Real-time video analysis of pedestrians to support agent simulation of people behavior

O. Junker[*], V. Strauss[*], R. Majer[†], N. Link[†]

Vitracom AG[†]
76133 Karlsruhe, Germany
majer@vitracom.de
norbert.link@vitracom.de

Airport Research Center GmbH[*]
52066 Aachen, Germany
olaf.junker@arc-aachen.de
verena.strauss@arc-aachen.de

Abstract Online simulation coupled with real-time measurements of pedestrians in public buildings is a novel application which can be used to increase the security and safety of pedestrians within those buildings. To receive realistic forecasts it is necessary to update the simulation constantly against reality. The real-time video analysis can thereby support the simulation with the necessary data. This proposed system is largely supported by the state observer of the control theory.

Within a laboratory one room model pedestrian behavior is monitored and analyzed by video cameras. Evolving data is subsequently provided for the simulation where flow rates are additionally recorded. Thus, two resulting passenger flow rates are available which can be compared by the simulation controller. The actuators, receiving information from the controller, can afterwards trigger an appropriate action. Two different actuators have been realized in the model in order to bring the simulation passenger flow closer to the observed passenger rates: the velocity controller adjusts the walking speed of the passengers and the flow generator actuator has the ability to match the passenger generation rate.

Results show that the simulation passenger flow curve converges to the real passenger flow. As expected, the simulation curve follows the real passenger rate with a certain delay. Nevertheless, the simulation model appears to reflect the behavior of the persons in an appropriate way. Further investigations will show which additional instruments can be used to refine the simulation actor behavior.

Introduction

People moving along a restricted spatial area represent a complex dynamic system due to their different objectives, capabilities and strategies, their mutual interactions and the geometric motion constraints.

Agent and flow based numerical simulation of the people motion system behavior is commonly used to plan traffic facilities. Also emergency and evacuation scenarios are simulated in order to derive pro-active measures to prevent critical situations due to external impacts or internal fluctuations. The pre-requisite of such pro-activity is the detection of the evolvement of a dangerous situation in advance to trigger counter measures in time.

Another issue is the capturing of the traffic situation of large pedestrian traffic areas such as airports, train stations and other pedestrian traffic hubs or event locations. In these cases it is not possible to economically monitor the behavior of the people on the whole area with sensors. Measurements alone do also not allow to predict the evolution of the situation. On the other side, a simulation cannot provide any real-time information on the situation and the situation trend. This would not even be possible if the simulation gets the base information about the parameter configuration at the starting time: since the reality changes permanently simulation and reality would most probably drift apart very soon if the simulation does not continuously receive updated parameter data.

To address those problems we propose to combine the (fast-time) simulation of a pedestrian traffic model of the whole considered area with local sensor measurement at certain sub-areas. To avoid that simulation and reality drift apart a synchronization system will be adapted which can be seen as a control loop. Therein the simulation will constantly be calibrated and adjusted against the sensorial perception of reality. We expect to recover a complete and sufficiently precise real-time image of the current situation, which can be used as a starting point for situation prediction and the assessment of traffic control measures.

Solution concept

On-line simulation integrated with real-time measurements of pedestrian traffic in public buildings like train stations or shopping centers is a novel approach which can be used to increase the security and safety of pedestrians within those buildings. Usually a model of the building structures and a course model of the people behavior are available, reflecting the prior knowledge about the situation. The model is capable to represent the microscopic state (cross product of the individual states of the people) of the system. Measurement could in principal capture the microscopic state in real-time. As mentioned before, the complete coverage of large areas is not feasible in most cases. Therefore we restrict ourselves to situations, where the people flow can be measured at only some dedicated points or areas. These values form the so-called observables of the system, which are only a few compared to the complete number of state variables. The problem of calculating the microscopic state from the observables is therefore underdetermined.

A solution consists in relating the microscopic state with the observables and adjusting the simulation parameters to produce the measured observables values.

General Approach

The idea of using measurements to calibrate simulation has been followed by different research groups. In [8] measurement data is acquired off-line and used to calibrate the simulation system once before employment. In [5], [6] and [7] mesoscopic simulation systems are presented, which use online measurements to set the initial values of a simulation system or to set the actual start values of an on-line simulation system.
In this work, microscopic simulation and on-line measurement data are combined into an overall situation capturing system where the simulation parameters are permanently adjusted to optimally reflect the currently measured figures.
The capturing of the present microscopic state of a dynamical system by means of measuring only a few observables is addressed by so-called “observer models” in the control theory of linear systems. The observer consists of a virtual system, which runs parallel to the real system. As shown in figure 1, the real system is assumed to be linear and to obey the same dynamical state space model as the virtual system. This observer is named after its inventor Luenberger observer [1].

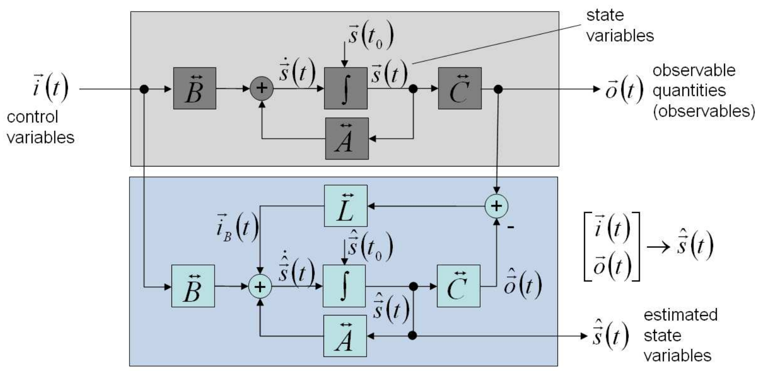

Fig. 1. Linear observer model for the estimation of the system state from observable values

This model is characterized by system matrix A, control matrix B and measurement matrix C. The system state is described by the state variables vector s. The evolution of s in time is determined by the system matrix (in the absence of external influence) and by external forces exerted by the control variables via the control matrix B. The measurement matrix C transforms the state variables into the observable quantities o, which can be measured with appropriate sensors.

The dynamical behavior of the system represented in Fig. 1 follows the following equations.

$$\dot{\vec{s}}(t) = \vec{A} \cdot \vec{s}(t) + \vec{B} \cdot \vec{i}(t); \quad \vec{o}(t) = \vec{C} \cdot \vec{s}(t)$$

$$\dot{\hat{\vec{s}}}(t) = \vec{A} \cdot \hat{\vec{s}}(t) + \vec{B} \cdot \vec{i}(t) + \vec{i}_B(t); \quad \hat{\vec{o}}(t) = \vec{C} \cdot \hat{\vec{s}}(t); \quad \vec{i}_B(t) = \vec{L} \cdot \left(\vec{o}(t) - \hat{\vec{o}}(t)\right)$$

These equations can be summarized in one dynamical equation for the estimated state depending on the known input quantities and the observables by

$$\dot{\hat{\vec{s}}}(t) = \left(\vec{A} - \vec{L} \cdot \vec{C}\right) \cdot \hat{\vec{s}}(t) + \vec{B} \cdot \vec{i}(t) + \vec{L} \cdot \vec{o}(t).$$

Matrix L must be chosen in such a way that the state estimation error governed by $\dot{\vec{s}}(t) - \dot{\hat{\vec{s}}}(t) = \left(\vec{A} - \vec{L} \cdot \vec{C}\right) \cdot \left(\vec{s}(t) - \hat{\vec{s}}(t)\right)$ converges to zero.

The virtual system is given an estimated start state and is evolving parallel to the real system. The sensors measure the values of the real observables, while the virtual system model produces estimates of the observable values. If the real and the virtual system were in the same state, the difference of the real and estimated observables would vanish.

The main idea of the observer is to use this difference to create an additional external force applied to the virtual system via matrix L to drive the state of the virtual system towards the state of the real system. The resulting state of the virtual system is then an estimation of the state of the real system.

After initializing the virtual system with a roughly estimated initial state, the linear observer model will converge towards the real state and thus track the system state from the observation of some measurable quantities.

Pedestrians within an observation area cannot be described by a linear dynamical model of the system states. Instead, sophisticated multi-agent models or fluid dynamics models are needed. In the non-linear case, the multiplication of matrices turns into general vector-valued functions.

$$\dot{\vec{s}}(t) = \vec{F}\left(\vec{s}(t)\right) + \vec{G}\left(\vec{i}(t)\right); \quad \vec{o}(t) = \vec{H}\left(\vec{s}(t)\right)$$

$$\dot{\hat{\vec{s}}}(t) = \vec{F}\left(\hat{\vec{s}}(t)\right) + \vec{G}\left(\vec{i}(t)\right); \quad \hat{\vec{o}}(t) = \vec{H}\left(\hat{\vec{s}}(t)\right); \quad \vec{i}_B(t) = \vec{J}\left(\vec{o}(t) - \hat{\vec{o}}(t)\right)$$

Despite this fundamental difference, we follow the basic idea of the observer model to adjust the model parameters such, that the simulation results and the measurements (observables) of people flow at dedicated positions have minimum difference. The force driving the estimated state quantities towards the real state quantities could be chosen to be proportional to the negative gradient of the squared difference between the measured and estimated observables $\vec{i}_B(t) = -\eta \frac{\partial\left(\vec{o}(t) - \hat{\vec{o}}(t)\right)^2}{\partial \vec{s}(t)}$ yielding an iterative adaptation scheme.

Extending the observer model to non-linear systems has already been considered before in chemistry [3] and production processes [2,4].
Within the state observer model two concurrent processes exist: (1) the real process with sensor systems giving observables values due to the real system state and (2) a pedestrian traffic simulation yielding an estimated system state.
The measured data allows to always use realistic start values for the current situation within the simulation and to continuously adjust the simulation parameters to minimize the difference between observed and simulated behavior. Since the simulated situation is always up to date based on the on-line real data the extrapolated forecast would increase in accuracy.

Measurement and Simulation

Real-time video analysis can be used to perform such measurements and deliver people flow, speed and track data as observables of certain observed areas.
Depending on the video processing technology and mounting situation, also flow distribution data of a larger area or precise track data of a smaller area can be acquired. Tracks can be evaluated with counter lines in the image to generate the actual boundary conditions of an analyzed area by measuring the current in-flow and out-flow of people at entrances and exits from counting data.
The video analysis is performed by the Vitracom SiteView system, which is able to extract the trajectories, number and speed of people at 25 fps. From this information, general rules e.g. regarding people behavior would be derived.
For the simulation and visualization the CAST engine of ARC is used, which allows a discrete event simulation, that integrates modeling, simulation and visualization abilities in a common environment.
CAST was chosen because new simulation actors can easily be developed and integrated into the full environment thus gaining all the advantages of the class hierarchy ancestors quickly and efficiently.
Inside the CAST engine, every agent represents an actor (e.g. passenger, a vehicle or aircraft) which is able to react to the given situation according to its individual characteristics. According to the BDI idea [4], every agent thus has a specific knowledge of his goals. In addition, agents may also have detailed knowledge about their environmental situation.
Following this idea, sensors reading real and simulation data as well as actors making adjustments to other actors have been implemented in CAST.

Communication between reality and simulation

The objective is to keep the simulation running parallel to reality, which is observed by the video analysis. In order to achieve this goal, the observables data gathered by the video cameras has to be delivered to the simulation. The interaction scheme –instantiating the observer control loop- is shown in figure 2.

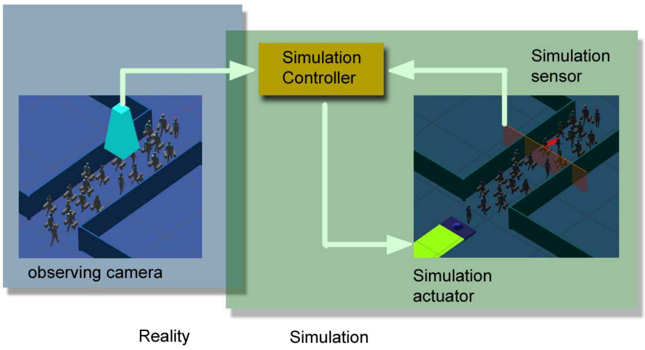

Fig. 2. Adjustment between Reality and Simulation

The observables of the real passenger flow captured by the video system are compared by the simulation controller with the data from the simulation sensor which extracts the same observables in the simulation model from the virtual agent flow. The simulation controller uses a simulation actuator to affect the simulation parameters in order to decrease the difference. This can be done with three different schemes. The respective effect on one traffic parameter (passenger flow rate in the example) is qualitatively shown in figure 3.

If the observed real passenger flow rate is higher than the current simulated flow rate it has to be increased. Increasing the simulation flow rate too fast by adjusting the passenger generation rate inappropriately will result in unrealistic, discontinuous passenger agent behavior (green curve). Using a certain attenuation factor (reflecting a realistic maximum passenger acceleration), the simulation curve will be slightly delayed against the real passenger flow and the simulation agents will additionally show a more realistic behavior.

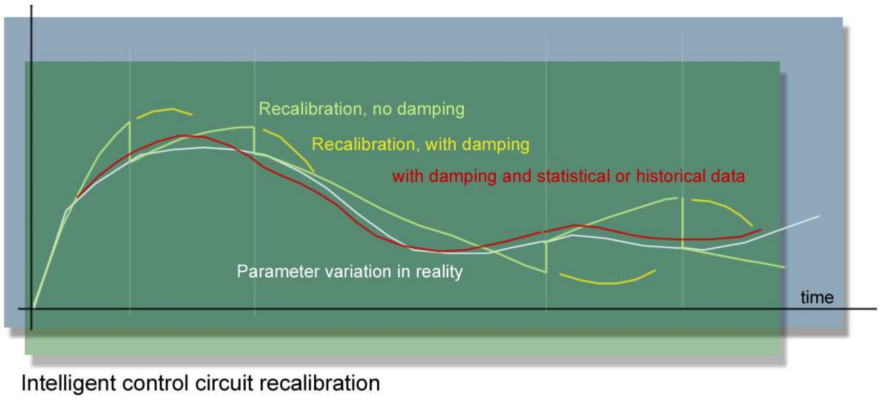

Fig. 3. Intelligent control circuit recalibration

If the simulation actuator is placed far apart from the sensor unit, a lag time will arise between the measurement itself and the time, where the action of adjusting simulation parameters is taken. This will result in unstable system behavior, which can be avoided by increasing the attenuation factor. Appropriate attenuation factor adjustment is a subject of ongoing research.

The most difficult part is to relate the observation results with actuator actions in order to bring the simulation closer to the reality. In the example above (fig. 3), the action that has to be performed - increasing the rate if it is too low - is obvious. For larger scopes, the real situation will never be covered completely but there is usually also more than one observer such as a camera sending data to the simulation. As a consequence, multiple simulation controllers as shown in fig. 2 might be employed having several data sources and even more than one actuator.

Future work will treat improvement measures. Stability can be improved by incorporating additional meta-information such as limits of certain traffic parameters which must not be exceeded. Precision improvement can be reached by sharing information among simulation controllers to benefit from the observations of the other controllers.

Interface between measurement and simulation

To prove the validity of this analysis, a real scenario is set up with the proposed system using pedestrian flow as observables. Differences between the pedestrian flows regarding direction and speed can be measured and quantified for parameter optimization of the multi agent simulation. For measurement and simulation SiteView and CAST were used.

The first integration step was to define an interface to exchange data between the systems.

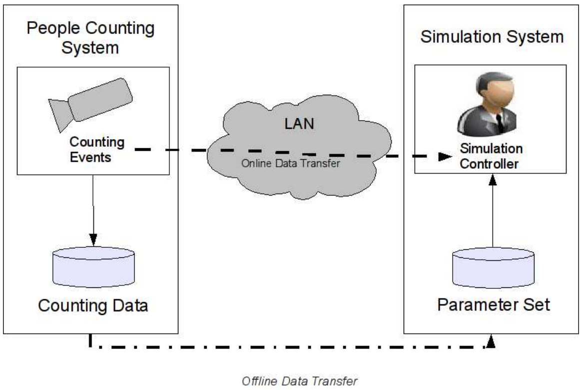

Fig. 5. System layout and online/offline data transfer

In figure 5 a technical overview of the system is given. For the experiments a file based offline exchange of data was implemented. Each trajectory which crossed a counting line, a time stamp and the direction are written into the CSV-file. Even though it is possible to exchange this data offline to run tests of both systems an asynchronous remote procedure call is currently implemented to exchange the data for each counting event. Therefore a standard network connection between the systems is needed, which is fast enough to exchange the data. The transfer has to be asynchronous because no system may wait for the other. If single data gets lost, this is no problem for each system in a technical matter since the parameter set of the simulation is given by historic data and “only” updated to the real situation. So this coupling of two existing and verified systems leads to more correct starting parameters of the simulation and to adapt better the real situation.

Test scenarios

A laboratory sample situation was set up for the development and testing of the system. The sample setup only consists of one room with one entrance and one exit situation (fig. 6). The area of the room is about 15 square meters in size. In contrast to real world scenarios the whole area was completely observed for validation of the simulation results. Only the people crossing events at entrances and exits were transferred to the simulation, the frequency of which was affected by the speed of people.

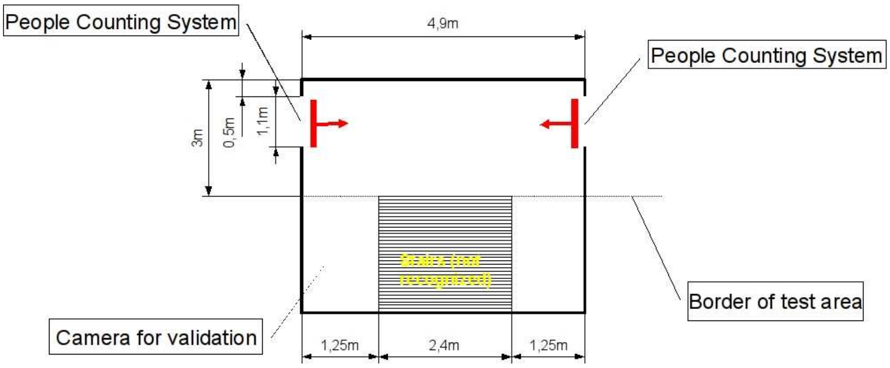

Fig. 6. Laboratory setup for test data acquisition

The experiments were about 20 minutes in total with no pre-defined number of participants. However 30 instructed persons (probands) wore a white cap for easier identification and for privacy reasons. Six behavioral scenarios were recorded for later analysis:

A. Unidirectional traffic

1. normal walking speed; test persons were told to behave as if they were on their way to the train station, few fast, few slow, many normal speed
2. hurried persons; as if leaving a show event, many leave fast, few normal, fewer slow
3. panic situation; everybody as fast as possible, only one exit used

B. Bidirectional traffic:

1. normal amount of traffic in one way, normal opposing traffic with normal speed
2. many walking in one way, with little opposing traffic
3. panic: everybody as fast as possible, both exits

In figure 7 some sample images are given to get an impression of the density and people moving in the example setup. The red lines in the left image show the trajectories of people and the green/red line is the virtual counting line with a hysteresis. The right image shows an overview of the test area, stairs are not included.

Fig. 7. Sample images from the people counting system and overview camera

Fig. 8 shows the CAST simulation setup corresponding to the sample scenario. The person agents have been given a plan which makes them walk bidirectionally through the investigated area in the middle of the model.

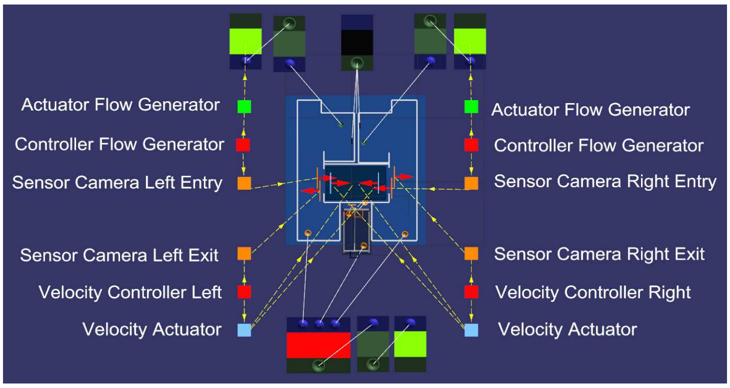

Fig. 8. Simulation Setup

The simulation camera sensor provides imported real passenger flow data and can additionally perform passenger flow measurements inside the simulation. Thus, two resulting passenger flow rates are available which can be compared. Sending the resulting virtual and real flow rates to the controller (red cube in figure 9), the actuators (green) can trigger an appropriate action on the simulation actors to bring simulation closer to reality. Two different actuators have been realized in the model. First, the velocity controller, working on a spatial area increases or reduces the walking speed of the passengers thus either increasing or reducing the flow rate on the successive area to adjust the exit rate. Second, the flow generator actuator has the ability to increase or reduce the passenger generation rate. In summary, the sensors are monitoring dedicated areas of both the simulation model and reality and perform appropriate decentral actions in order to bring the simulation passenger flow close to the observed passenger rates.
For future real world system tests a video sensor system was installed at Cologne central train station, Germany, where the test area counts for about 200 square

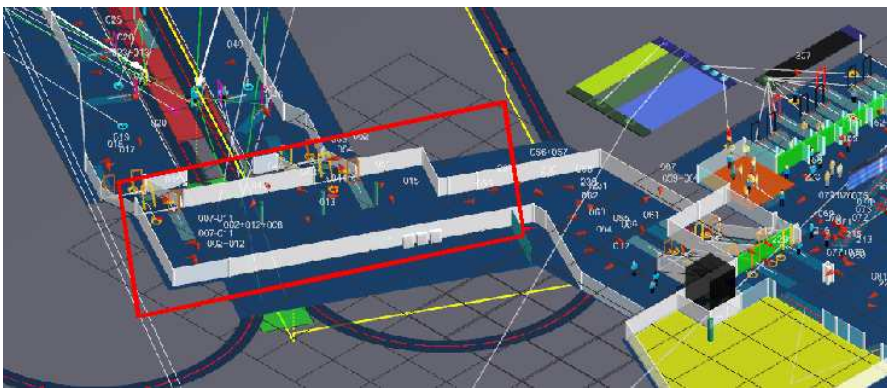

Fig. 9. Screenshot of simulation model in the real world installation, red rectangle shows the observed area

meters. Fig. 9 shows a screenshot of the corresponding simulation model.

Results

The curves in figures 10 show the simulated and the observed passenger flow rates at the entrance (a) and the exit (b). In the diagrams the people flow is plotted against time. The plot comprises all six subsequent behavior scenarios A.1 to B.3 as described before which are marked in the charts. Only the flow in entrance-to-exit direction which is also representative of the opposite direction is shown. It can be seen that the simulated curve converges to the real curve. The simulation curve shows latency as discussed before.

The simulation controller used two actuators at the entrance, one adjusting the generation rate (based on the entrance flow sensor data) and the second the velocity of the agents (based on the exit flow sensor data). Comparing the curves the simulation model appears to reflect the behavior of persons in an appropriate way. Figure 10b shows higher latency and lower accuracy due to the higher distance between sensor and actuator.

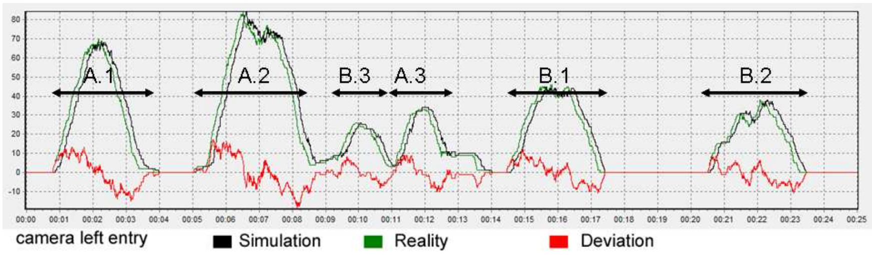

Fig. 10.a Results Entry: Comparison between Simulation and Reality

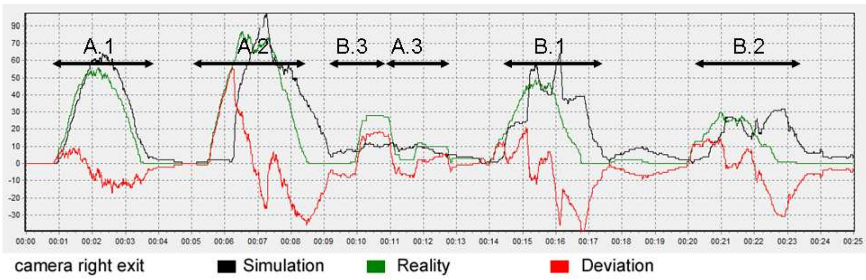

Fig. 10b. Results Exit: Comparison between Simulation and Reality

While the adjustment of the generation rate affects the simulation state directly with a small time delay the velocity adjustment of the agents based on the exit sensor data takes longer to take effect and the delay between the curves grows larger. These preliminary results show, that the model is capable to follow the observables by adjusting behavior parameters via the proposed controller. This changes the internal state of the simulation model according to the state of the real observed traffic situation. Further investigations will analyze the internal states dynamics, apply and assess the prediction capabilities and reveal which additional instruments can be used to refine the simulation actor behavior.

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References

1. Luenberger, D.G.: Observing the State of Linear Systems. IEEE Transactions on Military Electronics, 1964, 74-80.

2. Joseph Michael Istre and Yu Ming Zhang: Predictive generic model control for non-linear interval systems with application in arc welding, Int. J. Modelling, Identification and Control, Vol. 1, No. 2, 2006

3. Otmar Lorenz: Der Systembeobachter, ein Ansatz für komplexe chemisch-verfahrenstechnische Prozesse, Dissertation, TH Darmstadt, 14.3.2003

4. D. J. B. S. Sampaio, D. Zettel, N. Link, M. Peschl and L. Moscato: Process Surveillance and State Sensing with Generic Model Parameter Estimation, AISTA 2004 in Cooperation with the IEEE Computer Society Proceedings, Luxemburg, Germany, 15-18 Nov. 2004, ISBN: 2-9599776-8-8

5. Franziska Klügl: Multiagentensimulation - Konzepte, Werkzeuge, Anwendung, Addison Wesley, April, 2001, ISBN: 3-8273179-0-8

6. Hanisch, A., Tolujew, J., Raape, U., Schulze, T.: Online-Simulation für Personenströme in einem Frühwarnsystem. In: Simulationstechnik, 17. ASIM-Symposium in Magdeburg. R. Hohmann (Hrsg.), SCS Int., Ghent 2003, S. 221-226.

7. Hanisch, A., Tolujew, J., Meuschke, T., Schulze, T.: „Datenkollektion“ zur online Simulation von Personenströmen. In Proceedings Simulation und

Visualisierung 2004. Eds. T. Schulze, S. Schlechtweg, und V. Hinz, SCS-European Publishing House, pp. 27-38

8. Hanisch, A., Tolujew, J., Richter, K. and Th. Schulze: Online Simulation of Pedestrian Flow in Public Buildings Proceedings of the 2003 Winter Simulation Conference ; S. Chick, P. J. Sánchez, D. Ferrin, and D. J. Morrice, eds., pp.1635-1641

9. Daamen, W, & Hoogendoorn, SP (2003). Research on pedestrian traffic flows in the Netherlands. In Proceedings Walk 21 IV (pp. 101-117). Portland, Oregon, United States: Walk 21 conference.