Using VR Studies for Pedestrian Dynamics Research

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ABSTRACT

For pedestrian dynamics research VR studies allow the analysis of performed experiments from an egocentric view, e.g. to experience visual restrictions or proximity to others in the crowd. VR studies using models of pedestrian dynamics also enables the realisation of reproducible experiments. First research questions using the new framework could be (1) how cognitive maps are built up, when dynamic elements like people are present, and (2) how social norms are negotiated in movement. This report describes the idea and the steps that need to be taken to achieve this goal.

Index terms: Pedestrian Dynamics, VR Studies.

1 INTRODUCTION

At the Institute for Advanced Simulation: Civil Safety Research at Forschungszentrum Jülich, we are working in the scientific fields of pedestrian and fire dynamics. For analyzing physical and socio-psychological aspects influencing the dynamics and behavior in crowds controlled reproducible experiments are used. Gathered data include, e.g. the walking path or 3D motion of a person, personal characteristics like body measurements, age or gender, or psycho-physiological indicators of stress [1].

2 VIRTUAL REALITY STUDIES

VR studies complement our experimental approach and enable us to take two decisive steps forward: First, we want to use VR as a visualization tool. Our experiments are filmed from above throughout. This provides a very good representation of the overall dynamics and allows us to extract the walking paths. However, for psychological questions it is also relevant to capture the participants' perspective. It is from this perspective that people perceive and assess the situation and control their behavior. In an immersive VR environment, we can for example study the experience of visual restrictions or proximity to others in the crowd.

Second, a situation in a crowd can be reproduced identically in VR and thus used as an environment for experiments. In our real experiments, we can keep the external factors (spatial structure, instructions) constant, but not how people behave. As a result, we often get very different dynamics in the crowd under the same conditions. In VR, on the other hand, a large sample of test subjects could be placed consecutively in the same crowd situation (reproducability). In these VR-based studies we need to implement physical and social reactions of surrounding people with human-like and user-aware virtual agents.

In addition to reproducibility, once set up, a VR environment allows a cost-effective and flexible way to study even complex scenarios. The experiments can be carried out independently of time and place, if the necessary hardware is available. The relevant data describing the dynamics is available immediately and does not have to be extracted afterwards.

First steps of the visualization tool have been taken by an implementation of Julius Hündlings supervised by Andrea Bönsch, RWTH Aachen University, Germany as shown in Fig. 1 and 2 [2, 3]. Fig. 1 shows the overall visualization of a real experiment of people passing an entrance gate. Fig. 2 gives an impression of an egocentric view of one participant of that controlled experiment. The real path, height, shoulder width and gender of each person were considered.

For a better visualization and immersion of that framework the realism of the human representation, the body motion including body orientation and motion cycle as well as the user-awareness of the virtual agents has to be increased.

To be able to use the framework for VR-based studies a realistic real-time pedestrian dynamics model has to be integrated. To increase the immersion even more devices for natural motion, force feedback of surrounding people [4] as well as sound should be integrated. Augmented reality could help to combine the strengths of the real and virtual world by representing directly neighbouring persons and the geometry as real objects and the rest of the scene as virtual characters.

3 FUTURE RESEARCH QUESTIONS FOR THE PSYCHOLOGY OF CROWDS IN VR

Two research fields that can benefit significantly from VR are outlined here as examples. The first one is cognitive mapping in dynamic crowd environment, the second one the social psychological question of negotiating social norms in moving crowds.

3.1 Cognitive Maps

Cognitive maps, our mental representations of the physical environments surrounding us, have been extensively researched. However, almost all cognitive map studies – whether focused on navigation, memory, recall, or problem-solving – consider only static environments. These environments typically consist of landmarks that help individuals create mental representations. Whenever dynamic elements, such as other people, were included

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in research, they were usually treated as interference that disrupted the cognitive mapping process.

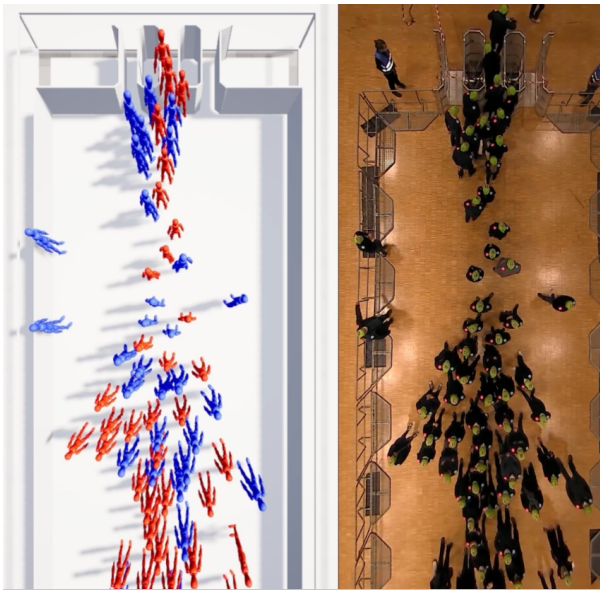

Figure 1: Controlled experiment of people passing an entrance gate: (left) a top view of the visualization (people represented as abstract mannequins color coded according to gender), on the right a snapshot of an overhead camera of the real experiment to the same time.

Figure 2: Egocentric view of one participant of the experiment visualized in Fig. 1 showing the visual restriction.

However, even though static landmarks do not exist in crowds, people seem to navigate them effectively or locate themselves within them – perhaps not as easily as in static conditions, but still to some extent. This raises the question of whether humans are capable of mapping crowds. On one hand, there are no stable landmarks, the environment is dynamic, and visibility is limited – both due to the forward-facing position of human eyes (unlike birds, which have lateral vision) and the obstruction caused by nearby individuals. On the other hand, people always seem to have a sense of what they are doing within a crowd, whether by loosely mapping their immediate surroundings or forming a representation of the entire crowd.

Preliminary results suggest that people can recall the position and shape of a crowd from a bird's-eye perspective after being part of a crowd formation (up to 15 people). However, more data are needed for a comprehensive investigation of this phenomenon.

Virtual reality offers a high-efficiency approach to studying this subject. Instead of gathering a large number of participants, positioning them, and replicating their compositions multiple times, existing crowd datasets can be transferred to VR. This allows researchers to test cognitive mapping by placing individuals in a virtual crowd multiple times under controlled conditions. This method enables repeated experimentation without replication issues, as real-life crowds rarely form identical formations, even when given the same instructions.

3.2 Negotiating Social Norms in Movement

In large-scale experiments with crowds moving towards and through a bottleneck, we have identified rapid transitions between behavioral repertoires such as racing, walking, queuing or overtaking [5]. What is not understood, however, is why these transitions occur and which factors can be used to predict them. Behavior, and thus behavioral changes, depend on the spatial situation, one's own position in the crowd, the perception of social norms and the form of being together.

VR can help us to explore these moments of transition. When we use VR as a visualization tool, we can place subjects in a crowd and ask them specifically what they perceive in this situation, who people orientate themselves towards and how they would act. We see particular potential here in combining VR and eye tracking – this allows us to systematically investigate which cues people use in a crowd. For example, one could ask whether all people who are visible are looked at equally often, or whether people specifically focus on people who play a leading role or initiate a certain behavior. It is equally interesting to observe how people who do not conform to social norms, for example, when they cut the queue, are looked at.

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References

[1] Forschungszentrum Jülich, Institute for Advanced Simulation. Data Archive of Experiments on Pedestrian Dynamics. doi: 10.34735/ped.da.

[2] A. Bönsch, M. Boltes, A. Sieben, T. W. Kuhlen. VR-CrowdCraft: Coupling and Advancing Research in Pedestrian Dynamics and Social Virtual Reality. Late-Breaking Report at VHCIE 2024. url: https://www.vr.rwth-aachen.de/publication/02254/.

[3] J. Hündlings. A VR-Driven Visual Analysis Framework to Advance Pedestrian Dynamics Research. Bachelor's thesis, RWTH Aachen University, Germany, 2024.

[4] F. Berton, F. Grzeskowiak, A. Bonneau, A. Jovane, M. Aggravi, L. Hoyet, A.-H. Olivier, C. Pacchierotti, and J. Pettre. Crowd Navigation in VR: Exploring Haptic Rendering of Collisions. IEEE Transactions on Visualization and Computer Graphics 28, no. 7, July 2022: 2589–2601. doi: 10.1109/TVCG.2020.3041341.

[5] A. Sieben, T. Postmes. Behavioural repertoires in moving crowds. An observational approach. Royal Society Open Science. doi to preprint: 10.31219/osf.io/rvgux. 2025.