A Concept for Coupling Empirical Data and Microscopic Simulation of Pedestrian Flows

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In this paper we present a concept for coupling empirical data and a microscopic simulation of pedestrian motion. Since there is no automatic detection method available for this task up to now the main focus is on developing such a system.
A review of the different detection methods is presented and the requirements are given an automatic system has to fulfil. Additionally, a possible realisation of such a detector is described. Experiences with such a system for vehicular traffic are reviewed.

INTRODUCTION

The simulation of pedestrian motion has reached a high interest in many fields of human live. There are two major directions of pedestrian flow simulation: One is the investigation of basic phenomena encountered in human motion like the formation of trails with opposite walking directions [14, and references therein] or the formation of temporary roundabout traffic [13]. The other field is the application of these simulations to optimise pedestrian flows in complex geometries for various intentions.

Our simulation was originally developed for the simulation of evacuation processes onboard passenger ships [7]. But due to its high flexibility it can also be used to simulate pedestrian flows within football stadiums or shopping malls.

Since our model provides a high simulation speed it is possible to perform calculations faster than real time for a large number of pedestrians. Combining this high calculation speed with an automatic detection system for pedestrian flows will enable medium term predictions for the distribution of people from detected initial conditions.

The outline of this papers is as follows: In the next section we present the basic elements of our model. The following section gives an overview over the available empirical data and problems that occur during the collection. Next, an overview over the currently available systems for the detection of pedestrians is given. A short discussion of the usability of these methods for our concept follows. From this we develop the requirements for an automatic detection system which is described in the next section. The last section gives an idea for a coupled detector/simulation system and its probable use.

MODEL DESCRIPTION

For the simulation of pedestrian flows a Cellular Automaton (CA) model is used [7]. Contrary to macroscopic models which pay no attention to individual behaviour of pedestrians our microscopic model simulates individuals.

The floor plan is divided into quadratic cells with a size of 0.4m by 0.4m. Each of these cells can be occupied by at most one pedestrian. The people are allowed to move from one cell to each neighbouring unoccupied cell. That means the coordination number is 8.

Walls, furniture and other obstacles are represented as inaccessible cells (see figure 1). The orientation of the pedestrians towards a certain target is done by a potential field. Walking in the direction of the gradient is the shortest way to a given target that is the source of the potential. The values for the potential field are subject to a metric that generalises the “Manhattan metric”. The distance to the target is coded in the grey shade of the cells. The lighter the grey the shorter the distance.

The update of the pedestrians is done in a random order. The order is set at the beginning of each time step. Moved pedestrians are deleted from the order. Because of that each pedestrian is moved only once in a time step.

Individual characteristics of the pedestrians are given by a set of parameters. These parameters are assigned according to a normal distribution between given limits. The parameter sets include the walking speed which is given in cells per time step, a swaying probability to describe a variation from the shortest path, a dawdle probability to describe the speed reduction due to orientation, a patience to give the ability to search for a new way when the currently chosen way is jammed, and a maximum vision range.

To reach higher walking speeds than one cell per time step (e.g., 0.4m/s) each time step is divided into sub time steps (see figure 2). In each sub time step a pedestrian can move from one cell to a neighbouring cell. By filling in as much sub time steps as the required maximum velocity is we can simulate higher walking speeds. In this context, lengths are measured in cells and speeds in cells per time step.

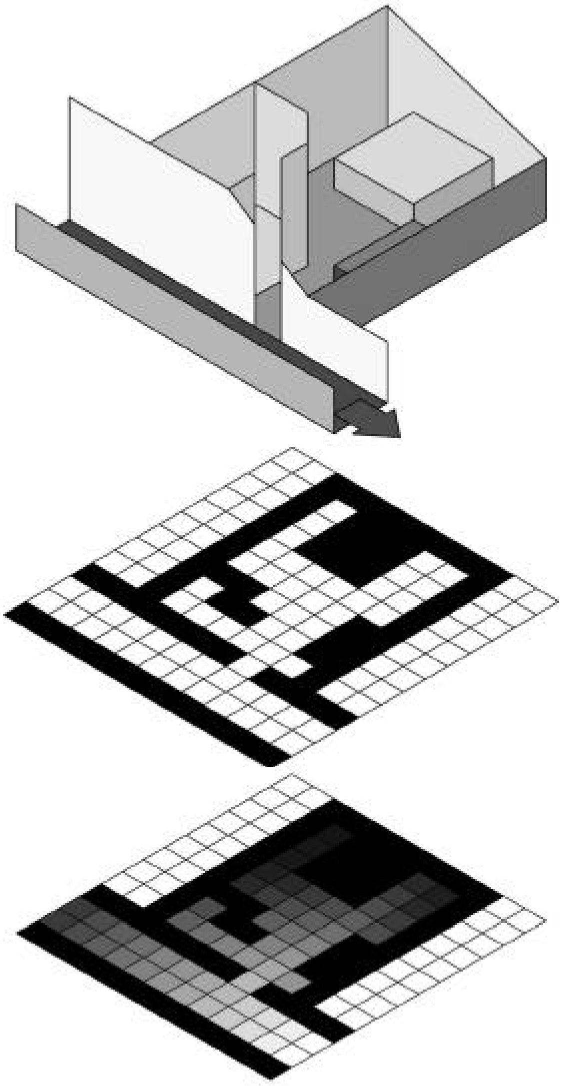

Figure 1: Discretisation of the floor plan. Inaccessible areas are marked as black cells. Accessible cells are white. The grey cells represent the potential field which leads to the exit.

The interactions between the individuals are repulsive. If a cell is occupied by a pedestrian no other pedestrian can use this cell in the particular time step. In this way accidents are prevented.

The outcome of the simulation is the total evacuation time. This is the time until the last person has left the facility. Since decisions of pedestrians are made by drawing random numbers a single simulation run can produce an arbitrary result. So we repeat each simulation a couple of times with different random numbers to make a statistical statement about the evacuation time (Monte Carlo simulation). Additionally, for each person the starting point and the exit coordinates are recorded together with some statistical information (e.g. which speed for how many time steps). In the upcoming version a density and occupancy plot will be available. These plots provide information on which cells are most frequently used during the evacuation.

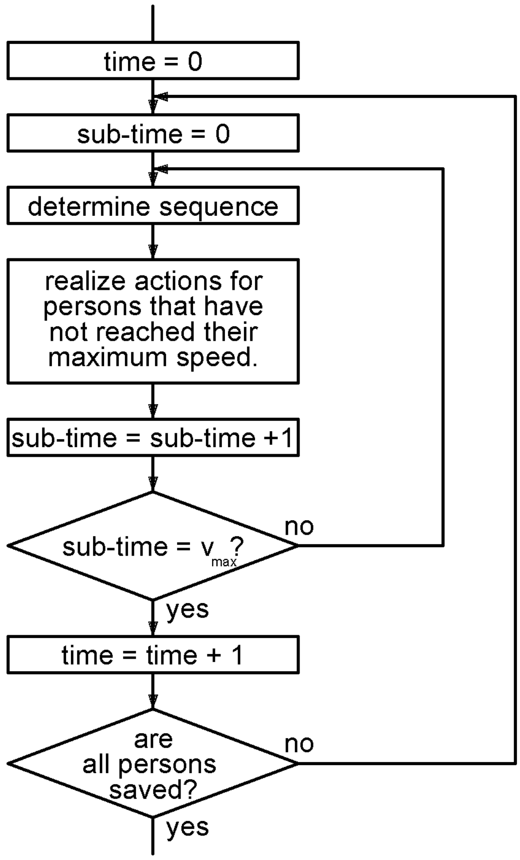

Figure 2: Algorithm of the microscopic simulation. The update sequence of the persons is random. The number of sub time steps equals the maximum walking speed.

EMPIRICAL DATA

For our simulation we use a small set of parameters. Nevertheless it is highly recommended to adjust these parameters for our simulation as well as for other simulations dealing with pedestrian motion. This is done either by extracting them from the literature [3], from observations, or by trial and error [10].

In the end there is always the need for observations since the outcome of the simulation is an evacuation time which has to be compared with full scale tests (unless the results are trustworthy).

To compare the simulation with full scale tests we have observed some evacuation drills in schools and on ships and we have undertaken some own experiments.

These observed drills, especially in the schools, showed some critical points of the simulation we did not pay much attention to before. For example, while the real exercise in a primary school [6] was done in about 85 seconds the simulation predicted about 160 seconds. This gap occurred because we did not consider the special circumstances that our observation produced: The exercise was done in a primary school with pupils of the age of 6 to 10 years (first to fourth grade). Our observation equipment (cameras, staff) produced a high grade of nervousness so that the pupils tried to make their job very good what means that they moved very fast. In the first simulation runs we did not consider this fact and worked with pupils which were too slow. By fitting the walking speeds to recorded values the simulated time dropped down to about 100 s.

By comparing the simulation to another evacuation exercise in a secondary school a second necessary point occurred. It showed up that neglecting furniture in the class rooms leads to a difference in evacuation time. Our first idea was that the class rooms basically serve as a reservoir for the pupils and when the alarm is given they just move out. It occurred that the furniture (tables) in the class rooms lead to a guidance of the pupils within the class room. This resulted in a better outflow through the door and not to the jam which appeared without tables. This increased the outflow and led to a simulated evacuation time which better fit to the measured time.

Phenomena like the influence of furniture are qualitative. They can be analysed by simply watching the recorded video films. But if we want to extract data like walking speeds from such drills we have to examine the films frame by frame. This is a very time consuming work.

From this fact the idea arose to use an automatic detection system. Looking at what is currently available for human detection we found nothing sufficient and we formulated some essential requirements. From these requirements we derived an idea for such a detector.

If such a detector would be available there is a wide field of applications for the detector itself as well as for a coupled detector/simulation system.

CURRENT DETECTION METHODS

In this section we give an overview of the detection methods which are currently available for human beings. Most of these detectors can only detect the presence of people but no individual data like walking speed and direction.

Detectors can be differentiated by several criteria. One differentiation can be done by the categories *active* or *passive* detectors. This differentiation is based on the measurement principles the detectors use. Active detectors are working on a sender/receiver basis. A sender emits some kind of radiation (in most cases electromagnetic radiation). Either the reflected signal is detected or it is detected that the signal is blocked by an obstacle (e.g., for light barriers). By measuring the travel time of the radiation the distance to the target can be computed. Microwave detectors, active infrared detectors, ultrasonic detectors, and laser scanners belong to this category.

Passive detectors do not emit any radiation but detect the environmental radiation field and react on changes therein. Typical passive detectors are passive infrared detectors and video cameras.

A second approach for the differentiation of sensors is the type of application they were developed for. In this case the detectors can be divided in the categories *static* and *dynamic* sensors. Dynamic sensors are only able to detected moving objects while static sensors can only detect fixed objects.

In the following a short description of the different sensors is given. For a more detailed view on the different detectors, see [2].

Active Infrared Sensors

Active infrared sensors emit infrared light with a wavelength close to the visible spectrum and detect the reflected part or the transmitted one. They are capable of detecting non moving objects. A special case of these sensors is the infrared light barrier. The light barrier is triggered when a beam of infrared light is interrupted. The need for an interrupted light beam enforces a special mounting position for light barriers which is not always possible.

Passive Infrared Sensors

Passive infrared sensors are frequently used as motion detector for automatic illumination, alarm plants, or automatic doors. They consist of a pyro-electric element which produces an electric current when infrared radiation acts on the element.

They react on rapid changes in the environmental infrared radiation field. Because of that they are only able to detect moving objects. The detected wave length is above 10 μm.

Microwave Detectors

By emitting and receiving electromagnetic waves with a wavelength of 1 to 10 cm microwave detectors belong to the group of active detectors. Sending and receiving is done with a single antenna. By measuring the travel time of the wave the distance to a target can be computed and by using the Doppler-Effect the velocity of a target can be measured.

A measure beam is emitted by the antenna and the mixed signal of all reflections is received. Because of that only the strongest signal is analysed.

By using the Doppler-Effect, microwave detectors are capable of detecting the velocity and moving direction of a target. This enables microwave detectors to measure only pedestrians who are walking in a certain direction. But it also produces problems when a detected person who fits detection criteria is superimposed by a signal of a person who does not match the criteria. Then there will be no person detected.

Ultrasonic Sensors

Some animals orientate by using ultrasonic (e.g., bats). The detection is done by emission of silent sonic impulses and receiving of echo.

While this technique is sufficient for animals it is not reliable for person detection. The strength of the reflected ultrasonic impulses depends on the clothing of the persons. A weak reflection leads to non-detection of persons. Additionally, for a strong reflection the impulse has to impinge vertically as the reflection has to.

An advantage of ultrasonic detectors is the ability to detect unmoving objects for infinite time periods.

Mat Detectors

Some materials change their behaviour under pressure. This effect is used in mat detectors. Mat detectors are placed instead of sidewalk slabs or beneath them.

There are two different systems of pressure sensitive mats available. One system consists of a piezo-electric coaxial cable which is embedded in rubber mats. When the cable is exposed to pressure like from a person standing on the mat an electric voltage is produced.

The other system measures and analyses the change in the optical properties of glass fibres.

In this configuration mat detectors are only useable to detect the presence of persons. To count persons the mats have to be divided in smaller elements and then arrays of these elements have to be installed.

Laser Scanners, Radar Scanners

The measuring principle of scanners is the computing of travel time of various electromagnetic radiation. Either infrared light (for Laser scanners) or microwaves (for Radar scanners) is used. The narrow bundled radiation is emitted by a moving emitter and reflected by the target. By computing the travel time or the phasing, the distance to the target can be detected.

Originally, scanners had been developed for the differentiation and counting of different road users. They are also used for the detection of persons in secured areas. Since the scanners are mounted overhead a use for the collection of pedestrian data is in principle possible but has not yet been tested.

Video Analysis

Currently, video analysis is used for data collection of cars. The video images are analysed by a grey scale analysis in pre-defined windows. For cars this technique works sufficiently good but does not satisfy the needs for pedestrians. The main problem is the definition of windows which fit to pedestrians anywhere in the plane.

A new system from the University of Minnesota [1] is able to track pedestrians in real time. This system works for single pedestrians with a frame rate of 30 frames per second but the frame rate drops down with an increasing number of pedestrians. The number given is 25 frames per second for 6 pedestrians. This drop down depends on the available computer power. Since the computational possibilities increase very fast it will be only a question of time since a larger number of pedestrians can be tracked in real time.

Thinking of a long term observation using video analysis the question of data security has to be addressed. Taking videos of persons is often not allowed unless they do not give their explicit permission.

DISCUSSION OF THE DETECTORS

Since most of the above mentioned systems have been developed for the detection of pedestrians waiting at crossings they are not able to extract any motion data of the pedestrians. Furthermore, some of the systems are not able to detect how many pedestrians are there. For example, infrared detectors give a signal independent of the total number of pedestrians. If there is at least one pedestrian they trigger the crossing light.

This limitation is not hindering if the detectors are used for presence detection at crossings. But it makes them unusable for collecting data like walking speed and direction.

Another disadvantage is the “loss” of pedestrians due to occlusion. This is the main problem of the optical systems like video analysis or radar scanners since they are usually not mounted overhead. But it is essential that pedestrians do not simply disappear or suddenly appear for the collection of data.

The great advantage of a video analysing system is variable size of the observed area. By simply changing the zoom of the camera a higher resolution can be reached.

IDEA FOR A NEW DETECTION METHOD

From the above mentioned points we can derive requirements for a detection system which can be coupled to our or any other microscopic simulation. The main requirement is the robustness against occlusion. The system must be able to detect the presence, walking speed, and walking direction independently from the level of occlusion to give a full set of data to the simulation. Since this can only be reached by mounting cameras or scanners overhead (what is not always possible) this is the main problem.

Another possibility to prevent occlusion is the detection from beneath. This idea is based on the inductive loops which are used for traffic detection [8]. Inductive loops are common in collecting data from moving cars. The metal parts of the cars trigger an inductive loop and this signal is analysed by a computer.

Since humans are (at least in the beginning) not metallic the use of inductive loops is impossible. The idea for the detection system is the use of footprints of the walking pedestrians on the above mentioned pressure sensitive mats (figure 3).

In the current configuration the mats are only able to give a signal when something exerts a pressure on the mat. A spatial resolution is not given. But by dividing a mat in small quadratic elements of 10cm by 10cm it would be possible to detect where a footprint is made. By measuring the distance of the footprint from the edges of the array it is possible to predict where a person enters the array. From the shape and orientation of the footprint a prediction for the walking direction can be made (see figure 3).

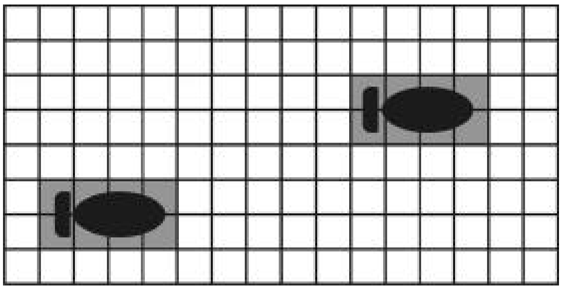

Figure 3: A possible situation on a spanned mat detector. The footprints (black) trigger the underlying elements (grey). Because of the closeness to the left edge of the array the next footprint is estimated near the right edge.

The analysis of the position and orientation of the first footprint starts the system to wait for the second footprint in walking direction. From the temporal and spatial distance between the footprints the walking speed and direction can be computed. By counting the footprints the number of pedestrians can be obtained to get the density on the detector.

It will have to be shown that this approach is feasible. However, up to now we do not know of any facts that make this generally impossible.

Details

To explain the above mentioned mat array approach in more detail we now give an explanation of the assumptions made.

To find a good balance between costs and benefits we estimate that a size of 10cm by 10cm for the elements is sufficient. A better spatial resolution would be given with smaller elements but the increase in elements (half the size means four times the number) will possibly slow down the data extraction.

From this starting point we can derive the other requirements like detection speed. The estimated mean velocity of the detected persons is about 1.3m/s and the step length is about 0.6m/s (see [3]). This means that the time delay between the first and the second footprint is about 0.5s. When we require a measured accuracy of 0.1m/s for the velocity and (due to the cell size) take a variation of 0.1m for the step length, the upper limit for the deviation in the time measurement is 0.08s.

The total length of a mat array must not be less than 2m. This is because of the required direction detection. To decide where the first footprint is made we need the first footprint to be made near one edge of the array. With a length of 2m the first footprint is in any case made closer to one edge than to the other.

The width of the mat can vary depending on how many persons should be able to walk side by side. The lower limit for the width is the width of one person, e.g., about 0.5m.

Every single element is then connected to a computer which is triggered by the first footprint. The orientation of the activated elements determine in which direction the next footprint is estimated and the time measurement starts. When the second footprint activates the underlying elements the time measurement is stopped. From the distance between the activated elements the step length is calculated and together with the measured time the velocity can be computed.

This has, of course, not to be done online, but the data can be recorded and stored and analysed later on.

COUPLING TO THE SIMULATION

The collected data are fed into the simulation as the initial entrance rate and velocity in the simulated area. This area can be all kind of route network. From that source the simulated pedestrians spread over the network and walk through it according to the algorithm mentioned above. At some points within the network additional detectors can be attached to adapt the simulated amount, velocity, and direction of persons to reality. This makes a complete surveillance of the area unnecessary while the simulation fills the gaps where no surveillance can be done. Additionally is it possible to get data on the occupation of unmonitored areas. A similar system is applied successfully to city [16] and highway traffic [17].

Furthermore, a prediction of jammed areas would be possible because of the high simulation speed. This enables for the specific positioning of staff to resolve such congestions. Especially in the case of protected areas it is necessary to prevent such congestions as people are impatient. If they have to wait at a waypoint (e.g., a bottleneck on a way) they will soon try to shortcut trough the woods. To prevent this, a staff member can be positioned there to hinder the pedestrians in taking a shortcut and to speed up the other pedestrians in the bottleneck. This increases the effectiveness of the staff.

This coupling of empirical data and micro simulations is done with great success for highway networks in Germany ([4,5] and references therein).

CONCLUSION AND OUTLOOK

The presented concept for a coupled system of detectors and a microscopic simulation offers a wide range of possible applications. Not only in the field of data collection an automatic detection system would provide great benefits but also in the field of simulation and prediction of pedestrian flows. This enables the optimisation of route networks as well as the optimal positioning of staff members. Through a combined system of a microscopic simulation and a couple of detectors a complete surveillance of large areas becomes unnecessary.

The next steps will be the transfer of the theoretical data of the detector into a working system. After a detailed analysis of the capabilities the coupling to the simulation can be done.

Even though at the present state this is only a concept, there are three strong arguments for pursuing this approach:

- It has been done successfully for vehicular traffic.
- The basic technologies are available.
- There is a plethora of potential applications.

REFERENCES

[1] O. Masoud, "Tracking and Analysis of Articulated Motion with an Application to Human Motion", Doctoral Thesis, University of Minnesota, March 2000.

[2] G. Schirrmacher, "Verbesserung der Fußgängerquerung an Hauptstraßen", Diploma Thesis, Fachhochschule Hamburg, June 1999 (in German).

[3] U.Weidmann, "Transporttechnik der Fußgänger", Schriftenreihe des IVT, Institut für Verkehrsplanung, Transporttechnik und Eisenbahnbau, Zürich, 1992 (in German).

[4] O. Kaumann, K. Froese, R. Chrobok, J. Wahle, L. Neubert, and M. Schreckenberg, "On-line Simulation of the Freeway Network of NRW", in Traffic and Granular Flow '99, pp. 351-356. Eds. D. Helbing, H.J. Hermann, M. Schreckenberg, D.E. Wolf (Springer, Berlin, 2000).

[5] M. Schreckenberg, L. Neubert, and J. Wahle, "Simulation of Traffic in large road networks", Future Generation Computer Systems **17**, 649-657, 2001.

[6] H. Klüpfel, T. Meyer-König, and M. Schreckenberg, "Microscopic Modelling of Pedestrian Motion – Comparison of an Evacuation Exercise in a Primary School to Simulation Results", in Traffic and Granular Flow '01 (accepted for publication), 2001.

[7] T. Meyer-König, "Simulation der Evakuierung von Fahrgastschiffen", Diploma Thesis, Gerhard-Mercator-University Duisburg, March 2001 (in German).

[8] L. Neubert, "Statistische Analyse von Verkehrsdaten und die Modellierung von Verkehrsfluß mittels zellularer Automaten", Doctoral Thesis, Gerhard-Mercator-University Duisburg, 2000 (in German).

[9] M. Schreckenberg and S.D. Sharma (eds.), "Pedestrian and Evacuation Dynamics" (Springer, Berlin, 2001).

[10] S.P. Hoogendoorn, P.H.L. Bovy, and W. Daamen, "Microscopic Pedestrian Wayfinding and Dynamics Modelling", in [9], pp. 123-154.

[11] A. Keßel, H. Klüpfel, J. Wahle, and M. Schreckenberg, "Microscopic Simulation of Pedestrian Crowd Motion", in [9], pp. 193-200.

[12] T. Meyer-König, H. Klüpfel, and M. Schreckenberg, "Assessment and Analysis of Evacuation Processes on Passenger Ships by Microscopic Simulation", in [9], pp. 297-302.

[13] S.A.H. AlGadhi, H.S. Mahmassani, and R. Herman, "A Speed-Concentration Relation for Bi-Directional Crowd Movements with Strong Interaction", in [9], pp. 3-20.

[14] D. Helbing, P. Molnár,, I. Farkas, and K. Bolay, "Self-Organizing Pedestrian Movement", Environment and Planning B: Planning and Design **28**, pages 361-383, 2001.

[15] C. Burstedde, "Simulation von Fußgängerverhalten mittels zweidimensionaler zellulärer Automaten", Diploma Thesis, University of Cologne, 2001.

[16] J. Esser, "Simulation von Stadtverkehr auf der Basis zellularer Automaten", Doctoral Thesis, Gerhard-Mercator-University Duisburg, 1997 (in German).

[17] O. Kaumann, "Online-Simulation von Autobahnverkehr: Kopplung von Verkehrsdaten und Simulation", Diploma Thesis, Gerhard-Mercator-University Duisburg, 2000.