An Untethered Multimodal Haptic Hand Wearable

Alexander C. Abad[1,2]*, Manex Ormazabal[1†], David Reid[1‡] and Anuradha Ranasinghe[1§]
[1]School of Mathematics, Computer Science and Engineering,
Liverpool Hope University, Hope Park — Liverpool L16 9JD. UK.
[2]ECE Department, GCOE, De La Salle University, Manila, Philippines
Email: *abada@hope.ac.uk, †20211323@hope.ac.uk, ‡reidd@hope.ac.uk, §dissana@hope.ac.uk

***Abstract*—Haptic primary colors correspond to temperature, vibration, and force. Previous studies combined these three haptic primary colors to produce different types of cutaneous sensations without the need to touch a real object. This study presents a low-cost untethered hand wearable with temperature, vibration, and force feedback. It is made from low-cost and commercial off-the-shelf components. A 26 *mm* annular Peltier element with a 10 *mm* hole is coupled to an 8 *mm* mini disc vibration motor, forming vibro-thermal tactile feedback for the user. All the other fingertips have an 8 *mm* disc vibration motor strapped on them using Velcro. Moreover, kinesthetic feedback extracted from a retractable ID badge holder with a small solenoid stopper is used as force feedback that restricts the fingers' movement. Hand and finger tracking is done using Leap Motion Controller interfaced to a virtual setup with different geometric figures developed using Unity software. Therefore, we argue this prototype as a whole actuates cutaneous and kinesthetic feedback that would be useful in many virtual applications such as Virtual Reality (VR), teleoperated surgeries, and teleoperated farming and agriculture.**

***Index Terms*—haptic wearable, haptic primary colors, Peltier device**

I. Introduction

The last decades have seen research on both haptics tactile transducers steadily increasing. Haptics has grown into an interdisciplinary research covering perception [1], psychophysics [2], vision substitution system [3], [4], bio-medical engineering [5], telecommunication [6], e-shopping [7], teleoperation [8], telerobotics [9], material recognition [10], Human-Computer Interaction (HCI) [11], [12], and Virtual Reality (VR) environments [5], [7], [13]–[15].

Recent research on haptic feedback tends to focus on the portability and miniaturization of actuators with applications in virtual reality (VR) to provide a more immersive experience [5], [7], [13], [16]–[18]. According to [19], aside from vision and audio, the development of the portable tactile display is needed for all VR technology. Tachi et al. theorized that haptics, like light, can be reduced to three components and named them as Haptic Primary Colors (HPC) known as force, vibration, and temperature that corresponds to tactile and thermal sensation receptors [20].

Some work has already taken place developing haptic devices for the hand to enhance the immersive experience and to facilitate interaction with objects in the virtual or remote environment [5], [7]. In addition to mechanical and electrical-based haptic devices, a multimodal tactile module combining vibration and temperature (vibro-thermal) feedback was proposed by Nakatani et al. [21]. This vibro-thermal tactile device was further improved by Kato et al. and combined it with force display to simulate degrees of softness [14].

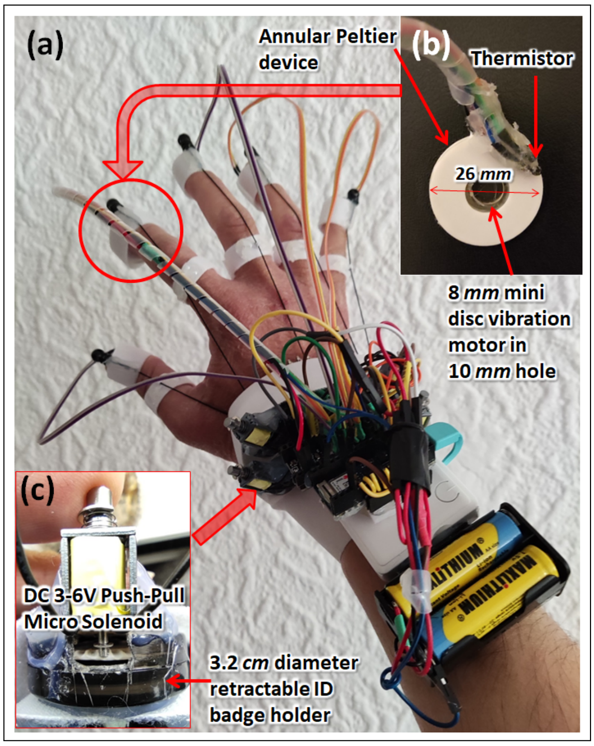

Fig. 1. Untethered haptic hand wearable with haptic primary colors feedback. (a) The hand wearable haptic has cutaneous and kinesthetic haptic feedback. Each fingertip has mini disc vibration motor. Aside from mini vibration motor, the index fingertip has an annular Peltier device making it a vibro-thermal haptic feedback as shown in Fig. 1(b). The force feedback that can restrict the movement of each finger is formed by combining a retractable ID badge holder and small solenoid stopper as shown in Fig. 1(c).

One of the major determining factors in the success of spatial computing involves natural interaction with the real, augmented, or virtual environment. Naturalistic interaction aids communications, cooperation, and integration between humans and robots [5]. Conversely, if the interaction is unnatural, then communication between these agents is severely hindered. The comfort and wearability of haptic devices are also significant considerations that come as a combination of form factor, weight, shape, ergonomics, and functionality [5], [7]. Haptic feedback for wearable can be in the form of cutaneous stimuli, kinesthetic stimuli, or the combination of both types of stimuli [1], [5], [7].

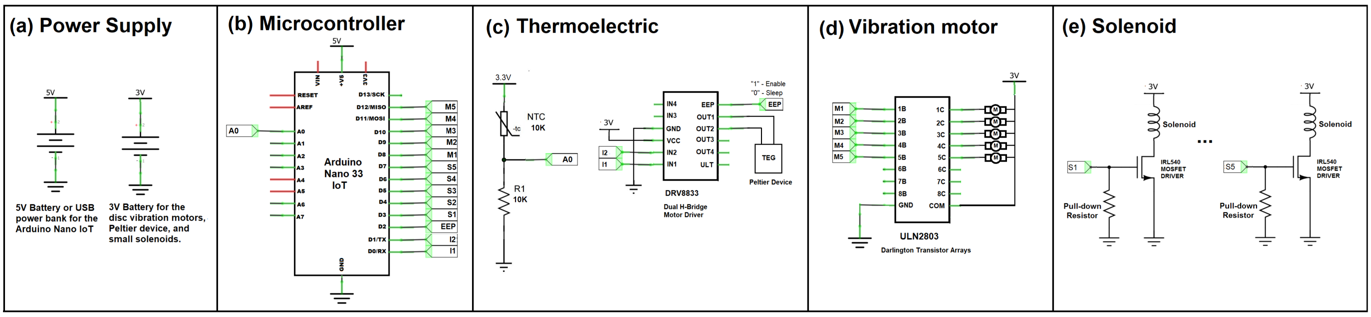

Fig. 2. Schematic diagram of the prototype has 5 sections: (a) power supply, (b) microcontroller, (c) thermoelectric, (d) vibration motor, and (e) solenoid.

Spatial computing research is starting to examine the wearability and portability of haptic devices [5], [7], [23], [24]. This can directly affect the immersive experience [12], [19], [23]. Cutaneous feedback enhances the performance and effectiveness of teleoperation and immersive systems by providing an effective and sophisticated way to simplify the design of a wearable haptic device [5].

Moreover, realization of a compact untethered hand wearable with fingertip cutaneous vibro-thermal tactile feedback aiming at integration with a kinesthetic force feedback systems such as restricting finger movements during grasping or touching a 3D VR object is a real challenge. More research is needed in reducing the size of tactile feedback mechanism to an acceptable level without compromising bandwidth, spatial resolution, and strength of the transducer [22], [23].

This paper presents a novel untethered haptic hand wearable as shown in Fig. 1(a) with temperature, vibration, and force feedback representing the haptic primary colors (HPC) [20]. The force feedback in this study restricts finger movement during touching or grasping VR objects. Details on the prototype are discussed in the following sections: construction of the prototype in section II, experimental setup in section III, experimental results in section IV, followed by conclusion in section V.

II. Construction of the Prototype

The construction of the haptic wearable focuses on two categories: They are hardware, and software.

A. Hardware: schematic and building blocks

This section focuses on using commercial off-the-shelf components to develop a haptic wearable with temperature, vibration, and force feedback. Although our prototype has temperature, vibration, and force feedback as [14], our focus is to apply a stopping force to restrict finger movement during touching or grasping of VR objects. Instead of using a DC geared motor to control the thread for force feedback, we used a retractable ID badge holder inspired by Lucas [25] and put a small solenoid to stop the reeling as shown in Fig. 1(c) and a CAD view in Fig. 4b. Unlike [25], we eliminated 3D printed parts, or potentiometer to sense finger movement.

The schematic diagram of our prototype is shown in Fig. 2. The schematic is divided into five sections, namely: (a) power supply, (b) microcontroller, (c) thermoelectric, (d) vibration motor, and (e) solenoid section. We used a 5V DC power supply for our microcontroller and a 3V DC supply for the disc vibration motors and solenoids.

We used Leap Motion Controller [26] for hand and fingertip tracking. An Arduino Nano IoT [27] is the microcontroller used to control the motor drivers (IRL540 and ULN2803) and h-bridge module (DRV8833). This microcontroller has WiFi and Bluetooth wireless connectivity. We developed a simple vibro-thermal feedback module composed of an 8 *mm* disc vibration motor with 11000 *rpm* inserted on an annular Peltier device (TES1-04903 Thermoelectric Peltier) with 10K NTC thermistor as its temperature sensor as shown in Fig.1(b). We used a 3.2 *cm* diameter retractable ID badge holder with a small solenoid [28] stopper to stop and release the retractable thread. The plastic disc inside the badge holder can be exposed by cutting some portion of the casing. Grooves on the edge of the badge's disc, as shown in Fig. 1(c), can be made using the tip of a hot soldering iron. When the solenoid shaft is pulled down towards the groove, like a door lock mechanism, it will stop the turning of the disc, thus restricting the pulling of the string connected to the fingertip.

B. Software: firmware and application layer

We used Arduino IDE to develop the firmware that controls the vibration motors, solenoids, and the Peltier device. Application software was developed using Unity. Leap Motion Controller is used as a hand and fingertip tracking device to monitor the position of the hands in virtual reality (VR). Each fingertip in the VR has a contact collider that detects a collision with a virtual object. If there is a collision between the VR hand fingertip with a 3D body, it signals to the haptic wearable's corresponding actuator. Both the vibration motor and solenoid are simultaneously activated whenever there is a collision. The solenoid stops the reeling of the retractable badge and restricts finger movement. Moreover, aside from the vibration motor, the index fingertip has an annular Peltier element activated to get hot or cold depending on the touched 3D VR object. In this study, the Peltier device gets hot, when the VR index fingertip touches the red cube and gets cold when it touches the blue cylinder as shown in Fig. 3. Actuation signals from the laptop are sent to the prototype via Bluetooth connection.

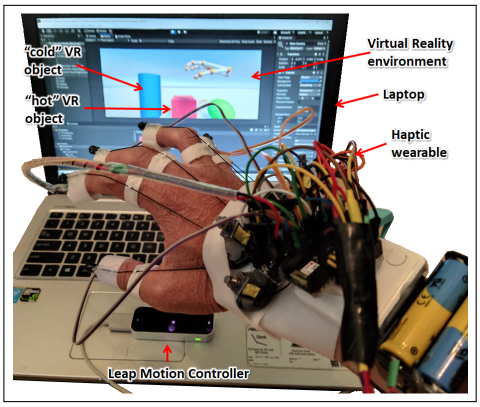

Fig. 3. Untethered Haptic wearable experimental setup. The blue cylinder in VR environment represent a "cold" VR object while the red cube represent a "hot" VR object.

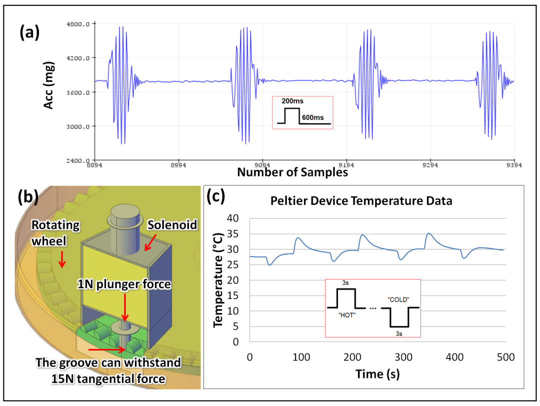

Fig. 4. Test results. (a) Vibration test using MPU-9250 accelerometer, (b) perpendicular plunger force, and stopping force on the retractable ID badge holder, and (c) Peltier device temperature test.

III. Experimental Setup

1) Description of Experimental Configuration: The experimental setup is shown in Fig. 3 has four basic elements: laptop, Leap Motion Controller, haptic wearable, and the VR environment. We used a Leap Motion Controller [26] as an input optical hand tracking device that captures hand and finger movements. It can track them even when they are obscured by other parts of the hand [26]. A VR environment was developed using Unity and has a blue cylinder, red cube, and green sphere with collision detection. Moreover, our haptic wearable prototype has an open palm design so that the Leap Motion Controller can track the hand and the fingers. When any of the fingers collide with any 3D VR object, an activating signal is sent to the corresponding vibration motor and solenoid stopper. However, unlike the other fingertips the index fingertip also checks if it has touched a red square or blue cylinder. When the VR index fingertip touches the red square, a "hot" signal is sent to the Peltier device controller to make it hot. In contrast, the blue cylinder will send a "cold" signal making the Peltier device cold when touched.

2) Current consumption: We used a 1200 *mAh* USB power bank for the microcontroller. We also used four 1.5V dry cells to form 2 sets of 3V DC supply for the actuators and Peltier device. Each 8mm disc vibration motor consumes 63 *mA*, while each solenoid consumes 700 *mA* of current at 3V. Moreover, the Peltier device that we used consumes a maximum of 1.5A at 3V, so only the index finger has it.

IV. Experimental Results

1) Vibration Test: We managed to activate all mini disc vibration motors and the corresponding solenoid that restricts finger movement whenever a fingertip in the VR hand touches a VR object. We used MPU-9250 accelerometer to capture the vibrations of motor as shown in Fig. 4(a).

2) Force Test: We used force gauge to measure the pulling strength of the retractable ID badge holders and the stopping force of the solenoid. By pulling a 15 *cm* string and measuring vertically using a force gauge, the pull force of ten pieces of 3.2 *cm* diameter retractable ID badge holders ranges from 1.3N to 1.5N with a mean value of 1.4N and standard deviation of 0.067N. On the other hand, when the solenoid is activated, it has a 1N push force perpendicular to the disc of the retractable ID badge holder as shown in Fig. 4(b). The groove can withstand 15N tangential force.

3) Temperature Test: We evaluated the performance of the Peltier device by cooling it down for 3 seconds and turning it off until it stabilizes, and warming it up by 3 seconds before turning it off again. We presented three cycles with 2 *Hz* sampling time as shown in Fig. 4(c). The ambient temperature is around 29°C. We observed that once the Peltier device was heated up, the cooling time is twice longer than the warming up from cold to ambient temperature. The asymmetrical cooling and warming time has been reported in many papers [14], [21] and four tile configuration has been proposed by [29] to improve the time to perceive temperature change by 36%.

V. Conclusion

This study presented a novel untethered haptic wearable with temperature, vibration, and force feedback that can be used for VR applications. There are five 8 *mm* disc vibration motors on each fingertip strapped using Velcro. The vibration motor is inserted in an annular Peltier device on the index fingertip to form vibro-thermal haptic feedback. A thermistor is attached to the Peltier device as a feedback mechanism. "Hot" and "cold" signals were assigned to VR objects that activates the Peltier device. Moreover, five retractable ID badge holders with a small solenoid stopper on each were used as force feedback that restricts finger movement. A VR application was developed using Unity, and a Leap Motion Controller was used as a hand tracking device. Vibration motors and solenoid stoppers were activated whenever the VR hand finger touches a VR object. The prototype can be used in extended realities such as VR, augmented reality, and mixed reality to enhance our immersive experience.

Acknowledgment

The authors would like to thank: Liverpool Hope University, De La Salle University - Manila, and DOST-ERDT for helping us in this study.

REFERENCES

[1] S. J. Lederman, R. L. Klatzky, "Haptic perception: A tutorial," Attention, Perception, & Psychophysics, 2009, 71(7), 1439-1459. doi: 10.3758/APP.71.7.1439

[2] M. Ide, A. Yaguchi, M. Sano, R. Fukatsu, M. Wada, "Higher Tactile Temporal Resolution as a Basis of Hypersensitivity in Individuals with Autism Spectrum Disorder," Journal of Autism and Developmental Disorders (2019) 49:44–53, https://doi.org/10.1007/s10803-018-3677-8

[3] J. C. Bliss, M. H. Katcher, C. H. Rogers, and R. P. Shepard, "Optical-to-tactile image conversion for the blind," IEEE Trans. Man-Mach. Sys., vol. 11, no. 1,pp. 58–65, Mar. 1970.

[4] S. F. Frisken-Gibson, P. Bach-Y-Rita, W. J. Tompkins, and J. G., Webster, "A 64-Solenoid, Four-Level Fingertip Search Display for the Blind," IEEE Transactions on Biomedical Engineering, VOL.BME-34, NO. 12, 1987

[5] C. Pacchierotti, S. Sinclair, M. Solazzi, A. Frisoli, V. Hayward and D. Prattichizzo, "Wearable haptic systems for the fingertip and the hand: Taxonomy review and perspectives", IEEE Trans. Haptics, vol. PP, no. 99, pp. 1-1, 2017

[6] Dong-Soo Kwon, Tae-Heon Yang, JoonYeon Cho, "Trend & prospects of haptic technology in mobile devices," Symposium on Industrial Electronics (ISIE), IEEE, pp.3778–3783, July 2010.

[7] D. Wang, M. Song, A. Naqash, Y. Zheng, W. Xu and Y. Zhang, "Toward Whole-hand Kinesthetic Feedback: A Survey of Force Feedback Gloves", IEEE Transactions on Haptics. Volume: 12, Issue: 2, April-June 1 2019

[8] Z. Kappassov, J.-A. Corrales, V. Perdereau,, "Tactile sensing in dexterous robot hands - Review," Robotics and Autonomous Systems, Elsevier, 2015, 74, Part A, pp.195-220.

[9] Y. Shen, Y. Liu, and L. Kejie,"Haptic Tactile Feedback in Teleoperation of a Multifingered Robot Hand," Proc. Third World Congress Intelligent Control and Automation, vol. 1, pp. 85-90, 2000.

[10] Yu Xie, Chuhao Chen, Dezhi Wu, Wenming Xi, and Houde Liu, "Human-Touch-Inspired Material Recognition for Robotic Tactile Sensing," Applied Sciences, June 2019, 9(12):2537, DOI:10.3390/app9122537

[11] Y. Visell, "Tactile sensory substitution: Models for enaction in HCI," Interacting with Computers, vol. 21, no. 1–2, pp. 38-53, Jan. 2009.

[12] M. Benali-Khoudja, M. Hafez, A. Kheddar, "VITAL: An electromagnetic integrated tactile display," Displays 28(3), 133-144(2007).

[13] F. Kato, Y. Inoue and S. Tachi: "Soft Finger-tip Sensing Probe Based on Haptic Primary Colors," Proc. of Int. Conf. on Artificial Reality and Telexistence and Eurographics Symposium on Virtual Environments (ICAT-EGVE), pp.107–114, 2018.

[14] F. Kato, Y. Inoue, S. Tachi, "Haptic Display Glove Capable of Force/Vibration/Temperature", 2019 IEEE International Symposium on Measurement and Control in Robotics (ISMCR), Houston, TX, USA, 19-21 Sept. 2019. DOI: 10.1109/ISMCR47492.2019.8955735

[15] E. L. Secco, A. T. Maereg, D. Reid, and A. K. Nagar, "An integrated haptic system combining VR, a markerless motion capture system and tactile actuators," ICST Trans. Ambient Syst., vol. 5, no. 17, p. 154375, Mar. 2018, doi:10.4108/eai.23-3-2018.154375.

[16] Hands-on: Dexmo Haptic Force-feedback Gloves are Compact and Wireless, https://www.roadtovr.com/dexta-dexmo-vr-gloves-force-feedback-haptic-hands-on/ (accessed on 24 May 2021)

[17] BeBop Forte Data Gloves, https://bebopsensors.com/arvr/ (accessed on 24 May 2021)

[18] HaptX Gloves DK2 haptic VR gloves with 133 tactile sensors per hand, https://www.geeky-gadgets.com/haptic-vr-gloves-28-01-2021/ (accessed on 24 May 2021)

[19] T. Fukuda, H. Morita., F. Arai, H. Ishihara and H. Matsuura, "Micro Resonator Using Electromagnetic Actuator for Tactile Display," 1997 International Symposium on Micromechatronics and Human Science, Nagoya, Japan, Oct 1997.

[20] S. Tachi, K. Minami zawa, M. Furukawa, and C. 1. Fernando, "Haptic Media: Construction and Utilization of Humanharmonized " Tangible" Information Environment," 2013 23rd Int. Can! Artif. Real. Telexistence, pp. 145-1 50,201 3.

[21] M. Nakatani, K. Sato, K. Sato, Y. Kawana, D. Takai, K. Minamizawa, et al.,(2016).A novel multimodal tactile module that can provide vibro-thermal feedback. in International AsiaHaptics conference, pp. 437-443.

[22] A. C. Abad, D. Swarup, D. Reid, and A. Ranasinghe, "4x4 Fingertip Tactile Matrix Actuator with Edge Detection Scanning ROI Simulator", 2020 IEEE Sensors, Rotterdam, Netherlands, 25-28 Oct. 2020. DOI: 10.1109/SENSORS47125.2020.9278765

[23] F. Salsedo, S. Marcheschi, M. Fontana, and M. Bergamasco, "Tactile transducer based on electromechanical solenoids," in 2011 IEEE World Haptics Conference, June 2011, pp. 581–586.

[24] Y. Shao, H. Hu and Y. Visell, "A wearable tactile sensor array for large area remote vibration sensing in the hand", IEEE Sensors J., vol. 20, no. 12, pp. 6612-6623, Jun. 2020.

[25] Lucas VRTech, "I made $22 Virtual Reality Gloves.", https://www.youtube.com/watch?v=nmP8iGaPbeI

[26] Leap Motion Controller, https://www.ultraleap.com/datasheets/Leap_Motion_Controller_Datasheet.pdf (accessed on 24 May 2021)

[27] ARDUINO NANO 33 IOT, https://store.arduino.cc/arduino-nano-33-iot (accessed on 24 May 2021)

[28] DC 3V 3.7V Push Pull Through Type Micro Electric Solenoid Electromagnet Magnet, https://www.ebay.co.uk/itm/252648852643

[29] K. Sato, T. Maeno, "Presentation of rapid temperature change using spatially divided hot and cold stimuli", Journal of Robotics and Mechatronics 25(3), 497-505 (6 2013)