A Demonstration of YUBI: Your Universal Body Interface Using Finger Force to Full-Body Motion for Avatar Embodiment

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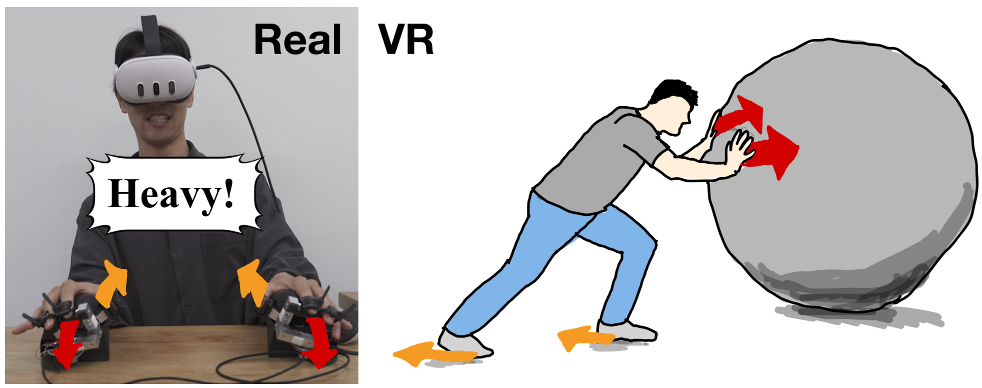

Figure 1: Immersive VR experience with the YUBI system: The user precisely controls the force exerted by the avatar's entire body through their finger strength (left). By perceiving the reaction force on their fingers and the effort required to push a virtual rock, the user realistically experiences the object's substantial weight (right). This full-body force feedback and interaction powerfully promotes Embodiment with the avatar in the virtual world.

Abstract

YUBI, a novel interface, translates nuanced finger force inputs into continuous, full-body avatar motion, fostering strong embodiment in virtual reality. It enables embodied interactions such as object manipulation and navigation using only finger force, overcoming physical constraints while delivering realistic haptic experiences. Crucially, YUBI renders reaction forces to the fingers, allowing users to perceive virtual object properties (e.g., weight and stiffness) through the effort of their input. By dynamically adapting the force-motion relationship based on object characteristics, YUBI provides intuitive haptic perception, significantly enhancing haptic realism and avatar embodiment.

CCS Concepts

• **Human-centered computing** → **Virtual reality**; **Interaction devices**; **Haptic devices**; *Accessibility technologies*; • **Hardware** → **Emerging interfaces**.

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Keywords

Virtual Body Manipulation, Avatar Manipulation, Pseudo-haptics, Embodiment, Body Schema

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1 Introduction

The notion of embodiment—where individuals experience a virtual avatar as their own body—has emerged as a central theme in virtual reality (VR) research, given its profound influence on users' realism, immersion, and sense of presence in virtual environments. Most studies in this area have primarily aimed at achieving a close morphological correspondence between the user and the avatar, relying heavily on motion tracking techniques. Such approaches allow users to transfer their pre-existing motor control schemes to the avatar, thereby facilitating a more intuitive manipulation. Nevertheless, these methods present limitations, particularly for users with restricted movement capabilities or physical impairments, who may find it difficult to fully engage. In addition, providing haptic feedback during full-body interaction poses another significant challenge. Full-body haptics often requires users to wear cumbersome equipment [Hashimoto et al. 2022], which can limit natural movement and reduce overall usability. Although these spatial and physical limitations are well recognized, alternative interface designs that allow for a strong sense of embodiment without such burdens remain underexplored. To address these issues, the present study introduces a new system that converts fingertip force inputs into continuous full-body virtual movements. This approach aims to offer embodied, continuous avatar control while circumventing the spatial and physical restrictions faced by many users, and simultaneously to enrich the virtual haptic experience. The system, named "YUBI" (Your Universal Body Interface—also indicating Japanese word for "finger"), represents a novel step toward realizing more immersive and accessible VR experiences.

2 YUBI

2.1 Rationale behind YUBI

This study introduces YUBI, a novel interface that enables users to embody objects with various physical characteristics distinct from their own bodies. Grounded in cognitive models of embodiment, YUBI allows users to manipulate tools or virtual avatars through fingertip force input while conveying the physical properties of both the "body" and the "environment." By leveraging the reaction force generated when pressing against a force sensor, YUBI evokes changes in proprioception, cutaneous sensation, and sense of effort. These force cues serve as haptic cues, enabling the formation and restructuring of perception–action loops without active actuators.

The design is informed by recent theoretical developments such as the free energy principle, which posit that embodiment arises from the alignment between predicted and actual sensory input in a motor–multisensory model. The body is thus understood as a relational construct emerging through environmental interaction, and transformation of embodiment as a reconfiguration of this perception-action loop.

While prior avatar embodiment research has focused on aligning visual and tactile or motion cues, it has largely overlooked the role of force cues, which are the essential for perceiving physical attributes such as weight, stiffness, inertia, and resistance. When the structure of the avatar or environment changes, embodiment cannot be sustained without corresponding updates to the perception–action model including force cues. Yet design principles for such adaptability remain underdeveloped. YUBI addresses this gap by enabling dynamic recalibration of the mapping between force input and object motion, based on the target's physical properties. This allows users to perceive differences in mass, stiffness, resistance, and inertia, thereby fostering embodied interaction with virtual avatars through visual–force predictive integration.

2.2 Hardware

Figure 2 shows the appearance and components of the device, as well as the system diagram. The hardware for one hand consists of a total of seven single-beam load cells and a spherical casing where users can place their hand in a natural posture. The seven load cells are allocated with three for the thumb, three for the index finger, and three for the little finger in an orthogonal arrangement. By connecting two devices, a total of 14 degrees of freedom input can be acquired for both hands. Figure 3 shows the correspondence between force inputs from the device and avatar movements. The

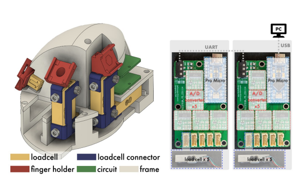

Figure 2: Left) Components. Right) System configuration.

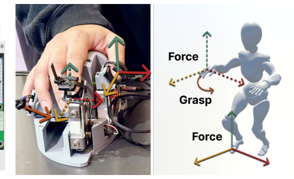

Figure 3: Correspondence between inputs and motion.

values from the three load cells on the index finger correspond to the movements along the respective coordinate axes related to the position of the virtual hands. The value from the thumb's load cell is used to control the lifting and lowering movements of the virtual legs, and locomotion in VR. Meanwhile, the value from the middle finger's load cell is used as a trigger for hand interactions, such as grasping and releasing virtual objects.

2.3 Physics-Aware Whole-Body Model

In our previous work [Hashimoto and Hirao 2024], the force applied to each load cell was converted into a force acting on the corresponding target point in VR space, and the avatar's limbs would then follow these target points using inverse kinematics (IK). While this target-following IK allowed for intuitive control of end-effectors, it did not fully account for how environmental reaction forces affect the avatar's entire body, limiting the sense of "wholeness" in interactions. For instance, if an avatar pushes against a wall, the hand's IK target might correctly stop at the wall's surface, but the reaction force would typically not cause the avatar's body to be pushed back or to adjust its stance realistically; the interaction remains localized to the end-effector rather than engaging the whole body.

To address this, the current study introduces a physics-based whole-body control scheme. Instead of only moving IK targets, we now treat the avatar itself as a dynamic physical model. The desired forces at the end-effectors, derived from the load cell inputs F are translated into whole-body motion by applying joint torques τ. These torques are calculated based on the avatar's Jacobian J and the desired end-effector force F_{EE} as $\tau = J^T F_{EE}$ (where F_{EE} represents the intended force in Cartesian space, analogous to F_v). This approach ensures that forces experienced by any part of the avatar propagate through its entire physical model, leading to more integrated and reactive full-body movements when interacting with the virtual environment.

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