Bare-Hand Continuous VR Locomotion Using Beyond-FOV, Around-HMD Unimanual Gesture

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Abstract

We present *Beyond-FOV* locomotion, a continuous VR navigation technique using above-neck unimanual gestures outside visual frustum of HMD-mounted cameras, supporting simultaneous navigation and object interaction without lower-limb movement, preserving natural head- and gaze-based exploration across diverse postures, and improving accessibility for bare-hand users with lower-limb disabilities. Evaluated as an imaginary interface using external motion tracking in a within-subjects study (N=16), Beyond-FOV matched or exceeded the performance of within-FOV bare-hand locomotion techniques, establishing it as a promising, accessible, and space-efficient method for bare-hand VR locomotion.

CCS Concepts

• **Computing methodologies** → *Motion capture*; • **Human-centered computing** → **Mobile devices**; **Empirical studies in ubiquitous and mobile computing**; **Gestural input**; • **Hardware** → **Emerging interfaces**.

Keywords

Virtual Reality, Continuous Locomotion, Motion Tracking, Unimanual Interaction, Beyond-field-of-view Interaction

1 Introduction

Modern consumer VR systems enable natural, controller-free interaction via hand tracking within the field of view (FOV) of cameras on head-mounted displays (HMDs) [2]. However, effective bare-hand continuous locomotion remains challenging — especially in space-constrained or accessibility-limited settings — despite its importance for immersive VR. Continuous locomotion better supports immersion, presence, and spatial awareness than teleportation [17], but most existing techniques rely on lower-limb input—such as room-scale walking [18], walking-in-place [23], or specialized seated hardware [5, 10] — which limits accessibility and practicality in seated or reclined settings [9, 21]. Upper-body alternatives, including arm-swinging, head movement, and gaze-directed navigation [4, 22, 24], often cause fatigue and interfere with interaction or visual exploration [8, 14]. Within-FOV bare-hand techniques preserve natural head and gaze movement, but suffer from gestural interference and visual occlusion during object interaction [11, 19]. Previous below-neck and behind-body approaches [3, 6, 7, 12, 13, 15, 20] can also cause gestural interference and visual occlusion during head movement — or are ergonomically unsuitable for sustained use.

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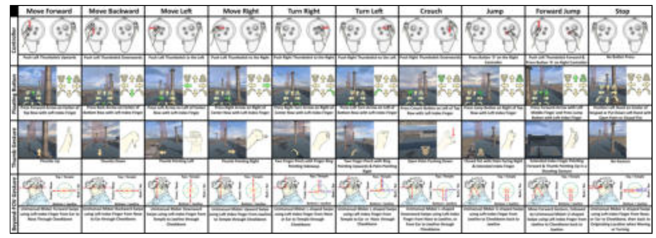
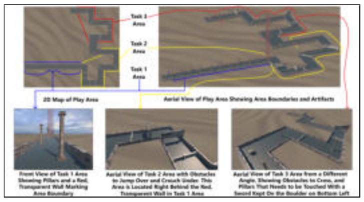


Figure 1: User interface for all locomotion approaches.

To address these limitations, we introduce *Beyond-FOV locomotion*, a bare-hand VR locomotion technique using above-neck, around-HMD unimanual gestures outside the visual frustum to separate locomotion from object interaction during natural head movement. By avoiding HMD contact, it prevents headset disturbance and visual jitter while supporting continuous movement, turning, crouching, and jumping without lower-limb input or body reorientation, and additionally enabling seamless transitions between unimanual locomotion and bimanual object interaction. We evaluated *Beyond-FOV* using external optical tracking, independent of current sensing limitations, in a within-subjects study ($N = 16$) against a controller baseline and two within-FOV bare-hand locomotion techniques, and found the performance comparable to or better than within-FOV approaches in most cases. This positions *Beyond-FOV* input around HMD as a promising direction for accessible and space-efficient VR locomotion, motivating further on-device sensing approaches for practical deployment.

2 Interaction and Environment Design

Figure 1 summarizes the gesture and key mappings for all four locomotion techniques. All techniques were performed seated on a stationary non-swiveling chair (Figure 2b). Gesture mappings were developed through a 2-hour co-design session with six participants, building on prior within-FOV locomotion techniques [1, 11, 19]. All locomotion input used the non-dominant hand, preserving the dominant hand for object interaction during navigation [16]. Figure 2a illustrates the VR environment, divided into three task zones of increasing complexity. Task 1 required navigating a $110m \times 10m$ corridor while touching pillars. Task 2 added turning, jumping, and crouching in a $143m \times 10m$ corridor. Task 3 combined complex locomotion with simultaneous object interaction in a $138m \times 10m$ corridor, where participants used a sword to strike pillars while



(a) VR Scene Map.

(b) Apparatus.

Figure 2: VR task zones and vicon+VR setup in apparatus.

moving. A $25m \times 25m$ transitional area separated Tasks 2 and 3, where participants acquired the sword using direct or distance grabbing.

For *Beyond-FOV*, we designed around-HMD midair gestures centered near the cheekbone region, exploring axial, L-shaped, and U-shaped swipe variants. Based on co-design feedback, locomotion used trigger-based input, where discrete gestures initiated continuous movement or turning until interrupted or replaced by another command. Because the non-dominant hand remained outside the visual workspace, interaction relied on proprioception relative to the HMD. To support learnability and error recovery, a transparent finger-tracking radar highlighted the non-dominant index finger within interaction zones, while successful gestures triggered visual confirmation cues in the lower-right corner of the VR scene.

3 Experimental Setup

The system (Figure 2b) featured a 16-core AMD Ryzen 9 workstation (32 GB RAM) running *Vicon Tracker 3.9*, a Unity-based VR application, and a custom Python tracking pipeline for real-time *Beyond-FOV* locomotion control. A *Meta Quest 2* headset with Vicon markers connected wirelessly to the workstation.

We conducted an IRB-approved within-subjects study with 7 female & 9 male participants (age: $\mu = 28.9$, $SD = 9.48$, range 18–64). 3 participants had limited lower-limb mobility & used assistive supports. Each participant completed 4 independent locomotion sessions across 4 counterbalanced techniques, spread over 2 days (135 min. total), and received 45 CAD. Pre-study questionnaires collected demographic and VR experience data. Before each technique, participants watched a 1 minute instructional video. Task completion times were recorded as objective performance measures. After each technique, participants completed questionnaires measuring self-reported *Ratings*, *System Usability Scale* (SUS), *NASA-TLX* workload, selected *Simulator Sickness Questionnaire* (SSQ), and *Device Assessment Questionnaire (DAQ)* items for upper-limb fatigue. SUS was converted to *Learnability* and *Usability* sub-scales according to standard practice. Post-study semi-structured interviews and observational notes revealed insights into different approaches.

4 Results

Controller achieved the fastest completion times across tasks, while *Beyond-FOV* emerged as the fastest bare-hand technique with the highest bare-hand subjective ratings, maintaining competitive performance to *Thumb Gesture* and consistently outperforming *Floating Button* across increasing task complexity (Figure 3). Participants reported that *Beyond-FOV* required greater initial learning effort and independent discoverability. However, once learned, its usability became comparable to other bare-hand techniques, suggesting

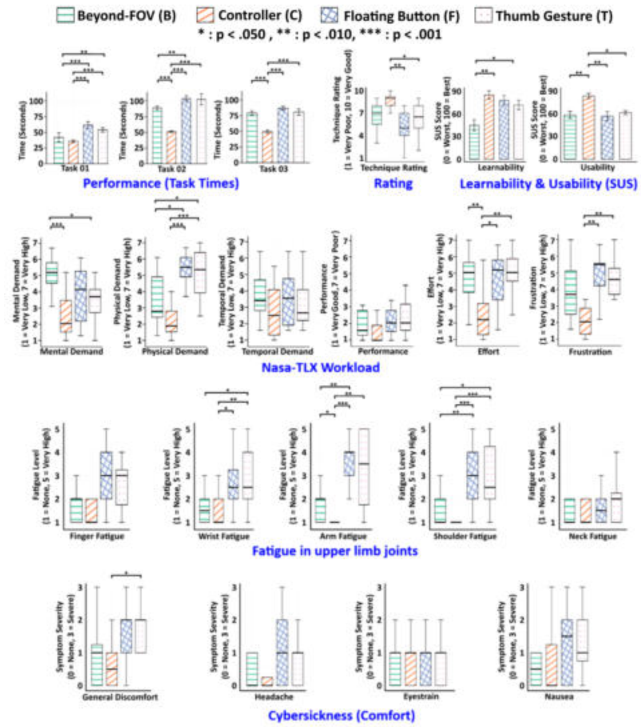


Figure 3: Metrics comparison among locomotion techniques.

that the primary limitation lies in onboarding rather than steady-state interaction. Improved guidance and early-stage feedback may help reduce this learnability gap.

Compared to within-FOV techniques, *Beyond-FOV* significantly reduced physical demand and upper-limb fatigue while introducing slightly higher mental demand. This cognitive–physical trade-off did not negatively affect perceived performance, overall effort, or temporal demand. Frustration levels were closer to the *Controller* baseline than to other bare-hand techniques, indicating a more balanced interaction experience. Trends in NASA-TLX, partial SSQ, and DAQ measures (Figures 3) further suggest that *Beyond-FOV* reduce & upper-limb joint fatigue & cybersickness relative to within-FOV bare-hand locomotion.

In post-study feedback, participants consistently preferred bare-hand interaction for manipulating virtual objects due to its naturalness and directness. *Beyond-FOV* was additionally perceived as particularly suitable for relaxed, seated, reclined, or mobility-constrained use cases where maintaining the hands within the visual workspace is difficult.

5 Conclusion

Initial results on around-HMD unimanual gesture-based continuous locomotion input outside the visual frustum show its viability as an alternative to within-FOV bare-hand locomotion. This approach enables VR in limited spaces and supports both standing and non-standing postures, potentially increasing accessibility for those with lower-limb mobility constraints. While further refinement is needed, this work aims to motivate broader exploration of beyond-FOV manual interaction for VR locomotion control.

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