Simulation of Handicapped People Finding their Way through Transport Infrastructures

Helmut Schrom-Feiertag[1], Thomas Matyus[1], Martin Brunnhuber[2]

[1]AIT Austrian Institute of Technology, Vienna, Austria
{thomas.matyus, helmut.schrom-feiertag}@ait.ac.at
[2]VRVis Zentrum für Virtual reality und Visualisierung Forschungs-GmbH, Vienna, Austria
brunn@vrvis.at

Abstract. This paper presents a research effort put into enhancing existing simulation models by including models for the motion and orientation behavior of handicapped people being unfamiliar with a transport infrastructure. On the tactical level the perception of guidance systems is modeled and makes it possible to simulate agent navigation through an unknown infrastructure using the present signage. The guidance information is determined against relevant influencing factors in a simulated virtual 3D environment. For the proof of concept the applicability of the wayfinding algorithm is demonstrated in three different scenarios. Results show that the proposed simulation model facilitates an agent to find its way autonomously through a transport infrastructure based on signage information only. This makes it possible to evaluate the visibility of the guidance system and can reveal areas lacking guidance information for people unfamiliar with the infrastructure especially for elderly and handicapped people with reduced reception capabilities.

Keywords: Pedestrian simulation, wayfinding, handicapped people, sensory impairment, visibility, virtual 3D environment.

1 Introduction

Public transport infrastructures must accommodate a large number of passengers while taking into account specific needs of certain groups such as elderly or handicapped people. Their design needs to facilitate wayfinding for people unfamiliar with the infrastructure.

However, different groups have different needs for their routes and their orientation depending on their sensory and mobility impairments. At the first visit of an infrastructure depending on the signage already finding the elevator can become a challenging task, especially for people having reduced reception capabilities. These individuals need much longer for their orientation, and potentially temporarily block passages for the others, if the design of the infrastructure does not support their needs sufficiently.

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Thus the design process is a nontrivial task which nowadays is supported by pedestrian simulations to predict passenger flows already in the planning stage. Current models do not integrate a detailed en-route route-choice model that implements orientation or navigation behavior but rather use the shortest-path or stochastic rules to get a route which is mainly applicable for people familiar with the infrastructure.

Therefore the main contribution of this paper is to propose a simulation model that represents handicapped people and their different behavior in orientation and navigation. On the tactical level the visual perception of guidance systems is modeled and makes it possible to simulate agent navigation through an unknown infrastructure using the present signage. No routing graph has to be defined in advance, only the information obtained from the signage modeled in a virtual 3D environment is used. The visibility depends on the agent's vision capabilities or the level of crowdedness respectively, especially for wheelchair drivers with a lower point of view. A virtual 3D environment including 3D human models representing the simulated agents gives the opportunity to calculate possibly occluded sections from one viewpoint realistically.

In the following Chapter 2 a review of the state of the art is given. Chapter 3 provides a system overview and detailed descriptions about the visible object identification and the agent based simulation allowing the characteristics of individual pedestrians to be assigned and varied as required. To parameterize the agent based simulation field experiments and data collections were made and the results are presented in this chapter. For the proof of concept in Chapter 4 three different scenarios are described to demonstrate the applicability of the wayfinding algorithm. The results are discussed in Chapter 5 and finally in Chapter 6 the conclusions are made and an outlook for future research issues is given.

2 Related Work

Agent based microscopic modeling is an approach for simulating pedestrians as single autonomous 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 single autonomous and emergent collective crowd behavior.

Compared to other models social force-based models has been found to describe pedestrian behavior in more detail concerning the spatial resolution (see e.g. [1]). The most prominent social force model is the model from Helbing [2] which is also used in the presented approach. This model has been calibrated and accordingly adapted using real world data by Johansson et al. [3]. The social force model was also extended by Braun et al. to include individualism [4]. Pelechano et al. [5] merged rule-based and social-force based models and incorporated psychological state into the pedestrian simulation model. Shao and Terzopoulos [6] used a complex cognitive and a behavior model for planning, but did not attempt realistic small-scale motion behavior like the social force model.

Many currently available simulation models are based on the assumption that all pedestrians know the infrastructure and consequently all pedestrians choose one of the known paths to reach their goal. 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. [7] have theoretically and through experimental trials demonstrated 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 non-linear 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 modeled. 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.

3 Simulation of Handicapped People

The presented approach combines a pedestrian simulation with real-time rendering techniques to identify visible objects in a virtual 3D environment. The visible object identification determines the visible objects in the infrastructure from a point of view, especially the visible elements of the guidance system. The returned information is feed to the tactical level of the simulation to support the wayfinding decisions.

3.1 Visible Object Identification

Visible object identification uses a 3D model of the environment to provide visibility information about objects to the simulation. The 3D model gives the opportunity to calculate possibly seen sections from a viewpoint accurately. In the first cycle position information of the simulated persons, so called agents are passed to the visible object identification which does the rendering of the 3D human models in the virtual environment.

In the second cycle the calculation takes place. A single agent is selected to determine the visible objects in his field of view under consideration of occlusions by other agents what possibly occur in dense crowds. A result set containing all visible objects for that agent is returned to the simulation.

The presented technique uses current graphics hardware to calculate visible objects from a viewpoint using the basic concept of shadow maps as shown in **Fig. 1**. A light source is placed at the point of view and shadowed parts are not visible to the viewer, details can be found in [8].

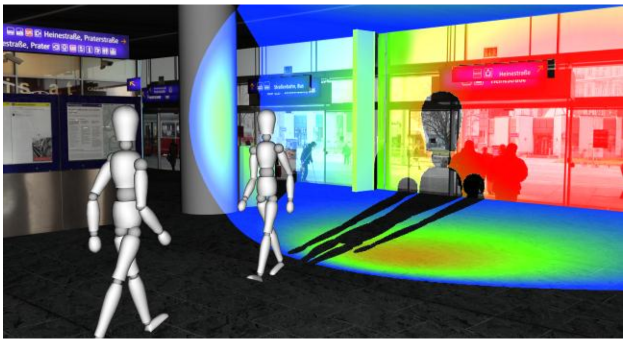

Fig. 1. Concept of visibility calculation.

The effect of occlusions due to other agents in dense crowds can be seen in **Fig. 2**. In the left image the empty main hall of the train station in Vienna, the "Praterstern" can be seen. For comparison in the right image the effect of dense crowds is shown where most signs are obscured. Especially for wheelchair drivers with lower point of view occlusions hinder information gathering and cannot be neglected for realistic behavior.

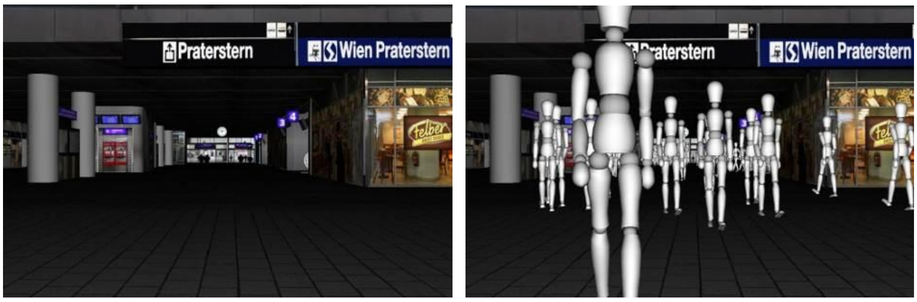

Fig. 2. Perspective for a wheelchair driver in the empty (left) and crowded train station (right), from the same point of view.

Information Coding. In addition to visibility, it is important to know the type of signage, like monitor or sign and the information provided. Therefore the 3D model is enhanced with Meta information in advance. The necessary information is annotated for each relevant object, like guidance elements, ticket machines or supermarkets. These data contain a semantic description of information related to the object. The agent's goal is also specified in a semantic way and it can be examined if the information is relevant.

Agent Perception. Each agent has a perception of the environment and a reaction to static and dynamic objects and agents. The guidance information is determined against relevant influencing factors such as line of sight, occlusion due to other pedestrians and the distances in three-dimensional space. At regular intervals of one second the visibility of the guiding system inside the infrastructure is calculated for the agent representing a person unfamiliar with the environment.

The visible object identification returns a list of visible objects and parameters for each object like unique identifier, distance to the viewer, position of the object, surface normal, angle between viewing direction and surface normal in 3D space and finally a visibility value indicating how much of the object surface is visible.

Xie et al. [7] have demonstrated that the maximum viewing distance depends on the viewing angle and that as the viewing angle increases, the maximum viewing distance decreases in a non-linear manner. For the proof of concept a much simpler classification scheme based on hard limits for distance and angle shown in **Fig. 3** was used to distinguish between the information interpretations.

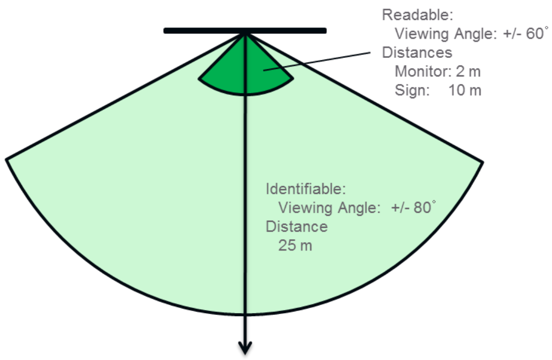

Fig. 3. Classification scheme between identifiable and readable.

An agent with full vision can recognize the type of the signage object within 25m and an angle ±80° and within 10m and ±60° for large signs or 2m for monitors the complete information can be obtained. The values for distance and angle in this classification scheme can be varied according to the visual impairment.

3.2 Pedestrian Simulation Model

Pedestrian motion behavior is often described in three different levels as specified in [9]. The *strategic level* determines the arrival time of the pedestrian at the transport infrastructure, the entry and the pedestrian's goal (e.g. train to Paris). In our case this level is not modeled separately and the origin and the destination at the transport infrastructure are predefined.

The *tactical level* describes the route a pedestrian will choose to move through the continuous physical space of the infrastructure.

The *operational level* calculates the actual movements towards the next intermediate goal performing collision avoidance with obstacles and other agents. Here an agent based approach is used allowing the characteristics of individual pedestrians to be assigned and varied as required.

Operational Level. The human motion on an operational level is modeled based on a social force model [2]. Here the resulting force is separated into three parts: First, the attractive force which is directed towards the pedestrian's next goal. Secondly, the sum of the repulsive forces which are directed away from other pedestrians and finally, the boundary forces which are directed away from the surrounding walls or obstacles. As a first approximation the basic social force equations are used for modeling both the pedestrian and the wheelchair movements varying two parameters: 1) The desired speed of the agent on which the attractive force and 2) the horizontal body size on which the repulsive forces are depending.

Tactical Level – Wayfinding for people being unfamiliar with the infrastructure. The tactical level describes 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 [10, 11]. 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 [12].

On the tactical level the perception of guidance systems as described before is applied and makes it possible to simulate agent navigation through an unknown infrastructure using the present signage. No routing graph has to be defined in advance, only the information obtained from the signage modeled in 3D is required.

The main wayfinding strategy, as shown in **Fig. 4** is searching randomly in the absence of any information. Information is obtained from signage elements (signs, monitors) in a certain area in front of the signage element.

The process of searching for information consists of two phases, first the visible signage element is identified and walked towards, subsequently at a smaller distance and a suitable angle the information provided is absorbed. In the second phase the semantic information is interpreted and if it is useful to achieve the agent's goal the instructions are utilized to identify the next goal at which the agent walks towards (operational level). Reaching the next goal the tactical level starts again by the first phase.

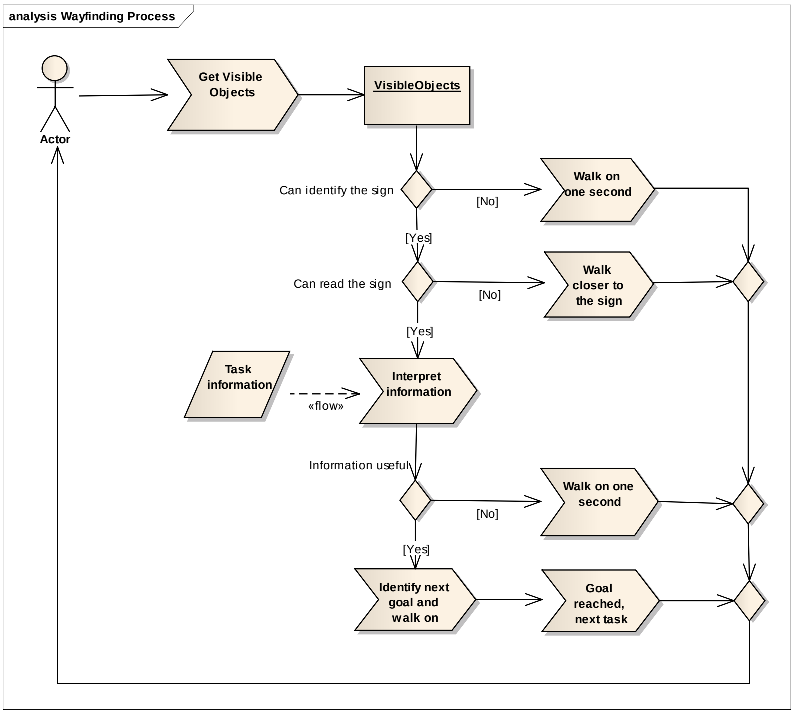

Fig. 4. Wayfinding strategy using guidance information only.

3.3 Field Experiments and Data Acquisition.

To gather information on group specific behavior comprehensive field experiments were made with 47 people. Eight groups of people were identified who may demonstrate mobility patterns clearly distinguishable from the general population: 70+ age, people with pram, visually impaired, blind, wheelchair users, mobility impaired, hearing impaired and deaf. The main research focus was to investigate differences in walking speed, patterns in gaining information from the environment, orientation and navigation.

The experiment took place at a major transit hub in Vienna, the train station "Praterstern". For each person in the experiment one out of two different scenarios with typical usage patterns and different levels of complexity was selected. The scenarios contain specific tasks such as buying a ticket and drink for the journey, locating timetable information, or using the restrooms in the station. Empirical methods were combined in order to gain relevant qualitative and quantitative data on pedestrian behavior. A detailed description can be found in [13].

The analysis of the collected data have revealed on the one hand surprising similarities between very different groups, on the other hand extreme deviations within a single group, indicating that the design and organization of the environment and the information have a greater influence on navigation and orientation behavior than disability. The spatial analysis of trajectory data revealed the main routes, deviations from these routes and clusters where people mainly stop. The analysis of the thinking aloud data related to the trajectory helped to identify elements of the guidance system that respondents used to navigate and pointed out typical areas for orientation in the infrastructure.

In the example of the Viennese train station “Praterstern” the monitors are the primarily signage to gain information. After knowing the departure information looking for the way to the train platform is the next step. The train platforms are indicated using a sign conveying the platform number. The visibility depends on the agent’s vision capabilities or the crowdedness respectively, especially for wheelchair drivers with a lower point of view.

For the evaluation of the pedestrian simulation model in addition to the knowledge of group specific motion and orientation behavior, information on the traffic volumes were required. Therefore the traffic volumes from 6 to 10 o’clock and 14 to 20 o’clock on one day were counted on all cross sections in both directions and aggregated in 15 minutes intervals. Additionally randomly selected individuals were followed by observers unobtrusively from an entry until they have left the area to obtain the origin-destination relations.

4 Proof of Concept

In order to demonstrate the functionality of the wayfinding algorithm three different scenarios in the main hall on the ground level at the train station “Praterstern” in Vienna were defined.

4.1 Scenarios

All simulation scenarios are based on the same tasks as shown in **Fig. 5**: Starting at the elevator exit into the main hall of the "Praterstern" station (*1*) a wheel chair driver has to get the train to "Stockerau". The main hall of the train station is on the ground level and the platforms are on the upper level which can be reached by wheelchair drivers by an elevator.

Apart from getting the departure information and buying a ticket, the next tasks are to go to the toilet and afterwards to get some snack for the journey. The order of activities is predefined: First go to the toilet (*2*), then buy the ticket, look for a monitor to get the departure information (*3*), go to the supermarket (*4*) and finally, use the elevator (*5*) to get up to the platform where the train is departing.

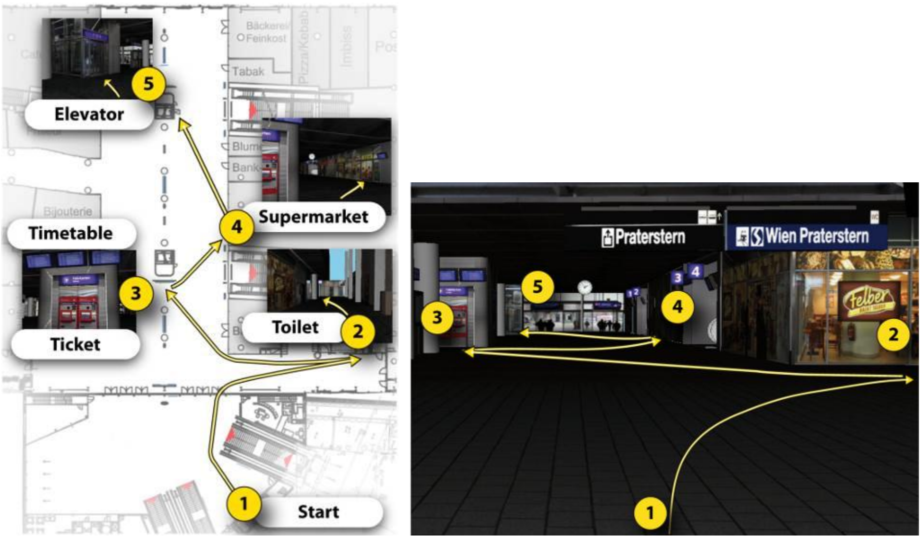

Fig. 5. Locations and shortest route for the scenarios in 2D (left) and in 3D (right).

The three scenarios differ in the level of crowdedness and the agent's vision. In each scenario only one agent is considered unfamiliar with the infrastructure while all others get a route assigned at start up.

Table 1. Simulation Scenarios.

Scenario	Crowd	Agent Vision
1	No other agents	Full and reduced vision to half the distance
2	Still standing groups of agents	Full vision
3	Crowd according to the morning peak (07:15 – 08:15)	Full vision

Scenario 1. This scenario should reveal the differences for pedestrians having different visual impairments. Therefore in the first simulation run one agent with no visual impairments and in the second run an agent with vision reduced to the half range was simulated. To focus on differences caused by the reduced vision only one single agent unfamiliar with the infrastructure was simulated. Consequently, interactions with other agents which can cause side effects were eliminated and allowed a better comparison.

Scenario 2. Is intended to demonstrate how occlusions of elements of the guidance system lead to changes in the agent's navigation. Here one agent with full vision is simulated in the hall where groups of agents are placed intentional in line of sight along the agent's route from scenario 1 in order to ensure occlusions.

Scenario 3. In contrast to the very theoretical scenario 2, scenario 3 demonstrates the agent's movement in a real world situation: A wheelchair driver with full vision moving during peak hour with about 7.000 passengers per hour. For the simulation of the crowd the agents are initialized with predefined routes based on the origin-destination observations described in section 3.3. In order to compute the routes for each origin-destination pair the visibility graph method of Overmars and Welzl published in [14] is used.

Simulation runs with slightly different start times for the wayfinding agent have been made in order to establish different conditions for the agent, providing situations where navigation is hindered by occlusions through other agents and where it is not.

5 Results

The proposed approach is capable to simulate realistic behavior of pedestrians in public infrastructures considering no knowledge of the infrastructure, route requirements, the orientation and the visual performance.

The combination of simulation and visual object identification in 3D space makes it possible to evaluate the visibility of the guidance system and to show the areas lacking guidance information for people unfamiliar with the infrastructure, especially for elderly and handicapped people with reduced reception capabilities.

A 3D environment including 3D human models for the simulated agents gives the opportunity to calculate possibly occluded sections from one viewpoint realistically.

5.1 Scenario 1

Fig. 6. a) Shows the results from the simulations of the first scenario, an empty train station and an agent having full and half vision. In both cases the agents start at the elevator exit at position *0* and move on to position *1* where they can get an overview of the hall. The overhead sign which indicates the direction to the toilet at position *2* is readable for both of them. Having walked through under the sign they both stop and search for the toilet in the given direction. The agent with full vision can read the sign at the entrance of the toilet (*3*) already from here and moves directly to position *3*. The agent with reduced vision moves on in the given direction searching five times for the toilet until position *2a* where he can read the toilet sign at position *3*. Leaving the toilet both agents cannot find any helpful information. Therefore they move back to the last visited sign. At position *4a* the agent with full vision can already read the sign at position *5* which indicates the direction to the ticket machine. The second agent needs to move to position *4b* where he is near enough to read the sign at position *5*. Having reached position *5* both can see the ticket machine at position 6 where they buy their tickets. Since a monitor is mounted above the ticket machine they get the departure information there as well. The train to "Stockerau" is leaving at platform 2. From position *6*, the entrance of the supermarket at position *7* is visible for both and they move directly over there. Leaving the supermarket the agent with full vision can read the sign at the staircase to platform 2 (position *8*), the second agent can only

read the sign at position *7a* which indicates the direction to platform 2. At position *7a* he can read the sign at position *8* as well. Having realized that at position *8* there are only stairs and escalators they look around and find the elevator to platform 2 at position *9*.

Once a valid intermediate goal is identified it remains valid until the goal is reached. During this phase no information is gathered and validated if it provides better information. For example the platform 2 sign indicates the right platform, but it cannot be seen if there is an elevator, so the platform sign remains the next goal and if it is reached and there is no possibility to change the levels, an elevator to the platform at the upper level is searched by the agent.

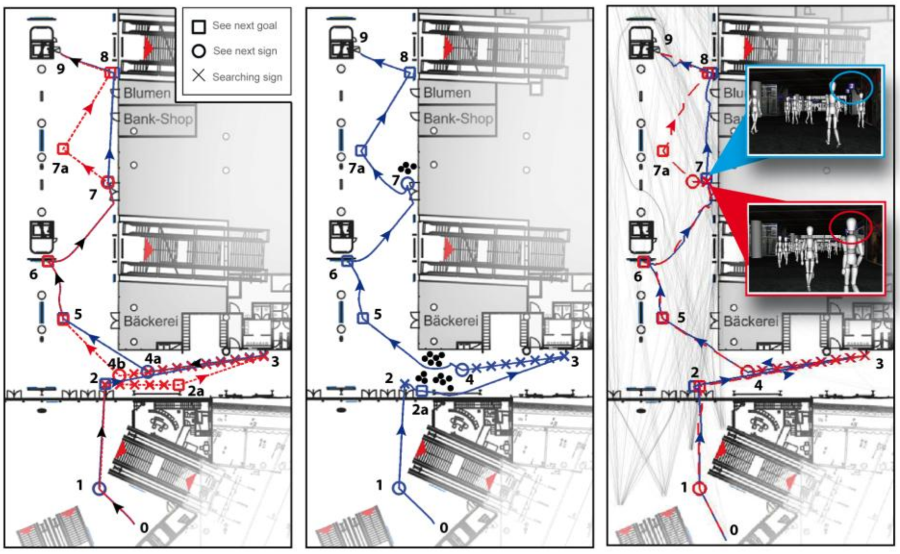

Fig. 6. Simulation results for the three scenarios, a.) Empty hall, b.) Groups blocking vision and c.) Crowd according to the morning peak.

5.2 Scenario 2

Fig. 6. b) Shows the results of the second scenario with still standing groups occluding signage information and an agent with full vision. Three points are worth mentioning. At position *2* the agent is not able to see the toilet sign at position *3* due to the pedestrian group in front of him. So he moves on in the direction the previous sign has indicated until he can see his goal at position *2a*. At position *4* the agent is able to read the sign at position *5* although a pedestrian group is standing in front of him. But in this situation the sign is mounted high enough so he could see it over their heads. Having left the supermarket at position *7* the other agents are very close and he is not able to see the platform sign at position *8* and therefore he takes the same route to *7a* as the agent with the reduced vision in the first scenario.

5.3 Scenario 3

Fig. 6. c) Shows the results of the third scenario where the agent with full vision is moving through the hall during the morning peak hour (7:15-8:15). Two runs with slightly different start times were selected to show the differences in dense crowds. In both runs the trajectories till the supermarket (position *7*) are identical among each other and also with the trajectory of the agent with full vision in Scenario 1. But after leaving the supermarket the agents are following different paths. One of the agent has free sight to the “platform 2” sign at position *8* (see blue circle in the upper screenshot) and moves on like in scenario 1 (blue path). Whereas, for the other agent the sign is hidden behind a pedestrian (see the red circle in the lower screenshot) and therefore the agent makes a detour via the sign at position *7a* (red dashed line) which indicates the direction to platform 2.

5.4 Summary

Each scenario showed different routes compared to the shortest route due to the differences in the range of vision and crowdedness. Especially for wheelchair users crowdedness has a significant impact. Crowds often occlude the signage or form obstacles leading to a higher rate of maneuvers, longer routes and travel discomfort. The approach has shown to be capable of simulating handicapped people finding their way through a transport infrastructure using signage information only.

6 Conclusions and Outlook

The proposed multi-agent based simulation model facilitates an agent to find its way autonomously through a building based on signage information only. This makes it possible to evaluate the visibility of the guidance system for different handicapped groups. It can reveal areas lacking guidance information for people unfamiliar with the infrastructure, especially for elderly and handicapped people with reduced reception capabilities. Especially by the integration of real-time rendering techniques dynamic occlusions through other pedestrians in dense crowds can be taken into account realistically.

Nevertheless the simulation has to be refined in some aspects. The wheelchair model has to be improved since physics of wheel chair movement is limited in the degree of freedom compared to pedestrian movement and in particular does not allow side steps. An interesting aspect if an object is in focus long enough to identify and recognize it.

Cognitive elements like readability, clarity of content, recognizing and understanding information and functional features are also not modeled in the current approach and are currently investigated in the project IMITATE. In this project a controlled test environment which lets the test persons immerse into a near-realistic interactive experience and at the same time measures her reactions to the environment is developed. Due to its increased realism the environment will greatly extend the possibilities to optimize the design of guidance systems in comparison to existing systems. Additionally, these data can be used to calibrate both the operational and the tactical model. This will enhance the standing in the areas of visualization, pedestrian simulation and design of guidance systems.

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