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Simulation and Visualization of the Behavior of Handicapped People in Virtually Reconstructed Public Buildings

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1 ABSTRACT

The planning of public transport infrastructures today must respect the needs of a wide variety of travelers. In particular the design of guiding systems needs to take the reduced reception capabilities of the elderly and handicapped people into account.

Therefore tools for the evaluation of guiding systems need to be developed. Such tools must be based on empirical knowledge on the perception capabilities of the various user groups as well as detailed microscopic pedestrian movement models in order to represent typical paths taken. We model the cognition of guiding systems to enable a realistic representation for the motion and orientation behavior of elderly and handicapped people having difficulties perceiving the guidance information and not being familiar with a building.

To demonstrate the feasibility of the approach we discuss a technique to virtually reconstruct public buildings in 3D and visualize the simulated crowd with detailed models for each individual. The lines of sight of selected, handicapped persons, who are moving amongst other persons, are also shown in order to evaluate the visibility of the guiding information in the infrastructure and to hint at possible improvements.

2 INTRODUCTION

Over the last few years, many advances have been made in the field of pedestrian simulation modelling. For a recent review see Bierlaire and Robin (2010). Many pedestrian simulation models have been developed and applied in a variety of disciplines like computer graphics for games and movies, robotics and evacuation dynamics (Thalmann and Musse, 2007). Most of these pedestrian models try to address evacuation scenarios of buildings or ships in case of emergency and look also at capacity issues at bottlenecks such as transport infrastructures.

The motivation to model pedestrians comes from the fact that scenarios at large infrastructures are too complex to be estimated dircetly using conventional methods. In such scenarios pedestrian simulations provide a tool to investigate the characteristics of an infrastructure with respect to bottlenecks reducing the safety and convenience of passengers. Based on the simulations possibilities for improvements can be obtained.

In addition, there is a shift towards providing greater pedestrian priority and safety at junctions, interchanges and town centres. Thus, simulation tools are not only used to evaluate designs for pedestrians in evacuation conditions but also in normal conditions. This leads to the demand to understand pedestrian psychology and model pedestrian behavior accurately at public transport infrastructures.

Currently, there are several commercial tools available that can simulate the flows of people on a microscopic level where every pedestrian is modeled explicitly (e.g. Exodus, Aseri. Legion, PedGo, Simwalk, the pedestrian module of VISSIM, to mention just a few). All these tools have in common that they represent the mobility needs of elderly and handicapped people inadequately. Usually these groups are simply represented only by lower maximum speed and larger space requirement in the simulation.

Especially in restricted areas like stairs, narrow passages, however, these groups can lead to significant traffic jams that strongly affect the overall efficiency of the various designs. Such problems can not be explained by lower average speed alone. Elderly and handicapped people also require different routes depending on their physical constitution and mobility impairment. For some people an elevator represents the only alternative to change levels. At the first visit of an infrastructure finding the elevator can become a challenging task. These problems are amplified for people having additionally reduced reception capabilities.

These individuals need much longer for their orientation, and potentially temporarily block passage for the others, if the design of the infrastructure does not support their needs sufficiently.

Consequently currently there is much research effort put into enhancing existing simulation models by including models for the motion and orientation behavior of mobility impaired passenger groups like individuals with prams, wheelchair users, individuals with sensory impediments and people being unfamiliar with the infrastructure.

The main challenge in this respect is the realistic adaption of existing models by adequatly representing and measuring group specific behavior. The main component here is the modelling of the cognition of guidance systems, as well as the interplay with the orientation- and navigation behavior. Such models necessarily contain two parts. First, the cognition of the visual guiding system (mainly signage) depends on the visibility of the signs which depends on the placement within the infrastructure as well as on the current situation as the line of sight might be blocked by other pedestrians. Secondly the reaction of the individuals to the guiding system need to be represented inside the model. This includes the mechanics involved in the dynamic building of a mental map for previously unknown infrastructures on the first walk-through. First approaches in this respect are discussed in Teknomo and Millonig (2007) Modelling needs to be supported by substantial amounts of real world data which are collected in controlled experiments and real scenarios.

By accurately calibrating the models via comprehensive real data, a valid forecast of passenger flows and hence an improved basis for decision-making in terms of planning and adapting traffic infrastructures will be achieved.

This paper discusses first steps of this research agenda while putting these results in the broader perspective outlined above. To this end we first review different approaches which are related to our concepts in the next section. In section 4 we discuss the virtual reconstruction of public buildings based on photogrammetric methods in combination with various maps of the considered infrastructure. Afterwards the models for group specific behavior of pedestrians is described. In section 5 the visualization of the crowd is described which provides as an output for each person the currently visible sections.

3 RELATED WORK

This work extends the work documented in Braendle et al. (2009). In that paper the focus was laid on the virtual reconstruction of an infrastructure while not much attention was paid to the guiding system. In particular the visibility maps derived there did not take occlusions due to the surrounding passengers into account. In particular for handicapped persons sitting in wheelchairs this clearly is inadequate in the context of this paper.

Somewhat surprisingly the topic of this paper has not attracted much research. To the best of our knowledge the only comparable study consists in Harikae (1999) where the visualization of a barrier free environment is discussed. One reason for this might be found in the fact that microscopic pedestrian movement models only recently have reached a sufficient state of maturity to allow the inclusion of 3D visibility information.

Recent advances in computational technologies have led to the development of applicaction-specific simulation models focusing on different aspects of the collective behavior, using different modeling techniques. It can be distinguished roughly between two broad areas of crowd simulations. The first area is high-quality visualization for movie productions or games, where usually the realism of the behavior model is not the priority (for a survey see Thalmann and Musse, 2007). These applications aim at a convincing visual result.

The second group focuses on realism of behavioral aspects with usually simple 2D visualization like evacuation or crowd dynnamic simulations. In this area, the behavior represented in the simulations is usually restricted to a narrow range with efforts to quantitatively validate the fit of results to real-world observations of particular situations (Thompson and Marchant, 1995). Visualization is used to help understanding simulation results, but it is not crucial and in most cases a schematic representation with colored dots is used. Some applications for building design purposes need large crowds to measure both the overall flow rate in different parts of the environment and percentage of people that can leave the environement in a given amount of time.

Techniques employed in both areas range from macroscopic models that do not distinguish individuals (such as the models implemented in Pedflow, Space Syntax methods, Pedroute), mesoscopic models using cellular automata (such as STEPS, PedGo) to microscopic models using agent based modelling (such as Legion, the pedestrian module of VISSIM and CAST). Agent based microscopic modelling is an approach for simulating pedestrians as single individuals by supplying a detailed representation of their behavior, including decisions on various levels (e.g. related to orientation and navigation) and interactions with other pedestrians in the crowd. The goal is to reproduce realistic autonomous behavior. A comprehensive survey of serveral systems and approaches that have been developed for animation and evacuation dynamic purposes can be found in Pelechano et al. (2008).

Most currently available simulation models are based on the assumption that all pedestrians know the infrastructure perfectly and consequently all pedestrians choose the shortest path to reach their goal. Another simplification is made by representing of the group specific behavior using only by varying maximum speed and space requirements according to the characteristics of the considered group. There are several phenomena and types of pedestrian behavior that have a major influence on the overall performance of an transport infrastructure but cannot be reproduced under these simplifications.

The probably predominant modelling approach for microscopic models is the so called social force paradigm. Compared to other models it has been found to describe pedestrian behavior more realistically (see e.g. Bauer, 2010). The most prominant social force model is Helbing's model (Helbing and Molnar, 1995). This model has been calibrated and accordingly adapted using real world data (see Johansson and Helbing, 2008). The social force model was also extended by Musse to include individualism (Braun et al., 2003). Pelechano et al. (2007) merged rule-based and social-force based models and incorporated psychological state into the pedetrian simulation model. Shao et al. (2007) used a complex cognitive and behavior model for planning, but did not attempt realistic small-scale motion behavior like the social force model.

Not every pedestrian is familiar with the infrastructure and for realistic simulation the wayfinding has to be represented in the model. Wayfinding abilities are influenced by a number of physical, psychological, and physiological factors that will influence the ability of people to detect and correctly interpret the information conveyed by the signs. Xie et al. (2007) has demonstrated theoretically and through experimental trials that the maximum viewing distance is dependent on the viewing angle and that as the viewing angle increases, the maximum viewing distance decreases in a nonlinear manner. These findings have been implemented in a comprehensive evacuation model. They have been shown to be sensitive to the complexity of the geometry and the scenario modelled. While the overall differences in the key evacuation indicators like average total evacuation time and average personal evacuation time resulting from the introduction of the new developments showed to be small, it is nevertheless essential to correctly represent these subtleties, if the model is to correctly represent reality.

In an evacuation scenario people in the crowd have the same goal of sharing their knowledge to find the fastest way out of the building. Contrary to that in a normal crowd scenario each person has its own goals, decisions and routes and typically does not share her information. This implies that autonomous wayfinding and in particular individual differences in wayfinding capabilities need to be carefully modelled. Wayfinding is supported by signage in the infrastructure. However, to use guidance information people must a) be able to physically see the signs and b) be able to interpret the information provided by the signs. In this paper we focus on the first point of visibility of the signs.

The next section describes the techniques used for obtaining a 3D-representation of the infrastructure which builds the basis for the visibility analysis. Subsequently data collection design is discussed and finally the derivation of the visibilitiy for a given position in the infrastructure is examined.

4 VIRTUAL RECONSTRUCTION

Every virtual 3D-representation of an infrastructure relies on sufficient and accurate data. Our approach uses photos made with a common SLR camera. In order to add more details to the representation additional data sources will be used. The main steps in the modelling process are described in the following. The developments will be demonstrated using the railway station "Praterstern" in Vienna as a test case. The station is a multi-functional building connecting rail, subway, tram and bus lines. It also provides access to one of the major recreation areas in Vienna. Consequently it is a rather complex building posing challenges for wayfinding for the uninitiated first time user.

4.1 Point Cloud Creation

The first step to create the 3D model of a public railway station is the calculation of 3D point clouds. We use "city dense modeling" as described by Irschara et al. (2007). The first step is the acquisition of pictures of all parts of the building which are to be reconstructed. A certain amount of overlap is needed between the pictures to get useful results. The advantage of the algorithm lies in the low level of user interaction needed to obtain a representation. In particular no further aids or manual registrations are required to obtain reasonably accurate results.

The created images are rectified and the lens distortion is removed. This process is supported by the strategic placement of 96 markers prior to taking the photographs as described by Irschara et al. (2007). The markers can be spotted from different angles in various photos. Thus these markers provide valuable information with respect to the rectification of every single image as well as for the linkage of different photos where they act as reference points. Figure 1 shows the markers arranged on the floor where they can be photographed to get images for the calculations as described. In addition the focal length of the camera is used for removing the lens distortion. A SIFT based method is used to find pairs of points in different images. By establishing a unified real world coordinate system the camera position for every picture taken can be estimated and iteratively improved with additional images. Based on point pairs and camera position the position in the unified real world coordinate system of the feature points on the pictures can be calculated in the 3D space. Figure 2 shows a reconstructed part with the point cloud in 3D.

Fig. 1: 96 calibration markers arranged in a 4 by 4 layout on the floor (Irschara et al. 2007)

The algorithm of Irschara et al. (2007) is designed for the reconstruction of outdoor facades. In public buildings like railway stations the high amount of reflecting glass surfaces poses serious challenges such as distance errors of sections which are mirrored in a glass surface. To reduce these problems additional information is needed to create a more accurate model.

4.2 Use of additional data sources

Usually there exist several maps of public buildings which can be used to improve their reconstruction. The best basis for the models needed is a 3D CAD plan. To be able to use it, it has to be converted into the same coordinate system as the already used data and manual comparisons have to be made, to find the best representation of the reality. This is necessary since typically CAD plans represent the planning stage rather than the completion of the infrastructure. Details can be changed during the building process and thus usually the 3D CAD plans cannot be trusted to be totally correct in particular for the details.

Another source which is available in many cases are the drawn plans of a public building. These plans provide a 2D view of the infrastructure, typically providing information on the projection of the building onto the ground floor. Consequently the plans need to be mapped onto the ground of the 3D-model to use them as a reconstruction source. Afterwards walls and other details are visible in a top view and the interior can be placed like seen on the plan.

Both methods are not enough as a standalone solution and can only be used for the completion of the model. The problem with plans no matter if they are 2D or 3D, is often, that they are created in an early planning phase and therefore later changes are not found there in detail. Another problem of 2D plans is that they typically do not contain any height information. Consequently as described above other sources need to be added to create an accurate model. The combination of plans and reconstruction leads to improved results because the weaknesses of several sources can be eliminated.

Fig. 2: Point-cloud in a reconstructed 3D environment based on photos

5 PEDESTRIAN SIMULATION

For the research project MASIMO an agent based approach is used allowing the characteristics of individual pedestrians to be assigned and varied as required. The model development will be supported by empirical data collection providing data how people behave in real life. This empirical data collection will enhance the understanding of parameters and their influence to individuals' decisions to walk a certain route and which measures provide a basis for model calibration on a tactical level.

5.1 Operational and Tactical Level

In the multiagent simulation the agent behavior is described on an operational and a tactical level. On the operational level agents move in the infrastructure driven by a social force model and serveral parameters that will allow a wide variety of individuals like elderly and handicapped people and emergent behavior. A review of agents' speeds and densities according to several studies from Fruin, Predtechenskii and Milinskii, SPFE handbook, etc. can be found in Pelechano et al. (2008).

The tactical level decribes the knowledge and the wayfinding process which is defined as the process identifying, determining and following a path or route from an origin to the destination (Bovy and Stern, 1990; Golledge and Stimson, 1997). Wayfinding will be performed to navigate through the transport infrastructure allowing different types of behavior and navigation abilities and requires an interactive behavior between agents and their environments (Li, 2008). For the route selection the wayfinding algorithm calculates dynamically the global path based on the agents' knowledge of the infrastructure. Agents will have access to the information stored at the paths based on their perception abilities. The attributes of both people and their environments influence how and how well wayfinding is achieved (Allen, 1999). Individual attributes allow to represent individual levels of knowledge about the infrastructure and the individual gathering of new information through exploration, learning and communication with other agents (like asking for the way).

5.2 Perception

Each agent has a perception of the environment and a reaction to static and dynamic objects and agents. Perception approaches in the literature are based on casting a set of rays to calculate intersections. Here guidance information is determined against relevant influencing factors such as line of vision, occlusion due to other pedestrians and the distances in three-dimensional space. At each time step in the simulation the visibility of the guiding system inside the infrastructure is calculated for each agent representing a person unfamiliar with the environment.

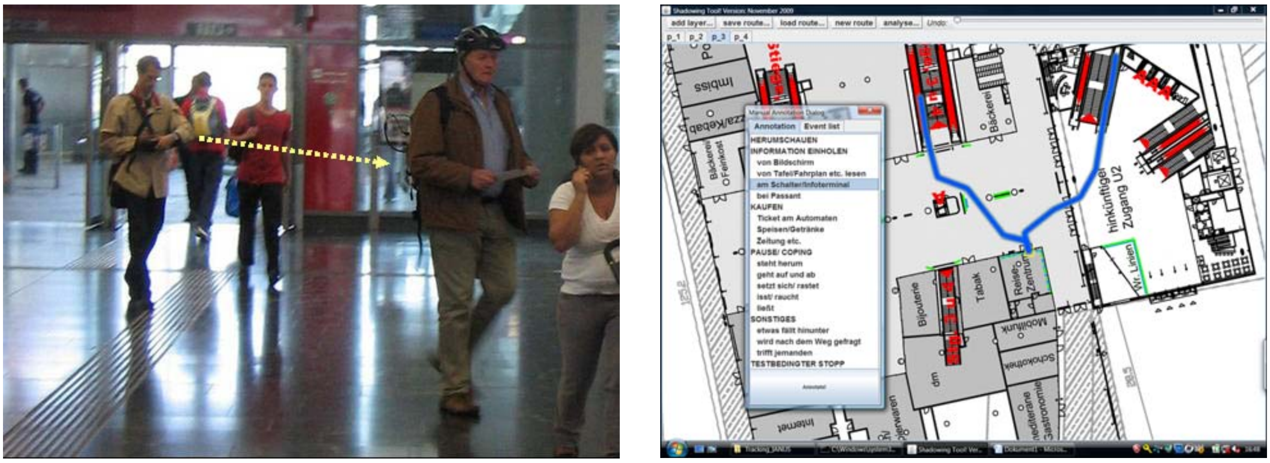
5.3 Empirical Data

Empirical data is collected in two different ways. First, nonobstrusive observations are obtained by videotaping critical elements inside the infrastructure in order to quantify effects on pedestrian flow through bottlenecks as a function of the percentage of persons with special abilities. One indicator in this respect is the number of persons per minute passing a staircase as a function of the percentage of person carrying a pram. A number of different scenes will be monitored.

Data collection in this respect is manual limiting the achievable sample size. Automatic analyses of video material currently do not support the level of detail required for our purposes. In particular the distinction of various user groups cannot be done reliably by currently available automatic methods.

Moreover automatic tracking applications only cover a limited area. Thus they are not capable of providing data needed for the analysis of wayfinding behavior.

To provide information on this aspect the second data source consists in an observation technique typically called “shadowing”, shown in Figure 3. For more details see e.g. Bauer et al. (2009). Hereby in Figure 3 (a) an observer (whose presence is known by the individual observed) follows the observed individual and records the major directional changes using a special application on a tablet PC. The graphical user interface and a recorded trajectory (blue polyline) is shown in Figure 3 (b).



(a) (b)

Fig. 3: Shadowing with a tablet PC (a) and the shadowing application (b)

Additionally the observed person carries a voice recorder which is used to document the wayfinding process. In this way it is possible to observe which guiding information is recognized at which positions inside the infrastructure.

The observation is followed up by face-to-face interviews to understand pedestrian’ psychological behavior and reasoning for their behavior are made. At this stage also the formation of a mental representation of the infrastructure can be tested.

5.4 Model Calibration

The models for the operational level of pedestrian behavior contain parameters determining the strength of reactions of pedestrians to other pedestrians coming close, the distance kept from walls as well as the behavior for collision avoidance. Therefore calibration on the operational level needs to use detailed information on the walking paths of pedestrians. Correspondingly the parameters are calibrated in order to closely represent the collision avoidance manouvers as well as the relative spacing of pedestrians as good as possible.

A number of publications describe calibration of miscroscopic models (Johansson et al, 2007; Bauer and Kitazawa, 2008; Hoogendoorn and Daamen, 2010).

For the tactical level the data collected will be investigated in order to derive quantitative information such as the distance at which signage is recognized, positions in the infrastructure where decisions are taken. The user comments will be used in order to gain insights into the factors determining route choice.

6 VISUALIZATION

Visualization is a powerful tool aiding the interpretation of complex data sets. This allows the presentation of results in a manner understandable also for non-specialists. In the present context both the path a person takes as well as the visible field need to be visualized in a dynamic, interactive manner. These two components will be described next.

6.1 Person Paths

For the visualization of person paths we use the technique documented in Brunnhuber et al. (2009). The paths are indicated using lines drawn one meter above the floor of the infrastructure. The speed of the persons is visualized using alternating colors to indicate the movement between consecutive time steps of the simulation. Thus longer strips of one color correspond to high walking speed and short strips to slow walking. Moreover several lines are animated to get an idea of the walking direction of the simulated crowd.

6.2 Crowd Rendering

The simulation data describes the position of every person of the crowd per time step. For dense scenes including many persons crowd rendering is nontrivial from a computational perspective. However, detailed representation of every pedestrian is vital because the analysis of the guiding systems in railway stations also needs the 3D representation of the people to know if the environment is also visible in crowds.

For the rendering of large crowds we use instancing as described by Dudasch (2007) as a technique which refers to render a mesh multiple times in different locations with different parameters. A secondary vertex buffer that contains the parameterizations of every instance is bound. The primary vertex buffer loops over each instance and the secondary buffer is incremented to parameterize these loops over the mesh.

The presented approach has to use the DirectX 10 API because instancing takes place in the core of this version of the API. By using the instancing techniques it is possible to rendering large number of persons in real-time. Dudasch (2007) describes tests with about 10000 characters at an acceptable frame rate of 30 frames/sec on an usual personal computer.

6.3 Creation of Visibility Maps

One of our major goals is to find out how the guiding system of public buildings works for mobility impaired people. Therefore we want to find the visibility of signs and information boxes inside the railway station from the perspective of the individual. The basic technique of shadow maps is used similar for one timestep or if every timestep of the simulation has to be visualized at once. The only difference is that the shadowmaps of every timestep are combined in the visualization of the whole timespan. The basic thought for the creation of the described visibility is the fact, that if a spot lightsource is used on the position of the viewer, the shadows it creates are the positions which cannot be seen by the person who looks in the exactly same direction. In other words it is not possible to see any shadows caused by a lightsource which is exactly on the same position as the camera.

The basic technique, that the Z-buffer-based renderer could be used to generate shadows quickly on arbitrary objects, is described by Akenine-Möller et al. (2008). The Z-buffer algorithm is used to render the scene from the position of the light source without additional content like lighting, texturing or colors. The shadow rendering is usually used for directional- or spotlights. In our approach we use the technique of spot lights to be able to use shadows like parts of the image which are not seen by the tested individual. The view volume of the spotlight is created and the image in the stencil buffer is moved. The pixels outside the light's view are ignored this way.

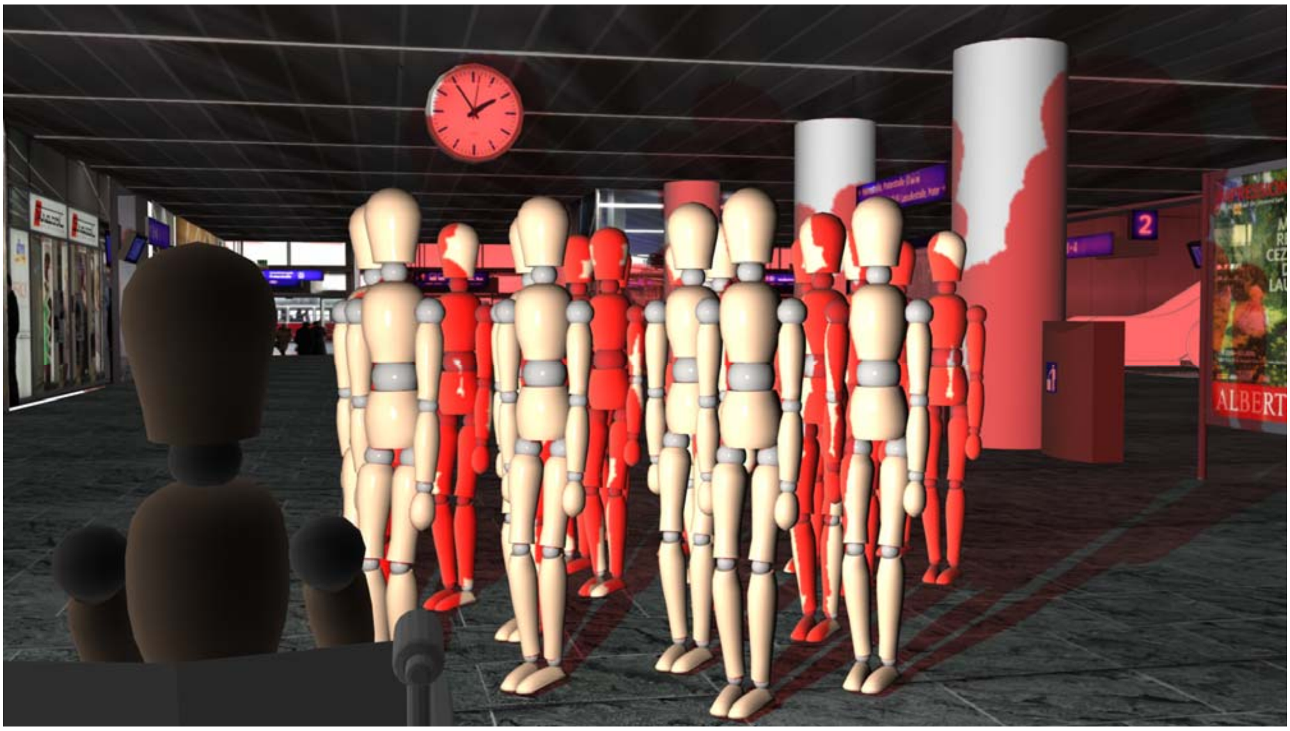


Fig. 4: Example for Visibility map concept

Akenine-Möller et al. (2008) also describe several techniques to use good resolutions for the shadow maps dependent on the viewpoint of the actual scene. The technique of cascaded shadow maps can be used to improve the visibility maps. There, a set of fixed shadow maps is generated to cover different areas of the scene. In the presented approach fixed empty maps are used first to cover the whole environment. The shadows for every light source in every time step, which represent a field of view of a handicapped person, are calculated and mapped on the created fixed maps. Instead of setting a shadow color we add a value (the visbility indicator) to the maps which depends on the total number of lightsources. Large values indicate dark regions while regions that are visible by many individuals correspond to small values. Correspondingly the maximum of the visibility indicator occurs at the sections which are never seen by the simulated, handicapped persons.

Fig. 5: Visibility Map detail on a sign of the guiding system

The cameras which are used as viewpoints in our case, are set to a width of almost 180 degree. The forward vector of the persons is their walking direction and the wide view angle is used to simulate the moving of the head when somebody looks around for guiding information to find his way through the railway station.

Finally a recoding of the color values on the several maps is performed to enhance readability of the resulting pictures. Sections which are perfectly visible are marked as white, while darker regions are not visible for most agents most of the time. This way it is easy to identify the visible sections from an analysis of the corresponding artificially coloured 3D- representation.

Figure 4 shows an example of a person in a wheelchair, who looks into the room. A crowd is standing in front of him and blocking his field of view. Shadows are colored in red and highlight the invisible sections of the person this way. Figure 5 shows a sign of the guiding system in detail. Big parts of the sign are marked in red showing that they are invisible for the person in the wheelchair. Future developments will include a more detailed colour coding to represent different degrees of visibility.

6.4 Visibility maps in different time dimensions

The visualization of the visibility maps is time dependent. It is possible to analyze one timestep or the whole dataset in one image to gain the needed findings. The described way for the creation of visibility maps combines every timestep to show the visibility on the way of the simulated, handicapped persons. The behavior of the people in various timesteps has to be analyzed too and the combination of the whole timespan with one moment may lead to further findings inside the dataset.

Therefore the maps are created as described in a preprocessing step. Usually the visualization shows the visibility maps directly inside the 3D-model. The crowd at a particular time stamp is shown at the simulated positions and the sight of one individual is visible with a light frustrum (as shown in Figure 4). The current situation is possibly comparable with the whole testcase and the space which is marked as nearly or completely invisible can be explored in detail to see why the section is not seen (e.g. persons stand in front of it, the guiding system is not seen without further obstacles and similiar cases).

7 CONCLUSION AND FUTURE WORK

In order to be applicable as a planning tool, the pedestrian simulation model must be able to simulate realistic pedestrian behavior. The MASIMO project aims to develop a simulation tool capable of the simulation of realistic behavior of pedestrians in public infrastructures considering the individual knowledge of the infrastructure, route requirements, the orientation and the visual performance especially for the elderly and handicapped people. The pedestrian simulation model will be properly calibrated against quantitative and qualitative empirical data to provide a reliable tool for the planning of pedestrian facilities like transport infrastructures. To apply the simulation model to another infrastructure some considerations should be made about influencing factors that may play a role, for example the percentage of elderly and handicapped people, carrying of luggage, having a pram, use of mobile phones and the variety of activities that can be made in the infrastructure. Furthermore, the combined approach of simulation and visualization makes it possible to evaluate the visibility of the guidance system and to show the areas with leaks of guidance information for people unfamiliar with the infrastructure, especially for elderly and handicapped people with reduced reception capabilities.

A realistic environment is important to represent the approach properly. Our presented reconstruction of a railway station is a fast way to get data, which can be used for a visualization which meets our requirements. The visual representation of the crowd and the visible sections is important to analyze the guiding system of the public buildings. Our approach uses the resources of current technology to present everything in real-time and to be able to change the data interactively.

In the near future we will have to proof our concepts in a real-time application. The basic ideas will lead to a program which can be used to test if a public building is really barrier free or if there are some problems with the guiding systems or bottlenecks for the moving crowds. It might be important to improve the resolution of the shadow maps dependent on the distance to the view point. The distance between the viewer and the signs at the creation of visibility maps is not handled in our approach yet. A method has to be found to get realistic information if a sign is still readable in a defined distance.

Currently the pedestrian simulation models and the visibility analysis are not coupled. Future developments will integrate the movement models to represent every person in the simulation. This improvement will lead to an application for presenting our findings in a way which is easy to interpret for anyone who is interested in the quality of a barrier free environment in public buildings.

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