Walking Balance Assessment with Eye-tracking and Spatial Data Visualization

Zhu Wang
zhu.wang@nyu.edu
New York University
New York, New York, USA

Anat Lubetzky
anat@nyu.edu
New York University
New York, New York, USA

Ken Perlin
perlin@cs.nyu.edu
New York University
New York, New York, USA

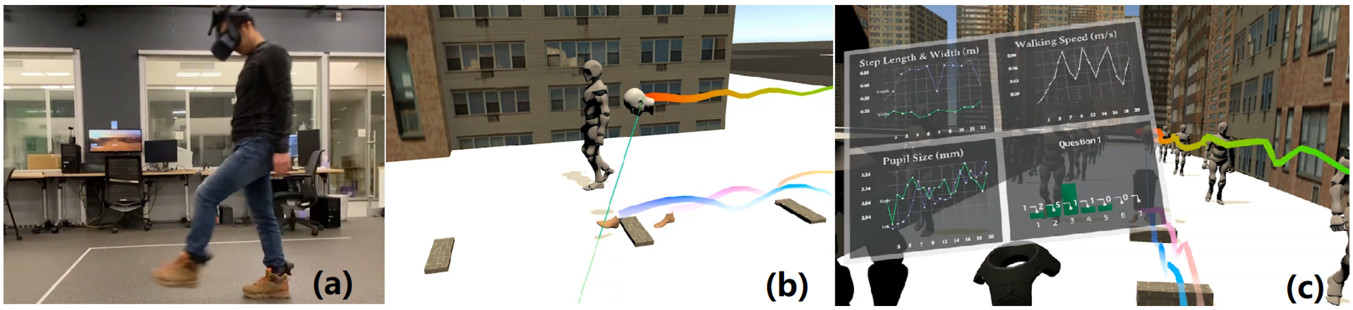

Figure 1: (a) Participant is crossing an obstacle; (b) VR view: eye tracking and motion trajectory; (c) Spatial visualization

ABSTRACT

Virtual Reality (VR) based assessment systems can simulate diverse real-life scenarios and help clinicians assess participants' performance under controlled functional contexts. Our previous work demonstrated an assessment paradigm to provide multi-sensory stimuli and cognitive load, and quantify walking balance with obstacle negotiation by motion capture and pressure sensing. However, we need to fill two gaps to make it more clinically relevant: 1. it required offline complex data processing with external statistical analysis software; 2. it utilized motion tracking but overlooked eye movement. Therefore, we present a novel walking balance assessment system with eye tracking to investigate the role of eye movement in walking balance and spatial data visualization to better interpret and understand the experimental data. The spatial visualization includes instantaneous in-situ VR replay for the gaze, head, and feet; and data plots for the outcome measures. The system fills a need to provide eye tracking and intuitive feedback in VR to experimenters, clinicians, and participants in real-time.

CCS CONCEPTS

• **Human-centered computing → Visualization systems and tools**; **HCI design and evaluation methods**.

KEYWORDS

virtual reality, data visualization, eye tracking, evaluation

SIGGRAPH '21 Immersive Pavilion, August 09-13, 2021, Virtual Event, USA

ACM ISBN 978-1-4503-8368-4/21/08.
https://doi.org/10.1145/3450615.3464533

ACM Reference Format:
Zhu Wang, Anat Lubetzky, and Ken Perlin. 2021. Walking Balance Assessment with Eye-tracking and Spatial Data Visualization. In *Special Interest Group on Computer Graphics and Interactive Techniques Conference Immersive Pavilion (SIGGRAPH '21 Immersive Pavilion), August 09-13, 2021.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3450615.3464533

1 INTRODUCTION

Gait and balance are essential for our overall health and quality of life due to their necessity in daily-life activities. Tripping over an obstacle and multitasking are two common causes of falls for aging adults[Eyal et al. 2020]. Virtual Reality (VR) based assessment systems carry a great promise in understanding dysfunction in motor tasks such as gait and obstacle crossing. They can simulate diverse real-life scenarios, provide graded levels of challenge, and allow for a detailed evaluation of performance and an individual's strategy of obstacle navigation. Within VR, clinicians can utilize motion tracking to assess participants' gait while participants experience sensory overload in a safe environment without fear or concern of experiencing a fall[Wang et al. 2019]. We have presented a novel VR system with pressure sensing and ankle tracking to assess walking balance and negotiation of obstacles under graded sensory conditions[Wang et al. 2020]. In addition to single-task walking assessment, the system helped to investigate anticipated or unanticipated virtual obstacle crossing with various visual, auditory, and cognitive load.

After testing the system and discussing it with PT researchers, we recognized two features that would be helpful but were not available: eye-tracking and spatial visualization. In gait tasks, eye movement can help to investigate cognitive mental activities, attention, and decision making[Hayes and Petrov 2016]. Given that tripping over an obstacle may account for approximately 60% of falls among older adults and eye movements are significant in gait and obstacle crossing, there is a crucial need to reveal these visual processes and patterns using eye tracking[Berg et al. 1997]. Eye tracking could help understand how sight relates to mental processes (involved in gaining knowledge and comprehension, e.g., thinking, paying attention, problem-solving). It could also help quantify the low-level parameters of oculomotor eye motion control (e.g., response latency, kinematics of eye movements)[Gibaldi et al. 2017]. Therefore, we integrate eye tracking features into the walking balance assessment system to measure the eye metrics, such as pupil dilation or the gaze fixation duration (i.e., the time during which the eyes rest on an object). With a VIVE eye-tracking VR headset, the system can help investigate cognitive mental operations underlying visual experience when participants are in the virtual environment. Applying a VR-based assessment system in clinics would have a major hurdle if the system collects raw data but relies on data analysis with external statistical analysis software rather than exploits VR's visualization abilities and engagement. To make our system more clinically relevant, we add spatial visualization as immediate output. Hence, experimenters and participants can get results on the spot, visually inspect balance performance.

In this work, we present a novel walking balance assessment platform with eye-tracking to investigate the role of eye movement during walking and obstacle crossing, and spatial data visualization to better understand and interpret the experimental data. The system tracks the kinematics of the head and ankles, and utilizes eye-tracking technology to measure pupil dilation and gaze fixation. The spatial data visualization can instantaneously provide VR playback and indicate the performance on gait and gaze.

2 DESIGN AND IMPLEMENTATION

With VIVE trackers attached to participants' ankles, the system can track the ankles, estimate foot clearance and foot collision with the virtual obstacles. VR systems cannot provide somatosensory input of the foot to simulate the impact when participants hit the obstacle. Therefore, the feet are represented by foot graphic models in VR for the participants to visually detect their own feet and identify whether their feet cleared the obstacle or not. In addition, the system provides auditory feedback for the success or failure of clearing obstacles. Embodied foot models could affect perceptual estimation and motor tasks[Jun et al. 2015]. For this reason, the system calibrates and aligns the foot models based on the foot dimensions and VIVE tracker's placement.

We implemented the visualization module on top of our previous walking balance platform. The module has the following features: 1. in-situ VR playback and trajectory visualization for the tracked body segments and gaze; 2. data plot for the measurements. For the assessment trials, the system only provides graded multisensory stimuli to the participants. The spatial visualization features will be available immediately after each trial. The experimenters and participants can view the VR playback and control it with play/pause buttons and a seek slider.

Motion trajectory visualization creates a trajectory behind the moving segments. It helps visualize the trajectory of the movement and could be useful for a better visual tracking and interpretations. Experimenters can set trajectory's color coding or textures to differentiate between trajectories from different body parts, and can set duration of the trajectories all the way from 0 (no trajectory) to the full duration of the trial (keep movement trajectory during the whole trial). This feature gives experimenters and participants intuitive visual feedback, each body segment's behavior as well as participants' performance

Experiments may need to use short closed-ended questions for trials, such as presence, preference, etc. However, eye tracking requires re-calibration when headset re-positions. Participants might need to remove the headset and fill out the questionnaire after each trial, which requires re-calibration. Therefore, our system has a VR questionnaire module for participants to fill out quick closed-ended questions in VR. Questions and options will be displayed in front of participants when trials end. All the questionnaire options are created as interactable buttons. Participants can use gaze or the controller with raycast to select their choices. The VR questionnaire module loads standardized or customized questionnaires from a text file, displays the questions and options in VR, and collects participants' input.

The measurement module calculates metrics in real-time. It measures: 1. walking velocity from headset: how obstacle negotiation affects walking speed; 2. step length, step width from Vive tracker: gait parameters that correlate risk of falls, obstacle, negotiation and attention-demanded tasks; 3. success/failure rate of obstacle crossing: correlates with obstacle height and anticipated/unanticipated condition[Eyal et al. 2020] 4. pupil dilation, percentage of gaze fixation: correlate with the mental process; 5. questionnaire selections from the VR questionnaire module. Experimenters and participants can view the data plot of the metrics in VR or on screen.

3 CONTRIBUTION

This novel system incorporates eye-tracking and data visualization in addition to motion tracking for the head and feet. For researchers, the system can help conduct experiments to understand gait deficits in different environmental contexts with rich data, which carries a huge potential for fall prevention programs. For clinicians, the real-time rich data on participants' performance allows them to set treatment goals, examine progress, and potentially determine risk for falls and the reason for that risk. For participants, they can get an immediate indication of their own performance and comparison between their trials over time.

REFERENCES

William P Berg, Helaine M Alessio, Eugenia M Mills, and Chen Tong. 1997. Circumstances and consequences of falls in independent community-dwelling older adults. *Age and ageing* 26, 4 (1997), 261–268.

Shlomit Eyal, Ilan Kurz, Anat Mirelman, Inbal Maidan, Nir Giladi, and Jeffrey M Hausdorff. 2020. Successful negotiation of anticipated and unanticipated obstacles in young and older adults: not all is as expected. *Gerontology* 66, 2 (2020), 187–196.

Agostino Gibaldi, Mauricio Vanegas, Peter J Bex, and Guido Maiello. 2017. Evaluation of the Tobii EyeX Eye tracking controller and Matlab toolkit for research. *Behavior research methods* 49, 3 (2017), 923–946.

Taylor R Hayes and Alexander A Petrov. 2016. Mapping and correcting the influence of gaze position on pupil size measurements. *Behavior Research Methods* 48, 2 (2016), 510–527.

Eunice Jun, Jeanine K Stefanucci, Sarah H Creem-Regehr, Michael N Geuss, and William B Thompson. 2015. Big foot: Using the size of a virtual foot to scale gap width. *ACM Transactions on Applied Perception (TAP)* 12, 4 (2015), 1–12.

Zhu Wang, Anat Lubetzky, Marta Gospodarek, Makan TaghaviDilamani, and Ken Perlin. 2019. Virtual Environments for Rehabilitation of Postural Control Dysfunction. *arXiv preprint arXiv:1902.10223* (2019).

Zhu Wang, Anat Lubetzky, Charles Hendee, Marta Gospodarek, and Ken Perlin. 2020. A Virtual Obstacle Course within Diverse Sensory Environments. In *ACM SIGGRAPH 2020 Immersive Pavilion*. 1–2.