PEDESTRIAN SIMULATIONS USING MICROSCOPIC AND MACROSCOPIC MODEL*

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1. Introduction

Pedestrians form an important component of a multi-modal transportation system. Planning and design of pedestrian amenities (multimodal points, airports, shopping malls, theaters etc) demand efficient, comfortable and safe walking operations for the pedestrians. Likewise, the movement of large numbers of people is important in many situations, such as the evacuation of a building, stadium in an emergency[1)]. Studies relating to pedestrian behavior and modeling is thus imperative. In contrast to vehicular movements, pedestrians interact continuously with other pedestrians and their surrounding infrastructure/environment, changing their direction and speed frequently. To represent this complex movement behavior of pedestrian, various models has been proposed; both microscopically and macroscopically[2) 3)]. This paper is intended to review the emerging microscopic and macroscopic pedestrian model with emphasis to the social force model (Microscopic) developed by Helbing et al.[1)] and the NOMAD (microscopic), SimPed (Macroscopic) model developed by Hoogendoorn and his team at Delft University of Technology, Holland[2) 4) 5) 6)]. Also this paper mention about the future study outline of authors for improving the exiting models based on the review.

2. Microscopic Versus Macroscopic Model

Microscopic model treats each pedestrian in the model as an individual agent occupying a certain space in time. It provides a valuable insight over a wide range of behavioral inputs. The microscopic model deals with the factors that drive pedestrians towards the destination by considering the interaction between the pedestrians [2) 3) 7)]. Such model gives a more realistic performance of pedestrian movements. However the problems of analytical manipulability, programming overhead and cost (cost is proportional to the level of details), unforeseen errors may have significant effect on the model.

Macroscopic model is basically concerned with the aggregation of pedestrian movements into flow, density and speed. It treats pedestrian movement like a continuous fluid and relies on the behavior of the fluid as a large scale interactive system and thus has easy applicability[1) 3)]. However, by making the particle (pedestrian) as unthinking elements in the model does not seem logical as the varied behavior of individual particle can significantly change the way in which the fluid (crowd) as a whole behaves especially in panic situation. Using a macroscopic model we can roughly estimate the level of comfort and occurring of congestion in the network. Subsequently microscopic model are used to analyze these locations in more detail thereby determining the causes for congestion [7)].

3. Social Force Model

The traditional approaches of pedestrian modelling predict the motion of crowds as if it were a continuous homogeneous mass that behaves like a fluid flowing along corridors. This traditional approach assumes that the crowd is made up of identical, unthinking elements. This is illogical in real world and especially considering the human behavior in a panic situation. Helbing *et al.*[1) 8)] deal with this particular problem through social force model which recognizes that the crowd is made up of individuals who possess the ability to think and react to events around them. In this microscopic model, the dynamics of each particle/ pedestrian (α) is given by three kinds of forces viz. Driving Forces (F_D), Social/Pedestrian Forces (F_P) and the Granular Forces (F_G) as given by the following expressions:

$$\vec{F}_D = m_\alpha \frac{1}{\tau_\alpha}(v_\alpha^0 \vec{e}_\alpha - \vec{v}_\alpha) \tag{1}$$

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$$\vec{F}_P = \sum_{\beta=1,\beta\neq\alpha}^{N_p} A_\alpha \exp\left(\frac{\varepsilon_{\alpha\beta}}{B_{ph}}\right)\vec{e}^{\,n}_{\alpha\beta}\left(\lambda_\alpha + (1-\lambda_\alpha)\frac{1+\cos\varphi_{\alpha\beta}}{2}\right) \tag{2}$$

$$\vec{F}_G = \sum_{\beta=1,\beta\neq\alpha}^{N_p} \left[(\varepsilon_{\alpha\beta}k_n)\vec{e}^{\,n}_{\alpha\beta} + (\varepsilon_{\alpha\beta}k_t\vec{v}_{\beta\alpha})\vec{e}^{\,t}_{\alpha\beta}\right]\theta(\varepsilon_{\alpha\beta}) \tag{3}$$

where, $\varepsilon_{\alpha\beta} = R_\alpha + R_\beta - D_{\alpha\beta}$, $\vec{v}_{\beta\alpha} = \vec{v}_\beta - \vec{v}_\alpha$, m_α is the particle mass, v^0_α and $\vec{v}_\alpha$ are its desired and actual velocity respectively, $\vec{e}_\alpha$ is the unit vector pointing to the desired target, τ is the relaxation time, N_p is the total number of particles in the system, A_α and B_{ph} are the constants related with the strength and influence of the social interaction, $\vec{e}^{\,n}_{\alpha\beta}$ is the normalized vector pointing from particle β to particle α, $\varphi_{\alpha\beta}$ denotes the angle between the direction of motion and the direction of the object exerting the repulsive force, parameter λ_α takes into account the fact that the situation in front of a pedestrian has a larger impact than things happening behind, $\vec{e}^{\,t}_{\alpha\beta}$ indicates the corresponding tangential direction, $D_{\alpha\beta}$ is the distance between the centre of mass of the particle with radius R_α and R_β, k_n and k_t are the normal and tangential constant respectively, $\vec{v}_{\beta\alpha}$ is the tangential velocity difference, and the function $\theta(\varepsilon_{\alpha\beta})$ is: θ=1 if $\varepsilon_{\alpha\beta} \geq 0$ (i.e. in panic situation) or θ=0 otherwise(i.e. in normal situation).

The social force model is quite similar in principle to Magnetic Force Model developed by Okazaki *et al.*[9] which is based on the Coulomb's magnetic force concept. However, the social force model uses the variables that have physical meaning in contrast to magnetic model where arbitrary values are assigned to variables. With the social force model, Helbing *et al*. model 'non-fluid' crowd properties such as the self-organizing phenomena (formation of lanes) occurring in pedestrian crowds as well as the 'faster-is-slower' phenomenon in which people in a rush end up going slower. Helbing found that at medium and high pedestrian densities the motion of pedestrian crowds shows some striking analogies with the motion of gases and fluids. These include viscous fingering, propagation of shock waves in dense pedestrian crowds. Apart from these phenomena, there are some analogies with granular flow. Also at bottlenecks (e.g. corridors, staircases or doors) the passing direction of pedestrians oscillates which is analogous with the fluid-dynamic "saline oscillator" and with the granular "ticking hour glass".

Helbing *et al.* also investigate the best evacuation strategy for people in a smoke-filled room. They simulate the tendency of people following the crowd, but also allowing for individuals to adopt personal strategies. They also show that a widening in a corridor actually slows down the movement of pedestrians, rather than allowing them to move faster, as one would assume. Helbing *et al.* demonstrate that, because of their increased speed and increased nervousness (time-dependent parameter), panicking individuals will block up an exit (due to clogging; an arch-like blockings) that they could pass through safely at normal walking speed. They found that velocities higher than 1.5 m/s reduce the efficiency of leaving the room which is due to pushing and at desired velocities about 5m/s, people are injured and become non-moving obstacles for others.

(1) Improvements to Social Force Model:

Teknomo[3] proposed a physical force based model similar to social force model where forward and repulsion forces are treated as the main force driver for the pedestrian movement. The repulsive forces, which consist of two kinds of forces, have been proposed for collision avoidance. One force is driving away the pedestrian actor while still quite far from other closest pedestrian, the other force strongly repulses against all other pedestrians in the surrounding. The proposed model has been calibrated and validated using real world data and the results seem promising.

Recently, D.R. Parisi and C.O. Dorso [10] have used the social force model to explain the asymmetry found to granular and social interactions at a certain threshold value of desired speed. By classifying into "social clogging" and "granular clogging", they have shown that at desired speed greater than 2m/s, granular clogging is dominant for clogging delay due to the formation of "blocking cluster". For quantifying the relationship between blocking cluster and clogging delay, they define the "arch-clogging" correlation coefficient as follows:

$$C_{ac} = \frac{1}{N}\sum_{cd=1}^{N} f(t_2^{bc}, t_1^{cd}, t_2^{cd}) \tag{4}$$

where N is the total number of clogging delays in each run, t_2^{bc} is the time at which some arbitrary blocking cluster brakes down, t_1^{cd} is the time at which the associated clogging delay starts, t_2^{cd} is the time at which this clogging delay finishes. The function f is equal to 1 if $t_1^{cd} \leq t_2^{bc} \leq t_2^{cd}$ and is otherwise equal to 0. With the arch-clogging correlation coefficient as defined in equation (4), they have plotted the correlation coefficient against desired speed. The simulation result show that the correlation between the presence of a blocking cluster and a clogging delay is almost one for delays longer or equal to 2.3 seconds and desired velocity greater than 2 m/s. That is to say, almost 100% of the clogging delays (for the considered range) were produced by blocking clusters. For shorter clogging delays (0.1s to 2.3s), the competition between social clogging and blocking clusters is also evident from the simulation result.

4. NOMAD and SimPed

Delft University of Technology, Holland has developed two simulation models for pedestrian flows to describe individual pedestrian behavior (NOMAD) and to describe pedestrian flows in transfer stations, including the interaction with public transport vehicles (SimPed). NOMAD, a microscopic model, is activity based, implying that the actions of the pedestrians are largely determined by the different activities pedestrians have planned to perform while being in the walking facility [2) 4) 5) 6)]. It describes the execution of human control tasks where pedestrians are assumed to minimize the so called the running cost of walking. The running cost $L^{(p)}$ as given by Hoogendoorn [11) 12)] as $L^{(p)} = \sum_k c_k^{(p)} L_k^{(p)}$ where $c_k^{(p)}$ denotes the relative weight of cost component $L_k^{(p)}$. Three running cost factors has been considered viz. (a) cost for drifting from the planned trajectory (b) cost of walking near the other pedestrians/obstacles (proximity cost) and (c) cost of applying acceleration (acceleration cost). NOMAD inhibits a feedback mechanism that predicts the effect of worsening conditions on flow behavior. Sometimes, a pedestrian may change his or her walking strategies when the current strategy does not yield satisfactory results. Having conducted a number of simulations, Hoogendoorn claims that the adaptive controller framework is very suitable to model changing behavior under safety-critical conditions [11)]. By considering the case of crossing pedestrians at an intersection, Hoogendoorn shows how crossing homogeneous strips of approximately the same width are self-formed at the intersection [12)].

SimPed [2) 4) 5) 6)] is a macroscopic modeling tool to estimate both mean and variability of walking times incurred by transferring passengers and to visualize walking patterns inside transfer stations and other pedestrian areas. It uses the macroscopic relations between density in the walking areas and pedestrian speeds instead of considering the interactions between individuals (microscopically) for showing the influences of spatial environment. Discrete choice utility maximizing models are derived and specified for all relevant choices with respect to activity scheduling, activity area locations, routes, and walking trajectories. Other remaining processes like performing activities, boarding, and alighting have been modeled as service queuing models. Besides, procedures have been developed to derive individual walking speeds and aggregate densities in all types of walking infrastructures. Likewise, G. Keith Still[13)] developed the model “Legion” that simulates the crowd as an emergent phenomenon using the concept of mobile cellular automata. The model treats every entity as an individual and it can simulate how people read and react to their environment in a variety of conditions, allowing the user to study a wide range of crowd dynamics in different geometries and highlights the interactions of the crowd with its environment which can be used to assess the limits of crowd safety during normal and emergency egress. The model has been tested for the case studies of crowd behavior at Wembley stadium, Balham Station, UK and Hong Kong Jockey Club, Hong Kong.

(1) Controlled experiment for pedestrian flow research

Delft University of Technology has recently collected data by carrying out experimental pedestrian flow research [2) 6)]. These experiments have been used to observe pedestrian walking behavior in different conditions. Free speed, walking direction, density and bottlenecks were the experimental variables considered. Experiments have been performed for station and shopping conditions, one, two and four directional traffic flows, and with narrow bottlenecks. The experiments produced achievements with respect to free speed distributions, speed variances, fundamental diagrams, self-organization, and capacity of bottlenecks both for one directional and multi directional flows. With respect to the fundamental diagram, a slight difference from car traffic flow theory was observed as for the fundamental flow density diagram, the congestion observations in front of the bottleneck do not appear to be concentrated around a single point in the phase space as in car flow theory. Capacity estimates show that the relation between the width of a corridor and its capacity is not linear, as is mostly assumed, but looks more like a step-wise capacity function, at least for bottlenecks of moderate width (less than 3 m).

5. Discussion

With the review of the emerging microscopic and macroscopic models, the authors are currently focusing on the further search and improvements on the reviewed models that may reveal better understanding on the behavior of pedestrians. The improvements in the current simulation models that the authors are outlining for the future study are:

I. Formation of stripe in crossing pedestrian flows:
   The formation of stripe in crossing pedestrian flows still needs to be investigated further for proposing the improvements in the intersection. The authors are focusing on the diagonal pedestrian crossing at the intersection. By comparing the results obtained from the simulation model with the real observed scenario, more insight on stripe formation is expected.

II. The inclusion of different individualities in the particle systems as well as group behaviors:
It is to be noticed that different people can react in different ways depending on their individual characteristics and on group structure. Therefore there is need of assigning attribute individually to each agent and then incorporating the aspect of changing individual behavior as a function of group. This improves the individualism and the homogeneity of particles considered in the existing simulation models.

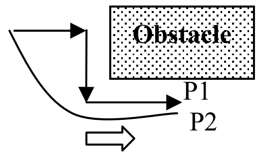

Figure 1: Path followed by agent without vision field (P1) and with vision field (P2)

III. Consideration of dynamic obstacles:
It is possible for some area to become really crowded causing a serious obstacle to pass and requires the avoidance of congestion. Therefore, an additional model that not only considers the static obstacles but also the dynamic obstacles needs to be considered in the simulation models. The additional force strong enough to lead pedestrians around the crowded area needs to be considered.

IV. Inclusion of visual field as a modeling element:
The existing simulation models are seen to lack the vision field for the agent. That is to say, they use the same model for collision with other pedestrians and obstacle avoidance. As shown in figure 1, this may lead to unrealistic walking behavior (P1) with tendency to go around the obstacles following its boundaries as compared to more realistic walking behavior (P2). Also suitable path finding algorithm needs to be developed in order to route the pedestrians around the environment for analyzing complex pedestrian scenarios as the driving force are not always sufficient to move the pedestrians.

Further search of microscopic and macroscopic pedestrian characteristics might help for the more in-depth analysis of pedestrian behavior. The additional models for obstructions and wall avoidance of the microscopic pedestrian may reveal improved capacity analysis. To decide whether a particular model is a precise depiction of real life scenario, or to determine which model is the 'best' for the situation under consideration, requires real data to compare with each model's predictions. The aforementioned model that we reviewed is yet to be tested fully with real life data though such data are scarce as well as difficult to collect. However, the simulation models can provide valuable information to guide the planning process and to deal with emergencies giving wider range of possible solutions to crowd problems if one is aware when it is appropriate to use the model. Although, ideal safety might be unachievable, but improved models of pedestrian dynamics can assist to enhance the safety in crowded situation.

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