Enhancing Natural Human Interactions in AR/VR Applications

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ABSTRACT
In the evolving landscape of immersive technologies, enhancing natural human interactions within AR/VR applications have a crucial role for creating intuitive and engaging user experiences. This article focuses on various innovative interaction techniques, including teleportation, tool manipulation, magic movement, and long grabbing functionality. By leveraging advanced VR controllers, hand recognition, and user-focused hand movements, we aim to bridge the gap between the virtual and physical worlds, promoting more natural and seamless interactions. Our research examines different user interface types and interaction modalities, showcasing how these methods can significantly enhance user engagement, improve task performance, and provide a more immersive and realistic experience in virtual environments. This study highlights the transformative potential of these technologies in the field of user-system interaction, setting the stage for future advancements in AR/VR applications.

Author Keywords
Virtual Reality (VR); Augmented Reality (AR); User Experience (UX); User Interaction; Human-Computer Interaction (HCI)

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces. H.3.2. Information Storage and Retrieval: Information Storage

General Terms
Human Factors; Design; Measurement.

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INTRODUCTION
Augmented Reality (AR) and Virtual Reality (VR) technologies have significantly advanced, transforming areas like education [1], healthcare [2], gaming [3], and entertainment [4]. These immersive technologies enhance user experiences by overlaying digital information onto the real world (AR) or immersing users in virtual environments (VR).

Human-Computer Interaction (HCI) is critical in AR/VR, focusing on intuitive and natural interactions that imitate real-world actions. Typical AR/VR interactions involve VR headset controllers, hand tracking, and gesture recognition. VR controllers enable users to navigate virtual environments and manipulate objects, while hand tracking and gesture recognition provide a more natural, immersive experience. AR applications often use handheld devices or smart glasses for real-time digital overlays and interactions.

This research explores innovative techniques like teleportation, tool manipulation, magic movement, and long grabbing functionality to enhance natural interactions in AR/VR. Teleportation allows instant movement within virtual environments, tool manipulation provides realistic interactions with virtual objects, magic movement enables unique object manipulations, and long grabbing extends users' reach in virtual spaces.

By leveraging advanced VR controllers, hand recognition, and nuanced hand movements, we aim to create seamless interactions between virtual and physical worlds. This paper discusses the development and implementation of these techniques, highlighting their potential to enhance user engagement, task performance, and the overall immersive experience in AR/VR applications.

This paper examines HCI's role in enhancing natural human interactions in AR/VR, focusing on intuitive techniques and their impact on user experience. We provide insights into developing more engaging and accessible AR/VR applications through innovative user interface types and interaction modalities.

ARCHITECTURE
In developing our AR/VR applications, we focused on creating an intuitive and immersive user experience by leveraging advanced technologies and interaction modalities (see Figure 1 for more details).

Unity Game Engine
Unity is a versatile and powerful game engine used for creating immersive AR/VR applications. For our project, we utilized Unity version LTS 2021.3.31f1. The scripts were written in C# using Visual Studio 2022. Unity's XR Plugin Management, XR Interaction Toolkit, MockHMD XR Plugin, Oculus XR Plugin, and OpenXR Plugin were crucial for ensuring compatibility with a range of VR headsets and for enhancing interaction capabilities.

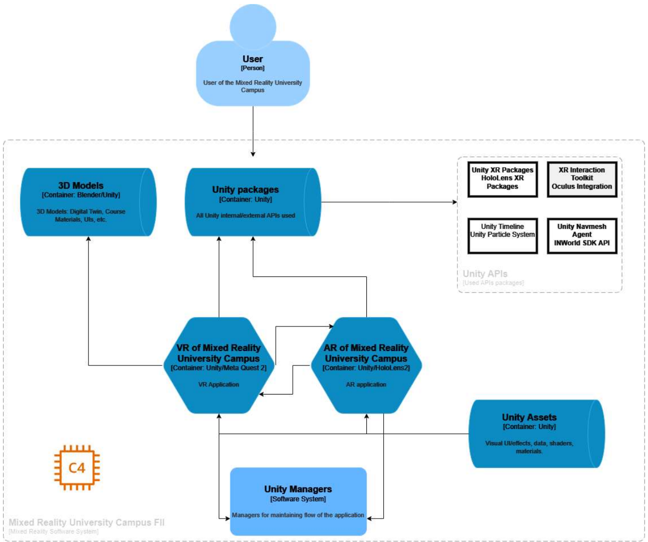

Fig. 1: Example of XR application architecture. C4 Level 2 Diagram

Blender

Blender was used for 3D modeling and creating realistic digital objects and environments. This open-source 3D creation suite allows for detailed and complex modeling, essential for creating immersive VR experiences.

Hand Tracking and Gesture Recognition

Hand tracking and gesture recognition technologies were integrated to provide a more natural and immersive interaction experience. These technologies allow users to interact with virtual objects using their hands, enhancing the sense of presence in the virtual environment.

Hardware and Software Integration

Meta Quest 2: This standalone VR headset was chosen for its high performance, portability, and affordability. It supports hand tracking and provides a robust platform for our VR applications.

HoloLens 2: This AR headset was selected for its advanced capabilities in mixed reality. The HoloLens 2 offers high-resolution holographic displays and supports hand tracking, eye tracking, and spatial mapping, making it ideal for creating immersive and interactive AR experiences.

VR Interaction Techniques

Teleportation: This technique allows users to move instantly within the virtual environment, reducing physical strain and enhancing immersion.

Tool Manipulation: Users can interact with virtual tools to manipulate objects, providing a realistic experience similar to handling physical tools.

Magic Movement: This enables users to move objects in unique ways, such as floating or rotating in mid-air, offering novel interaction possibilities.

Long Grabbing Functionality: Users can extend their reach to interact with distant objects, expanding their ability to explore and engage with the virtual space.

VVR User Interface: The VR interface was designed to provide an intuitive and immersive user experience. We used Unity's XR Interaction Toolkit to optimize the interface for the Oculus Quest 2, ensuring accurate tracking and input fidelity. The interface allows users to conduct experiments, interact with virtual assistants, and navigate the VR environment through natural movements and voice commands.

Augmented Reality User Interface: For AR applications, we tailored the user interface to the capabilities of the HoloLens 2. This includes high-resolution holographic displays and intuitive hand and eye-tracking interactions, enabling users to interact with digital content seamlessly overlaid onto the real world.

Voice Interaction and NLP

Integration of the Inworld API enabled advanced Natural Language Processing (NLP) capabilities, allowing for real-time voice recognition and response. This facilitates dynamic conversational interactions between users and virtual assistants, enhancing engagement and realism.

Spatial Audio Components

Spatial audio was incorporated to provide a fully immersive audio experience, further enhancing the realism of the virtual environment. This ensures that audio cues align with visual interactions, providing a coherent and engaging user experience.

IMPLEMENTATION

Designing and implementing a system that enhances natural human interactions in AR/VR applications involves integrating advanced technologies and addressing various challenges. This section outlines the key components and steps involved in our implementation process.

Application Areas of Our AR/VR Solutions

Our AR/VR solutions are designed to enhance various domains through immersive technology, combining AI techniques with mixed reality environments to create interactive and engaging experiences.

Training and Education

Our VR solutions provide simulations and interactive training modules that help learners grasp complex concepts effectively (see Figure 2 for more details). This includes real-world scenarios where users can practice skills and apply theoretical knowledge in a controlled virtual environment. For instance, medical students can use VR to simulate surgeries, providing a safe space to hone their skills.

Fig. 2: People using and interacting with VR equipment in training sessions [5].

Social VR

Social VR applications, such as VRChat, enable users to meet in virtual spaces like libraries or coffee shops, engage in activities like reading or playing board games, and even interact with virtual pets (see Figure 3 for more details). These applications offer a platform for social interaction and community building in immersive environments.

Fig. 3: People using and interacting with hands using Virtual Reality headsets [6].

Healthcare

In collaboration with medical professionals, we develop VR applications to train healthcare personnel and provide therapeutic environments for patients. For example, VR can be used to create controlled scenarios for mental health therapy, helping patients manage anxiety and stress through immersive experiences (see Arch Virtual application [7] in Figure 4).

VR Interface Implementation

The VR interface for our applications is built using the Unity Game Engine, leveraging its robust capabilities and specialized VR libraries to create seamless and immersive experiences.

Integration of XR Packages for Oculus Quest 2

We optimized the VR interface for the Oculus Quest 2 using Unity's XR Interaction Toolkit. This ensures responsive and accurate tracking, allowing users to navigate and interact within the VR environment through natural movements and voice commands. The XR Interaction Toolkit provides comprehensive support for various VR headsets, ensuring broad compatibility.

Fig. 4: Example of using VR in medicine - Arch Virtual [8].

Inworld API for Natural Language Processing (NLP)

A crucial component of our system is the integration of the Inworld API, which provides advanced NLP capabilities. This enables the system to process user inputs in real-time, delivering accurate and contextually relevant responses. The use of NLP enhances the realism and engagement of interactions within the VR environment.

AR Interface Implementation

For AR applications, we utilize the HoloLens 2, a cutting-edge mixed reality headset known for its high-resolution holographic displays and advanced interaction capabilities.

HoloLens 2

The HoloLens 2 supports hand tracking, eye tracking, and spatial mapping, making it ideal for creating interactive and immersive AR experiences. Users can interact with digital content overlaid onto the real world, using hand gestures and eye movements to manipulate virtual objects and access information.

Hand Tracking and Gesture Recognition

Hand tracking and gesture recognition are pivotal in providing a natural and intuitive user experience. These technologies allow users to interact with virtual objects using their hands, mimicking real-world actions and enhancing the sense of presence in the virtual environment [9].

Spatial Audio Components

Spatial audio enhances the immersive experience by providing realistic sound cues that correspond to the user's interactions and movements within the VR environment. This ensures that audio feedback aligns with visual interactions, creating a cohesive and engaging user experience [10,11].

These types of feedback offer a greater immersion to the user, making him believe even more that he is part of the virtual world he is discovering [12, 13].

Voice Interaction and NLP
Voice interaction is facilitated through advanced speech-to-text (STT) and text-to-speech (TTS) technologies integrated with the Inworld API. This enables dynamic and conversational interactions with virtual assistants, enhancing accessibility and user engagement.

GENERAL TYPES OF INTERACTIONS IN AR/VR
Creating interactive and immersive experiences in AR/VR involves leveraging various interaction techniques and technologies. This section outlines the general types of interactions used in our AR/VR applications, focusing on XR movement, controllers and input handling, and specific interactions for both VR and AR environments.

XR Movement
In the context of XR projects, the Unity system offers comprehensive support through the use of XR Rig, which has evolved into the XR Origin. The XR Origin serves as the central point of the tracking environment within an XR scene, composed of GameObjects and components that convert data from XR tracking systems into the world coordinate system.

XR Origin
The XR Origin is the core component managing the tracking environment. It consists of several GameObjects and components that align tracking data from XR devices with the virtual world.

Tracking Data: XR devices generate tracking data in real-world measurements relative to an initialization point at the start of the scene.

GameObject Hierarchy: GameObjects representing tracked elements, like the user's headset or controllers, are nested under the XR Origin GameObject (see Figure 5 for more details).

Fig. 5: XR Origin(RIG) composition in Unity scene.

Movement: Positional and rotational changes derived from tracking updates are relative to the XR Origin. As users navigate the physical world, these GameObjects move within the scene.

Controllers and Interaction
The XR Origin configuration includes controller GameObjects set up for both action-based and device-based input. This setup allows users to interact with the virtual environment using XR controllers or other input devices.

Action-Based Input: Utilizes the XR Interaction Toolkit to handle interactions.

Device-Based Input: Uses XR.InputDevice and XR.Node APIs for accessing device states and tracking data.

XR Input Options
Handling input in an XR game or application involves several options (see Figure 6 for more details):

- *XR Interaction Toolkit:* Provides components for handling XR input and defining interactions between the user and the environment.
- *OpenXR Interaction Profiles*: Supports a variety of XR devices and controllers with standardized input and tracking data access.
- *Traditional Input Systems*: Use the Input System or Input Manager for binding controller functions and accessing tracking data.
- *XR.InputDevice and XR.Node APIs*: Allow direct access to XR input hardware and tracking data.
- *Third-Party Input Libraries*: Supplement Unity's built-in options with additional features provided by device manufacturers or other third parties.

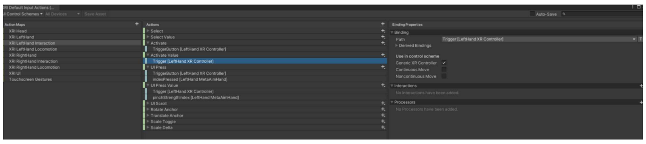

Fig. 6: Example of XR input bindings for Meta Quest 2 personalized.

XR Interaction Toolkit
The XR Interaction Toolkit builds on Unity's Input System and XR API to provide ready-to-use components for XR input and interaction, including:

Interactors: Objects that allow user interaction with scene GameObjects.

Interactables: Objects in the scene that users can interact with.
UI Interaction: Supports interaction with Unity's built-in UI elements.

Locomotion: Various modes of movement, including continuous movement, teleportation, and climbing.

Key Components
XR Origin (XR Rig): Manages the overall XR setup, ensuring all tracking data is correctly aligned with the virtual environment (see Figure 7 for more details).

Input Action Manager: Manages the input actions defined for the XR controllers, allowing for customization and mapping of various input commands.

Locomotion System: Handles different modes of locomotion, such as walking, teleportation, and continuous movement.

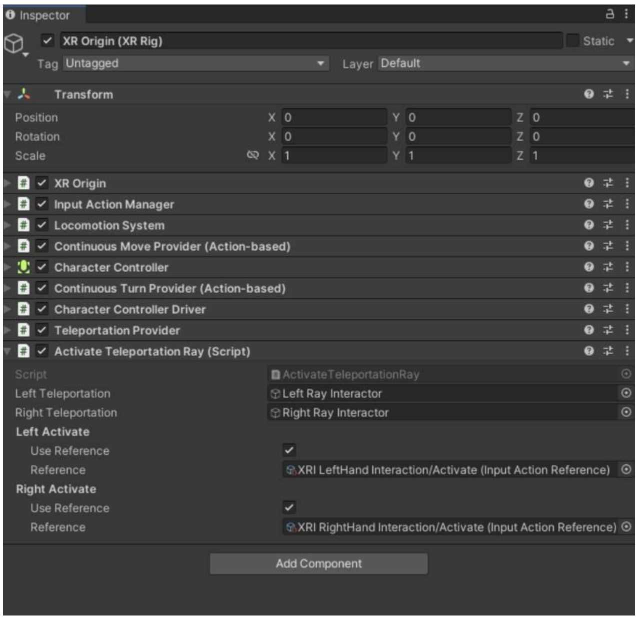

Fig. 7: The components and associated scripts of the XR Rig.

Continuous Move Provider (Action-based): Facilitates smooth, uninterrupted motion within the scene based on user input from the XR controllers.

Character Controller: Provides collision detection and response for the user's avatar in the virtual environment.

Continuous Turn Provider (Action-based): Allows for continuous turning based on user input, enabling smooth rotation within the virtual environment.

Teleportation Provider: Manages teleportation, allowing users to move instantaneously within the XR environment (see Figure 8).

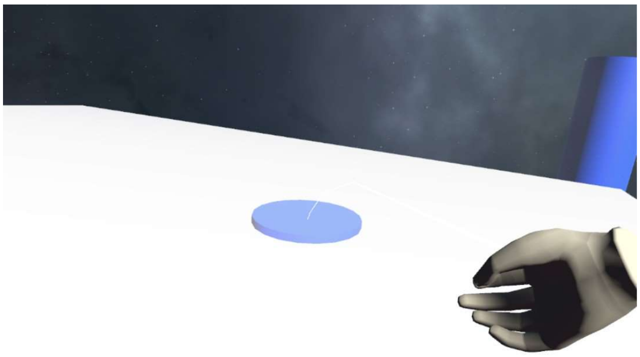

Fig. 8: Teleportation in Unity VR.

Activate Teleportation Ray (Script): Custom script that activates teleportation rays for navigation.

AR Interactions

In addition to VR, our AR solutions require specific interaction techniques to integrate digital content with the real world seamlessly.

Resizing Objects Using Hand Movements:

In AR, users can interact with digital objects overlaid onto the real world using hand gestures. One common interaction is resizing objects through hand movements.

Hand Tracking: The system tracks the user's hands in real time, allowing for natural interactions.

Gesture Recognition: Specific gestures, such as pinching or spreading fingers, are recognized to resize objects.

Object Manipulation: Users can grab, move, and resize digital objects by interacting directly with them using their hands, providing a tangible and intuitive experience.

PROJECTS

Pizzeria Simulator

The scope of the Pizzeria Simulator is to instruct players on how to prepare different pizza recipes in an enjoyable and interactive environment (see Figure 9 for more details).

The game is designed not only to improve culinary knowledge but also to engage players in the dynamics of running a restaurant, balancing time management, and customer service.

Receiving Orders and Assembly process: initiate orders by pressing a bell, which brings up a new customer order on the screen; Following the order details, players must assemble the pizza by selecting the correct ingredients in the right sequence to match the given recipe.

Fig. 9: Sample of the Pizzeria Simulator.

Immersive Experience: To enhance realism, the game features background sounds of a busy restaurant, alerts for ready or burnt pizzas, incoming orders, and score updates. Interactions with hands play a crucial role here in improving players' coordination in different stressful environments.

CPR Simulator

The CPR Simulator is an interactive virtual reality application designed to teach users essential cardiopulmonary resuscitation (CPR) techniques through hands-on simulation. This app serves as a practical training platform for managing real-life crises, demystifying CPR by allowing users to practice and refine their skills in a controlled, immersive environment.

Different learning phases: It starts with an easier mode (learning mode), using color-coded zones and written and verbal instructions to guide users through CPR techniques. The training and validation mode removes these aids, challenging users to apply their skills independently, relying solely on the knowledge gained from the initial learning.

Real-life simulation: The application simulates real-life emergencies to ensure that users can confidently apply CPR skills when faced with real medical crises (see Figure 10 for more details).

Fig. 10: Main scene in CPR Simulator.

Mixed Realities University Campus

The Mixed Reality University Campus is a VR application designed to provide an immersive educational experience (see Figure 11).

Fig. 11: Featured scene in the Virtual Campus.

This application is developed to avoid the common issue of motion sickness typically associated with VR headsets, making it accessible to anyone passionate about XR technologies or seeking a comprehensive educational tool.

The project replicates various activities that students can perform at the Faculty, offering a virtual space that enhances learning and provides a friendly study environment (see an example in Figure 12). This VR campus is particularly beneficial for students who cannot attend the faculty in person, offering a practical solution in challenging situations.

Fig. 12: Student in the classroom scene interacting with the environment.

EVALUATION OF USABILITY TESTS

We conducted usability tests to assess the effectiveness and accessibility of our VR solutions, involving individuals with a range of technical proficiencies. The evaluation was organized into two distinct stages to ensure a comprehensive analysis.

Initially, participants were acquainted with the application's capabilities through detailed ramp-up sessions complemented by video tutorials, designed to provide a solid understanding of how to interact with the systems within the VR setting.

Subsequently, these individuals were invited to engage with the applications, using the Oculus Quest 2 headset and HoloLens 2 glasses to navigate the virtual environment and experiment with its features. Their experiences and impressions were then captured via post-test questionnaires, allowing us to summarise the application's usability and the overall user experience effectively.

Methodology: Our evaluation methodology for the AR/VR solutions involved a streamlined three-part process: (1) introducing participants to the system, (2) engaging them in VR using the devices, and (3) gathering feedback through a post-test questionnaire. To understand user experience across different skill levels, we divided participants into technical and non-technical groups, enabling a focused analysis of the usability and interaction dynamics.

Participants: We involved two groups: 9 software engineers, including 2 with VR knowledge (8 men aged 22-24, and one woman aged 21), and 5 non-technical individuals aged between 40 and 50. Their feedback is presented in the next table (details about participants are in Table 1).

Table 1: Opinions of Technical and Non-Technical Participants on Virtual Reality Systems

Opinions	Technical	Non-Technical
Found the VR application to be an engaging way to learn and receive information	X	X
The system is user-friendly and intuitive	X	X
Navigating the VR environment felt overwhelming at first		X
Believe the system can be easily updated with new information and features	X	

Performed tasks: participants engaged with the VR systems across diverse contexts, including making pizza, experiencing CPR simulations and evaluating a virtual campus. These interactions also encompassed casual conversations and focused discussions with interactive assistants on specific topics, demonstrating a wide range of user-system interactions.

Remarks: Both groups expressed satisfaction and excitement interacting with the applications. The technical group found the controls easily, while non-technical participants preferred the conventional method after some initial challenges. Some participants reported motion sickness, a common problem with XR systems. After conducting usability tests, we presented some of our systems to a panel of medical professionals and technology experts, initiating a comprehensive dialogue that merged healthcare insights with technological innovation. This collaboration was instrumental in identifying areas for refinement, particularly in enhancing in the future the capabilities of virtual assistants for users with specific health conditions. The valuable feedback from these sessions is pivotal for our ongoing development efforts, ensuring that our solution not only meets current healthcare and technological standards but also anticipates future needs and trends in training and simulations.

While the usability tests revealed certain constraints, such as a limited participant pool and the scope of the experiment, the positive user feedback underscores the appeal of our AR/VR systems. Users appreciated the novelty of engaging with different but customized management content, signaling a strong interest in the broader application of those technologies for health and education using Artificial Intelligence tools and techniques. This enthusiasm is a crucial remark to the growing demand for innovative, interactive solutions in user-system interaction, highlighting the significant potential of applicability to revolutionize how information is accessed, delivered, and applied.

During the evaluation process, several key metrics were measured, including task completion time, ease of use, user satisfaction, and the frequency of errors or difficulties encountered. Participants' feedback was systematically analyzed using methods presented above. The data was first categorized based on the technical proficiency of the participants, then further examined to identify patterns or discrepancies in their experiences. It was observed that technical participants generally provided more detailed feedback on system functionalities and performance, while non-technical participants focused more on the overall ease of use and comfort. This distinction in feedback highlights how users' backgrounds significantly influenced their perceptions and interactions with the VR systems, underscoring the need for designing adaptable interfaces.

CONCLUSION AND FUTURE DIRECTIONS

Throughout this article, we have explored the significant potential of enhancing natural human interactions within AR/VR applications. By integrating advanced techniques such as teleportation, tool manipulation, magic movement, long grabbing functionality and so on, our research has shown how these methods can bridge the gap between the virtual and physical worlds. Our approach focuses on leveraging advanced VR controllers, hand recognition, and user-focused movements to create more intuitive and engaging user experiences.

The diverse applications of our AR/VR solutions, ranging from educational platforms to healthcare simulations, illustrate the versatility and transformative power of these technologies. By enhancing user-system interaction through innovative user interface types and interaction modalities, we provide a more immersive and realistic experience in virtual environments. The feedback from usability tests confirms the effectiveness and accessibility of our solutions, highlighting their potential to significantly improve user engagement and task performance.

Looking ahead, the future development of user-system interaction in AR/VR applications will focus on enhancing new types of interactions in order to create even more intuitive and immersive experiences. This includes incorporating advanced haptic feedback for tactile sensations, expanding eye-tracking technology for gaze-based interactions, and developing adaptive user interfaces that dynamically adjust to user preferences and behaviors. Additionally, further integration of AI-driven packages will enhance conversational interactions with virtual assistants, making them more responsive and contextually aware. By continuously refining these interaction techniques, we aim to provide users with seamless and engaging experiences that make the virtual and physical worlds blend together.

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