Towards Inducing Weight Perception in Virtual Reality Through a Liquid-based Haptic Controller

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Rendering haptic sensations while interacting with virtual objects, such as experiencing weight is essential for creating natural virtual reality (VR) experiences. However, accurately providing the forces required to sense an object's weight poses a demanding challenge. Hence, standard VR setups do not allow users to experience different weight sensations. In this paper, we propose a haptic VR controller design that renders the weight of virtual objects by regulating the mass of the controller through liquid transfer. Our planned system consists of two tracked controllers that contain a water bag. They are connected to a liquid reservoir in the back, to or from which water is transferred to change the weight of the controller. A Microcontroller determines the weight of each reservoir via a bi-directional water pump and a set of solenoid valves. To evaluate the prototype, we are planning to investigate in a study whether our system can enhance the VR experience and sense of presence while lifting and swinging virtual objects. Furthermore we plan to examine, whether the device can be used to amplify avatar embodiment.

CCS Concepts: • **Human-centered computing** → **Haptic devices**; **Virtual reality**; • **Hardware** → *Haptic devices.*

Additional Key Words and Phrases: virtual reality, haptic controllers, weight perception

1 INTRODUCTION AND BACKGROUND

Simulating weight of objects in VR is crucial for providing realistic haptic feedback and creating immersive experiences. One of the most natural human behavior is grasping and lifting objects. When lifting objects, humans use their proprioceptive system to sense the mass of the lifted objects. As perceiving and handling objects are inherently connected, the perception of weight affects how we interact with objects. For example, the grip force while grasping objects is adjusted based on their (expected) weight and other physical properties [17]. To ensure a natural and realistic interaction in VR, it is, therefore, vital to make virtual objects feel heavier or lighter based on their virtual properties. However, simulating weight of virtual objects in VR is still an unsolved challenge.

Previous work (for a review, see [11]) explored overcoming these physical limitations by manipulating grip forces [16], actuating downward forces [5], deforming skin on the fingers [2], or shifting the center of mass within the controller [18]. Other approaches rely on pseudo-haptic feedback to render weight, i.e. the illusion of force through visual changes [15] or passive forces [10]. Lim et al. [11] reviewed 65 research papers on weight perception in VR and concluded, that due to the lack of real gravity forces, the task of providing weight sensation in VR remains challenging (p. 23). The authors argue that realistic weight perception requires the exertion of gravitational forces [11, p. 7]. A solution to generate gravity forces in VR could be based on the mass transfer system presented by Niiyama et al. [13]. The authors demonstrated simulating objects of different weight by moving liquid metal via a bi-directional pump in or out of a bladder.

Cheng et al. [1] applied the concept of weight change through liquid transfer to VR and developed *GravityCup*, a cup-shaped device that simulates inertia. The system consists of two units, that are connected with tubing: A water

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bag worn on the waist, and a cup-shaped handheld device, that contains a second water reservoir. Each of the units features an electric water pump, that is controlled by an Arduino Nano microcontroller. To provide the perception of the inertia of liquids or containers, the system transfers water from one unit to the other, reaching a flow rate of 19.62 ml/s. Consequently, it takes 16.8 seconds to fill the handheld device with 330g of water. To demonstrate the system, the authors provided the scenarios of watering a plant, filling a cup of coffee, scooping up dog food, and holding an empty cup. However, the perceptible liquid inertia within the cup and the slow speed at which the weight adjusts severely limit the use of the system for generic weight perception. Another restricting factor is the lack of double-handed interaction, which Lim et al. [11] point out as a problem of most present interfaces for weight perception.

We argue that by tackling these limitations, liquid transfer can be an adequate means to induce a weight sensation in VR beyond simulating inertia or fluids. Therefore we propose a system, that moves liquid through a bi-directional high-performance pump and a set of solenoid valves to dynamically change the weight of the VR controllers.

2 SYSTEM

In the following, we describe the requirements, envisioned implementation, and potential applications of our planned prototype.

2.1 Design Goals

To overcome the limitations of previous approaches, we defined the following requirements for our implementation:

- Rendering distinguishable levels of weight
- Maintaining an acceptable response time
- Maintaining a size and weight that can be worn on the back comfortably
- Allowing double-handed interaction
- Preventing disturbing forces, i.e. liquid inertia and air resistance

2.2 Planned Implementation

Our planned prototype consists of two controllers, each containing a sealed water bag, that can be filled by the system with up to 0.5 l of liquid. This design was chosen, as water bags prevent liquid inertia through contracting under negative pressure. To prevent the user from sensing the bag's air resistance, the water bag is placed inside a bottle-shaped housing. It is designed to be held by the bottleneck to amplify the leverage force and as such, the perceived weight. Optionally, the devices can be strapped to other parts of the body, e.g. the forearm to allow the fingers to operate other input devices, or the legs to provide weight feedback in sports applications such as ski simulations. To enable positional and rotational tracking in the virtual environment, an HTC Vive Tracker is screwed on each housing. Hoses connect the controllers to an electrical water pump, which has a tubing connection to a third water bag (1l cap.) acting as water tank. The pump works with a flexible rubber impeller, that allows reversing the direction of the water flow. A portable and high-capacity bilge pump is suited for this purpose, as this type of pump can provide high output while maintaining a low voltage circuit and low weight. For instance, the specifications of Marco UP1-JR[1] report a flow rate of 460 ml/s at a weight of 1.8 kg. Between each controller and the pump are two one-way solenoid valves to be able to direct the flow of water in or out of a single controller, or both controllers simultaneously.

[1]marco-pumps.shop/marco-up1-jr-reversible-impeller-pump-28-l-min-with-on-off-integrated-switch-12-volt-16201112

The fill levels of the water reservoirs are regulated by a control unit consisting of a microcontroller, a Bluetooth Transceiver Module, and six Single Pole Double Throw Relay modules. Four of the relays switch one solenoid valve each. The two other relays act as a polarity switch to set the direction of the impeller pump. As the pump motor operates at high current, the relays are used to isolate the microcontroller and the Bluetooth module. For the same reason, the microelectronic components are powered by a separate power supply. A circuit breaker further protects the hardware. The control unit is mounted together with the water tank, the pump and the solenoid valves on a board that can either be placed stationary or carried on the back.

To integrate the prototype into the VR system, a serial Bluetooth connection needs to be set up between the game engine and the Bluetooth Transceiver module (Optionally, a USB connection can also be used). The microcontroller can listen to in-application events, actuate the relays to set the direction of the water flow and open the corresponding valves, depending on the virtual object's weight.

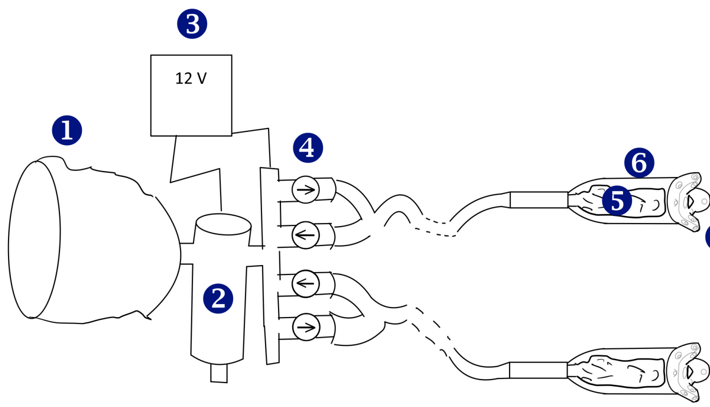

Fig. 1. Schematics and components of the system. (1) 1l water bag. (2) Reversible pump. (3) Control unit, consisting of a microcontroller, a Bluetooth transceiver, and six relay modules. (4) Solenoid valves. (5) 0.5l water bag. (6) Housing. (7) HTC Vive Tracker

2.3 Applications

We envision a broad range of application scenarios, in which the system can be used to enhance the VR experience. Therefore we plan to implement two demo applications. As the device is designed to provide a weight sensation of arbitrary virtual objects, the first application features interacting with various melee weapons, that players can pull from an inventory on their back. Inventory systems in games are frequently used to allow users to switch items of their inventory, such as weapons, clothes and other resources. We expect our prototype to enable a more natural inventory system by simulating weight of different items. For example, users can switch between heavy and light melee weapons while experiencing different weight sensations.

To explore, whether the system can also be used to enhance the sense of body ownership in VR, users embody a skinny avatar and transform to a bulky one in the second application. We expect the users to associate the increased weight exerted through our prototype with an increased body fat, which, in turn, results in a stronger sense of embodying the avatar. Such findings would have implications for research on the Proteus effect showing that avatars with stereotypical appearance can increase users' performance in VR [6–9]. We plan to evaluate the system in a user study, in which we analyze presence, joy of use, perceived effort and embodiment during the scenarios.

Besides simulating weight, the apparatus could be used to adjust the difficulty within VR applications. For instance, the system could add weight during exercises in fitness applications to provide new challenges [4], or during video games to dynamically balance the difficulty level [3, 12], e.g. by using weight to hamper movements. Other conceivable game mechanics could be indicating life points or stamina through perceived weight or adjusting the weight and thus exertion depending on the selected player character.

3 CONCLUSION

In this position paper, we proposed a design for a liquid-based device to provide a generic weight sensation in VR. In the next steps, we plan to manufacture the system accordingly and develop the required hard- and software. If our planned studies confirm that the device can enhance presence, joy of use and embodiment by simulating weight of virtual objects, our prototype contributes to the progress of haptic interfaces for VR. Further studies could examine the capability of the device for other applications and mechanisms, like novel game mechanics or weight feedback on other body parts. Moreover, coupling our system with other haptic controllers like haptic gloves [14] could be explored to combine multiple haptic properties.

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