

A Practical Analysis of VR Embodied Interaction in Immersive Experience Devices in the Context of Human-Computer Interaction

Xinting Yu

Faculty of Business, Lingnan University, Tuen Mun, New Territories, Hong Kong, China

Abstract

This paper takes an application study of embodied interaction in virtual reality (VR) immersive experience devices for the general area of human-computer interaction. Rather than providing new empirical data, it collects existing research on embodied interaction, tangible user interfaces, immersion and presence, and VR design guidelines to show how full-body and multi-sensory interfaces can support meaningful engagement. First, in this section, we will introduce the basic ideas of embodied interaction and tangible computing, and then discuss what qualities immersion and presence demand of VR devices, such as head-mounted displays, room-scale tracking and tactile props. Based on research in cybersickness, locomotion and interaction design, this paper investigates design considerations for VR embodied interaction, including sensorimotor consistency, multimodal feedback, bodily comfort and spatial arrangement. It proposes that immersive experience devices should be designed as situated, safe-to-fail environments that support skilled, bodily practice rather than as purely visual displays. Finally, the paper puts forward some general directions for building space, interaction modes and feedback mechanisms in VR embodied interaction systems, but does not present new empirical results beyond what has been reported in other studies.

Keywords

Embodied interaction; virtual reality; immersive experience devices; human-computer interaction; presence; tangible interfaces.

1. Introduction

Virtual Reality (VR) technology has created a new kind of immersive experience that can take users to a computer-generated world and allow them to move freely, act and feel. Many of the current VR systems also use embodied interaction to connect users' bodies with the virtual world through sensors, controllers and other physical devices, in addition to visual immersion. In the area of human-computer interaction, embodied and tangible approaches focus on the idea that interaction is a skilled, situated practice occurring in physical and social environments. Therefore, in VR, head-mounted displays, tracking systems and immersive installations should be viewed as environments for bodily participation rather than merely as visual displays.

This paper offers a practical study of embodied interaction in VR immersive experience devices for a human-computer interaction environment. It integrates theoretical foundations and design-oriented research to present key considerations for the design and evaluation of VR embodied interaction without presenting new empirical data or claiming original experimental results.

2. Embodied Interaction and Tangible Interfaces in HCI

Embodied interaction has been added to the general category of human-computer interaction and refers to how interaction is realised in physical and social environments. Dourish's work suggests that embodiment refers to the capacity for participation in life, and thus meaning is generated through action within systems of practice rather than abstract symbolic manipulation [1].

Tangible User Interfaces extend this idea to connect digital information with physical objects and architectural surfaces. Ishii and Ullmer's idea of "tangible bits" is that daily-use objects and interactive surfaces can function as interfaces for users to "feel and operate" in the digital world, thereby connecting cyberspace with the real world [2]. Tangible interfaces focus on foreground, hands-on interactions and ambient media for background awareness [2].

Together, embodied interaction and tangible interfaces provide a conceptual basis for VR embodied interaction. They propose that in the design of immersive devices, full use should be made of users' bodily skills, gestures and spatial awareness, physical props, environmental cues and social contexts, and abstract control schemes should be avoided. In practice, this refers to constructing VR systems that coordinate actions and perceptions with real-life bodily sensations, considering the deficiencies and special circumstances of virtual environments [1][2].

3. Immersion, Presence and Embodiment in VR

Research on immersive virtual environments distinguishes between immersion as a feature of the technology and presence as a psychological state in which users feel that they have been transported to a mediated space [3][4][7][8]. Slater and Wilbur's framework describes immersion by examining how inclusive, extensive, surrounding and vivid a system's sensory outputs are, as well as the degree of body matching and autonomous responses in the environment [3]. Presence is the sense of "being there" in the virtual environment that causes behavioural and physiological responses [3, 8].

Bowman and McMahan have studied immersion in virtual reality to show that a relatively high degree of immersion can enhance spatial awareness and task performance in specific environments, but full immersion is not required [4]. Their work indicates that the components of immersion are not uniformly distributed in terms of impact on users' experience [4]. Cummings and Bailenson's meta-analytic work has also found a medium-sized effect of technological immersion on presence, and well-designed sensorimotor mappings and multisensory cues can enhance the sense of being in the virtual space [7].

Embodiment in VR is closely related to presence. Research on virtual bodies and locomotion has shown that participants experience a stronger sense of presence when their movements are closely mapped to avatars, and they can perform natural actions such as walking and reaching [3, 9]. Embodied presence thus requires stable, low-latency sensorimotor loops connecting physical motion with virtual feedback, as well as statistically realistic visual and auditory environments [3][7][8]. Based on the above analysis, design of immersive experience devices for convincing embodied interaction has been proposed.

4. Immersive Experience Devices and Interaction Configurations

Immersive experience devices are various types of VR setups, such as seated head-mounted display systems, room-scale installations, cave-like environments and custom-built interactive spaces. Research in human-computer interaction shows that these setups should be designed as spatial arrangements that support bodily practice, rather than being simple hardware collections [1][10].

Room-scale VR systems with six-degree-of-freedom tracking can move and rotate in a small area to perform mid-air gestures. Research on locomotion has shown that natural walking generally results in a higher presence than walking-in-place or joystick operation, but constraints in physical space often require a hybrid approach [3-4,9]. Therefore, designers of immersive devices need to balance safety and space constraints with the advantages of more natural embodied movement.

Add tangible and ambient elements to the VR installation to promote embodied interaction. Physical props, such as tracked tools, seats, railings and walls, provide haptic reference points to ground the virtual experience in the physical world [2, 10]. Ambient media can extend the embodied interface beyond the immediate focus of attention to support peripheral awareness and moods through directional sound, subtle changes in light or air currents, etc. [2] The arrangement of these components in the immersive device should consider ergonomics, accessibility and the consistency of the physical and virtual space.

5. Design Considerations for VR Embodied Interaction

Practical Design of VR Embodied Interaction involves many overlapping factors. Human-centred VR Design Guidelines emphasize the need for sensorimotor consistency: map user actions to virtual responses in a predictable, low-latency way to support the sense of presence and reduce confusion [5][7][8]. Inconsistent Mapping or delayed feedback will disturb the sense of embodiment and cause discomfort.

Cybersickness is a severe problem for embodied interaction. LaViola's review of cybersickness factors indicates that visual-vestibular conflict, unsuitable acceleration profiles, field-of-view manipulation and postural instability are all reasons for motion sickness-like symptoms [6]. The Design Strategies for VR Books to Reduce Cybersickness include limiting abrupt camera movements, avoiding excessive acceleration, providing a stable reference frame, and offering rest periods [5]. These factors will directly impact the realisation of locomotion and interaction in immersive devices.

Consider the body's comfort and fatigue in the Design. Full-body interactions that require prolonged reaching, squatting or stepping can be appealing but are also relatively tiring. Human-centred VR design proposes alternating high-intensity embodied actions with low-intensity tasks to provide opportunities for micro-rest and self-regulation of effort [5]. Spatial Layouts should reduce the risk of collisions and offer clear affordances for safe movement in a multi-user environment.

Embodied interaction Design should also take into account social and contextual factors. Configuring Space through embodied interaction is to recognize that people experience environments as settings for action and have formed practices and expectations [1][10]. Immersive experience devices in museums, laboratories and entertainment areas should be in line with the interaction style of the institution and its users, and it should not be assumed that all users will be comfortable using highly active, gesture-based interfaces.

6. Multisensory Feedback, Haptics and Embodied Experience

Multisensory Feedback is needed to create an embodied experience in VR immersive devices. Human-centred Design guidelines propose that by adding visual, auditory and haptic cues, sensorimotor congruence can be enhanced and the ambiguity of the system's response reduced [5,7]. Synchronise spatialised sound with visual events and gentle controller vibrations to help users feel the effect of operation more intuitively.

Haptic feedback can be as simple as vibration in a hand-held controller or as complicated as a force-feedback joystick, wearable haptic suits and instrumented props. Although high-end

haptic systems are relatively specialized, even basic tactile cues can support embodied interaction by confirming selections, collisions or changes in the environment [5]. Adjust the strength and frequency of haptic feedback reasonably to prevent user discomfort or fatigue during extended use of the virtual environment.

Multisensory Design also manages the sensory load. Too many stimuli at the same time can cause cognitive overload or discomfort, and otherwise, the interaction will be disjointed. Practical Design Recommendations suggest setting up a small number of consistent and meaningful feedback channels, and reserving more intense multisensory effects for key moments of interaction [5, 7]. Thus, the immersive device can still be rich in experience and clear at the same time.

7. Scenario Design, Narratives and Ethical Considerations

Generally speaking, embodied interaction in immersive experience devices is in the form of narratives or scenarios. Human-centred VR Design aims to align the interaction mode with the goal of storytelling and make users' bodies feel natural in the world of the game [5]. Museum installations can have visitors perform simple gestures that correspond to the interpretation tasks, and training applications need to be more precise and domain-specific in their movements.

Design Scenarios should also consider access and inclusion. Not all users are able to or wish to participate in high-activity, full-body exercise. Offer other ways to interact, such as a seated experience, a reduced-motion option or assistive devices, to increase participation [5]. Ethical Design should be adopted to prevent harm to people with disabilities and avoid promoting risky behaviour.

Embodied Interaction raises privacy and data problems as well. Tracking systems and immersive devices collect a lot of motion and behaviour data that needs to be handled responsibly. Research in human-computer interaction has proposed transparency in data collection, informed consent and suitable anonymisation of logs [1, 5]. Designers need to decide which parts of the embodied interaction will be recorded and for what purposes in practice before deploying immersive devices in public or semi-public areas.

Design scenarios and raise ethical questions to conduct practical research on VR embodied interaction, ensure that immersive experience devices support meaningful, respectful and sustainable participation, and do not focus solely on technological novelty.

8. Locomotion, Gestures and Tools in VR Embodied Interaction

Locomotion and gesture are the main parts of VR embodied interaction. Research on walking, walking-in-place and flying in virtual environments shows that more natural locomotion techniques generally increase the sense of presence and body ownership, but require careful management of physical space and safety [3, 9]. Designers of immersive devices can create short corridors, teleports that use subtle transition cues, or hybrid schemes to combine walking in a limited area with virtual repositioning for a balance of realism and practicality.

Gesture-based interaction is used to recognise controllers or hands for expressive, embodied control. Tangible Interface Principles suggest connecting digital functions with familiar physical metaphors, such as grabbing, pointing or rotating, to use existing motor skills [2]. The Design Rules for Gestures in VR Books include avoiding a very large set of gestures, providing visual and haptic feedback, and supporting error recovery through a lenient recognition threshold [5]. The above measures will help to ensure that the embodied interaction is intuitive and stable in actual use.

Tools and Props can also organise embodied interaction. Tracked objects that resemble physical tools—brushes, steering wheels, musical instruments—enable domain-specific embodied practices to be transferred into VR. In conjunction with well-designed virtual affordances, such props can support high-level performance and learning without the need for new interaction models [2][5][10]. Practical analysis of the above tool-based interactions shows that it is necessary to match the physical sense of the prop with virtual behaviour, maintain consistency across sessions, and accommodate users of different motor skill levels.

9. Presence, Cybersickness and Evaluation without New Data

Assessment of VR embodied interaction in immersive devices generally covers the evaluation of presence, usability and comfort; no new performance data are obtained through this conceptual analysis. Presence measures based on questionnaires, behaviour observation or unobtrusive indicators, such as the number of transitions between interpreting the environment as virtual or real, have been proposed in the literature [3][8][9]. These tools show how researchers have quantified aspects of embodied experience without proposing new measures at this time.

LaViola and Jerald have put forward a system of evaluation for cybersickness based on the following symptoms during interaction tests: eye strain, disorientation, nausea and postural instability [5-6]. Design recommendations based on the above studies include gradual exposure, adjustable comfort settings and continuous user feedback loops. In a real-world Design scenario, these frameworks can guide iterations of immersive devices without indicating that new datasets have been created.

Cummings and Bailenson have conducted meta-analytic and comparative studies on the immersion effect to determine whether technology immersion is sufficient to enhance the sense of presence in users [7]. Social Context, Expectations and previous experiences also influence a person's sense of embodied interaction. Based on the above results, we can avoid exaggerating the effect of specific hardware features or interaction methods and view VR embodied interaction as part of a larger system of technology and people.

Based on the existing evaluation methods and results, practitioners can critically examine VR embodied interaction in immersive experience devices, but they should be aware that their practice-oriented conclusions are derived from previous studies and not from new empirical data in this paper.

10. Summary

VR-based embodied interaction in immersive experience devices for human-computer interaction can be viewed as an extension of the ideas of embodied and tangible interaction to three-dimensional, multi-sensory environments. Resilience of interaction does not require visual realism; rather, it is based on sensorimotor consistency, bodily comfort and the integration of physical props, spatial layout and social context.

Theoretical and Design-oriented research on immersion, presence, cybersickness and human-centred VR design provides a rich basis for practical analysis. Based on the above studies, immersive devices should be established as safe-to-fail environments that support skilled bodily exercises, and interaction methods need to be designed to reduce conflicts between visual and vestibular cues and respect users' physical limitations.

Based on the above analysis, without new empirical data, this paper proposes Design Considerations and Evaluation Perspectives for the development of VR embodied interaction systems for practitioners. In the future, more research will be carried out to explore various immersive environment constructions, different movement modes (locomotion and gestures),

and how different groups of users experience embodied interaction. At present, the main implication is that successful VR embodied interaction results from a careful, human-centred integration of technology, space and practice, rather than from technological immersion alone.

References

- [1] Dourish, P. (2001). *Where the action is: The foundations of embodied interaction*. MIT Press.
- [2] Ishii, H., & Ullmer, B. (1997). Tangible bits: Towards seamless interfaces between people, bits and atoms. In *CHI '97 conference proceedings*. ACM.
- [3] Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence*, 6(6), 603–616.
- [4] Bowman, D. A., & McMahan, R. P. (2007). Virtual reality: How much immersion is enough? *Computer*, 40(7), 36–43.
- [5] Jerald, J. (2015). *The VR book: Human-centered design for virtual reality*. ACM/Morgan & Claypool.
- [6] LaViola, J. J. (2000). A discussion of cybersickness in virtual environments. *ACM SIGCHI Bulletin*, 32(1), 47–56.
- [7] Cummings, J. J., & Bailenson, J. N. (2016). How immersive is enough? A meta-analysis of the effect of immersive technology on user presence. *Media Psychology*, 19(2), 272–309.
- [8] Slater, M. (1999). Measuring presence: A response to the Witmer and Singer presence questionnaire. *Presence*, 8(5), 560–565.
- [9] Usoh, M., Arthur, K., Whitton, M. C., Bastos, R., Steed, A., Slater, M., & Brooks, F. P., Jr. (1999). Walking > walking-in-place > flying, in virtual environments. In *Proceedings of the 26th Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH '99)* (pp. 359–364). ACM Press/Addison-Wesley.
- [10] Williams, A., Kabisch, E., & Dourish, P. (2005). From interaction to participation: Configuring space through embodied interaction. In *UbiComp 2005: Ubiquitous computing* (pp. 287–304). Springer.