Enhancing VR Experience Through Electrical Muscle Stimulation (EMS) System

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ABSTRACT

Virtual reality (VR) systems have augmented human-computer interaction. However, currently available and affordable systems are limited to visual and audio representations of the three dimensional world, and haptic feedback which is restricted to hand controllers of the system. In this paper, we strive to further current research conducted on integrating electrical muscle stimulation (EMS) with virtual reality by proposing a three-part system in which a user is able to interact with various virtual reality scenes and receive appropriate EMS feedback to further the immersiveness of the VR experience.

Author Keywords: HCI; virtual reality; electrical muscle stimulation.

INTRODUCTION

Recent virtual reality (VR) systems have taken our human-computer interaction into the three dimensional world. In order to simulate real-world interactions in virtual spaces, current virtual reality consoles can easily provide comprehensive visual and audio feedback via the highly developed headsets and sensors. Meanwhile, relative to visual and audio feedback, the quality of haptic feedback producible by modern VR systems pales in comparison, with users constrained to holding hand-held controllers. Although controllers do offer button customization and multiple degrees of freedom of movement, they can only provide a single form of haptic feedback – a feeble set of vibrations to the hand. As a result of this constraint, virtual reality applications often fall short of their goal of inducing users into an immersive experience that feels truly authentic.

With the aim of expanding the horizon of possibilities for feedback, another dimension to combine with modern VR systems would be muscle actuation. Specifically, the implementation that seems most promising to accomplish customizable muscle actuation is electrical muscle stimulation (EMS) technology. In EMS systems, electrical pulses are sent from a battery-powered device to your motor nerves via pairs of electrodes in order to create muscle contractions. These electrodes can be easily moved to target different muscle groups of the human body. In this paper, several new developments in the use of EMS in the VR space will be discussed, which help in improving the experience of physical interaction in the VR space. We will also discuss our work that uses EMS in new scenarios such as a gun range, emulating the recoil of the gun through muscle stimulation. We tested its effect on the overall VR experience.

RELATED WORKS

The conception of EMS technology has its roots grounded in the medical industry. Electrical muscle and nerve stimulation techniques have proven particularly useful for patient care and rehabilitation. Various works, such as those by Banks and Reddy, cover carefully executed experiments with electrical peripheral nerve stimulation for medical rehabilitation, specifically pain relief and muscle growth [1, 2].

With EMS technology advancing to become increasingly reliable and safe, exploration began to be conducted in using EMS's capacity to actuate specific muscles for various diverse applications. Focusing specifically on implementations of EMS systems in tandem with VR/AR technology, we found that Hasso Plattner Institute of Digital Engineering (HPIDE) has been the main pioneer in exploring this field. They worked on quite a few projects involving the stimulation of muscle groups to make virtual interactions feel much more realistic.

One of these projects was "Adding Force Feedback to Mixed Reality Experiences and Games using Electrical Muscle Stimulation," led by Pedro Lopes [3]. It consists of a mobile system that enhances mixed reality experiences and games with force feedback by means of EMS . The experiences, which included a marble balancing game, escape room puzzles, and virtual lighting adjustment for real world artwork, proved to be much more realistic with the addition of EMS to simulate object resistance forces from pressing buttons, pushing boards, and turning switches. Additionally, this project highlights one of the best selling points of using EMS as opposed to mechanical actuators; while bulky gloves or cumbersome wearable pulley systems are required for mechanical actuators, EMS systems circumvent this issue by providing force feedback without the need for such heavy, uncomfortable equipment. The hands-free setup in this project also enables much more freedom and dexterity to interact with the physical world. We look to take advantage of such unrestricted interaction for our own mixed reality experiences.

Pedro Lopes and his team at the HPIDE also worked towards simulating interactions with heavy and immovable objects in "Providing Haptics to Walls & Heavy Objects" research [4]. One of their goals is to prevent users' hands from penetrating virtual objects by adding haptic feedback for heavy/immovable objects by generating a strong counter-force using EMS. This effect is created by electrically actuating opposing muscle groups such as wrists, biceps, triceps, and shoulders. To create weight in biceps, the opposing muscle group is triceps, and to create tension in user's pectoralis, they used an opposing force in the deltoids. They were successfully able to create magnet-like repulsion from objects but were not able to replicate realism for touching a hard rigid surface such as a solid wall. From this, we learned that simulating tactile texture and rigidity would not be the most effective use case for EMS in making virtual interactions more realistic. On the other hand, we also realized that imitating repulsion and tension forces showed real promise, so we recalibrated our goal to work with simulating such forces with EMS.

Lastly, the HPIDE work that relates most to our own project is "Impacto: Simulating Physical Impact by Combining Tactile Stimulation with Electrical Muscle Stimulation" [5]. Impacto involves using a device to render the haptic sensation of punching and getting punched in virtual reality. It renders the tactile aspect of initial impact of hit by tapping the user's skin with a solenoid and then adds a strong impulse to the hit by using EMS to thrust the muscles to simulate an impact.

SYSTEM DESCRIPTION AND IMPLEMENTATION

For our project, we seek to further contribute to exploring impact forces involving conservation of momentum for EMS and VR.

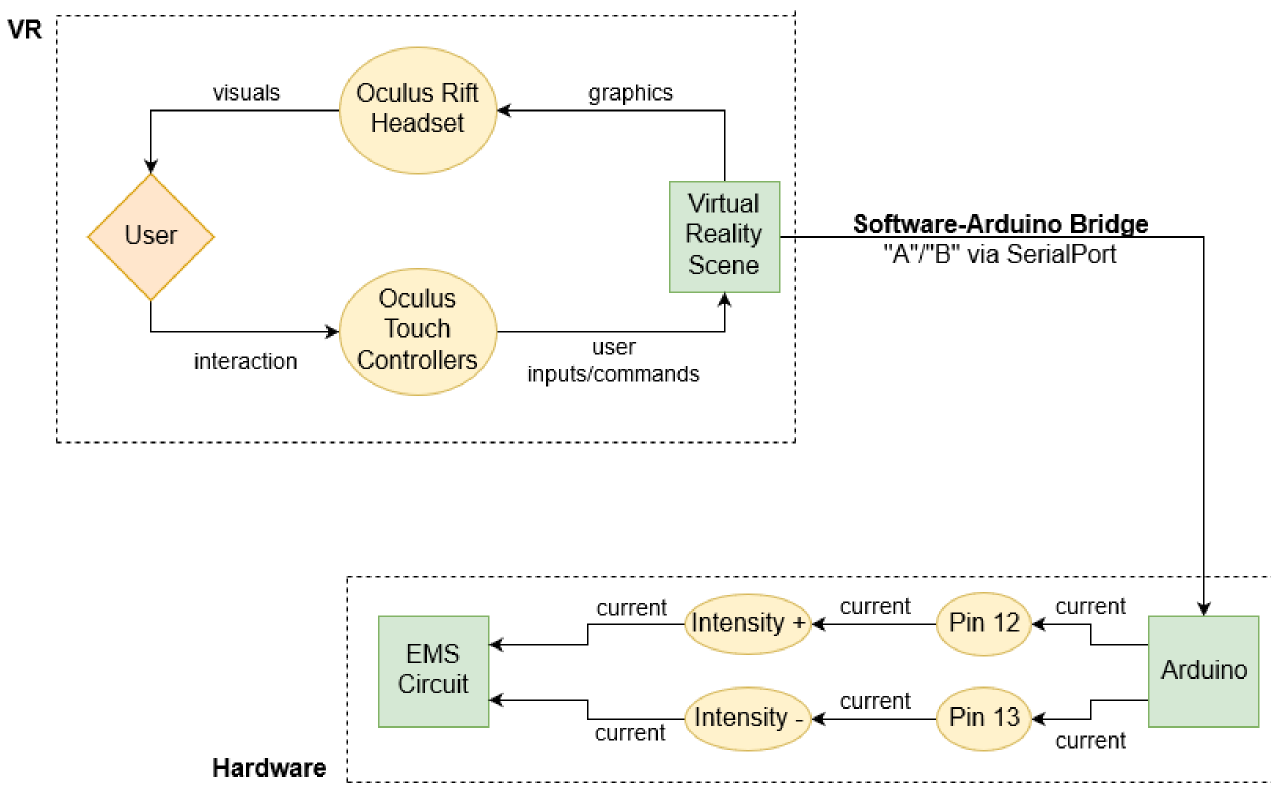

Figure 1: Three part system diagram: virtual reality, software-Arduino bridge, hardware.

To successfully emulate logically appropriate physical feedback from interactions in the virtual scenes, we divided the system into the following three parts (seen in Figure 1):

Virtual Reality

A user is placed in a virtual reality scene through the use of an Oculus Rift system. Each scene is designed to engage the user in a physical activity, such as pressing a trigger to shoot a gun (see Figure 2c) or hitting the bongos (see Figure 2b). We developed several scenes: a gun range where a user shoots a pistol or a shotgun at a target and receives EMS feedback which forces their wrist to flinch in order to recreate gun recoil, a basic patty cake game (see Figure 2a) where a user receives EMS feedback upon contact with virtual opponent's hands, a goalie scene where a user receives EMS feedback upon catching a soccer ball with their virtual hands, a tennis scene (see Figure 2d) where a user receives EMS feedback upon bouncing a tennis ball on the racquet, and a bongos scene where a user receives EMS feedback upon hitting the drum with their hand.

To account for latency, we choose to employ expectant tactics in software rather than in hardware. This design choice was driven by the fact that we were working with an existing EMS integrated circuit. Thus, in each VR scene, we placed canaries to determine when an action that should be followed by EMS feedback will take place. For example, in the gun range scene, when the user pulls the trigger to 10% of the full press, we send the signal to increase intensity, and only at full trigger press do we release the bullet and provide the user with visual stimuli to signify a successful shot.

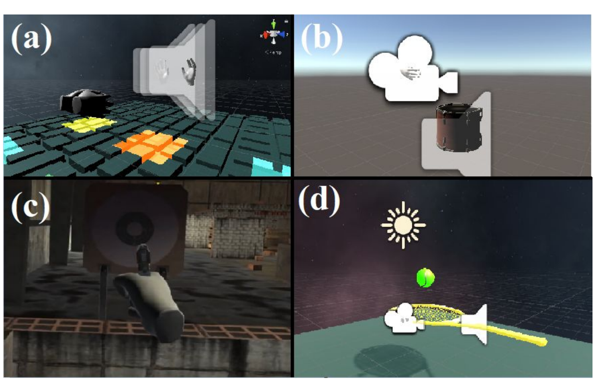

Figure 2: VR scenes: (a) patty cake game, (b) bongos, (c) gun range, (d) tennis.

Arduino-Unity-EMS Bridge

Each VR scenario, upon a physical interaction which could logically trigger a physical response, such as gun recoil affecting your shooting hand, sends a signal through a serial port to the Arduino. The signal signifies to either (A) increase intensity or to (B) decrease intensity.

EMS Hardware

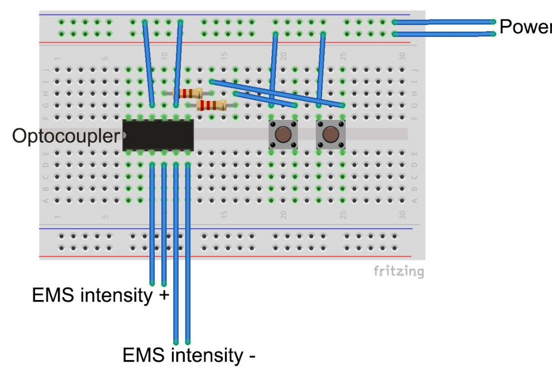

Figure 3: Fritzing diagram of the hacked EMS circuit.

To emulate the recoil of the gun through muscle stimulation, we choose to use an FDA approved EMS system sold on the market**.** This design choice was driven by cost and safety concerns: the existing system was cheaper than $40 and was cleared by FDA in terms of electrical current safety when applied to users. We have altered the circuit in the system to operate with an Arduino. By soldering the connections to new connectors, we were able to digitally manipulate the electrical pulse intensity. We used an optocoupler (see Figure 3) as a switch between the Arduino circuit and the EMS. We selected an optocoupler as they provide "electrical isolation" between the higher voltage on the primary side and the lower voltage on the secondary side **[6].** This allowed for separation of the Arduino and EMS circuit to prevent accidental damage to electrical components. To minimize any potential injuries to the user, we also installed an Emergency Stop button that breaks the power supply to the EMS system in an instant.

EVALUATION

Through rough user feedback consisting of our team members and some close friends, we have found that the EMS sensation varies by user. The threshold in which the device becomes uncomfortable is somewhat unclear due to the range of user's physical qualities. For the majority, an intensity level of 4, somewhat arbitrary as it is pre-defined by the EMS system integrated circuit, was the threshold at which the user began to feel uncomfortable. To ensure the comfort of the user, we chose to use a relatively low intensity level that none of its users have reported to be overly discomforting or painful. Currently, we have limited our tests to the user's arms as these extremities already hold the VR controller providing a prime opportunity for engagement.

We have also asked our users to report whether or not they believed a virtual reality experience they engaged in felt more or less immersive with the introduction of an EMS system. Upon attempting a virtual reality scene, each user was given a run through with and without EMS so that they could serve as their own control and experimental. This sort of study is inherently structured to yield qualitative data. To summarize, certain users felt certain scenarios were more immersive with the integration of EMS. For example, the gun range scene was reported to feel more immersive. We believe certain VR scenes lent themselves to be more immersive with EMS due to the simplicity of the feedback required (ex. gun recoil) and due to a better match between what the EMS system allowed us to feedback to the user and what the user expected (ex. from gun recoil from a pistol, a user expects just expects their wrist to flinch, which the EMS system that we employed allowed us to do).

DISCUSSION AND LIMITATIONS

From our own team's user testing, we found that each of the VR scenes benefitted from EMS to an extent, as the system was able to recreate muscle movements involved in shooting a gun, playing pattycake, hitting the drums, and bouncing a tennis ball with a racquet.

There are, of course, numerous limitations to our project. Given the relatively short time window to conduct a research project, we had to make some sacrifices. We had to hack a cheap commercialized EMS kit rather than building an entire system from scratch, leading to frustrating debugging sessions, multiple short-circuits frying our hard work, and unchangeable latency delays between our Arduino inputs and EMS outputs. Furthermore, using an existing integrated circuit restricted us to the EMS feedback that the original circuit itself was restricted to, as well as restricted our control of the circuit itself to that which the board provided us with. Another major sacrifice that the sparsity of time forced us to make, was the lack of formal mass user testing at this point in time. However, we look to augment to our user dataset and formalize our user studies at the Jacobs Design Showcase demos. We hope to design and run specific tests via a feedback form in order to gather accurate user reviews concerning our system.

CONCLUSION AND FUTURE WORK

We contribute to the exploration of augmenting virtual interactions with EMS haptic feedback. Starting with an FDA approved EMS kit that directly stimulates motor neurons to elicit muscle contractions, we hacked our way into the hardware to control the intensity via an Arduino. We then provided inputs to the Arduino through scripts in our VR Unity scenes that would send signals in order to provide feedback for certain actions or interactions. In this process, we were able to experiment with the intersection of EMS and VR for multiple interactions involving impact forces and momentum, ranging from gun recoil to pattycake to drums to tennis.

In future work, we would like to investigate the possibility of simulating more complex and intricate force interactions. In particular, the idea of simulating fluid viscosity via soft EMS simulation of the hand has piqued the curiosity of all of our team's members. Another area we would love to explore is the simulation of different textures such as wood grain or sandpaper. Both of these new research directions would require a much more customizable and robust EMS system. To accomplish this, we would create our own EMS hardware system based on guides such as that of Pedro Lopes, whom we have contacted. Lopes has graciously offered to provide all of the hardware supplies necessary to follow his guide if we decide to continue this project in the next calendar year.

References

1. Department of Neurosurgery, Columbia University. Evolving Techniques and Indications in Peripheral Nerve Stimulation for Pain. *Neurosurg Clin N Am.*2019.https://www.ncbi.nlm.nih.gov/pubmed/30898277

2. Reddy CG, Flouty OE, Holland MT, Rettenmaier LA, Zanaty M, Elahi F. Novel technique for trialing peripheral nerve stimulation: ultrasonography-guided StimuCath trial. *Newurosurg Focus.* 2017;42(3):E5. https://thejns.org/focus/view/journals/neurosurg-focus/42/3/article-pE5.xml
3. Pedro Lopes, Alexandra Ion, Sijing You and Patrick Baudisch. Adding Force Feedback to Mixed Reality Experiences and Games using Electrical Muscle Stimulation. In Proceedings of CHI'18. Full paper. https://hpi.de/fileadmin/user_upload/fachgebiete/baudisch/projects/mobile_force_feedback/2018-CHI-AR_Haptics_using_EMS_AuthorsCopy.pdf
4. Lopes, P., You, S., Cheng, L., Marwecki, S., and Baudisch, P. Providing Haptics to Walls and Other Heavy Objects in Virtual Reality by Means of Electrical Muscle Stimulation. In Proceedings of CHI'17. https://hpi.de/fileadmin/user_upload/fachgebiete/baudisch/projects/mobile_force_feedback/2017-CHI-VRwalls.pdf
5. Lopes, P., Ion, A., Baudisch, P. Impacto: Simulating Physical Impact by Combining Tactile Stimulation with Electrical Muscle Stimulation. In Proc. UIST'15. pp. 11-19. http://alexandraion.com/wp-content/uploads/Impacto-authors-copy.pdf
6. https://www.electronics-tutorials.ws/blog/optocoupler.htm