Ungrounded haptic rendering device for torque simulation in virtual tennis

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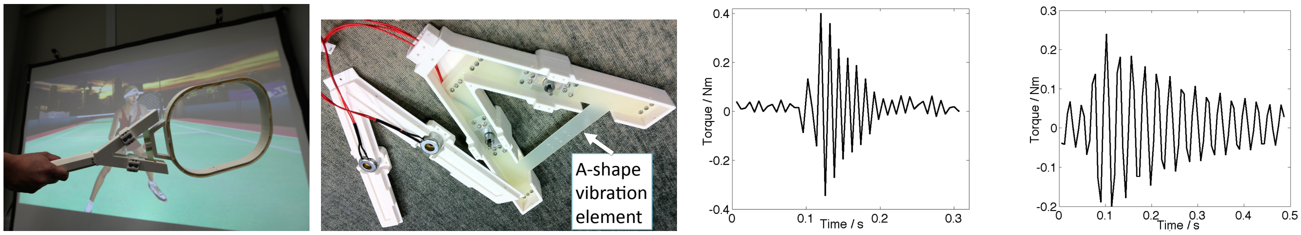


(a) Racket prototype in virtual tennis (b) A-shape vibration element (c) Device generated torque for ball impact (d) Device generated torque for racket twisting

Figure 1: *The haptic device shown in (a) utilizes the A-shape vibration element and high-power push-pull solenoids shown in (b). The large moment of inertia of the racket rim makes it an effective counterweight to generate torque at the handle, as shown (c) and (d)*

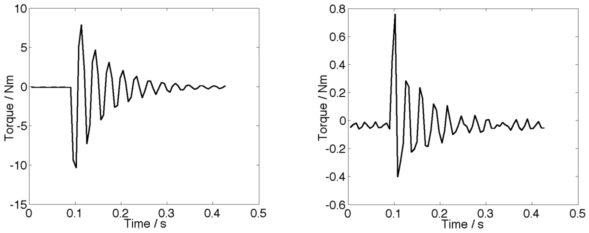
1 Introduction

We present an ungrounded haptic device to render a variety of tennis ball impact accelerations and torques in an interactive virtual tennis system. Impact forces are common in real life, particularly in sports. Our daily experiences shows that our sensory system can discern the variations in these resulting strong vibrations. Common eccentric mass vibration motor-based haptics cannot create the magnitudes of the force and torque, or the variations in frequencies and waveforms, or the immediacy of such impacts[Yao and Hayward 2010]. Our device overcomes the above deficiencies and increases the richness of user experience in virtual reality.

Novel features are the A-shape vibration element actuated using dual push-pull solenoids, and utilizing the inertia of the racket rim to act as an counterweight to generate torque at the handle. The rim has low mass, but acting like a ring, it has a large moment of inertia, which make it as an effective counterweight that is also light. Compared to our previous work [Fong et al. 2011], the ability to render high accelerations of different frequencies and waveforms is extended to rendering torque at the handle.

2 Haptic Device Design and Performance

The A-shape vibration element, constructed using FR4 fiberglass, can be considered as two of the haptic devices described in [Fong et al. 2011] forming the slanted sides, and joined by a horizontal beam coupling. Part of the handle of the racket, shown in Figure 1(b), houses the above vibration element, while the rim is mounted to the horizontal beam of A. Therefore, the racket is divided into two flexibly coupled moving masses. Each slanted side of A can render large accelerations of varying frequencies and waveforms[Fong et al. 2011]. Actuating the slanted beams bends the rim relative to the handle, which generates a torque laterally about the handle that simulates ball impacts. Additionally, actuating the beams out of phase adds a twisting effect that simulates off-center line impacts, where the racket twists in the player's grip. By using the inertia of the rim, and bending the A-shape vibrating element appropriately, it is possible to generate fairly strong torque up to 0.4Nm while swinging in the air. This is without any anchor to the ground or use of large mass. Device generated torques are shown in Figure 1, and those typical of ball drops from a height of two meters are shown in Figure 2. The device is actuated using a 70Hz signal, lasting 14ms. These measurements are measured by clamping the handles of the prototype and real racket, respectively, to the FT9039 multi-axis torque sensor from Industrial Automation. The data was sampled at 200Hz. We can observe that the the device generated ball impact torque is two orders of magnitude lower, while that for racket twisting is within one order of magnitude. As with accelerations shown in [Fong et al. 2011], it takes less than 10ms to use the recoil effect to build up the maximum torque, which compares well to hundreds of milliseconds that rotary motors take to spin up.



Ball impact torque Racket twisting torque

Figure 2: *The torques measured for a typical tennis ball drop from a height of two meters onto a real racket.*

Though the torques generated are lower than real tennis, visual observation and videos show that they are sufficient to deflect and twist the device while held in the hand, giving the sensation that it is impacted. We are conducting perceptual studies to determine how far our device is perceptually, from real impacts, particularly in the presence of strong visual and auditory simulations in virtual reality.

References

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