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An Open-Source Ungrounded Hapkit for Educational Applications

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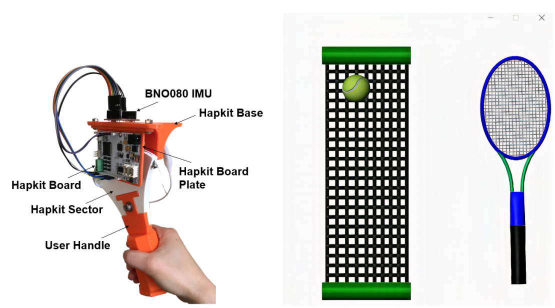
***Abstract*— The Hapkit is an open-source kinesthetic device used by educators to teach fundamentals of haptic interaction. Despite its pedagogical benefits, it cannot showcase ungrounded interactions. Here, we introduce an ungrounded Hapkit variant that generates moments at the wrist as the user interacts with a virtual environment. The device utilizes existing Hapkit hardware with 3D printed modifications to enable ungrounded kinesthetic feedback. We developed Arduino and Processing code that simulates ungrounded impacts, such as hitting a tennis ball, to demonstrate functionality. This device can serve as a valuable pedagogical tool in conjunction with the well-established Hapkit.**

I. INTRODUCTION

Grounded kinesthetic devices represent a significant portion of the haptics research literature. Manipulators like the Phantom Omni and Novint Falcon, which are rigidly linked to a table or the ground, leverage grounding surfaces to generate forces for haptic feedback. Yet, the rapid growth of virtual reality interfaces and mobile interactions has catalyzed the development of a new category of ungrounded kinesthetic devices [1], [2]. Unfortunately, no low-cost pedagogical tool exists for ungrounded kinesthetic interfaces. Here we present an open-source ungrounded kinesthetic device based on the popular Hapkit device.



(a) (b)

Fig. 1: (a) Ungrounded Hapkit with modified user handle, base, board plate, and and IMU. (b) Example virtual environment rendered in Processing.

II. HARDWARE AND SOFTWARE

The ungrounded Hapkit device is modified from the Hapkit 3.0 [3] (see Fig. 1(a)). To hold the Hapkit upside-down, we designed and printed a Hapkit board plate that mounts onto the ungrounded Hapkit base while maintaining the MR sensor alignment with the motor shaft magnet. A BNO080 IMU secured to the top of the base returns Euler angles relative to the gravity vector. The device uses the original Hapkit motor, capstan pulley, and sector pulley. A custom handle was printed for the virtual tennis environment described below.

The device displays impact forces resulting from hitting a virtual tennis ball with a tennis racquet (represented by the Hapkit) as shown in Fig. 1(b). We modified the original Hapkit Arduino code to read the base position using the IMU and generate appropriate torques based on interactions in the virtual environment. The Arduino code controls the moment of inertia of the manipulator and thus modulates the impedance of free space via the rendering algorithm below. Upon impact with a virtual object, the controller allows the base to fall, and a reaction torque is generated on the user's hand when the motor reengages to catch the base. The binary rendering algorithm is shown below.

$$\tau = \begin{cases} 0 & \text{, initial object contact} \\ k_d \dot{e} + k_p e & \text{, otherwise} \end{cases} \tag{1}$$

where τ is the Hapkit motor command torque, k_d is the derivative gain, k_p is the proportional gain, and e is the error between the actual and desired vertical base position. As a result, users felt a strong, recoil sensation. However, due to the device's weaker motor, unstable vibrations are occasionally felt.

III. CONCLUSIONS AND FUTURE WORK

Here we present an ungrounded haptic device that enables users to kinesthetically experience hitting a tennis ball. All source files can be accessed at `https://bit.ly/3ngUQQg`. We will continue to develop the hardware and software to improve performance as we plan to deploy the ungrounded Hapkit in the Fall 2021 Johns Hopkins University Haptic Interface Design course.

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