Steering Locomotion by Vestibular Perturbation in Room-Scale VR

Misha Sra*
MIT Media Lab, 75 Amherst St., Cambridge, MA 02142 USA

ABSTRACT

Advances in consumer virtual reality (VR) technology have made using natural locomotion for navigation in VR a possibility. While walking in VR can enhance immersion and reduce motion sickness, it introduces a few challenges. Walking is only possible within virtual environments (VEs) that fit inside the boundaries of the tracked physical space, which for most users is quite small and carries a high potential for collisions with physical objects around the tracked area. In my thesis, I explore visual and physiological steering techniques that complement the traditional redirected walking technique of scene rotation to alter a user's walking trajectory in the physical space. In this paper, I present the physiological technique.

Keywords: Virtual Reality, Redirected Walking, Galvanic Vestibular Stimulation, Orientation Response;

Index Terms: H.5.1 [User Interfaces]: Prototyping

1 INTRODUCTION

Following their introduction in the 1960s, head-mounted devices (HMDs) focused on visual and aural senses. Since then a lot of research has gone into the design of natural interaction techniques predominantly using gesture and voice input. As the next step towards realism and immersion, there is a lot of research on different navigation techniques in VR since the visuo-vestibular conflict, often accompanying non-natural moving techniques, causes motion sickness. My thesis addresses a limitation of real walking in VR where users cannot walk to navigate VEs that are much larger than the working area of a tracking system.

A participant is "immersed" in the VE in two ways. First, through the visual display of the virtual surroundings in the HMD. Second, through a representation of the self in the VE such that proprioceptive signals from real world body movements become overlaid with visual and haptic feedback from the virtual representation of the human body [3]. In addition, I believe, the credibility of the scenario being depicted and it's match with the user's expectations and mental models also impacts user immersion. For example, walking is fundamental to our negotiation of natural environments and moving in VR using teleportation with a hand-held device, while learnable, is not the expected means of locomotion.

2 EXPOSITION

Flow Motion is an intelligent agent that dynamically applies designed reorientation techniques to allow users to explore large virtual environments by walking in smaller physical spaces. One visual reorientation technique I have designed is the "*reduced field of view (r-fov)*", commonly seen in real world tasks such as looking through a telescope or using focus lights for on-stage events. Using *r-fov* in VR along with a constantly moving target (e.g., a dancer in the spotlight or an enemy in the sniper's scope) causes the user to continuously adjust their body and align themselves with the target they are looking or aiming at from short distances. When this does not provide enough change in the user's physical orientation, the scene is additionally rotated according to classic redirection techniques. A physiological reorientation technique I use is based on modulating the user's orientation perception through galvanic vestibular stimulation (GVS). Due to space limitations, I will only describe GVS below.

When combined with existing redirection techniques like rotational gain, the proposed visual and physiological techniques can substantially augment the effective walking area, allowing potentially vast synthetic worlds to be explored using natural body movement within small-sized physically spaces. The Flow Motion agent uses the user's physical position, distance from tracking area boundary, direction they need to be steered in the virtual environment, and potential collaborative tasks that may need to be performed with others in the VR space to determine when and what to introduce into the VR scene as well as which technique to apply.

2.1 Vestibular Perturbation

Our sense of orientation during walking is based on our spatial relationship with the environment sensed by sight and sound and from proprioceptive signals of motion from the muscles and joints. However, all sensory channels operate in different frames of reference and the central nervous system needs to combine the various inputs to create a coherent internal representation of self-motion [5]. Normally, the sensory cues provide congruent information on a person's trajectory; however, when one or more of the senses are altered, there needs to be a recalibration for providing a unitary representation of self-motion [5]. I alter the user's orientation sense by creating a vestibular perturbation of the orientation sense through transmastoidal galvanic stimulation, a technique generally used to evoke balance reflexes. The GVS stimulus is most commonly delivered with an anodal (positive) electrode on the mastoid process behind one ear and a cathodal (negative) electrode behind the other ear. It elicits three types of vestibular responses in the user depending on the following three conditions [5]:

- **R.1 Standing**: transmastoidal current applied during standing disrupts balance and causes sway to the anodal side.
- **R.2 Standing with head upright and body vertical**: galvanic stimulation generates movement illusions, described as sway-like movements.
- **R.3 Standing with head pitched forwards**: vestibular stimulation causes navigation errors unrelated to balance when walking, causing smooth turning in the direction of the anodal (positive) electrode without balance response.

Inami et al.[2] use the balance reflex response (**R.1**) causing users to stagger and deviate from the intended straight-line path (see Figures 2A and B). Balance perturbation is noticeable to the user who makes a conscious effort to regain their balance, following which they continue on a straight line path.

2.2 Thesis Focus

I focus on the physiological redirection technique using GVS response **R.3** to steer a user in VR, where changing head posture changes the interpretation of the galvanic vestibular signal for orientation responses (see Figure 2C). Since with appropriate head alignments during locomotion, the galvanic stimulus can be used

*e-mail: sra@media.mit.edu

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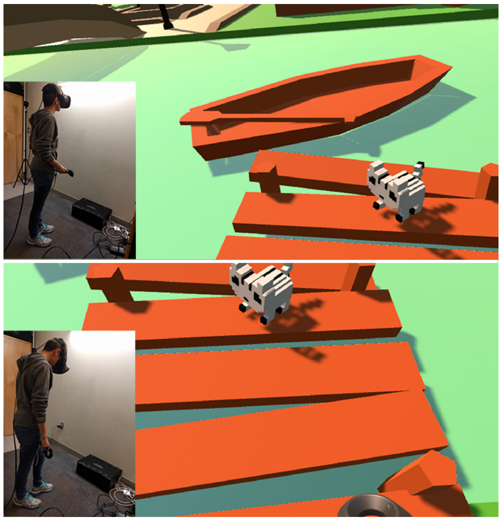

Figure 1: Top: The VR scene as seen from the user's point of view with their head upright and body vertical. The user is looking up, at the boat and the park beyond the water. Bottom: Scene from user's point of view with their head pitched forwards. The user is looking down at the slats of the bridge and the cat. Both screenshots are taken from the Unity editor connected to the HTC Vive headset and thus not exactly what the user sees in the HTC Vive HMD.

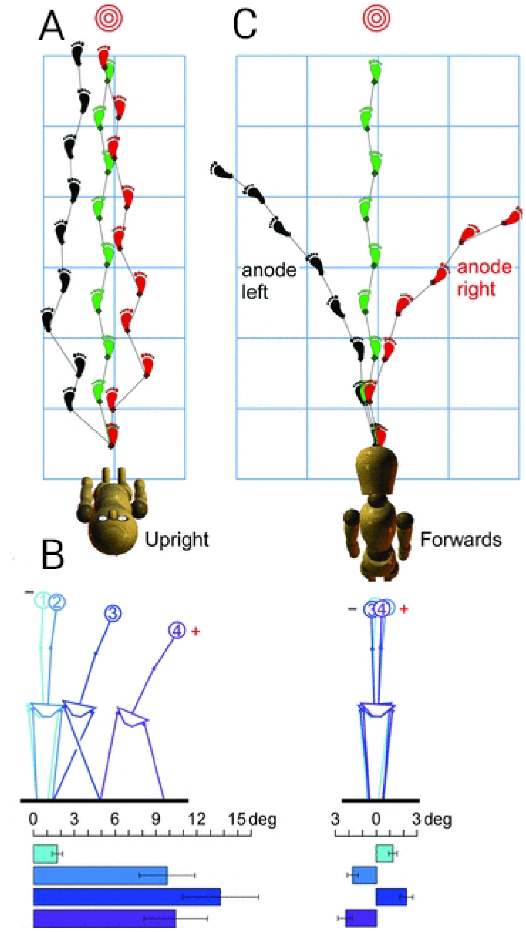

Figure 2: A: The trajectories of a user attempting to walk to the target with their head upright, shown as foot placements [1]. The galvanic stimulus produces staggered foot placements to the side of the anode because of balance responses, not orientation responses. The balance responses, seen in B, show large body tilt during the first four steps following which balance is regained and the user continues walking towards the target. C: With the head pitched forward, the galvanic stimulus causes smooth turning in the direction of the anodal electrode without balance responses [5].

to steer trajectory over the terrestrial plane, the VE needs to be designed in a way that the user's head is pitched forwards when they are walking. If the users raise their head to look straight ahead while walking, as with unexpected foot contact, they will stumble sideways attempting to regain balance similar to condition **R.1** [5].

2.3 GVS in VR

In my VR design, the user needs to follow a cat (see Figure 1) on a straight long virtual path. As the cat is small and always walks a little bit ahead of the user, the user is forced to look down while they are walking behind it. Every now and then the cat stops, which makes the user stop, giving them a chance to look up and around. In an earlier user study [4], I observed that all users looked down while walking across a bridge, taking care to step only on the slats so as to not "fall" through the gaps. To take advantage of that behavior, I added a short bridge to the GVS VR scene. Since the virtual path is straight and long, the physical path needs to be curved in order to allow the user to navigate without running into obstacles. A use a custom built GVS circuit that connects to the VR scene and automatically sends current through the electrodes for a specific duration as determined by the Flow Motion agent. The current is applied continuously to perturb the orientation sense and make the user walk in a curved path in a small space and applied only when the user is approaching an obstacle to steer them away from it when in a larger physical space.

3 Conclusion

Galvanic stimulation is a simple technique that can evoke controlled sensations of self-motion and altered orientation as well as balance and ocular responses when delivered appropriately. While prior research has used the balance reflex and ocular responses for creating new interfaces, in my thesis, I take advantage of the altered orientation response to steer users on a curved trajectory to allow them to walk in virtual spaces much larger than their physical space. I propose GVS as a new redirected walking technique and a user safety mechanic in VR where the amount, duration and timing of transmastoidal stimulation is controlled by an intelligent VR agent. Similar to other techniques for enabling natural walking through large-scale VEs, the proposed visual and physiological reorientation techniques likely have a lower limit on the size of available physical space, which I have yet to establish. However, for spaces the size of a small living room, when the size of the virtual space is many times larger, the techniques would allow users to navigate by walking, allowing for natural movement in shared virtual spaces for gaming, tourism, socializing and more.

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