Development of a Wearable Embedded System providing Tactile and Kinesthetic Haptics Feedback for 3D Interactive Applications

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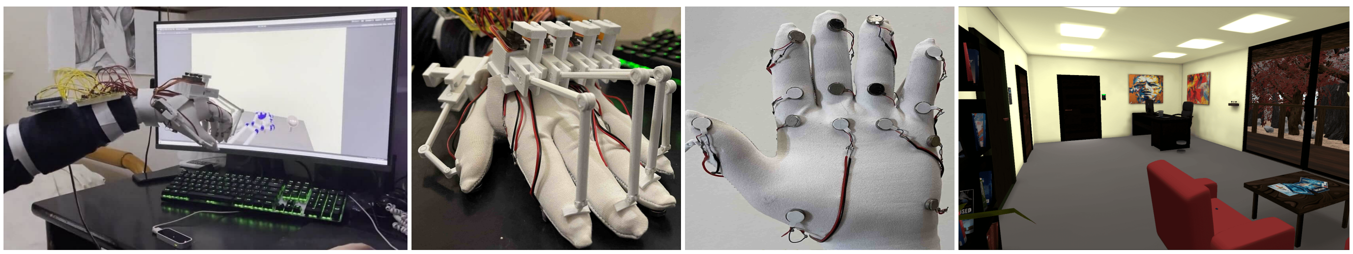

Figure 1: (a) Haptic interface side view (b) Exoskeleton view (c) Vibration motors placement in the hand (d) Game application

ABSTRACT

Existing haptic interfaces providing both tactile and kinesthetic feedback for virtual object manipulation are still bulky, expensive and often grounded, limiting users' motion. In this work, we present a wearable, lightweight and affordable embedded system aiming to provide both tactile and kinesthetic feedback in 3D applications. We created a PCB for the circuitry and used inexpensive components. The kinesthetic feedback is provided to the user's hand through a 3D-printed exoskeleton and five servo motors placed on the back of the glove. Tactile feedback is provided to the user's hand through fifteen coin vibration motors, placed in the inner side of the hand and vibrating at three levels. The system is ideal for prototyping and could be customized, thus, making it scalable and upgradable.

CCS CONCEPTS

• **Computer systems organization** → *Firmware*; **Sensors and actuators**; • **Human-centered computing** → **Haptic devices**.

KEYWORDS

Embedded Systems, Haptics, 3D Environments

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1 INTRODUCTION

Touch is a sense deployed on touch screens or along with haptics. Haptic technology simulates touch while interacting with 3D objects, employed in virtual reality (VR), tele-operation, robotics, cultural heritage etc [Pierce et al. 2014], [Ma et al. 2015]. Haptic devices that provide tactile and kinesthetic feedback are heavy and cumbersome because of exoskeletons, motors and circuitry placed on the upper side of the hand [Pacchierotti et al. 2017]. Past work focused mainly on grounded implementations rather than wearable ones, limiting user's motion and sense of immersion [FundamentalVR 2018], [Roboligent 2018], [Nisar et al. 2019]. Haptics for cultural heritage utilized grounded devices [Ceccacci et al. 2021], [Jamil et al. 2018]. Microfluidic technology for tactile feedback and an exoskeleton for kinesthetic feedback results in a wearable but expensive and heavy system [Haptx 2018]. A haptic glove provides tactile, kinesthetic and temperature feedback, but, only for one finger [Kato et al. 2019]. Recently, wireless embedded systems for hand motion capture and tactile feedback either lack kinesthetic feedback [Efraimidis and Mania 2020] or even with superb tactile and kinesthetic capabilities, are quite expensive and cannot be fully customized [Gu et al. 2016]. In this poster, we propose an innovative, wearable, embedded system on a glove consisting of an exoskeleton comprising of 5 servo motors placed on the back of the hand for kinesthetic feedback (Figure 1b). On top, we used 15 vibration motors placed on the palm and the fingers, controlled by an Arduino microcontroller providing scalable tactile feedback to the user. Our system is lightweight providing both tactile and kinesthetic feedback to be deployed along diverse 3D scenes.

2 IMPLEMENTATION

We propose a wearable, lightweight, embedded haptics system providing both tactile and kinesthetic feedback for 3D interactive applications. The motors providing the haptic feedback are controlled by the Arduino Mega 2560 Rev3 (Figure 2, black box 3), connected with the computer via USB. Hand tracking employs the Leap Motion controller. The haptic interface simulates touch and manipulation of virtual objects employing a lighter exoskeleton for kinesthetic feedback and multiple vibration motors for tactile feedback (Figure 2). The system comprises of:

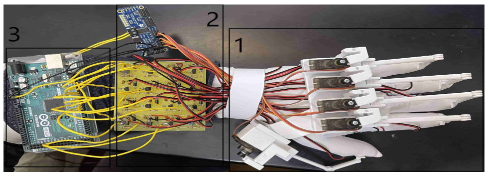

Figure 2: Haptic interface top view

15 independent points of tactile feedback. 15 2.5-3.8V 10mm, shaftless vibration motors of 3.4mm button type were placed on the glove, one on each fingertip, one on the bottom part of each finger, 5 on the top part and one on the side of the palm (Figure 1c). Each motor is enabled independently, according to which finger operates a touch action. These motors require higher current than the output current from the Arduino pins, therefore, we created a driver circuit. The pins are powered with 5V and the motors' with 3V, thus, we used PWM to reduce the applied voltage.

3 independent levels of vibration intensity. The user can perceptually distinguish the strength of the contact with a 3D object by adding a low level of vibration for light touching, a medium level for average touch pressure and a high level for strong touch pressure. We connect the motors to PWM pins and setting the duty cycle lower for low level or higher for high level vibration.

3D printed exoskeleton for the kinesthetic feedback. The exoskeleton consists of 16 independent parts designed from scratch forming the exoskeleton, divided into the finger and the servo motor section. The kinesthetic feedback is provided by adding one micro 4.8-6V 2.8kg*cm servo motor on each servo motor section (Figure 2, black box 1) connected with a rotational joint and constraining the finger's movement whenever the virtual finger collides with virtual objects. The servo motors were not directly connected to the Arduino. If they were, each servo would have consumed a pin and Arduino processing power. We used the PCA9685 Servo Driver connected with the Arduino over I2C with only two pins.

Wearability by adding PCB. To decrease the weight and bulkiness of the device, a printed circuit board was designed and printed instead of a breadboard as regards the connections of the electronic components (Figure 2, black box 2).

3 EVALUATION

We implemented a 3D escape-type game to be customized in any context, modern or historical. Users are placed outside of a room. Their first task is to open the front door by placing their hand in a black box which works as a scanner. They feel vibrations as the hand is being scanned. Users' next task is to pull three levers in order to open the balcony door. Finger movement is blocked by the exoskeleton's braking part controlled by the servo motors (kinesthetic feedback) while vibration motors are enabled (tactile feedback). Then, users are required to grab and place two spheres on top of a platform/scale revealing a code unleashing the fourth task. Their finger movement is blocked and vibration motors provide both tactile and kinesthetic feedback. Users enter the code using a keypad, feeling three levels of vibration intensity depending on the power of the impact between the finger and the button.

Apparatus & Discussion. 3 graduate and 7 undergraduate computer engineering students wore our haptic interface and played the game. They successfully completed the tasks fast and were fascinated by the multi-level vibration intensity and kinesthetic feedback. Hand tracking based on the Leap Motion device requires improvement. The system was lightweight but also fatiguing at times, especially after long exposure. Users were immersed in the experience and reported that the sensory feedback was remarkable.

4 CONCLUSION AND FUTURE WORK

We propose a wearable embedded system providing tactile and kinesthetic haptics feedback for 3D interactive applications. In the future, we aim to decrease the size and weight of the device by redesigning the exoskeleton. A new system utilizing machine learning will be implemented to replace the Leap Motion device for more accurate hand tracking. Furthermore, we would like to adjust the stiffness of the servo motors in order to provide feedback on the softness or hardness of the objects. Finally, we target to make the device wireless so that the user is not constrained by cables. We will test this device in diverse scenes including for cultural heritage.

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