Walk This Way: Enhancing agency in Redirected Walking with Haptic Nudges

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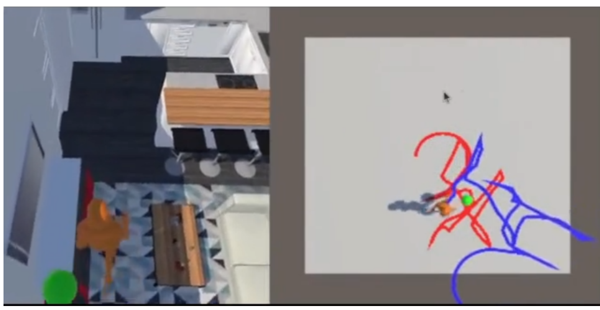
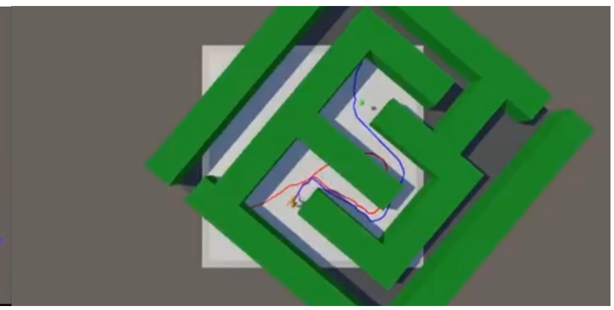
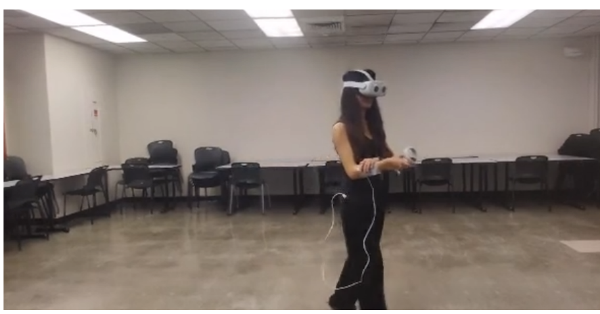


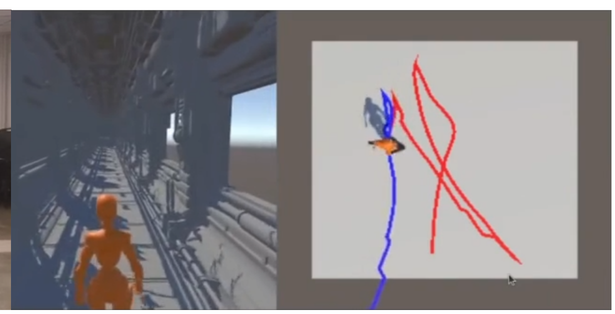
(a) House Tour Scene with Virtual Avatar



(b) Classical Maze Example



(c) Haptic device & redirection in 7x7 meter space



(d) Corridor redirection

Figure 1: Walk This Way applied across different environments.

Abstract

We propose "Haptic Nudges," an extension to redirected walking (Razzaque et al. 2002) techniques to provide an intuitive, unobtrusive understanding of the real-world space. Haptic Nudges maximise virtual traversal distance while increasing agency. In addition, we update existing Open Source redirected walking toolkits (Azmandian et al. 2016), (Li et al. 2021) with new redirection algorithms and expose artificial potential fields (Dong et al. 2020) for all techniques. The combination of these techniques can be applied as a drop-in addition to any existing Unity project.

Introduction

"How far can you walk in a straight line, blindfolded?"

This well studied problem shows the dominance and reliance of the visual system when determining straight lines; proprioceptive senses are insufficient and result in drifting. However the dual of this problem allows for visual system to manipulate otherwise straight motion imperceptibly.

How we can break the limitation of movement in physical space when interacting with virtual reality?

Manipulation Techniques

Subtle Gain-based Redirection

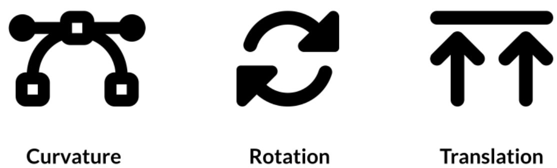


Figure 2: Techniques for Gain Redirection

The most well-studied technique for redirection that maintains coherency in virtual space is "Gain-based" Redirection.

A gain describes a relative difference between real and virtual motion, traditional locomotion techniques will enforce a one-to-one mapping and a gain of 1. A translation gain manipulates the virtual velocity of the user causing the user to walk faster or slower with respect to the real world. Rotational gains causes the viewpoint in the virtual space to rotate faster or slower relative to the tracked head rotation. Curvature based techniques apply rotation to the world during forward motion causing straight lines to curve alongside this vibration.

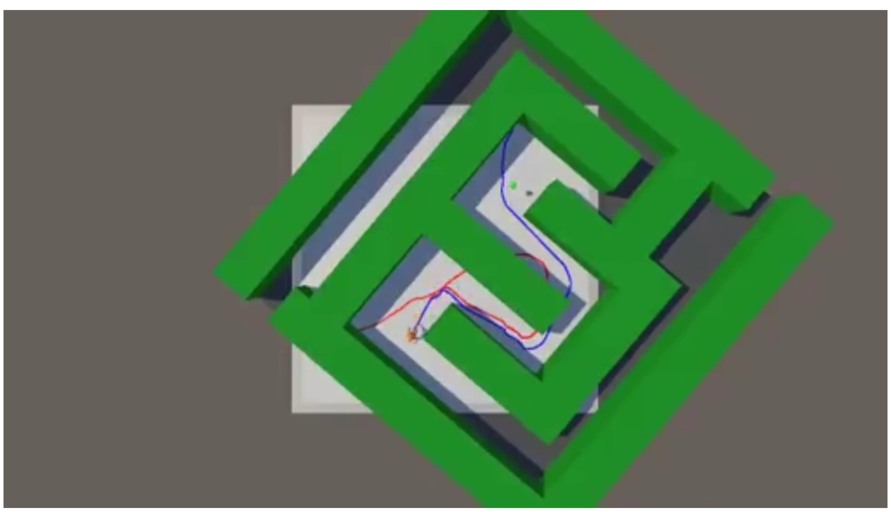


Figure 3: Our extension of OpenRDW / RDWTK which performs Gain-based redirected walking, and supply "Resetters" such as the 2-1 turn. As part of these changes the setup was updated for modern Unity releases and XRTK HMD allowing for additional Headset types.

Due to the lack of real visual input in a virtual reality setting, people have a threshold for noticing both positive and negative gains (with a preference for positive gains). There have been extensive studies specifying maximal thresholds for awareness which we used to define parameters in our model / framework.

Even with this restriction however the virtual-space compression is exponential. The larger the existing tracking space, the larger the virtual space you can recreate allowing for any arbitrary movement.

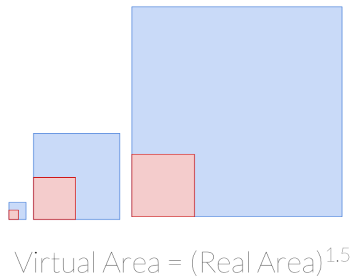


Figure 4: Virtual Space compression example with a 1.5 exponential factor

Restricting movement, e.g. a straight corridor (Fig. 5) allows for potentially infinite walking within moderate sized areas. The width of a tennis court, 36ft, was sufficient for our testing.

Gain-based Resetters

Subtle Gain-based techniques only apply when there is existing motion, and have limits to their redirective force. In essence, they are under-actuated dynamic control systems.

As such we often need a overt technique to add additional motion to produce additional input. The primary technique we use is the 2-1 rotation that coverts a 360 degree virtual rotation into a 180 degree physical rotation. This technique is imperceptible (beyond the overt command to spin) and allows for rapid direction change at the cost of observability.

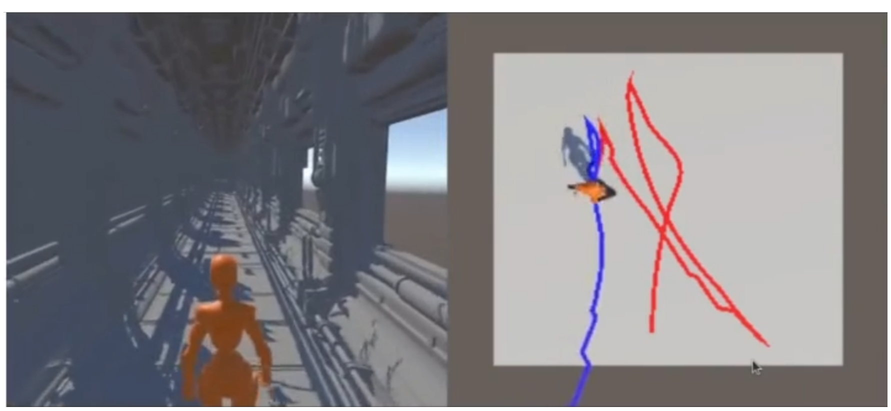


Figure 5: 2-1 Spin used to continue a 21m straight line path despite a 7x7 tracking space

Modern Redirection via APFs

These redirection techniques are best applied with some awareness of the tracking-space and the "ideal" points for which to be located to maximise both current trajectory and possible future trajectories.

The redirection that then direct the user to these optimal points. For instance, an unobstructed square will have the center point as the minimum potential point that allows for the maximum distance given no current motion.

This notion can be formalised as Artificial Potential Fields Dong et al. (2020). This provides a gradient vector for optimal movement and we use this for all redirection algorithms for our haptic nudges.

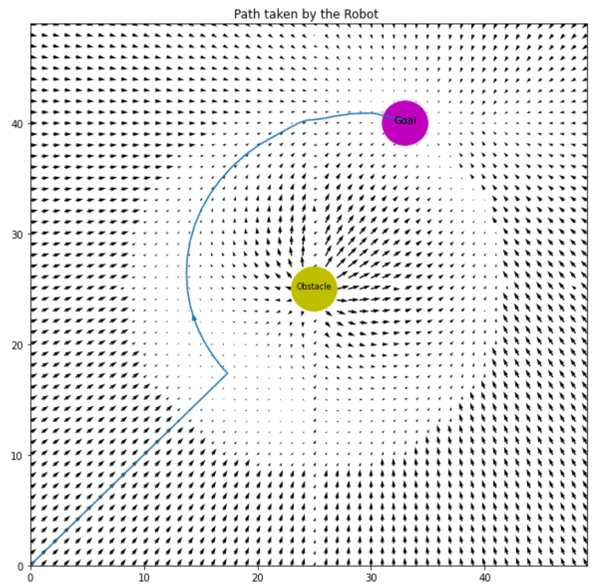


Figure 6: An example APF used for Robotic Planning by AslanDevbrat

Haptic Nudges

All the techniques discussed so far use the visual system primarily. However we could apply additional senses - not just rotating the viewpoint, but also suggesting direction to the way that minimises the potential field alongside vibration.

We call this “Haptic Nudging,” because unlike redirection, we do not directly control where the user goes; we merely aid them in decision making.

Consider moving round a house in virtual reality, there are often multiple decision points where you could move in multiple ways. Typically this choice occurs by chance, or by whichever direction is most desired visually. However sometimes a direction will lead to a tracking space boundary and cause a overt redirection, often the preference is to avoid these overt redirections and we can allow the user to chose a different circulation. When applied alongside gain redirection, the user can often return to the same point in virtual space and instead be nudged to the alternative direction that they did not originally pick (as their position in the real world is different).

This increases agency because unlike redirection the user is in control, and due to the haptic feedback this redirection is subtle and ignorable if desired for a particular game-play element.

In addition, after usage the user will often subconsciously prefer directions that lack vibration, allowing for nudging without the user paying conscious attention to the feeling.

However, the key disadvantage of this technique is that it requires choice to be influential. It applies well in high complexity environments where multiple pathways exist, but not in simple environments such as the straight line corridor. That isn’t to say it is un-utilised in such an environment as it can still encourage wandering paths & head rotation that can be utilised by subtle gain-based techniques.

(a) Nudge 'Right'

(b) Nudge 'Left'

Figure 7: Haptic Nudges

We apply Haptic Nudges by considering the global space top-down vectors X_{dir} (the normalised direction from current user pose) and $X_{mingrad}$ the vector to the nearest local minimum in the APF field.

Together these encode the haptic amplitude, $A(t)$, and signal frequency $F(t)$ at time t. Note that R here denotes the "bounding" circle of the tracking space.

$$A(t) = A_{max} \frac{|X_{dir}(t)\dot{X}_{mingrad}(t)|}{180}$$

$$F(t) = 1 + F_{max} \frac{|X_{mingrad}(t)|}{R}$$

These signal commands are serialised with a simple convention of <device_name>:O<dc_offset>A<amplitude>F<frequenr and broadcasted via Bluetooth serial to connected device.

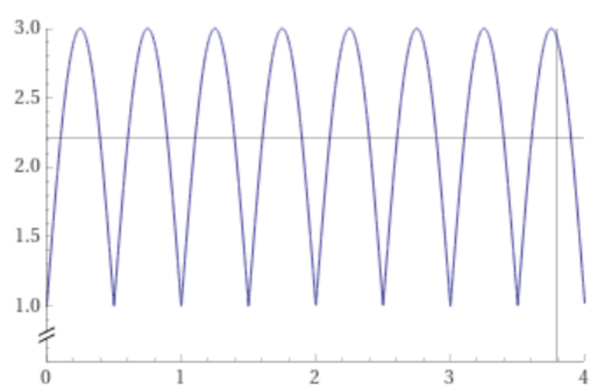


Figure 8: Haptic Rendering of "Bump" wave given the input O1A2F1 (offset 1V, amplitude 2V and frequency 1Hz)

The ESP32s render the given waveform by adjusting the duty cycle of a PWM controlled ERM motor on a maximum period of 1ms. This allows up to 1000Hz frequencies to be rendered. We use n to denote the loop counter.

$$D(t) = O + |A \sin(\frac{2 * (n \mod 1000) * \pi * f}{1000})|$$

Next Steps

Virtual Environment Awareness

All the algorithms for redirection currently implemented are tracking-space aware but virtual-space blind. This means they do not take into account the variations in virtual space to reduce potential trajectories and hence optimise the redirection because of it. This is exemplified in fig. 9, where the blind algorithm will attempt to optimise position to the center point assuming that all possible trajectories are equally likely. Meanwhile a virtual-space aware algorithm will adjust the possible trajectories to realign the desired tracking-space, virtual-space mapping to support right-wards movement at the detriment of left-wards movement which is blocked by a virtual wall.

(a) Virtual Environment Blind Algorithm (b) Virtual Environment Aware Algorithm

Figure 9: Virtual Environment Awareness

Saccadic Redirection

Gain redirection produces consistent, smooth transformation of trajectories in real and virtual space. However, the continuous nature prevents small spaces ($< 100m^2$) from being used for redirection; instead a rapid and discrete method would allow for greater compression in small spaces.

Detection of Saccadic suppression and redirects the users during the resulting temporary blindness allows for this (Sun et al. 2018). Expanding our system to apply both Gain Redirection, Saccadic Redirection and Haptic Nudges is likely to vastly improve the potential compression.

Azmandian, Mahdi, Timofey Grechkin, Mark Bolas, and Evan Suma. 2016. "The Redirected Walking Toolkit: A Unified Development Platform for Exploring Large Virtual Environments." In *2016 IEEE 2nd Workshop on Everyday Virtual Reality (WEVR)*, 9–14. IEEE.

Dong, Tianyang, Xianwei Chen, Yifan Song, Wenyuan Ying, and Jing Fan. 2020. "Dynamic Artificial Potential Fields for Multi-User Redirected Walking." In *2020 IEEE Conference on Virtual Reality and 3d User Interfaces (VR)*, 146–54. IEEE.

Li, Yi-Jun, Miao Wang, Frank Steinicke, and Qinping Zhao. 2021. "OpenRDW: A Redirected Walking Library and Benchmark with Multi-User, Learning-Based Functionalities and State-of-the-Art Algorithms." In *2021 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, 21–30. IEEE.

Razzaque, Sharif, David Swapp, Mel Slater, Mary C Whitton, and Anthony Steed. 2002. "Redirected Walking in Place." In *EGVE*, 2:123–30.

Sun, Qi, Anjul Patney, Li-Yi Wei, Omer Shapira, Jingwan Lu, Paul Asente, Suwen Zhu, Morgan McGuire, David Luebke, and Arie Kaufman. 2018. "Towards Virtual Reality Infinite Walking: Dynamic Saccadic Redirection." *ACM Transactions on Graphics (TOG)* 37 (4): 1–13.