Submission Template for ACM Papers

A novel combination of haptics and lean to move

Combining haptics in an omnidirectional lean to move system for virtual reality locomotion

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There is a compelling body of literature on the use of lean to move functions for VR locomotion, supporting its role in aiding vection, presence, locomotion performance, and overall locomotion experience in VR. There is also a growing body of literature supporting the use of haptics being administered to the feet to augment vection, presence and experience. However, to date, there is only a minimal albeit compelling body of literature combining the two, demonstrating that it can enhance the experience of locomotion even further than either of these modalities alone. Yet, this was only been tested in simplified form factor with limited directional capabilities available to the user. We propose an omnidirectional lean-to-move apparatus that incorporates haptics to simulate footsteps and to improve the aforementioned metrics related to locomotion in VR.

Additional Keywords and Phrases: Virtual Reality, Lean to Move, Omnidirectional, Haptics

ACM Reference Format:
Stefanos, F. Lazarides. 2025. A novel combination of haptics and lean-to-move: ACM Conference Proceedings Manuscript

Introduction

Computer gaming is an evolving industry. Locomotion in virtual reality (VR) spaces can be a key component of many interactive games, particularly those involving gaming and entertainment. However, many solutions for locomotion in VR spaces have feature limitations, and this is likely a sticking point for many VR applications and a hindrance to the wider adoption of VR. Effective human-machine interfaces can enhance the interaction with, and enjoyment of, the game or other virtual experiences. The issues pertaining to locomotion in VR include usability, immersion, locomotion performance, vection, and, perhaps most notably, motion sickness [1].

There are many core causes of motion sickness including the often cited role of the vestibular system, as well as other factors such as latency and field of view (FOV). Many attempts to address motion sickness look at the role of tricking the vestibular system or visual auditory system [2,3].

Separately, lean to-move functions have shown to be an effective means of navigating virtual environments (Citation). A multitude of VR locomotion solutions exist, including the default handheld joystick that comes with many headsets, in-game teleportation, lean-to-move, arm swing, treadmills, and others [4]. As discussed below, lean to move has shown promise in several academic studies as means of addressing many of the aforementioned issues with modern VR locomotion.

At the same time, the use of haptics to enhance Virtual Reality simulations and applications has become commonplace. While most of these efforts have focused on the hands, via controllers or gloves, there has also been increasing attention placed on other areas of the body such as the torso, arms, head, legs and feet. These applications can take many forms such as one to one simulations of virtual events (such as a vest vibrating to simulate a bullet impact to the chest) or non-identical representations of virtual events such as controllers vibrating to indicate a change of scene or other non-direct information in the environment.

Of particular interest in this paper is the way haptics can be used as a solution for locomotion, particularly when combined with lean to-move functions, presenting what we feel is a novel, accessible way of addressing the issue of locomotion in VR. We propose a method for combining haptics and lean to move in an omnidirectional system, and discuss ways in which the proposed system may improve locomotion.

1 RATIONALE

1.1 Lean to Move for VR locomotion

Multiple studies have explored the use of lean to move haptics and found that it offers advantages over traditional joystick movement for movement accuracy, immersion, vection, immersion, and nausea reduction [1,5]. Several tasks by Riecke et al. showed the advantages of such a system pertaining to performance and nausea reduction, and found that they could be effectively implemented in an omnidirectional platform [5]. Figure 1 illustrates some of their findings. We found similar results on a test conducted by our team at VIMA Perceptions, though our results were limited by a small sample size.

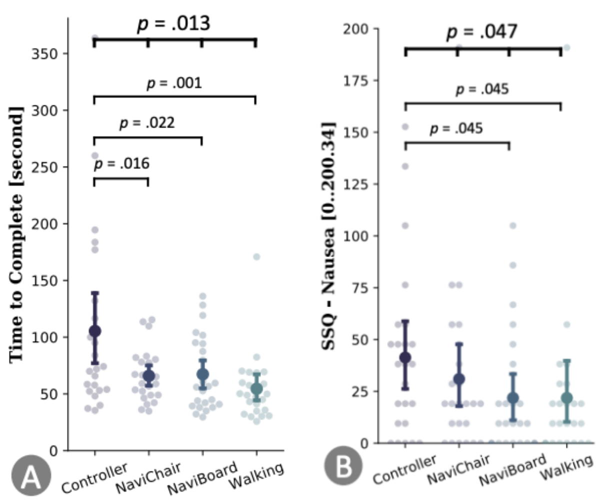

Figure 1: Task performance and nausea reduction of lean to move system compared to walking as measured by Nguyen et al 2019. Navichair and Naviboard are the lean to move interfaces.

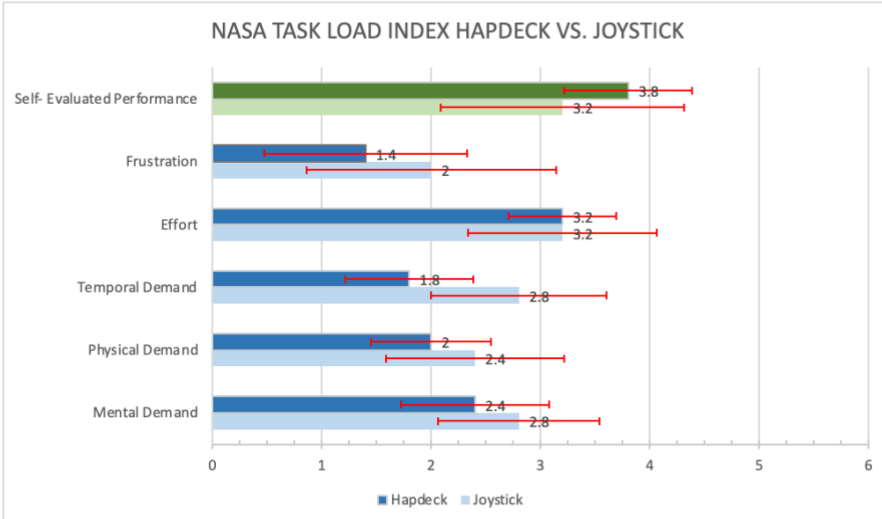

Figure 2: Assessment of various perceptual and cognitive parameters on lean to move system (Hapdeck) vs Joystick. Statistical significance limited by small sample size.

It is believed that lean to move works effectively as a VR locomotion method and can reduce nausea by activating the vestibular system [5]. However, while well represented in academic literature and despite being one of the more evidentially grounded approaches to VR locomotion, many of the more prevalent VR headsets on the market still ship with joysticks as the default locomotion method. We propose that one missing link in this gap in adoption is the absence of a "vection separation factor" (i.e. a sensory indicator separating general leaning from locomotion) such as haptics.

1.2 Haptics for VR locomotion

Multiple studies have shown that using haptic simulations of footsteps can lead to increased immersion in virtual environments [6]. At least one study has shown that haptics used with the feet can reduce motion sickness in VR [7]. Most of the aforementioned studies of haptically simulated footsteps have focused on applying vibrations to the heel and ball of the foot to simulate the heel strike and toe off portions of the footstep. The theory behind this is that the heel strike and toe off portions of the footstep exert the highest peak forces during the cycle. However, as shown in [8], singular vibrations, representing the totality of the foot contact with the ground, are actually preferable for user experience when simulating footsteps then double vibrations. This may be because the contact forces during the footstep are fully bimodal, and maintain a high percentage of the peak force throughout the footstep cycle (as shown in Figure 3). This bodes well for being able to simulate haptic footsteps in a less constrained form factor such as a more open-ended platform, potentially eliminating the need to pinpoint the heel and ball of the foot during footstep simulations.

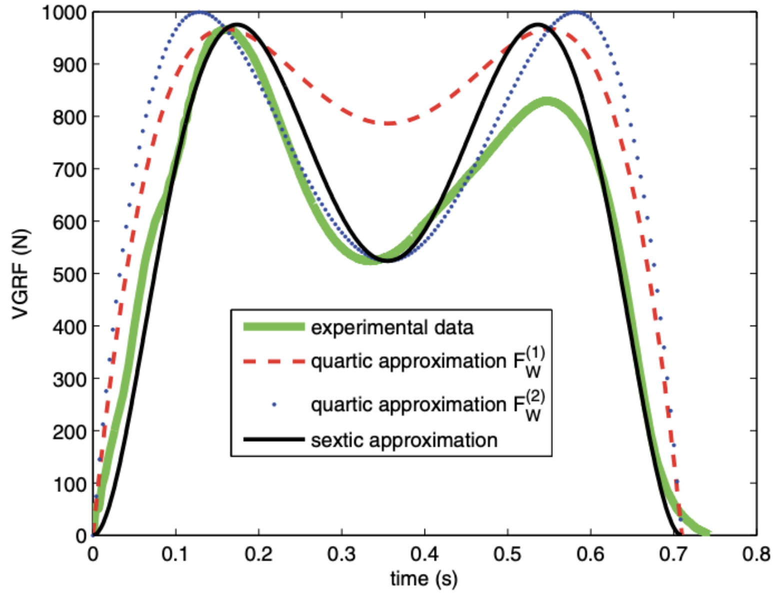

Figure 3: Example of Bimodal peak taken from Tongen et al 2010.

1.3 Combining haptics and lean to move for VR locomotion

The concept of combining leaning with haptics for locomotion has a solid theoretical basis given the aforementioned literature. However, the idea has received only a small amount of attention in existing academic literature. Data from [9] showed that combining haptics with leaning based interfaces improved both vection and involvement/presence in virtual environments. However, the form factor in this setting was limited to two planted feet in a single location (picture below). While the overall hypothesis of the study, that a leaning combined with haptics could elevate user experience metrics, the limited form fact may have hampered the potential of the system and its findings relative to other locomotion methods.

We believe that a form factor that uses an omnidirectional design could maximize the full potential of such a concept. By allowing users the freedom to move their feet, with a central neutral zone, it will give them more freedom to interact with the virtual world and will ultimately be more intuitive to users than the design in [9]. Moreover, given the results of [8] there is no need for isolated vibrations on the heel and ball of the foot. The only lingering questions of such a system are whether or not haptically simulated footsteps can still be convincing when feet are straddled on the platform (e.g. one foot in the inner zone while one is in the outer zone), or if it can still be convincing when administered to one foot if another is planted in the inner zone of such a system. To our knowledge, these questions have yet to be explored.

Our team is actively working on a solution that combines these features into a single solution – an omnidirectional lean to-move interface with haptics. We believe this allows maximal immersion by simulating two of the most essential cues for movement, leaning and vibrational ground reaction feedback, while also requiring minimal effort from the user. User effort is generally believed to be one limiting factor in the adoption of some systems such as omnidirectional treadmills or walk-in-place methods [1]. Such a system is intuitive to use, and allows for a wide array of immersive experiences thank to the haptic feedback. Since movement in game is not tied to one-to-one movement of a user, users may have an easier time embodying non-human avatars such as animals or vehicles, robots, etc. Lastly, such a system would be easier to deploy and set up than other commercial systems such as treadmills and wearables, as the user mere needs to stand on the platform to center themselves (and tactile cues on the mat could assist with these efforts). We have addressed many key technical challenges, such as how to administer haptics consistently under the full weight of a person. We have conducted user testing, have an issued utility patent and are actively seeking partnerships to test and implement the technology.

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