First Steps Towards Walk-In-Place Locomotion and Haptic Feedback in Virtual Reality for Visually Impaired

Julian Kreimeier
Nuremberg Institute of Technology
Nürnberg, Germany
julian.kreimeier@ohm-university.eu

Timo Götzelmann
Nuremberg Institute of Technology
Nürnberg, Germany
timo.goetzelmann@ohm-university.eu

ABSTRACT

This paper presents the first results on a user study in which people with visual impairments (PVI) explored a virtual environment (VE) by walking in a virtual reality (VR) treadmill. As recently suggested, we have now acquired first results from our feasibility study investigating this walk-in-place interaction. This represents a new, more intuitive way of for example virtually exploring unknown spaces in advance. Our prototype consists of off-the-shelf VR components (i.e., treadmill, headphones, glasses, and controller) providing a simplified white cane simulation and was tested by six visually impaired subjects. Our results indicate that this interaction is yet difficult, but promising and an important step to make VR more and better usable for PVIs. As an impact on the CHI community, we would like to make this research field known to a wider audience by sharing our intermediate results and suggestions for improvements, on some of which we are already working on.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; **Haptic devices**; **Accessibility**; • **Social and professional topics** → **People with disabilities**;

CHI'19 Extended Abstracts, May 4–9, 2019, Glasgow, Scotland UK

ACM ISBN 978-1-4503-5971-9/19/05.
https://doi.org/10.1145/3290607.3312944

KEYWORDS

Virtual reality; visual impairment, haptic feedback, orientation and mobility, locomotion

ACM Reference Format:
Julian Kreimeier and Timo Götzelmann. 2019. First Steps Towards Walk-In-Place Locomotion and Haptic Feedback in Virtual Reality for Visually Impaired. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI'19 Extended Abstracts), May 4–9, 2019, Glasgow, Scotland UK*. ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3290607.3312944

INTRODUCTION AND RELATED WORK

After the first hype at the end of the 1990s, Virtual Reality (VR) technology is currently coming again back into the focus of research and industry. There are many areas of application, such as immersive entertainment or educational training. Thereby visual perception is the most often addressed sensory feedback, people with visual impairments (PVIs) have a considerably restricted access to this technology. However, previous research has already approached this field and achieved interesting results, e.g., to non-visually sense objects and textures [2], visualize data [3] or experience 3D art [4]. More recent work describes the haptic representation of spatial information [7].
Apart from exploring small virtual objects close by, there also exist approaches that enable PVI to explore a large virtual environment (VE) either by actually walking it using a white cane [8] or using interactive teleportation and an interactive sonification approach [6]. There are several known approaches for implementation by means of hardware and there is evidence that practicing in a VE supports orientation in the real model. It is unknown so far, however, how the way of locomotion in the virtual environment influences the achievement of a spatial model and the usability of the system. In principle, there are several possibilities for locomotion in VR [1], at the present time a VR treadmill appears as an intuitive and available realization. In this paper, we present the first steps of PVIs walking in a VE using a treadmill [5] and report for the first time on both arising problems and opportunities.

OUR EXPERIMENT

Following our previously only theoretically proposed approach to use a VR treadmill for walk-in-place locomotion, we conducted a feasibility study to check whether PVIs can basically use this locomotion technique. In contrast to other modes of locomotion such as teleportation or walking in a real place, a treadmill (see Fig.1) allows VEs of any size to be intuitively explored by foot. In order to test the general feasibility of this functionality, we created a simplified test environment (see Fig.1 and Fig.2) which the subjects could explore with a virtual white cane providing vibrotactile feedback. We expect this first result to be improveable, as the implementation of hardware and software certainly does not

VR does not mean only Visual Reality
When talking about VR, most people think of VR glasses and impressive visual effects, but in VR, haptic and auditory information can be also conveyed. Especially due to the advanced development and even partial availability of such hardware, a non-visual interactive VR becomes more and more applicable to support PVIs.

VR for PVI
Especially for PVIs, the interface to an interactive VE must convey precise and faultless haptic and auditory feedback in order to convey spatial information, such as objects and environments. This sensory feedback and its real world application is already known, but still being researched (e.g., [8]).

VE for PVIs
VR technology can basically enable PVIs to explore virtual environments independently and safely. These environments can be, for example, models of real public spaces [5], so that orientation and mobility can be practiced in a VR proxy before visiting the real place. Thus, PVIs could profit from VR technology as well as sighted and could increase their independence and mobility in public spaces.

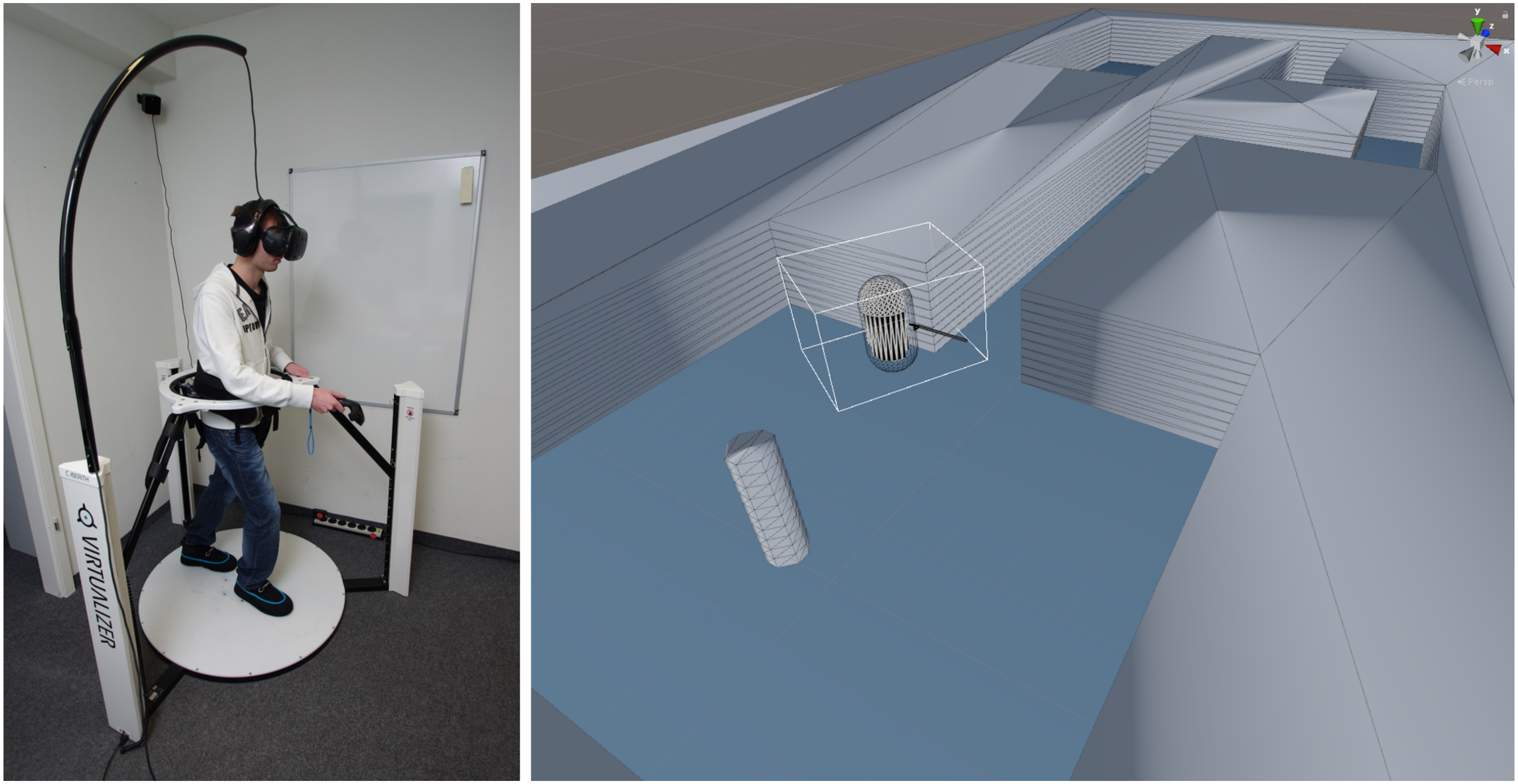

Figure 1: Left: Real situation with subject walking inside the treadmill while holding the VR controller as virtual white cane and wearing headphones. Right: The parallel situation in the VE, for visualization purposes with a wire frame rendering and without ceiling. The player is represented as the capsule object inside the white box, one can also see the virtual white cane which is in this moment used to navigate around the corner.

have the same level of maturity as specifically dedicated full papers. Therefore, we used a SUS and a Raw-TLX questionnaire regarding a navigation task. The range of SUS scores covers values from 0 to 100 and each Raw-TLX scale covers values from 1 to 21.

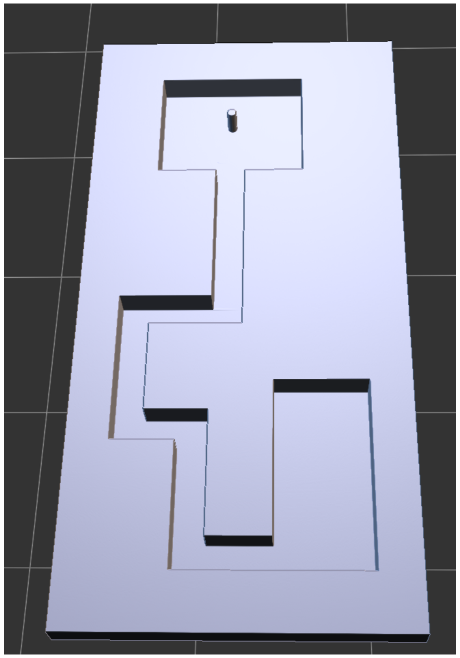

Figure 2: The VE which the subjects explored by feet (size approx. 36 by 16 by 2 metres). For the real world 3D model and a better visualization in this figure, the ceiling was removed so that the two chambers at the start and finish as well as the aisle between them are visible.

Walking in VR without Visual Feedback

In order to travel as intuitively as possible in VR, the hardware must allow locomotion on two legs (Bipedalism). Especially for our application we chose the *Cyberith Virtualizer* treadmill (see Fig.1) because it is available as an commercial product and has a flat floor, on which the feet slide. We assume that this characteristic and the stable securing in the harness are primarily decisive for the well-being and trust of the visually impaired subjects. By using this walk-in-place device, the subjects' steps are detected by sensors in the base plate and trigger the equivalent movement of the subject's avatar in the VE (see Fig.1). To register the changing position in the VE non-visually, an audio clip imitating a step sound was play every time the position change reached 70 cm (i.e., one virtual step).

Subjects

Our preliminary user study involved six blind and visually impaired subjects (5 male, 1 female) from 18 to 57 years with a mean of 38.7 and a standard deviation of 13 while involving 3 congenitally and 3 late blind (see Tab.1). All of them were familiar with common digital support devices, but had no VR experience at all. We expect this admittedly small, but intentionally very diverse group to provide an as well diverse and informative feedback.

Hardware and Virtual Environment

For the actual implementation using hard- and software, we used the following setup: The subjects input (locomotion, viewing direction an and orientation of the controller) was captured by the treadmill, a *HTC Vive* controller and HMD. These information where processed in a desktop computer running the common VR engine *Unity*. Here, the respective haptic and auditory feedback was calculated using the integrated physics engine and *Google Resonance Audio*. The subjects could feel and hear this feedback in real time by the *Vive* controller and a *Logitech G933* surround sound headset. Our VE was modelled using *IceSL* and *Meshlab* and had a size of 36 x 16 x 2 metres (see Fig.1). Additionally, a real world model in 1:180 scale was 3D printed to provide an easy to understand real world reference to the subjects. Although this helps in the development of a mental model of the environment, it is very important as a reference for understanding and assessing the interface to the VE.

Haptic and Auditory Feedback

Whenever the virtual cane would collide with the environment, a tap sound was played right at this spot and the controller gave vibrotactile feedback. There was no differentiation between surfaces like wall and floor and the vibration of the controller lasts as long as the virtual white cane collided with the environment. However, spatial audio and room acoustics were covered by using *Google's*

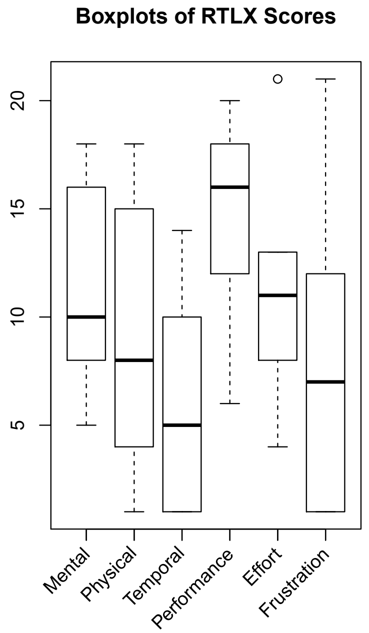

Figure 3: Results from the NASA-TLX questionnaires

Table 1

Subject	Gender	Age	Onset of blindness
#1	M	57	37
#2	M	29	congenitally
#3	M	43	33
#4	F	50	congenitally
#5	M	35	congenitally
#6	M	18	11

Resonance Audio. This implementation is certainly upgradeable (especially when compared to [6] or [8], but a first prototype with the actual focus on the feasibility of walk-in-place locomotion.

NAVIGATION TASK AND PRELIMINARY RESULTS

After a detailed briefing and explanation, the subjects entered the treadmill with the help of the authors and basically learned to walk in this apparatus, each subjects completed this first stage in less than 20 minutes. In stage two, they used this ability to walk from the starting position between the wall and the pillar to a waterfall sound placed between the pillar and the aisle entrance using only auditory feedback (see Fig.2).

From time to time this caused problems because the directional alignment of the treadmill and VR glasses was occasionally disturbed, sometimes there were also steps not correctly detected or wrong evaluated. These implementation related issues represent a major problem for PVIs in particular, as such errors cannot be detected as quickly and easily as with the wide sensory bandwidth of vision; the mental model of the environment gets rapidly destroyed. Finally, however, it was possible for all test persons to walk to the waterfall and to understand what their current position in the VE was (also with the aid of the 3D printed model and assistance from the experimenter). The last stage's task was to walk down the aisle only by haptic and auditoy feedback. Therefore, each subject was introduced to the function of the virtual white cane by exploring a wall or the pillar. As soon as they felt confident, they had to go from the entrance of the aisle to the second chamber by navigating along the walls in the aisle. Due to the unfortunately not always reliable step detection and evaluation, the experimenter occasionally had to provide information on the current position and walking direction, so that the subject was aware of these problems in the background. However, all subjects were able to fulfill this task and mentioned afterwards the very little amount of haptic and auditory information. They also said that step recognition and evaluation must be better implemented, but they found the basic idea to walk-in-place locomotion very interesting and promising. A SUS and (raw) NASA-TLX evaluation represent this problems, but also opportunities for improvement. The six subject's mean SUS score was 56.7 with a standard deviation of 17.7. The results of the raw Task Load Index (RTLX) scores are shown in Fig.3.

Nevertheless, all subjects were able to walk independently in this treadmill in less than 45 minutes of training and were able to explore the VE in a rudimentary manner. Thus the feasibility study on non-visual treadmill locomotion in VR was basically successful and identified issues that one can and must develop further.

IMPLICATIONS AND SUGGESTIONS FOR FURTHER IMPROVEMENTS

This paper revealed for the first time that blind and visually impaired people can successfully use a VR treadmill to explore a VE. For example, unknown real spaces (respectively, their digital models) can be virtually explored and learned before visiting in the real place. The presented walk-in-place approach is particularly interesting because one can explore unlimited large environments and use white cane exploration as in real life. As a result of our feasibility study, subjects were able to explore a simplified environment in less than an hour, but also encountered problems with the quality and quantity of haptic and auditory feedback and the step interpretation reliability. But these points of criticism are also a signal for the fact that the treadmill based locomotion works in principle. Therefore, one can consider the combination of the improved 'walk-in-place locomotion' module and other aspects of VR for PVIs like sophisticated virtual white canes [8] and adapting spatial information from VR to a real space [6]. An interesting aspect could also be the area of collaboration (as suggested in [5]), which makes particular use of the improved interaction in terms of sensory feedback. We are already working on some of the mentioned improvements and hope to make this exciting research field known and interesting to more researchers.

ACKNOWLEDGMENTS

We thank all volunteers for their participation in the user study and their helpful feedback.

REFERENCES

[1] Ian Bishop and Muhammad Rizwan Abid. 2018. Survey of Locomotion Systems in Virtual Reality. In *Proceedings of the 2nd International Conference on Information System and Data Mining (ICISDM '18)*. ACM, 151–154. https://doi.org/10.1145/3206098.3206108

[2] Chetz Colwell, Helen Petrie, Diana Kornbrot, Andrew Hardwick, and Stephen Furner. 1998. Haptic Virtual Reality for Blind Computer Users. In *Proceedings of the Third International ACM Conference on Assistive Technologies (Assets '98)*. ACM, 92–99. https://doi.org/10.1145/274497.274515

[3] J. P. Fritz and K. E. Barner. 1999. Design of a haptic data visualization system for people with visual impairments. 7, 3 (1999), 372–384. https://doi.org/10.1109/86.788473

[4] Gunnar Jansson, Massimo Bergamasco, and Antonio Frisoli. 2003. A new option for the visually impaired to experience 3D art at museums: manual exploration of virtual copies. 5, 1 (2003), 1–12. https://doi.org/10.1076/vimr.5.1.1.15973

[5] Julian Kreimeier and Timo Götzelmann. 2018. Real World VR Proxies to Support Blind People in Mobility Training. *Mensch und Computer 2018-Workshopband* (2018).

[6] Orly Lahav, Hadas Gedalevitz, Steven Battersby, David Brown, Lindsay Evett, and Patrick Merritt. 2018. Virtual environment navigation with look-around mode to explore new real spaces by people who are blind. 40, 9 (2018), 1072–1084. https://doi.org/10.1080/09638288.2017.1286391

[7] Matteo Palieri, Cataldo Guaragnella, and Giovanni Attolico. 2018. Omero 2.0. In *Augmented Reality, Virtual Reality, and Computer Graphics* (2018) *(Lecture Notes in Computer Science)*, Lucio Tommaso De Paolis and Patrick Bourdot (Eds.). Springer International Publishing, 21–34.

[8] Yuhang Zhao, Cynthia L. Bennett, Hrvoje Benko, Edward Cutrell, Christian Holz, Meredith Ringel Morris, and Mike Sinclair. 2018. Enabling People with Visual Impairments to Navigate Virtual Reality with a Haptic and Auditory Cane Simulation. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, 116:1–116:14. https://doi.org/10.1145/3173574.3173690