Engineering Integrated Multimodal Sensing and Feedback Ring System for Advanced Interactive Metaverse Platform

Guanyu He[1], Yuxin He[1,2*], Hu Liu[2*], Zhanhu Guo[3]

[1] College of Materials Science and Engineering, College of Chemical Engineering and Pharmaceutics, Henan University of Science and Technology, Luoyang 471023, China

[2] Key Laboratory of Materials Processing and Mold (Zhengzhou University), Ministry of Education; National Engineering Research Center for Advanced Polymer Processing Technology, Zhengzhou University, Zhengzhou 450002, China

[3] Integrated Composites Lab, Department of Mechanical and Construction Engineering, Northumbria University, Newcastle Upon Tyne, NE1 8ST, UK

*: *Correspondence authors*

E-mail: heyx@haust.edu.cn (Y.X. He), liuhu@zzu.edu.cn (H. Liu)

Nowadays, the newly interactive metaverse platform, which provides an immersive experience via the virtual reality (VR) technology that integrates the virtual world with the real world, shows huge potential applications in all facets of life. To achieve this goal, wearable devices, i.e., data jacket, data glove, etc., have received widespread concerns arising from their perception and feedback capacity to simuteneouly sense human motion and simulate real human feelings [1]. Due to its rich terminal nervous system, human fingers have excellent dexterity and can perform precise interactive movements in VR scenarios [2]. Although various wearable self-powered sensing device (i. e., pressure sensor, strain sensor, temperature sensor, etc.), thermo-haptic feedback device [3-5], and vibration feedback device (i.e., electrotactile simulators [6], vibrotactile devices [7], etc.) have been widely developed, most of the current wearable devices for VR scene interaction are based on flexible gloves and have complex structures that require external power supply to drive [8]. Therefore, further technological breakthroughs are urgently needed to achieve the highly integration of various advanced functional units, acquiring the high-performance wearable VR sensing/feedback devices.

Recently, Lee et al demonstrated a novel ring system with highly integrated multimodal sensing sensor and haptic-feedback unit for VR application [9]. As depicted in Figure 1a, the integrated multimodal sensor includes a triboelectric nanogenerator (TENG) tactile sensor for continuous bending perception and a pyroelectric sensor for thermal perception; the haptic-feedback unit contains an eccentric rotating mass (ERM) vibrator for vibrotactile feedback and a nichrome (NiCr) metal wire for thermal haptic feedback. Speciafically, finger bending can enable the pyramid structured TENG tactile sensor on the inner side of the ring to generate electrical potential change (Figure 1b), and various bending degrees of finger can be easily discriminated by processing the output voltage signal based on the voltage integration, showing good responsiveness without being affected by the bending speed. As a result, the bending of single robotic finger can be controlled timely according to the output signals of TENG tactile sensor induced by the corresponding human finger bending (Figure 1c(i)), and there is also almost no interference in the whole signal acquisition and transmission process of multiple robotic finger control (Figure 1c(ii)), proving its application in a robotic collaborative operation system. Considerig the impact of pulsed and continuous signals on interpretation performance of TENG tactile sensor, the outputs of 14 American sign language (ASL) gestures was analyzed based on the voltage integration signal, and a better aggregation effect for easy identification was successfully achieved. As for the detection of tempearature imformation, a self-powered PVDF based pyroelectric sensor was attactched to the outer surface of the ring, showing reliable and linear temperature perception capacity in a wide external temperature range based on the temperature gradient between them.

Excepet the excellent multimodal perception capacity, reliable haptic feedback that can create a sense of ambience and enhance the interactive experience for users is also necessary for VR devices. As a result, a low power driven haptic feedback system was construtcted by simply intergrating the ERM vibrator on the top of the ring, and the actual vibration amplitude increased with increasing the supply voltage, which allows the user to perceive significant differences in haptic feedback by providing different vibration intensities. Additionaly, thermal feedback capaicity of the ring was also achieved by embedding the high-efficient low power driven NiCr metal wire heater into the TENG tactile sensor, enabling it to aquire accurate tempearature feedback via the heating of NiCr metal wire according to the predefined temperature value in the virtual space. As a proof of concept, a VR chat platform supported by this highly intergrated ring system is proposed, as depicted in Figure 1d, in which two users can achieve cross-space perception and sensation due to the multimodal sesning and feedback capability. It can be expected that the novel ring system can be served as an interactive metaverse system connecting the real world and the virtual world, providing people with the real face-to-face like immersive experience.

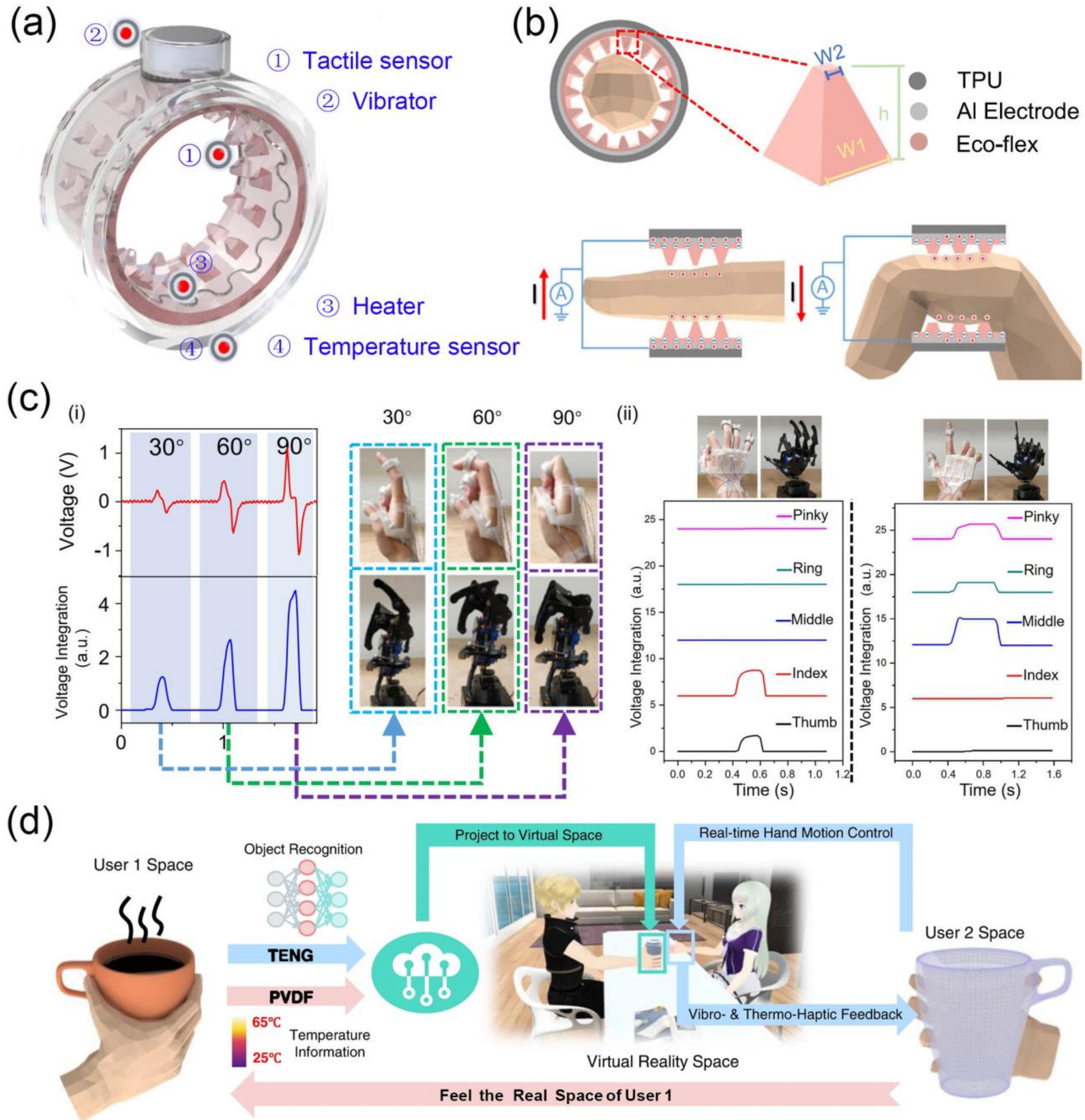

Figure 1 (Color online) (a) Structural diagram of highly integrated Ring system. (b) Structure and sensing mechanism of the TENG tactile sensor. (c) (i) Single and (ii) multiple robotic finger control based on the output signals of TENG tactile sensor. (d) The interactive meta-spatial platform based on this novel ring system provides users with an immersive sense of interaction across space [9]. Copyright © 2021 Springer Nature.

Although the highly integrated ring system demonstrates excellent sensing and feedback performance for immersive experience, some more works also still can be conducted to resolve the following challenges: (1) The internet of things (IoT) module used for data acquisition and transmission in this study is large in size and connected to the novel ring system through wires, which seriously affects the comfortability of wearable VR devices. So the miniaturization and wireless tranmission of the IoT module need to be further optimized; (2) High-precision gesture/sign language perception was achieved for TENG sensor via the integration of voltage output, but the problem of recognition accuracy that can be affected upon the drastic voltage change should also be further explored; (3) The thermal feedback unit of the ring system also encounters the problem of longer response time at low power, which will undoubedly affect the immersive experience of users in VR scenarios, thus some other substitutes for the NiCr wire heaters is necessary; (4) The novel ring system is composed of two sensing sensors and two feedback units, and the problem of complicated structure is still not well solved, hindering the miniaturization of wearable devices to a certain extent. Hence, it is imperative to develop new single functional materials for the detection of multiple stimulus simuteneouly.

In summary, a ring system with highly integrated multimode sensing and feedback capabilities has been clearly revealed, and an interactive metaverse platform that provides users with cross-space perception capability is successfully achieved. Here, it is important to note that the proposed novel signal processing method based on the voltage integration is beneficial for realizing continuous motion monitoring of the self-powered TENG sensor, enabling the ring system to be long-sustainable in practical applications. All these will undoubtedly provide important guidance for the design and fabrication of wearable devices with somatosensory sensation capacity for immersive VR and metaverse applications, and the successful resolution of the problems and challenges facing this work can further propel the commercialization of related products.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (12072325), Key Scientific and Technological Project of Henan Province - China (202102210043), and the Student Research Training Plan of Henan University of Science and Technology - China (2022191).

References

[1] Sun ZD, Zhu ML, Lee CK. Progress in the triboelectric human-machine interfaces (HMIs)-moving from smart gloves to AI/haptic enabled HMI in the 5G/IoT Era. Nanoenergy Adv 2021; 1(1): 81-120.

[2] Zhu ML, Sun ZD, Lee CK. Soft modular glove with multimodal sensing and augmented haptic feedback enabled by materials' multifunctionalities. ACS Nano 2022; 16(9): 14097-14110.

[3] Lee JW, Kim DK, Sul HY, et al. Thermo-haptic materials and devices for wearable virtual and augmented reality. Adv Funct Mater 2021; 31: 202007376.

[4] Kim DK, Bang JH, Lee WH, et al. Highly stretchable and oxidation-resistive Cu nanowire heater for replication of the feeling of heat in a virtual world. J Mater Chem A 2020; 8: 8281-8291.

[5] Lee JW, Sul HY, Lee WH, et al. Stretchable skin-like cooling/heating device for reconstruction of artificial thermal sensation in virtual reality. Adv Funct Mater 2020; 30: 201909171.

[6] Yao KM, Zhou JK, Huang QY, et al. Encoding of tactile information in hand via skin-integrated wireless haptic interface. Nat Mach Intell 2022; 4(10): 893-903.

[7] Ding WB, Wang AC, Wu CS, et al. Human-machine interfacing enabled by triboelectric nanogenerators and tribotronics. Adv Mater Technol 2019; 4(1): 1800487.

[8] Pyun KR, Rogers JA, Ko SH. Materials and devices for immersive virtual reality. Nat Rev Mater 2022; 7: 841-843.

[9] Sun ZD, Zhu ML, Shan XC, et al. Augmented tactile-perception and hapticfeedback rings as human-machine interfaces aiming for immersive interactions. Nat Commun 2022; 13: 5224.