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Mobility analysis of the aged pedestrians by experiment and simulation

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ABSTRACT

The relative weight of the population shifts from younger to elderly in the most of the region on the planet. Current aging rate in the advanced nations varies from 12% to 13% and is expected to increase up to 21–37% in 2050. The increase of aging rate in the society especially in the large city will lead a mobility problem. From a social quality point of view, it is important to achieve the compatibility between safety and mobility respectively for younger and elderly generation. For the purpose of understanding the basic characteristics of the pedestrian dynamics under cohabitation of younger and elderly generation, a Cellular Automata (CA) model is created with the aid of pedestrian experiments. Simulations are carried out to reproduce the experimental results and had shown a good agreement.

1. Introduction

The world is aging. The aging rate on the planet is in the increasing trend as a result of decreasing birth rate and increasing life expectancy in advanced nations. The aging rate is defined as the ratio between the elderly populations over 65 years old against of the younger populations and is shifting toward the elderly side. According to WHO report, current aging rate in the advanced nations varies from 12% to 13% and is expected to increase up to 21–37% in 2050. The rapid change in the aging rate is forcing society change into a more elderly oriented. As well as creating specific welfare services, transportations, impediments removal, the safety issues of elderly generation in public areas would appear to be an important topic. Elderly generations often face to progressive deterioration of physiological and psychological functions which causes slowdown in cognition, reaction and action speed. And health impediments are attributable compare to the younger generations and such health impediments become more frequent as age increases. Such physiological and psychological deterioration affect in the walking speed, endurances and sensitivities. According the review report on behavior and characteristics of older pedestrians by the Department of Transport in UK (Dunbar et al., 2004), the average walking speed of the elderly is about 75% of the younger generations. The increase of the elderly people in the society makes a large change in the social mobility. Considering in the public place, when the elderly people and young people shares the same space, it is foreseen that there would be a major change in the macroscopic pedestrian dynamics. This study focuses on such mobility issues in the public space where the pedestrians with different characteristics are mixed. Extensive studies on pedestrian modeling have been made in recent years and they are classified into two main streams such as continuum and discrete model. The "Social Force model" is the one of the successful approaches in the continuum system introduced by Helbing and Molnar (1995). The model describes the pedestrian's velocity in terms of the collision avoidance mechanism by considering the repulsive force between each pedestrian and is well studied in Helbing et al. (2000) and Helbing (2001). One of the important factors in this approach is the expression of the interaction force where Chraibi and Seyfried (2010) introduces generalized centrifugal-force model to satisfy the collision avoidance by means of excluded volume effect.

On the other hand, Cellular Automata (CA) is defined in a discrete lattice and time. CA is defined by update rules such that the state of the current cell changes according to the states of surrounding cells in discrete time step. For pedestrian simulation, the state of a cell is either 0–1 to express the existence of a pedestrian in a regular spatial grid. Then the dynamics is defined by interaction between a cell of interest and the neighborhood cells. There are two types of neighborhood selection namely as "Von Neumann neighborhood" and "Moore neighborhood". The former considers the surrounding four cells orthogonal to the current cell while the latter considers all of surrounding eight cells. The application of CA to hydrodynamics referred to as Lattice Gas Automaton (LGA) is discussed in Wolfram (1994) and then the extended study for pedestrian simulation is implemented by Helbing et al. (2003). Although LGA model is based on the random walk, in order to give a characteristic behavior, biased random walk is implemented by Nagatani (2002). Further, based on Nagatani's model, Jiang and

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Wu (2006) performed a simulation on pedestrian interaction between the large object. Besides the application of hydrodynamics model to pedestrian simulation, Derrida et al. (1993) made a theoretical study on one dimensional Asymmetical Simple Exclusion Process (ASEP) which plays a fundamental role in traffic models. ASEP is a simple binary CA in open boundary such that a particle moves one cell forward if the cell in front is unoccupied which is relating to the Rule 184 in elementary CA studied by Wolfram (1994). In this way, the excluded volume effect is implemented in relatively simple manner. Nagel and Schreckenberg (1992) introduced a model which allows a particle to move more than one cell at a time often referred to as Nagel–Schreckenberg model (NaSch model). Thus, the homogeneity of the velocity in ASEP is solved to demonstrate the acceleration and deceleration of particles in discrete expression. Although NaSch model is designed to model the traffic on the highway, Kirchner et al. (2004) applied this model to two dimensional pedestrian interactions such as lane change and bottleneck in egress behavior. For more general applications to give characteristic behavior to pedestrian simulation, Floor Field (FF) Model is introduced and applied to analyze variety of pedestrian phenomena (Burstedde et al., 2001; Kirchner and Schadschneider, 2002; Kirchner et al., 2003). FF is predefined geometrical information statically or dynamically given to each cell to give the behavioral characteristics. FF is widely applied for various applications such as egress and counter flow behaviors. Henein and White (2007) uses FF for agent based egress model while Yanagisawa and Nishinari (2007) made a theoretical study on CA model for pedestrian behavior at the exit of the room during egress behavior. Ezaki et al. (2012) further extended the study for multiple bottleneck case and shown the existence of symmetry braking on the pedestrian flow. Based on these studies, the general issue is to determine the volume exclusion for each pedestrian for improving the model to fit the realistic situations. While these referred studies consider the excluded volume in the same size as a single pedestrian, more complex interaction occurs when number of pedestrians is increased and the effects of the volume exclusion become significant. For real world applications, personal space and headway distance should also be considered. These extra spaces can be considered as part of the excluded volume. Jelić et al. (2012) performed experiments to show the spatial effect of headway distance greatly affects the pedestrian velocity. In addition of such spatial effect, negotiation process also occurs at pedestrian interaction e.g. give way to another pedestrian to avoid collision. Asano et al. (2010) studied tactical model by implementing pedestrian eyesight and game theory. Among numerous studies on pedestrian modeling, those which deal with heterogeneity of the walking speed and overtaking behavior are rare (Kirchner et al., 2004). Firstly, for different walking speed, other than NaSch model, a method of applying the different update intervals defined by the speed ratio is studied by Weng et al. (2006). But the application of the models is limited to specific variations of speed in the system. When there is wide variation in walking speed, more flexible expression is necessary. Thus we have chosen to implement walking speed by values of transition probabilities. On the other hand, the conventional implementation of overtaking behavior in CA is often carried out by as a simple lane change such that, a particle directly moves to the adjacent cells which are perpendicular to the walking direction if the cell in front is occupied. The description of this particle motion in real pedestrian follows that, the walking pedestrian quickly slides into a position where directly left or right of his current position if there is someone in front. But the fact is that, the pedestrian has a momentum thus he moves into a position where diagonally in front. One of the aims for this paper is to clarify the necessary mobility for this movement. Throughout this paper, the study is carried out through experiments, modeling and simulations to supports the consistency of the model.

2. Experiment

In order to obtain the basic characteristics of pedestrian's motion when two different speed walkers are cohabitated, we have performed series of the following experiments. In these experiments, we are especially interested in the overtaking phenomenon and the emergent formation after overtaking. Fig. 1 illustrates the experimental arrangements. The experiment is held in Research Center for Advanced Science and Technology (RCAST), The University of Tokyo. First we prepare 25 healthy young Japanese persons (no distinguish between male and female) and make them aligned in 5×5 matrix formation, asking them to start walking unidirectional to the right direction at once with the starting command. The total length of the experimental lane is 17 m and an experimental run ends when everyone crosses the goal line. Three video cameras are set at the starting, middle and the goal, where the positions referred to as Videos 1, 2 and 3 in Fig. 1 respectively. The control of walking speed is by informing them as "Walk as normal" and "Walk with 75% speed of the normal". Although male and female has different walk speed due to their physical characteristics, for the purpose of obtaining the quantitative data, the pedestrians are informed to walk along with the floor tiles where the "normal speed" is defined as two floor tiles per foot step thus the participants can maintain the constant speed. Moreover the floor tiles are used to obtain the quantitative data for the post-processing of the videos. The normal walkers ware white cap and the slow walkers ware red cap. The initial formations of the pedestrians are shown in Fig. 2. It is trivial that there are no overtaking action and interaction between the slow and normal speed walkers if the slow walkers are arranged behind the normal walkers. Thus we made three initial configurations for of slow walkers at the front part with various formations. Fig. 2(a) and (b) are the low-density arrangement. Fig. 2(c) illustrates the relatively high-density arrangement where the slow walkers act as a bottleneck to the normal walkers behind. During the experiments, the normal walkers overtake the slow walkers so we can observe the overtaking phenomenon. Two runs are taken for each experimental condition. Figs. 3–5 illustrate the captured image with corresponding pedestrian formation of the video for experiments 1, 2 and 3 respectively. The frame number superimposed in the picture shows the elapsed video frames from the start. The frame rate is 29.97 frames per seconds (fps). Thus the time step for each consecutive frame is 0.033 s. The pedestrian formation of normal walkers is observed from Figs. 3–5. For the experiment 1, the formation after over taking as seen from Fig. 3 is that, three pedestrians with a space in between aligned vertically. Although some jitters in their positions are seen but the alignment remains for alternative columns. For the experiment 2, it is seen from Fig. 4 that three pedestrians are vertically aligned with no space in between for first several columns. And thereafter, the number of the pedestrian in the vertical alignment reduces to two with more space in between. As shown in Fig. 2, the initial space in between the slow walkers is set just enough for three pedestrians to pass through. This initial arrangement causes the vertical alignment of three pedestrians in the front part of the line as seen in experiments 1 and 2. On the other hand, for experiment 3, the space for the normal walkers to overtake the slow ones is as narrow as for one single person to pass through. Since then, the formation after overtaking appears as a single horizontal line. For all the cases, first several columns after overtaking have the same structure as the first front column of the initial formation. This is because of there is less interaction between each of the normal pedestrians in the front regions. Then the initial