Simulation of Pedestrian Dynamics and Model Adjustments: A Reality-Based Approach

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Summary. One focus of recent research activities in the field of pedestrian simulation is the evaluation of commonly used dynamics models: The results of computer simulations are compared to empirical data gained from observation of real-life pedestrian movement. For this, simple scenarios such as bottlenecks or corridors were arranged with human test subjects and then computer-simulated accordingly. When the same scenarios were simulated by a number of common simulation tools, significant deviations between the data generated by the different applications were found, concerning e.g. the calculated evacuation time for a simple building [1]. These findings lead to the conclusion that established models e.g. the Social Force model will have to be re-evaluated. Only then it is possible to draw reliable conclusions for real-life pedestrian traffic flow.

This article presents a modified Social Force model, which can be used to simulate scenarios such as single file movement or bottleneck flow, but also more complex ones. As a first step, empirical pedestrian traffic studies [2] were simulated. Results were then compared to empirical data used for evolutionary model adjustment. The new modeling approaches are also applicable to other models and will therefore be a contribution to simulating pedestrian dynamics in the closest possible accordance to reality.

1 Introduction

Computer simulations are used with increasing frequency when emergency exit routes of public buildings have to be designed. Particularly with this application it is important that simulation results are realistic and reliable.

Our objective is to develop a pedestrian dynamics model which describes reality in both qualitative and quantitative terms. Therefore, we present a modified Social Force model reproducing characteristic collective phenomena and also a density-velocity relation of pedestrians on a single lane.

2 A Modified Social Force Model

The Social Force model was developed by *Helbing et al.* [4][5]. It is based on the idea that pedestrian movement is determined by the surrounding social context and inter-relations. These influences can be described by means of "social" forces consisting of a driving term f_i^0 as well as repulsive terms f_{ij} and f_{ib} originating from other pedestrians j resp. from obstacles b.

$$\frac{d^2\mathbf{x}_i(t)}{dt^2} = \mathbf{f}_i^0(t) + \sum_{j\neq i}\mathbf{f}_{ij}(t) + \sum_b \mathbf{f}_{ib}(t) \tag{1}$$

Our advice is to calculate the repulsive force f_{ij} between two pedestrians i and j with a dynamic elliptical motion range R_{ij} resp. R_{ji} and a dynamic range of influence r_{ij}. The repulsive force only works if the viewing angle φ_i^s is larger than the relative angle φ_{ij}, which is between the relative position x_{ij} and the moving direction of i.

$$\mathbf{f}_{ij}(t) = \begin{cases} s_j \cdot \exp\left(\frac{R_{ij}(t)+R_{ji}(t)-\|\mathbf{x}_{ij}(t)\|}{r_{ij}(t)}\right) \cdot \frac{\mathbf{x}_{ij}(t)}{\|\mathbf{x}_{ij}(t)\|} & : \varphi_{ij}(t) < \varphi_i^s(t) \\ 0 & : \varphi_{ij}(t) \geqslant \varphi_i^s(t) \end{cases} \tag{2}$$

$$\mathbf{x}_{ij}(t) = \mathbf{x}_i(t) - \mathbf{x}_j(t) \tag{3}$$

The dynamic elliptical motion range of a pedestrian i (see Fig. 1) depends on his step length R_i^e, the scale of his lateral swaying R_i^t and the relative angle φ_{ij}. R_i^e and R_i^t are calculated with the absolute velocity v_i. For the increase or also the decrease of lateral swaying, experimental data is still missing. For a first approach we take

$$R_{ij}(t) = R_i^t(t) + \left[R_i^e(t) - R_i^t(t)\right] \cdot |\cos(\varphi_{ij}(t))| \tag{4}$$

$$2 \cdot R_i^e(t) = 0.235 + 0.302 \cdot \|\mathbf{v}_i(t)\| \tag{5}$$

$$2 \cdot R_i^t(t) = 0.465 + 0.183 \cdot \|\mathbf{v}_i(t)\| \tag{6}$$

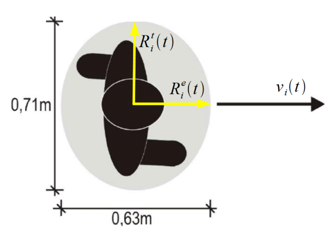

Fig. 1. Mean Elliptical Motion Range of a Pedestrian [6]

The dynamic range of influence of pedestrian j depends on the relative angle φ_{ij} and the relative velocity v_{ij}. If pedestrian i is subject to an influence in front of him, the relative velocity exerts full impact. Up to the edge of the field of view with the angle φ_i^s the range of influence is a constant.

$$r_{ij}(t) = \left[1 + \gamma_i \cdot \|\mathbf{v}_{ij}(t)\| \cdot \left(1 - \frac{1 - \cos(\varphi_{ij}(t))}{1 - \cos(\varphi_i^s(t))}\right)\right] \cdot r_j \tag{7}$$

$$\mathbf{v}_{ij}(t) = \mathbf{v}_i(t) - \mathbf{v}_j(t) \tag{8}$$

γ_i sets the individual scale of the relative velocity v_{ij}. It is a culture-dependent parameter adjusted with empirical data taken from [3]: European pedestrians can be simulated with $\gamma_i = 10$, Indian pedestrians with $\gamma_i = 4$.

3 Quantitative Model Validation

A density-velocity relation of a single file movement was empirical measured by *Seyfried et al.* [2]. Fig. 2 illustrates the set-up and a video sequence of the experiment.

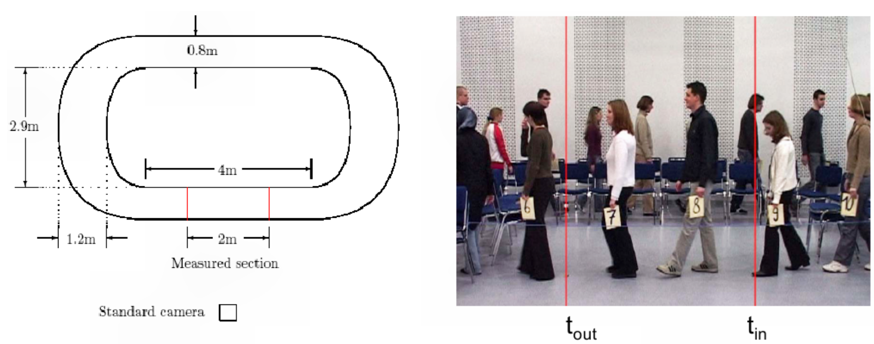

Fig. 2. Single File Movement - Experimental Set-Up and Video Sequence

In order to validate our Social Force model, we simulated the experiment with the tool *JWalkerS* [7] using a 17.3 m long periodic system. The motion equations were integrated with Adams Bashford 2nd order and a time step of 0.05 s. Fig. 3 shows a simulation with 30 pedestrians characterized by elliptical motion spaces increasing according to velocity.

Fig. 3. Single File Movement - Simulation with *JWalkerS*

The simulation reproduces an approximation of the empirical fundamental diagram. Fig. 4 shows a comparison of experimental and simulated data. However, fluctuations are larger in simulation than in reality.

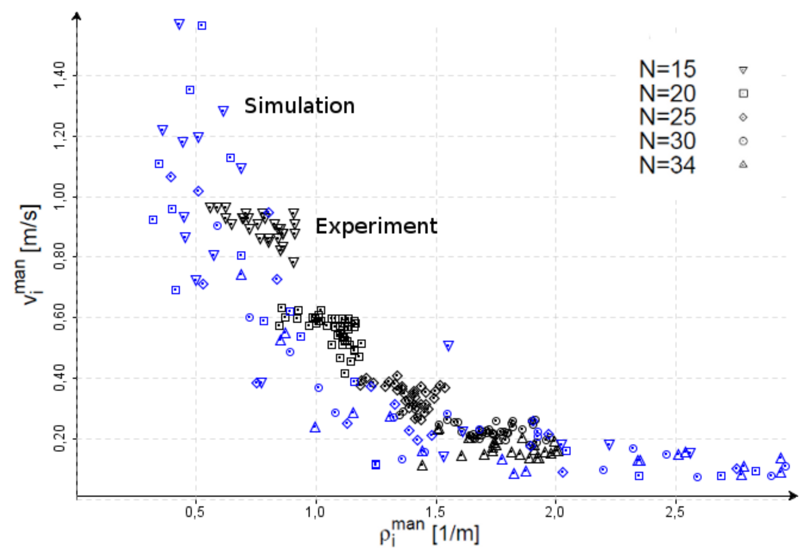

Fig. 4. Single File Movement - Experimental and Simulated Fundamental Diagram

4 Application Example

The Hanover Central Station is an important crossing station in Germany. It connects high-speed railroad lines from North to South and from West to East and vice versa. There are 622 trains stopping at 12 platforms and approx. 200.000 travelers and visitors passing the station per day.
By means of the modified Social Force model, pedestrian flow inside Hanover Central Station was simulated. The objective was an optimization of the passenger traffic, including transfer processes. For the simulation, the infrastructure was spacecontinuously modelled. Fig. 5 locates the station within the city center of Hanover. The black surfaces and the red polylines represent the outline of the simulated part of the building.

The simulation is restricted to the ground floor of the station (see Fig. 6 and 7). The front of the building has 5 exits toward the city center. Inside, there are 3 passages to the area with platform access and several shops. According to actual usage (Mainline passengers, commuters and shoppers), individual destinations were specified.
Fig. 6 shows trajectories of individual pedestrians. It is clearly visible where

Fig. 5. Hanover Central Station - Reality and Model (Source: Google Earth)

the main routes are located and where they cross. At these junctions, the probability for conflicts between pedestrians and thus for traffic jams increases. The pedestrians are depicted by elliptical motion spaces (see model above). The size of each ellipse correlates with the individual velocity. In addition, Fig. 6 illustrates how the modified Social Force model reproduces certain collective movement phenomena, for example lane formation.

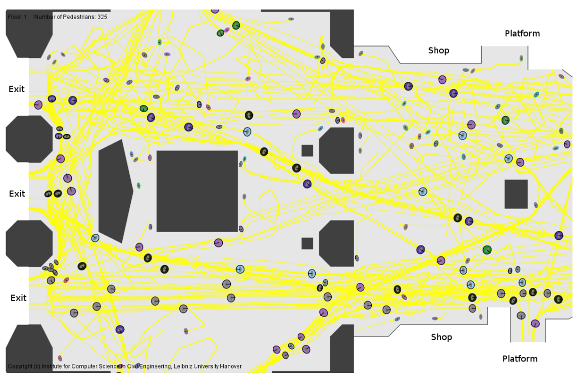

Fig. 6. Hanover Central Station - Trajectories with JWalkerS

Fig. 7 shows the mean velocity at a specific time point as well as the maximum density of a simulated number of pedestrians. The instances are indicated on a regular grid structuring the simulation data. The velocity distribution is represented by blue arrows originating from the grid elements. The arrows point to the mean collective motion directions. The density is indicated by the intensity of red: Light red stands for a low density while dark red means dense crowding. The absence of color is used for sections where no pedestrians are positioned. The calculated congested areas (entrances etc.) are in accordance to our daily observations.

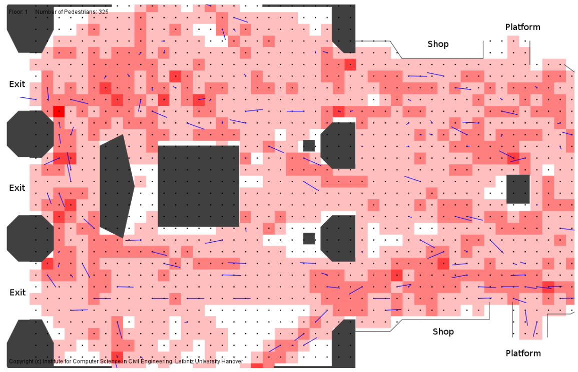

Fig. 7. Hanover Central Station - Density and Velocity with JWalkerS

5 Conclusion

In this contribution we introduced a modified Social Force model, taking into account a dynamic space requirement. Model parameters are calibrated by means of single file movement. Further calibration steps along with more general experimental setups are in preparation. Along with an application example we demonstrated that the model is suitable to simulate pedestrian traffic scenarios like building evacuations or passenger flows.

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