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Analyzing Visual Perception and Predicting Locomotion using Virtual Reality and Eye Tracking

Niklas Stein*
Westfälische Wilhelms-Universität Münster
Otto Creutzfeldt Center for Cognitive and Behavioral Neuroscience

Abstract

Locomotion and vison are closely linked. When users explore virtual environments by walking they rely on stable visible landmarks to plan and execute their next movement. In my research I am developing novel methods to predict locomotion paths of human subjects for the immediate future, i.e. the next few seconds. I aim to connect different types of behavioral data (eye, hand, feet and head tracking) and test their reliability and validity for predicting walking behavior in virtual reality. Such a prediction will be very valuable for natural interaction, for example in redirected walking schemes.

My approach begins with an evaluation of the quality of data gathered with current tracking methods. Informative experimental conditions need to be developed to find meaningful patterns in natural walking. Next, raw tracked data of different modalities need to be connected with each other and aggregated in a useful way. Thereafter, possible valid predictors need to be developed and compared to already functioning predicting algorithms (e.g. [2, 6, 12]). As a final goal, all valid predictors shall be used to create a prediction algorithm returning the most likely future path when exploring virtual environments.

Index Terms: Virtual Reality—Locomotion—Path Prediction—Eye Tracking

1 Motivation and Related Works

The new tracking technologies evolving with the progress of virtual reality (VR) allow quick and precise tracking of human behavior. Because visual input and motor action can be separated from each other in VR, it is possible to create experimental settings that allow a deeper inside in the motor and perceptual functions of the brain.

One interesting behavior is locomotion when exploring a virtual environment (VE). It is fundamental not only for most types of VR simulations but also for setting up virtual enhancements in physical environments in augmented reality. One goal of analyzing locomotion data is to predict future walking paths. This estimation has various applications: In simulation, the VR software can react if subjects decide to walk in unwanted directions. Following this approach various techniques of imperceptibly changing the users path have been developed in the past (e.g. [13, 14, 18]): In redirected walking (RDW) users are steered away if they approach the borders of the available physical space. Although we showed that perception thresholds for RDW techniques could be altered through adaptation [3], they still are a boundary of the effectiveness of RDW.

On the other hand, improved path predictions of locomotion also have the potential to make RDW more effective, as the developed techniques could be applied earlier on the pathway. Also in approaches in which physical obstacles are automatically included in the design of the VE (e.g. [5]), the level generation process could be implemented with fewer resetting levels. Additionally, good prediction algorithms could also be applied in relevant non-virtual contexts (e.g. automated wheelchairs, anticipatory prostheses etc).

In order to predict future walking paths in virtual environments, different approaches using head position, current moving direction, or typical walking patterns (e.g. [9, 12]) have been evaluated. From psycho-physical research it is also known that eye movements precede most motor actions in everyday behavior [10]. Moreover, because the visual perception is used to plan and execute movements, imperceptible movements of the optic flow lead to deviations from a planned path [16]. Additionally, constraining natural eye movements changes steering behavior [15]. Therefore, it seems plausible that locomotion behavior and eye movements are closely linked.

Since eye movements have been proposed as possible predictors for future locomotion [8], different groups have presented algorithms that include fixation positions obtained via eye tracking with promising results [7, 19]. However, in both experiments fixation positions were analyzed to predict a user decision in a 2AFC two path setting in which subjects also did saccades exploring the path they did not follow, reducing the certainty of the prediction following from the fixations. To differentiate these two types of eye movements (exploring and planning a path), new experimental designs also including more complex eye tracking analysis need to be evaluated.

As eye tracking technologies in HMDs get better with every generation, the possibilities for more complex online analysis of eye movements are evolving quickly (e.g. analyzing saccade dynamics and saccades instead of interpreting fixation positions only). Therefore, looking for saccade-patterns and saccade-action patterns will become a fruitful approach to VR.

2 Comparison of VR Eye Trackers for Research

The first target in my project was to get an overview of the data provided by available HMDs including eye tracking. Latency and delay between stimulus presentation on the display and tracking of the eye are fundamental to many methods of analyzing saccade dynamics in vision research. We, therefore, set up an experiment to measure the temporal quality of several commercially available HMD eye trackers in comparison to simultaneous ground through measurements using electrooculography (EOG, [4]). The results

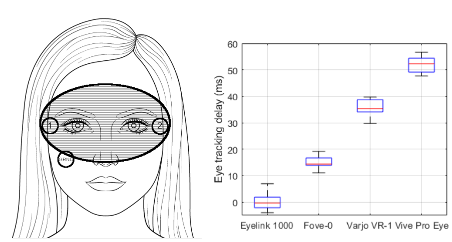

Figure 1: Eye tracking delays of several commercially available HMDs were compared to ground truth eye movement obtained through simultaneous electrooculography. Data from the Eyelink 1000 desk-mounted eye tracker were included as a gold standard baseline for eye tracking research in vision in the past decades.

*e-mail: niklas.stein@uni-muenster.de

model (e.g. user position and eye tracking data). To find the most effective approach here is a similar challenging task.

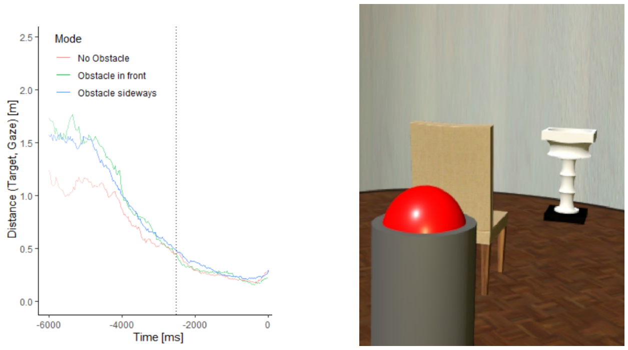

Figure 2: Comparison of the average distance between the subjects fixation and the final locomotion target during the trials. Differences between obstacle and no obstacle conditions can be detected at the beginning of the path (-6 s to -4 s). The vertical line presents the average time at which subjects passed the obstacles position. 0 s represents the time subjects activated the target with their controller.

(Fig. 1) showed clear differences between the HMDs [17]. Delays ranged from 15 ms to 52 ms, and latencies from 45 ms to 81 ms. Although these HMD delays appear overall short for some applications, many of them are in fact too large for time-critical research in vision [11] and for high-quality gaze-contingent rendering [1]. In our tests the Fove-0 appeared to be the fastest device and best suited for gaze-contingent rendering.

3 Gaze During Walking and Obstacle Avoidance

In step two of my PhD research I set up a VR experiment including eye tracking with various natural walking conditions to obtain data to distinguish as early as possible between a walking target and an obstacle, when predicting future paths.

In this experiment I want to determine whether it is possible to distinguish between the target and obstacle based on characteristics of the saccade and fixation patterns. or, if this is not the case, whether fixation data can be combined with other behavioral data in order to get a good estimation of the intended walking path. To detect possible characteristics in fixation patterns, the appearance of obstacles in the middle of the path towards an instructed target was systematically varied (no obstacle, obstacle in front and obstacle on the side). In 40 trials subjects were instructed to walk to a target at the end of an oval room at a distance of 4 m (see Fig. 2).

4 Outlook and Open Questions

Analysis of the fixation data from the experiment (Fig. 2) shows that the condition without an obstacle can indeed be distinguished simply from the average distance between the fixation point and the target. However, to distinguish the two obstacle positions from each other will require additional and more refined methods. In a next step we will look into lengths of fixations, slow pursuit movements and the amplitudes of consecutive saccades. Moreover, we will try to connect walking parameters and saccade occurrence as a predictor. If valid prediction patterns can be found, these would then need to be to included in existing path-prediction-models to evaluate their incremental usefulness. Enhanced prediction models could then be applied in many other applications.

One open question is the choice of analyzing methods. On the one hand the amount of available data with a clear criterion (the chosen path) could mean data driven approaches might be fruitful. On the other hand it seems handy to try to apply theories from visual perception to find valid prediction patterns. Additionally, one can think of many ways to merge valid predictors in a path prediction model (e.g. user position and eye tracking data). To find the most effective approach here is a similar challenging task.

References

[1] R. Albert, A. Patney, D. Luebke, and J. Kim. Latency requirements for foveated rendering in virtual reality. *ACM Trans. Appl. Percept.*, 14(4), Sept. 2017. doi: 10.1145/3127589

[2] M. Azmandian, T. Grechkin, M. Bolas, and E. Suma. Automated path prediction for redirected walking using navigation meshes. In *2016 IEEE Symposium on 3D User Interfaces (3DUI)*, pp. 63–66, 2016. doi: 10.1109/3DUI.2016.7460032

[3] L. Bölling, N. Stein, F. Steinicke, and M. Lappe. Shrinking circles: Adaptation to increased curvature gain in redirected walking. *IEEE transactions on visualization and computer graphics*, 25(5):2032–2039, 2019.

[4] B. Bolte and M. Lappe. Subliminal reorientation and reposition in immersive virtual environments using saccadic suppression. *IEEE-VR*, 21(4):545–552, 2015.

[5] L.-P. Cheng, E. Ofek, C. Holz, and A. D. Wilson. Vroamer: Generating on-the-fly vr experiences while walking inside large, unknown real-world building environments. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 359–366. IEEE, 2019.

[6] Y.-H. Cho, D.-Y. Lee, and I.-K. Lee. Path prediction using lstm network for redirected walking. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 527–528. IEEE, 2018.

[7] J. Gandrud and V. Interrante. Predicting destination using head orientation and gaze direction during locomotion in vr. In *Proceedings of the ACM Symposium on Applied Perception*, SAP '16, p. 31–38. Association for Computing Machinery, New York, NY, USA, 2016. doi: 10.1145/2931002.2931010

[8] R. Grasso, P. Prévost, Y. P. Ivanenko, and A. Berthoz. Eye-head coordination for the steering of locomotion in humans: an anticipatory synergy. *Neuroscience Letters*, 253(2):115 – 118, 1998. doi: 10.1016/S0304-3940(98)00625-9

[9] C. Hutton and E. Suma. A realistic walking model for enhancing redirection in virtual reality. In *IEEE Virtual Reality Conference 2016 The walker was designed around a waypoint mode of travel to 19–23 March, Greenville, SC, USA align with current redirection techniques used and was developed*. IEEE, 2016.

[10] M. F. Land. Eye movements and the control of actions in everyday life. *Progress in Retinal and Eye Research*, 25(3):296 – 324, 2006. doi: 10.1016/j.preteyeres.2006.01.002

[11] L. C. Loschky and G. S. Wolverton. How late can you update gaze-contingent multiresolutional displays without detection? *ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM)*, 3(4):1–10, 2007.

[12] A. K. Markus Zank. Using locomotion models for estimating walking targets in immersive virtual environments.

[13] N. C. Nilsson, T. Peck, G. Bruder, E. Hodgson, S. Serafin, M. Whitton, F. Steinicke, and E. S. Rosenberg. 15 years of research on redirected walking in immersive virtual environments. *IEEE Computer Graphics and Applications*, 38(2):44 – 56, 2018.

[14] S. Razzaque. Redirected walking. Master's thesis, University of North Carolina, 2005.

[15] R. Reed-Jones, J. Reed-Jones, L. A. Vallis, and M. Hollands. The effects of constraining eye movements on visually evoked steering responses during walking in a virtual environment. *Exp. Brain Res.*, 197(4):357–367, Aug 2009.

[16] G. Sarre, J. Berard, J. Fung, and A. Lamontagne. Steering behaviour can be modulated by different optic flows during walking. *Neuroscience Letters*, 436(2):96 – 101, 2008. doi: 10.1016/j.neulet.2008.02.049

[17] N. Stein, D. Niehorster, T. Watson, F. Steinicke, K. Rifai, S. Wahl, and M. Lappe. A comparison of eye tracking latencies among several commercial head-mounted displays. *i-Perception*, in press.

[18] F. Steinicke, G. Bruder, J. Jerald, H. Frenz, and M. Lappe. Estimation of detection thresholds for redirected walking techniques. In *IEEE Trans. Vis. Comput. Graph.*, vol. 16, pp. 17–27, 2010.

[19] M. Zank and A. Kunz. Where are you going? using human locomotion models for target estimation. *The Visual Computer*, 32(10):1323–1335, apr 2016. doi: 10.1007/s00371-016-1229-9