Standardized experimental estimation of the maximum unnoticeable environmental displacement during eye blinks for redirect walking in virtual reality.

Adrian Borrego[1], Roberto Llorens[1, 2]

[1]*Neurorehabilitation and Brain Research Group, Instituto de Investigación e Innovación en Bioingeniería*
Universitat Politècnica de València
Valencia, Spain.

[2]*NEURORHB.*
Servicio de Neurorrehabilitación de Hospitales Vithas
Valencia, Spain.

Belen Masia[3], Diego Gutierrez[3]

[3]*Graphics and Imaging Lab*
Universidad de Zaragoza
Zaragoza, Spain

***Abstract*— Redirect walking is a technique that aims to manipulate the walking trajectories in immersive virtual reality settings by inducing unnoticeable displacements of the virtual environment. Taking into advantage the change blindness phenomenon, visual occlusion during eye blinks has been recently proposed to perform those displacements. This study determined the maximum unnoticeable displacement that can be performed in practical scenario, which proved to be near 0.8º of occlusion and disocclusion in both horizontal and vertical axes.**

***Keywords*— Redirect walking, virtual reality, change blindness.**

I. INTRODUCTION

Implementation of real walking in virtual environments has always been a technological challenge for Virtual Reality (VR)-technology. Different alternatives have been proposed to facilitate more natural locomotion through the years, such as walking-in-place [1]. However, navigation in VR is still commonly enabled by more abstract metaphors using external keyboards or controllers, such as gamepads or joysticks. Although these user interfaces are worldwide known and used, and, over all, easier to implement, natural locomotion may be a requirement for rehabilitation application, which aim to maximize ecological validity of the training environment, and, ultimately, the transference of improvements from the virtual to the real world.

The last-generation of VR head mounted displays enable certain degree of free navigation as they include built-in tracking mechanisms that allows for estimating the position and orientation of the head in real time in a wider area [2]. However, when more space is required multi-camera solutions [3] or other alternatives [4] are needed. Interestingly, room-size walkable VR solutions enables implementation of redirect walking (RDW) in VR [5]. RDW recreates the sensation of volitional real walking in any direction and distance of a virtual environment by rotating and translating the environment during walking. If changes of the virtual environment are sufficiently small and slow, they remain unnoticed to the users, which tricks their perception and, consequently, make them correct their trajectory to adapt to the updated environmental conditions. For instance, it is possible to make users believe that they are walking straight in an infinite path, while they are actually walking in circles [6]. Therefore, importance of RDW is that it allows recreating walkable virtual environments that are larger than the real environment itself.

The use of this technique has been reported by a number of interesting studies that have proved that RDW can be equivalent to real walking in terms of proprioceptive and subjective feedback [7]. Traditionally, manipulation of the virtual environment is smoothly and sequentially performed while users walk. Recent articles, however, have proposed that manipulation of the environment can also be performed during eye saccades [8] and blinks [9]. Efficacy of using natural eye occlusion relies on the phenomena known as change blindness, which describes the inability to notice small changes that occur during visual disruption [10]. In spite of the potential of using visual occlusion to implement RDW techniques, it could be extremely difficult to put it into practice. Only one study has attempted to determine the maximum rotation and translation that could be actually done during an eye blink in VR [9]. However, the results of the study were only valid for the virtual environment used in the study and the results cannot be extrapolated. In addition to the lack of parametrization, the presence of different objects and textures could also produce motion parallax effects that could affect the results and were not controlled.

The objective of this study was to determine the maximum displacement that can be performed in any virtual environment without being noticed during an eye blink, which would facilitate implementation of RDW in VR.

II. METHODS

A. Participants

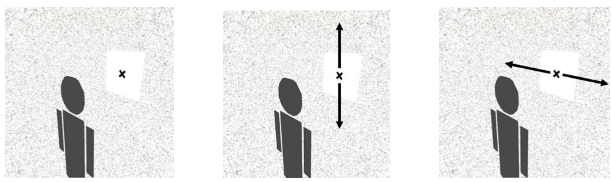
A total of 45 healthy subjects participated in the study (27.9±7.1 years old, 30 men and 15 women). All of the participants provided written consent to participate in the study.

B. Instrumentation

A HTC Vive Pro system (HTC Corporation, Taoyuan City, Taiwan) was used to display the VE. An eye-tracking system, the Pupil (Pupil Labs, Berlin, Germany) was embedded into the HMD using the HTC Vive Binocular Add-on of the same manufacturer. The Pupil includes two 120 Hz-cameras, each one illuminated by 10 IR LEDs.

A virtual environment, consisting of a cloud of random black dots over a white background and a white panel with a black cross on its center, which was initially located between the user and the background (Fig. 1).

Fig. 1. a) Virtual environment displayed during the experiment; b) and c) Different possible displacements of the virtul environement.



a) b) c)

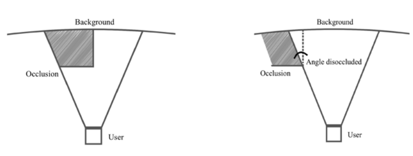
The VE was implemented and rendered using Unity3D version 2018.1 (Unity Technologies ApS, San Francisco, CA) and blinks were detected using the Pupil Capture Software v1.9-7.

C. Procedure

Initially, participants were asked to comfortably sit in a chair, were informed about the objective of the experiment, were equipped with the head mounted display, and were asked to remain as still as possible. Two conditions were designed to detect the maximum noticeable horizontal or vertical displacement. For both conditions, participants were asked to look at the black cross of the panel and follow the instructions given during the experiment. A dedicated program detected the eye blinks and, during the blink, translated the whole virtual environment horizontally or vertically, depending on the condition, in one direction or the other, or remain the same. Three seconds after a blink, a message appeared asking participants whether or not they had detected any change. An experimenter introduced each answer into a Quest staircase algorithm [11] implemented in the program, which estimated the translation to be made during the next eye blink. The experiment finished when the difference between the last two environmental translations created an angle occlusion smaller than 0.1º.

The maximum background angle that was successfully occluded or disoccluded during the experiment without being noticed was estimated for each condition (Fig. 1).

Fig. 2. Angle disoccluded after a left displacement.



a) b)

III. Results

The mean maximum angle that could be performed without being noticed was 0.82º in the horizontal axis and 0.80º in the vertical axis.

IV. Discussion

This study determines the maximum translation that can be made in a virtual environment without being perceived in both the horizontal and vertical axis in angular measures that allow extrapolation to any practical scenario. By using a simple environment were only motion parallax effect is present, experimental results do not depend on the depth or size of the occlusion. Human perception seems to present limitations to detect occlusions and disocclusions near 0.8º in both horizontal and vertical axis. Considering a practical scenario that consists of a wall located 4 meters away from the user and an occluding object situated in the centre point between the user and the wall, the whole environment could be translated 3.85 cm horizontally and 3.72 cm vertically without being perceived.

In conclusion, the noticeable thresholds estimated in this study could be used in future implementations of RDW techniques in VR to maximize the environmental translations that can be applied without being noticed during eye blinks.

Funding

This work was partially supported by Ministerio de Economía y Competitividad of Spain (Project RTC-2017-6051-7, and Grant BES-2014-068218), Fundació la Marató de la TV3 (Grant 201701-10), and by Universitat Politècnica de València (Grant PAID-06-18).

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