of this model shows a relatively continuous and smooth movement. Thus, this simulation using the wall vector field model could represent a more microscopic natural movement pattern than Turner's EVA model.

Fig.11. Microscopic Movement Pattern of Agents

5. Conclusion
This study proposed a simulation model of natural movement using a wall vector field based on the hypothesis that a natural movement is generated by physical substances like walls within the visibility range from the previous experimental studies and applied this as the rule of route selection. Thus, this model could obtain better movement patterns than previous models both locally and globally. If a natural movement related to microscopic analysis is needed, a result more similar to reality could be obtained by using this model. Also it reflected variables related to visual factors which affect an agents movements, and so could help us understand the relationship between visibility and movement, its effects on spatial usage, and the affordance of configuration in a built environment concerning natural movement. It could have a significant meaning in the way that an agent's vision in real time is considered for the natural movement model.

As a result of the simulation performed in the test space, an environment considering visual field angle, visible distance, looking around (noise), moving speed, attraction factor and multi-agents showed movement patterns similar to reality. However, the values of these variables need to be refined according to an analysis of the environment or the agent's condition, and the variables proposed in this study and other variables need to be modified and complemented through comparison with more actual movement data.

Furthermore, the suggested model compared the previous research experimenting on natural movement by actual subjects in virtual environments. Although there was a limit regarding sufficient examination due to a lack of data, it was able to obtain a simulation result more similar to the movement pattern of the experiment than the EVA model.

Lastly, it compared the actual movement data at the Tate Gallery with the simulation result carried out in an environment similar to this. As a result of an examination of the correlation concerning gate-counting values at major points, a relatively high correlation coefficient value was obtained.

Inversely, it could be said that this result shows the verification of the hypotheses proposed in the experimental studies related to natural movement; which is that the relationship between humans and physical substances like walls, not empty space itself, might generate a natural movement. However, actual human movement occurs at various levels other than this, which is hard to predict, and is consequently difficult to model. Also there is not sufficient data available related to natural movement to secure the validity of the model. Therefore, subsequent studies should continue to represent more predictable movement, and to secure the validity of the model from more accurate data.

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