Haptic Tube for Hand-Sensed Motion of Objects

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***Abstract* - This project explores a magnetic haptic feedback mechanism with the goal of creating more convincing Mixed Reality experiences. We built a Haptic Tube that is accompanied by a magnetic glove. The aim is to emulate rotational sensation of cylindrical objects in the hand. Through pilot testing, it was found that a rotating armature fitted with magnets placed inside a pipe was sufficient in producing rotational sensations to a user wearing a glove containing a magnetic array.**

I. Introduction

In recent years, there have been research efforts in the field of mixed reality (MR) [1, 2]. These primarily focus on visual augmentation [3]. As a result, headsets, such as the Oculus and HoloLens, have been developed. However, to create a more immersive virtual environment, feedback from the other senses would to be provided. Currently, of the five senses, touch or haptic feedback is the least researched with respect to MR applications most probably due to the level of difficulty in reproducing the same sensations.

Currently, interaction with virtual objects in these MR environments does not emulate real-world interactions. For example, when using HoloLens 2, users can manipulate virtual objects by using 'pinching' and 'dragging' gestures which are akin to a computer mouse-screen interface [4]. However, to make a MR environment more convincing the users should be able to interact with virtual objects the same way they would with real ones. For example, picking up a virtual ball while feeling haptic and kinesthetic feedback in the same way they would a real one.

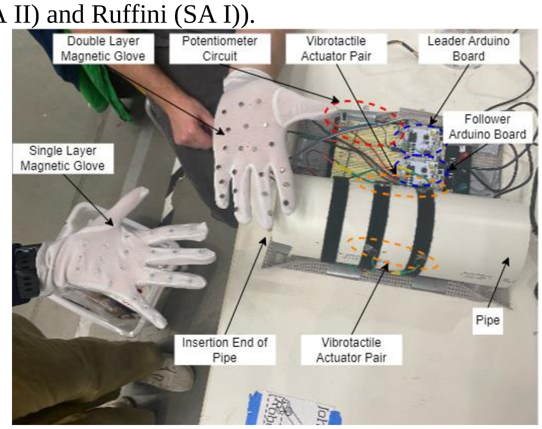
Haptic feedback would improve the MR experience as virtual interaction based on purely visual feedback is not sufficient [5]. The virtual object could be occluded, or perspective could create undesired visual illusions. While there has been research into integrating haptic feedback for static objects in the hand [6, 7], research lacks in trying to represent moving objects in the hand. Modelling dynamic objects via haptic feedback is needed as these often precede any visual feedback such as when a mug starts to slip out of hand or a climber begins to lose their grip on a rock-climbing hold. Thus, in this project, we investigated the efficacy of producing effective haptic feedback sensations using a glove actuated by magnets in order produce the perception of moving objects in the hand.

II. Methods

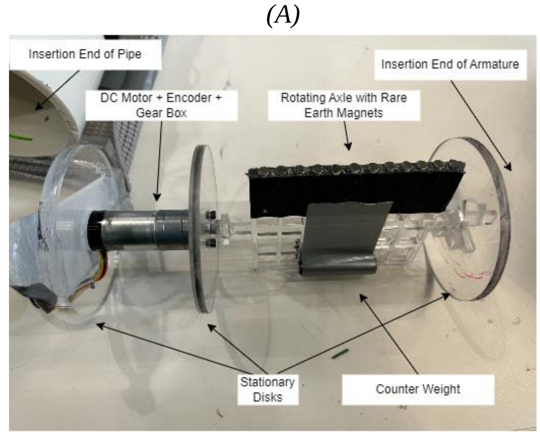
In order to examine our proposed haptic feedback method performance in emulating moving objects we designed a haptic tube (*HT*) device. Various actuators were considered for the *HT*, such as voice coils for cutaneous excitation as well as a capstan system to provide kinesthetic feedback. However, after initial haptic sketches, we chose magnets and vibrotactile actuators to provide the cutaneous haptic feedback in conjunction with a rigid structure (tube) to provide kinesthetic feedback. It was found that using magnets of opposing polarity provides both compression and shear forces on the skin, which makes this a cutaneous device.

A. Device Description

The final design, depicted in Figure 1, is a cylindrical PVC pipe that houses an armature containing a rotating axle fitted with magnets. This device is accompanied by a glove impregnated with an array of magnets of opposing polarity to those fixed to the armature's axle. Thus, we aim to target the relevant receptors located on the palm and inner side of the fingers of the hands (i.e. Meissner (RA I), Pacinian Corpuscle (PC / RA II) and Ruffini (SA I)).



(A)



(B)

Figure 1: Final design (A) custom magnet glove and haptic tube (B) rotating armature

1) Mechanical

Our mechanical housing consists of a 4-in inner diameter PVC pipe of ¼-in thickness. The PVC pipe was adhered to an acrylic sheet via supports. An armature was laser cut out of 5.56mm acrylic sheets. The design of the armature included cut-out holes to reduce its weight as well as provide attachment spaces for the magnets. The armature was rigidly attached to a DC motor to allow for rotation. Vibrotactile actuators were attached to the PVC pipe using Velcro to accommodate varying user hand sizes.

2) Electronics

The DC motor and vibrotactile actuators were controlled using two Hapkit Arduino Uno boards. A potentiometer was used to vary the rotational direction and speed of the DC motor. As illustrated in the figure below, the center band mapped to a speed of 0 (no rotation). And increasing in either of the two directions will increase the speed in a direction.

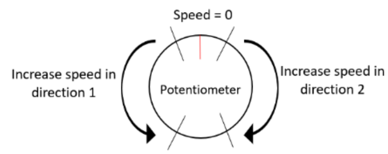


Figure 2: Potentiometer mapping

The motor was controlled by using the motor direction and PWM pins on the Leader Hapkit board. Due to the limited number of motor driver pins on a single board as well as the total current draw limitation of approximately 1A for the Arduino Uno, a Follower Arduino board was used to control the four vibrotactile actuators. There is a simple 2-pin (digital-to-digital) communication schema between the two boards with each pin signaling which vibrotactile actuator pair to actuate. The Leader sets two digital pins high or low determined by the output of the motor's quadrature encoder. The Follower reads these in from digital pins and fires the vibrotactile actuators when needed. The vibrotactile actuation signals are synchronized with the rotation of the magnetic half of the armature's axle as it passes under the vibrotactile actuators.

B. Preliminary Results

We successfully built our design of the *HT*. Based on pilot testing, some users confirm spinning sensation, while others perceived feeling oscillations like that of a beating heart.

Our first design of the apparatus tried to incorporate the vibrotactile actuators and kinesthetic feedback directly into the glove. However, in addition to difficulty building current supply circuits for multiple actuators, we discovered that commercially available vibrotactile actuators could not be miniaturized enough to fit as many of them as needed onto the glove. Our second and final design of the apparatus converged to the current *HT*. While this design eventually proved successful, we had initial heat and vibration problems due to our initial use of a hobby stepper motor that produced excessive heat and generated excessive vibrations at higher speeds. We were able to mitigate these issues by switching to a quadrature encoder plus DC motor (Tsiny Motor TS-25GA370H-10) as well as a layer of compressible, vibration dampening material attached to the *HT's* base. However, a common criticism of the system is still that vibrations induced by movement of imprecisely laser-cut parts within the *HT* cause vibrations strong enough to make the vibrotactile actuators difficult to sense.

III. FUTURE WORK

A. Future Development

Our current *HT* injects unwanted vibrational noise into the system due to the need to use moving parts. The design can be optimally improved by using small electromagnetic coils arranged in a radial array within the pipe instead of the moving armature and axle with magnets. The number of electromagnetic coils would likely number around one hundred. The firing of these electromagnetic coils can be individually timed and synchronized to produce a variety of feedback options to mimic movement. Furthermore, this *HT* design will be smaller, portable and handheld, allowing it to be more easily paired with Mixed Reality applications (e.g. via the HoloLens 2). In order to achieve this quantity of electromagnetic actuators, we would need a more robust power circuit; we would need an op-amp circuit with enough current/voltage supplies (one per actuator) that can be controlled by the analog pins on one to two Arduino Uno boards.

B. User Study Protocol

For the user study, we seek a minimum of ten participants. We would attempt to find a balance of genders in the study as well as a uniform distribution of hand sizes and occupations. We would reject any participants with non-hand dominance, hand amputations, hand injuries (cuts, bruises, missing fingers, extra sensitive skin etc.) or conditions that inhibit normal sensation and flexibility of the hand. We will need an equal number of representatives from occupations that require heavy manual labor involving the hands (e.g. construction workers) as compared to the number of representatives of occupations that don't require much forceful use of the hands (typists).

Our user study would take place at Johns Hopkins University's HAMR Lab and would be a system performance study with the aim of determining the efficacy of our *HT* in portraying the sensation of a rotating cylinder within the hand. We would perform a within-subject user study. Each subject will test our proposed *HT* and compare its sensations to a mechanized rotating cylinder of identical dimensions to the *HT* with each hand. The subjects will be blindfolded during the test and wear noise-cancelling headphones to reduce extraneous sensory feedback. After each hand trial, the subjects will complete a survey detailing their answers to the evaluation metrics discussed below.

C. Evaluation Metrics

Our quantitative metrics will be: 1) The error rate of the user's perceived rotational speed versus the intended rotational speed in terms of three speed bands (i.e. low, medium and high) which equally partition the range 0.1-10Hz and 2) the error rate of the user's perceived direction of rotation versus the intended rotational direction (i.e. clockwise vs counter-clockwise when viewing the *HT's* pipe down its longitudinal axis from its insertion end).

Our qualitative metrics will be: 1) strength of rotational perception in terms of three strength bands (i.e. low, medium, high) and 2) their overall thoughts and comments on the dimensions and hand-portability of the system.

REFERENCES

[1] Y. Chen, Q. Wang, H. Chen, X. Song, H. Tang, and M. Tian, "An overview of augmented reality technology," Journal of Physics: Conference Series, vol. 1237, no. 2, p. 022082, 2019.
[2] P. Cipresso, I. A. Giglioli, M. A. Raya, and G. Riva, "The past, present, and future of virtual and Augmented Reality Research: A network and cluster analysis of the literature," Frontiers in Psychology, vol. 9, 2018.
[3] J. Xiong, E.-L. Hsiang, Z. He, T. Zhan, and S.-T. Wu, "Augmented reality and virtual reality displays: Emerging technologies and future perspectives," Light: Science & Applications, vol. 10, no. 1, 2021.
[4] Mamaylya, "Hololens 2 gestures for authoring/navigating in Dynamics 365 guides - dynamics 365 mixed reality," HoloLens 2 gestures for authoring/navigating in Dynamics 365 Guides - Dynamics 365 Mixed Reality | Microsoft Learn, 2021. [Online]. Available: https://learn.microsoft.com/en-us/dynamics365/mixed-reality/guides/authoring-gestures-hl2. [Accessed: 18-Dec-2022].
[5] H. Liu, Z. Zhang, X. Xie, Y. Zhu, Y. Liu, Y. Wang, and S.-C. Zhu, "High-fidelity grasping in virtual reality using a glove-based system," *2019 International Conference on Robotics and Automation (ICRA)*, 2019.
[6] Y. Zhang, D. Wang, Z. Wang, Y. Wang, L. Wen, and Y. Zhang, "A two-fingered force feedback glove using soft actuators," *2018 IEEE Haptics Symposium (HAPTICS)*, 2018.
[7] M. Bouzit, G. Popescu, G. Burdea, and R. Boian, "The Rutgers master II-ND Force Feedback Glove," *Proceedings 10th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems. HAPTICS 2002*.