Tangible Objects in Virtual Reality for Visuo-Haptic Feedback: A Marker-Based Approach

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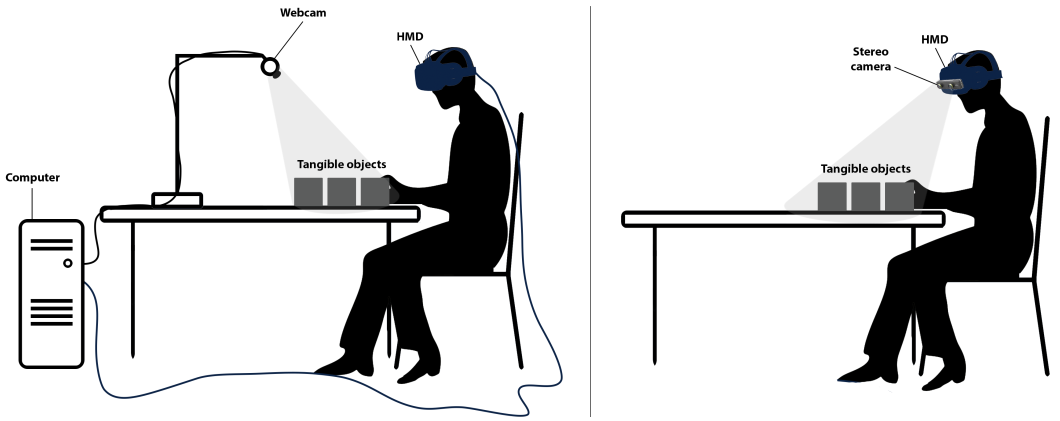

Figure 1: Tangible objects are tracked using a marker-based approach for passive haptic feedback. Each object is tagged with a static image captured by cameras to determine the object's position and orientation in the virtual world.

ABSTRACT

Including tangible objects in Virtual Reality (VR) experiences leverages the interaction and immersion in virtual experiences. Users' hands are freed to interact directly with physical objects and thus receive haptic feedback that complements the primarily visual information offered by the Head-Mounted Display (HMD).

The challenge in this area relies on tracking and mapping physical objects in the Virtual Environment (VE). Approaches have been proposed to integrate tangible objects into the virtual world. Most methods require attaching sensors to the physical objects, usually resulting in object-oriented solutions, making the system inflexible to track different objects.

This position paper discusses different methods to include tangible objects in VEs. As a flexible solution suitable for different objects and requiring few additional hardware resources, we present our marker-based approach, which uses computer vision technology to track the physical objects.

CCS CONCEPTS

• **Human-centered computing** → **Haptic devices**; **Virtual reality**.

KEYWORDS

virtual reality, haptics, physical props

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1 INTRODUCTION

Virtual Reality (VR) mainly relies on visual and audio feedback generated by the Head-Mounted Display (HMD). Although the handheld controllers commonly used in VR produce vibrating patterns, they offer poor haptic feedback and imply a learning curve to introduce working with them.

Haptics becomes essential to improve immersion, interaction, and imagination by transmitting information that is hard to interpret only through vision and audio. One open challenge relies on more abundant haptic feedback patterns, such as texture, thermal feedback and skin stretch. The standard handheld controllers poorly offer these sensations. Although more complex devices (e.g., Phantom Desktop, wearable devices) could reproduce more tactile stimuli, they are expensive solutions not always comfortable and suitable for all scenarios.

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True haptic interfaces should allow users to interact with the system with their bare hands for highly realistic stimuli. Approaches have been proposed to integrate tangible objects into the virtual world. Most methods require attaching sensors to the physical objects, usually resulting in object-oriented solutions, making the system inflexible to track different objects.

We propose a marker-based solution to create tangible VR experiences with high-quality haptic feedback and low hardware costs. Marker-based approaches are commonly used in Augmented Reality (AR) applications for tracking static images (markers) through computer vision technology. We suggest applying these methods in VR applications.

2 RELATED WORK

The core concept of VR is the multisensory stimulation of the user, which makes it possible to feel present in a virtual world. HMDs produce visual stimuli, and headphones provide audio information. The handheld controllers produce vibrations that stimulate the touch; however, haptic feedback goes far beyond vibration patterns. In the real world, textures, shapes, materials and temperatures are sensations that influence human perception. To enhance the realism of virtual experiences, it is essential to transport these haptic sensations to VEs.

2.1 Haptic Interaction in Virtual Reality

Enabling haptic feedback in VR has contributed to more realistic virtual experiences such as surgical training [10], rehabilitation [15], or storytelling [8] scenarios.

Haptics means both force feedback - simulating object hardness, weight, and inertia - and tactile feedback - simulating surface contact geometry, smoothness, slippage, and temperature. Haptic feedback can be classified into three categories [17]: active, passive and a combination of active and passive.

Active haptic feedback consists of computer-controlled actuators that exert forces on the user during operation. Lightweight vibrotactile actuators, skin stretch mechanisms, Phantom haptic interface, and wearable devices (e.g., gloves) are examples of active haptic devices.

Passive haptic feedback does not require actuators since the physical props in the real environment provide tangibility to virtual objects. It is a low-complexity approach that provides highly realistic haptic feedback by letting users interact with real objects, called proxies or props.

Mixed haptic feedback combines the strengths of active and passive haptics. The actuators are not used to actively render forces on the user but to transform the prop itself to change how it feels. This enables a single prop to provide different passive haptic impressions. A prominent example is the concept of encounter-type haptics or Robotic Graphics [9].

Besides these approaches, other techniques rely heavily on pseudo-haptics [12] that use visual feedback to trigger haptic perception. Other concepts like redirected touching and haptic retargeting [3, 18] use the visual dominance effect by warping the virtual space or the user's hand to modify how users touch tangible objects.

Active haptic feedback provides flexible feedback; however, the complexity, limited mobility, or limited workspace are significant limitations. Passive haptics offers much more realistic feedback by enabling touching real surfaces and materials. The challenge relies on mapping everyday props onto VEs; they need to be tracked to determine their position and orientation in the virtual world.

2.2 Tracking Physical Objects

Developing tangible interfaces in VR usually requires additional hardware to track physical objects' position and pose. Diverse systems have been proposed, from active to passive haptics.

Most methods involve attaching sensors or devices to the objects intended to be tracked. In recent years, the Vive Tracker has been frequently used for this purpose as it allows accurate gathering of position and pose information [4, 14]. The Bonita Vicon system has also been used, attaching its markers directly to objects and/or the user's body [6, 13, 16]; one or more optical cameras then track the markers. Other works propose the creation of their own devices or systems to be subsequently incorporated into tangible objects [1, 7, 8]. Below we will present research works that exemplify the different methodologies listed.

Cheng et al. [4] created a game with props to make the experience more engaging. One of the objects used was a ball on a pendulum representing objects that move and demonstrate proactive behaviour, such as a group of flying droids that physically attack the user. Tracking was ensured by attaching Vive Trackers to the physical objects used. Another method was presented by Tingyu et al. [16], using the Bonita Vicon optical tracking system. Whenever users grasp the physical object, they also hold its virtual representation since the system tracked subjects' thumb and index fingertips using markers placed on the dorsal side of their fingers. A 3D-printed support was used to ensure a good matching between the positions of the tangible object and the virtual object.

Harley et al. [8] presented a system for diegetic tangible objects in VR narratives. A device-agnostic sensor unit was attached to the physical object, featuring active and passive haptics. In this work, the tactile sense's inclusion helped immerse the user in the narratives being told. Also presenting a new toolkit, Arora et al. [1] proposed VirtualBricks as an alternative to conventional VR controllers; it is a LEGO-based toolkit to create custom controllers, enabling actions such as shooting targets using a gun or catching a fish by rotating the fishing reel.

The examples covered comprised a variety of methods used to integrate tangible objects into the virtual world. All methods involve adding devices to the system beyond the standard VR setup, and solutions like Tingyu et al. [16] require prior knowledge of the props so that the system can be custom designed. Adding hardware to the system every time a new prop is introduced shows to be expensive and challenging to scale solution.

3 A MARKER-BASED APPROACH

This section presents the marker-based method commonly used in AR applications. Next, we present our proposal that builds on these methods to integrate passive haptics in VR applications.

3.1 Marker-Based Augmented Reality

A typical marker-based AR system consists of a camera, a processing unit, a display and markers (i.e. static images) [5]. The camera captures the real-world scene containing the markers while the processing unit generates and renders the virtual contents over the captured scene. The display unit - usually a smartphone display - shows the seamless integration of the virtual object with the real world. For marker detection, global thresholding method has been used that is prone to illumination changes and blurring. The marker's inner boundary includes an image fed to the system a priori, and the identification is achieved through template matching.

Vuforia Engine SDK is a platform widely used for AR development that uses computer vision technology to recognize and track planar images and 3D objects in real-time. Briefly, the Vuforia library uses Natural Feature Tracking (NFT) algorithms with an approach similar to Scale Invariant Feature Transform (SIFT) to detect feature key points and determine the scale of the marker. Thus, the target images should be markers rich in feature key points, i.e., images with sharp, spiked, chiselled details and contrasts, with bright and dark regions and well-lit areas. Knowing the image and its key points beforehand, Vuforia will track them to calculate the object's position and orientation. The more key points, the less likely tracking failures will occur.

This computer vision technology allows multiple markers to be tracked simultaneously, requiring only one camera and static images previously fed to the system.

Mobile VR comprises virtual experiences in which a smartphone is used as HMD. This VR category allows using AR methods since smartphone cameras are compatible with this technology.

Cardoso and Ribeiro [2] proposed a tracking solution for smartphone-based VR. The system does not require additional hardware instrumentation since the smartphone used to display the VE also detects a physical book's pages through marker-based computer vision. The book pages have been marked with target images that will be crawled and rendered in the virtual world with the desired content.

Applying marker-based approaches to standalone and stationary HMDs will pave the way to create tangible experiences that are cheaper and more flexible to diverse objects; adding a new prop would only require presenting the system with the new target image to be tracked.

3.2 Marker-Based Virtual Reality

Our vision is to create a scalable and flexible tracking system suitable for objects with different morphologies that may not be known in advance. To this end, we propose a marker-based approach for VR applications, in which physical objects are pre-tagged with target images known in advance by the system. These markers are tracked in real-time by cameras that can be positioned in the play area (e.g., standard webcam) or installed on the HMD (e.g., ZED Mini), as shown in Figure 1.

Figure 2 presents a high-level architecture that shows the connection of the main components of the proposed framework. The user receives visual and audio feedback through the HMD and passive haptic feedback by interacting directly with tangible objects. The objects are tracked by an application that uses a camera and computer vision technology to recognize and track the planar images stuck to the objects. The position and orientation gathered are then used in the VR application responsible for rendering the virtual world, including the virtual representation of the props.

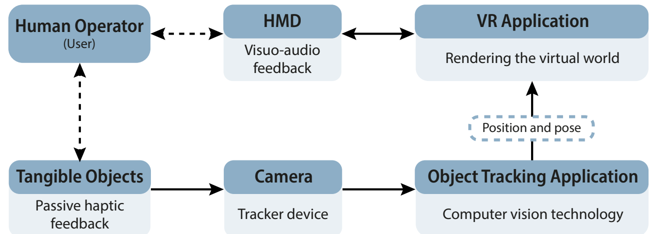

Figure 2: High-level architecture of the marker-based system.

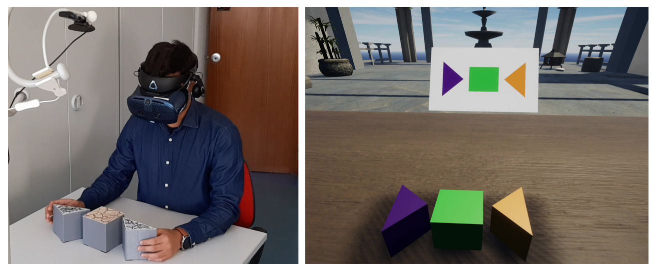

Figure 3: Proof of concept of the marker-based approach using a webcam and three objects tagged with static images.

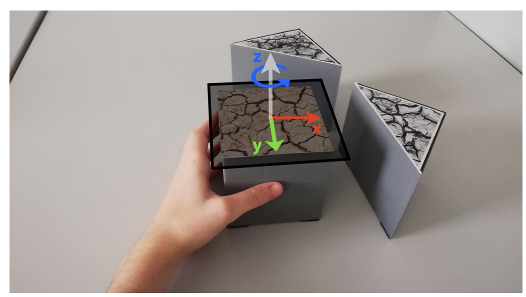

Figure 4: The tasks used as a case study required the user to rearrange the tangible objects by translations along the x-axis and z-axis and rotate them about the y-axis (vertical).

As a proof of concept, we applied this approach to tracking three tangible objects whose top face was previously marked with a static image. We used a webcam positioned under the table and the Vuforia SDK to determine in real-time the position and pose of each object. According to these coordinates, virtual objects were mapped into the virtual world, as illustrated in Figure 3. In this example, we can evidence the capabilities of the proposed haptic system. The user had to arrange the objects to match the puzzle displayed at the head of the table. This task would become more time consuming if the user had to rearrange the pieces using the handheld controllers. Allowing the user to assemble the objects with their bare hands offers greater precision, especially in the more detailed rotations; the interaction becomes more natural and effective.

With the same system, we studied other scenarios to explore a novel haptic redirection technique using non-Euclidean geometry [11]. The position of the objects was mapped on the virtual table according to hyperbolic functions. Due to the constant negative curvature of this geometry, users had the illusion of having more space to play, although the physical space remained the same.

User studies were conducted with 28 participants. Once the system was introduced to the participants, they were asked to rate on a 7-point Likert scale the subjective ease of the task, that is, how easy they found the task and respective interaction (1 = strongly disagree that the task was easy, 7 = strongly agree that the task was easy). The median of the answers was 7 (Q1 = 6, Q3 = 7), which showed that users found the haptic approach quite intuitive.

4 CONCLUSION AND FUTURE WORK

This position paper presented different methods of integrating haptics into VR experiences. Both active and passive haptics alternatives offer their advantages and disadvantages. Active haptic feedback applies devices with actuators to generate various tactile stimuli. A single device, such as sensor gloves, can reproduce numerous sensory patterns; however, they are expensive devices, not always comfortable and suitable for all application scenarios. In contrast, passive haptics offers much more realistic stimuli because they allow users to feel real objects with their bare hands. The challenge of this category is tracking the objects and mapping them into the virtual world.

Different systems have been proposed to integrate everyday objects into virtual experiences. Most require attaching sensors to the objects, using Vive trackers, Bonita Vicon system markers or device-agnostic sensor units. While all of these approaches are valid and serve the purpose of creating more immersive VR experiences rich in haptic feedback, they position themselves as purpose-designed systems for a given object, making it complex and expensive to scale the system for multiple and diverse props.

We suggest applying computer vision algorithms commonly used in AR applications to create cheap, scalable, and flexible VR systems for physical objects of different shapes and sizes. These mechanisms allow collecting real-time information about the position and orientation of each object; this information is made available to the VR application to render the VE and the virtual representation of the physical entities. In hardware-based approaches, including a new object requires adding hardware to the system; this does not happen in marker-based methods. Adding a new prop only requires marking the object with an image and adding that image to the marker database that the system must track.

Finally, we briefly presented an initial study where we tested our proposed system. From the preliminary results of the conducted user study, we could verify that the haptic interaction showed to be quite intuitive for the users, who performed the tasks without any difficulty. Being the first experiment, the objects used had simple geometric shapes. In future work, we aim to test with more complex properties and mark multiple faces to mitigate the possible occlusion of the markers due to users' hands. We also seek to experiment with scenarios where the tracking camera is installed on the HMD to enable higher mobility tasks.

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