Virtual reality device incorporating EEG sensors

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Abstract*—*This paper aims to integrate the VR headset Meta Quest 2 and EEG headband Muse 2 to serve experimental research on personalised user experience in virtual and Metaverse environments. This integration has provided a prototype design solution aiming at user comfort while wearing VR glasses, reducing fatigue when wearing too many devices. Using the existing VR glasses structure as a base, this design targets a sustainable product that can be mass-upgraded during production, extending its product lifecycle.

I. Background

The field of research on tracking the human brain when they interact in a virtual reality environment using HMD (Head-mounted display) glasses is highly appreciated for its vision results for research results on human cognitive processes, neural feedback, and immersive interaction experiences of users in virtual environments [5], [11]. Nevertheless, we must now consider equipment's optimality in experiments and human life. Since the integration of electroencephalogram (EEG) with Virtual Reality (VR) has caused many technical barriers and challenges, besides the bulky connection of the two devices when used, physical problems between the two devices, such as electrode pressure and cable movement, also hinder the accuracy of the results collected [12]. Furthermore, virtual environments characterise interaction by fully immersing users to achieve an optimal interactive experience. However, wearing and adjusting two separate headsets can decrease usability and accessibility for casual users and experimental participants. Several participants in the study by Tauscher have responded to the discomfort caused by carrying the pressure of these two devices simultaneously [12].

For this reason, when conducting experimental research with VR headsets and EEG headbands, researchers often consider using gel electrodes more than dry ones [5]. This also increases the cost of research and limits access to and the ability to conduct research widely.

Many EEG equipment manufacturers know this problem and have launched long-term wearable EEG devices such as Muse 1 and Muse 2 to support users in monitoring their physiological health status and brain signals. These devices also significantly reduce research costs for experimental investigation studies.

The simultaneous use of EEG and HMD devices is optimal for non-invasive user data collection, but it causes physical pressure on users. [10] and [13] gave illustrative examples of wearing an EEG headband, as shown in Figure 1.

User comfort in use is one reason that the device's design needs to be optimised in the current period. Therefore, it is necessary to investigate, generate research ideas, and design a sophisticated integrated device that combines an EEG headband and a HMD to meet academic and life research needs.

However, from a technical point of view, integrating two complex systems, such as an EEG headband and a VR headset, also causes certain difficulties related to the synchronisation of device compatibility. [4] report that EEG headbands typically sample brain activity at 250 Hz, 300 Hz, or higher frequencies. VR headsets, on the other hand, work on displaying visual and auditory stimuli. Therefore, if the EEG has high latency, it will affect the real-time response level of the user in VR [12].

Studies comparing users' sense of presence in virtual and real environments based on EEG data [1] and steady-state visual evoked potential (SSVEP) experiments [2]. These studies incorporate user states in virtual interactions through EEG data that underscore the need to create devices that facilitate such research.

Fig. 1. HMD and EEG headband devices used in experimental studies [10], [13]

II. Related work

In wearable technology, there is a growing need for continuous and discreet monitoring to understand people's physiological states and seamlessly monitor physical and mental health. However, the development of artificial intelligence (AI) has led to much research on sensors that monitor human health to prevent diseases [14]. The study proposed an EmoTracer wearable human physiological data monitoring system, which provides real-time monitoring of heart rate, blood oxygen saturation, skin conductivity, and skin temperature [14]. The result is a compact, wearable device integrated with various sensors to provide users with personal data.

ModBand [8] is one of the outstanding projects for designing a low-cost modular headband for multimodal data collection. It has been designed to overcome the current limitations of expensive EEG systems on the market today, but it is not yet integrated with head-mounted AR devices. This development has inspired the potential to design devices that are easily accessible and adapt to physiological data from users in the context of immersive virtual interaction using HMDs.

The VR headset and EEG headband combination study by [5] developed the application of conductive poly polystyrene sulfonate/melamine (PMA)-based soft foam electrodes and integrated them into the VR headset. The headset is compatible with hair and contacts the scalp through skin-friendly materials, achieving relatively low contact impedance even in hair-heavy locations. The method aims to improve comfort for users who wear the device for extended periods.

III. PROTOTYPE SKETCHES

A. *Inspired by existing devices*

The researchers of this project aimed to solve the device need by creating a prototype as a sketch of a new VR device integrated with Muse 2 to measure the user's brain activity during the immersive experience. Integrating and creating this new device aims to apply it to experimental research and enhance the user's life experience. A personalised user experience in the metaverse created by GenAI from users' EEG data should be designed to serve the project's needs. The prototype combines the Meta Quest 2 and Muse 2 with a leaner and more refined design. The design of each device separately before measurement, including:

- Meta Quest 2 has the main design with the headset part, including the front panel with four cameras mounted at four corners, foam padding, a Fresnel lens optical system, inter-eye adjustment, and an elastic fabric default strap (Figure 2).

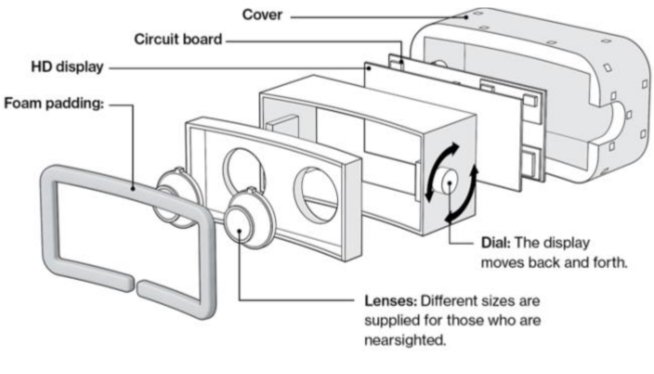

Fig. 2. Components of VR headset [9]

- The Muse 2 has a thin, lightweight headband that hugs the forehead and a sturdy over-ear design. It is compact but equipped with various sensors to monitor brain activity and provide real-time feedback (Figure 3).

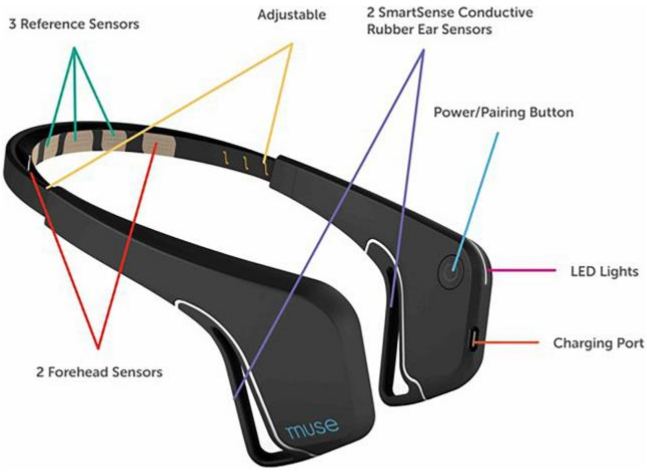

Fig. 3. The 2016 Muse EEG system made by InterAxon Inc [3]

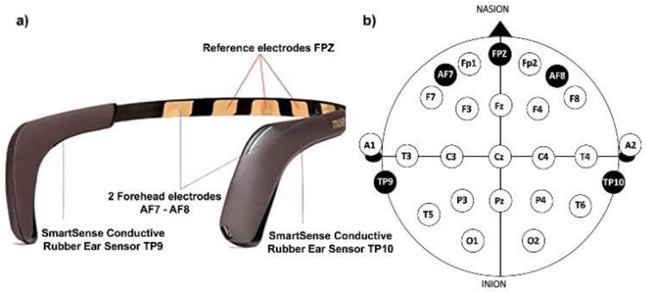

Fig. 4. MUSE 2 headband sensors overview. b) Top-down view of the EEG electrode positions on the subject's head [7]

This paper will connect the "three reference sensors" of Muse 2 to the frontal cushion of Meta Quest 2. The advantage of this connection is that it uses the strength of sticking to the forehead of the cushion so that the headset does not move too much during use. Conventional EEG devices, when worn, are prone to deviation from the forehead area when moving, causing inaccuracies in the data collected.

The second factor in the prototype's design is the integration of the VR headset strap's over-ear element with the "Smartsense conductive rubber ear sensor" behind the ear. The VR headset strap obstructs the Smartsense conductive rubber ear sensor, preventing accurate data collection from the user's brain area when observing the image, and the user employs two devices concurrently. If we solve this problem, the device will become lean and turn its disadvantages into advantages.

B. *Design Sketch*

This paper provides a detailed sketch of the device's use in life and experimental research. Requirements for improvement of the device in practice include the application of advances in e-textile, headband-integrated sensors and signal transmission using only textile materials [6] to be able to connect the sensors of Muse 2 to the HMD. Figure 5 shows prototype design sketches enable users to customise the operation of virtual reality glasses and EEG sensors. The current design has the same functionality as Meta Quest 2 and Muse 2 but can adhere to the bridgehead area where the user's EEG data is measured.

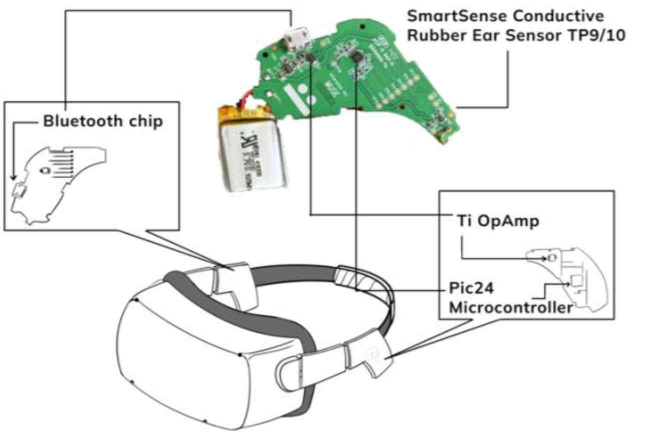

Fig. 5. Sketch prototype of device that combines virtual reality and brainwave measurement

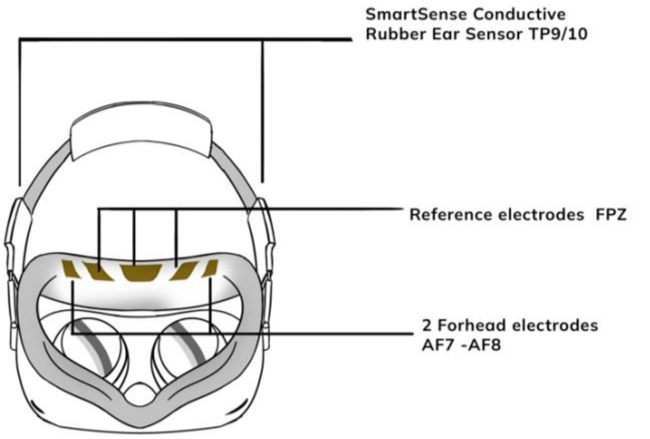

Fig. 6. Sketch of the location where the device's sensor can measure frontal brain waves

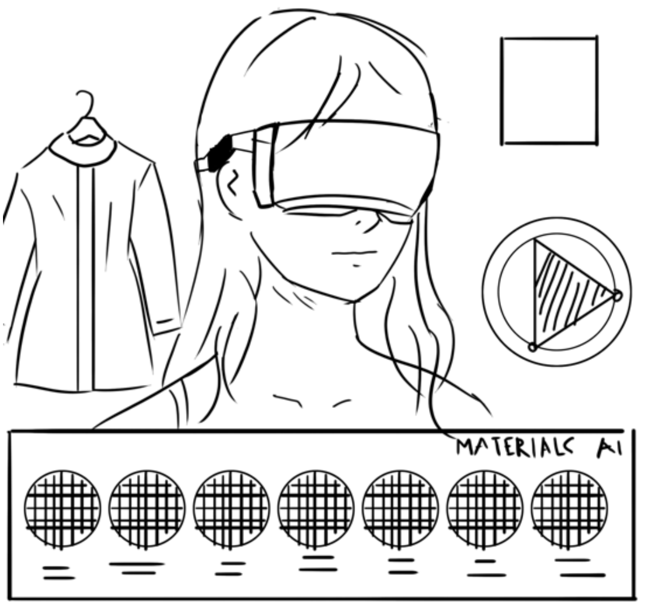

Fig. 7. Sketch how users wear and experience

C. *Sensor Combination Design Approach*

1) SmartSense Conductive Rubber Ear Sensor TP9/TP10

Figure 5 depicts the application of Garment-EEG and Dry-EEG headband technology [6] as a basis and technology for system design. The two **SmartSense TP9 and TP10 conductive electrodes** are arranged on either side of the user's ears, with the position designed based on the application from the Muse 2 product. **SmartSense TP9 and TP10 are motherboard systems consisting of the main parts of** a microcontroller (PIC24), Ti OpAmp signal amplifier, Bluetooth chip, and Li-ion battery.

The fabric surrounding the ears discreetly integrates the sensor, providing a comfortable user experience and helping it adhere to the head for more accurate EEG data collection.

2) Reference and Forehead Electrodes

Figure 6 illustrates the integrated electrodes as FPZ reference electrodes, 2 Forhead electrodes AF7-AF8, respectively. They are delicately designed through hiding it under the silicone, which is integrated into the pre-forehead cushion of the Meta Quest 2. This design is highly applicable, adheres to the forehead, and is difficult to move when the user moves, contributing to enhancing the quality of EEG signals.

D. *The flow*

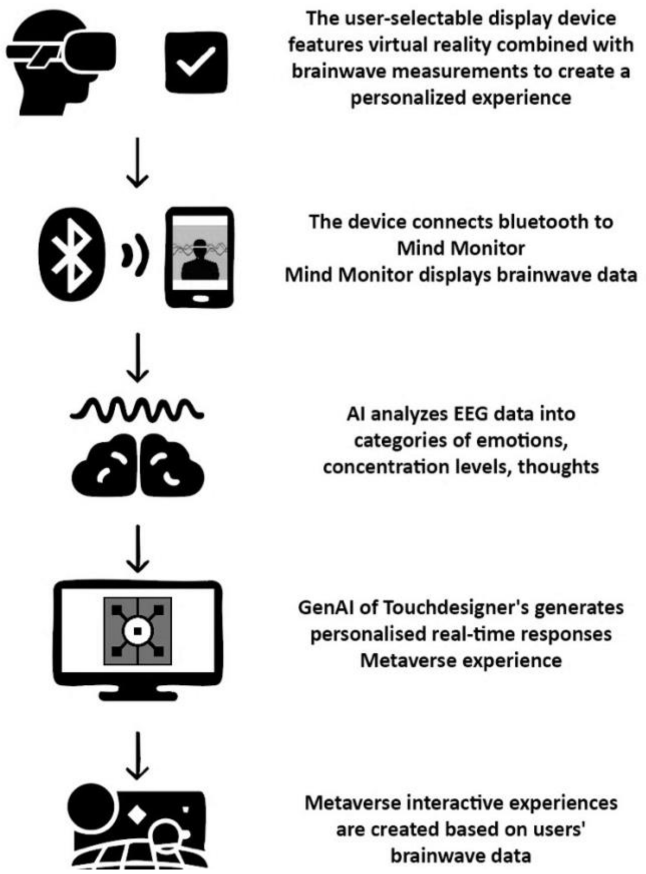

Fig. 8. Flow of how the device works

In the experimental study, researchers often use headband EEG devices and VR glasses to track participants' brain data as they interacted in a virtual environment. With the device designed as a prototype in this paper, the researchers only need to instruct the user to wear it properly, like wearing VR glasses—Meta Quest 2—in a usual way, boot the device's power at Meta Quest 2's location, and proceed to interact in the virtual world. The device is designed to measure EEG data directly from the user. Then, the AI will analyse these types of data, such as emotional states (expressed in the EEG data near the ear), thoughts, and concentration levels (expressed in the EEG data of the forehead area). These data will be the input source for generative AI of Touchdesigner to create real-time user response experiences in Metaverse interactions, which shows on figure 8. Participants can have their own personalised interactive experiences and easily satisfy their emotions.

IV. Responsible innovation

From an environmentally sustainable perspective, we all know that producing a technological device consumes many materials. This research aims to achieve a more sustainable goal by exploring the strengths of the materials available in devices and integrating them with other adaptable materials. Moreover, by integrating Muse 2 and Meta Quest 2, the manufacturer can provide users with a more personalised interactive experience and manage e-waste at the end of its lifecycle.

As HCI researchers, we are responsible for advocating for a user-centric approach. Researchers who conduct experiments with EEG data and interact in a virtual environment are the primary users of this device. Ordinary users can also utilise it daily. Although the innovation of this device does not completely transform it to suit the future of humanity better, it remains a valuable tool for empirical studies that use EEG data to create virtual user interaction experiences in the Metaverse and virtual world. Additionally, the device lowers the expenses of conducting experiments on many participants. For example, in the past, if a researcher wanted to run an experiment to measure users' emotions in a virtual setting, they had to use EEG caps and gels, as shown in Figure 1. With the potential of this new device, researchers can conduct experiments using a convenient, wirelessly connected device. With the combination of GenAI, the EEG data provided by this device can be transformed into data on the user's emotions, thoughts, and concentration levels.

V. Author bio

This research inspired me to create equipment for my doctoral thesis. The thesis aims to use GenAI to create personalised interactive experiences for users in the Metaverse by utilising EEG data from them. This device is key to giving my project participants more comfort during the interaction process.

My expertise involves designing user experiences in 2D and 3D contexts. I have been exploring product design and designing to create user interaction experiences with games towards sustainability through Arduino hardware and software since I studied for a master's in user experience design. I pay close attention to ensuring that every design provides users a sense of comfort and attracts them to the next experience. I focused this design project on the comfort level of wearing. However, I was also interested in the design that could give the researcher the convenience of accurately collecting data from the user. I am creating a prototype for this research device before summer school starts.

VI. Refernces

[1] Baka, Evangelia, Kalliopi Evangelia Stavroulia, Nadia Magnenat-Thalmann, and Andreas Lanitis. "An EEG-based evaluation for comparing the sense of presence between virtual and physical environments." In *Proceedings of Computer Graphics International 2018*, pp. 107-116. 2018.

[2] Goh, Teck Lun, and Li-Shiuan Peh. "Walkingwizard—a truly wearable eeg headset for everyday use." *ACM Transactions on Computing for Healthcare* 5, no. 2 (2024): 1-38.

[3] Krigolson, Olave E., Mathew R. Hammerstrom, Wande Abimbola, Robert Trska, Bruce W. Wright, Kent G. Hecker, and Gordon Binsted. "Using Muse: Rapid mobile assessment of brain performance." *Frontiers in Neuroscience* 15 (2021): 634147.

[4] Lee, Seungchan, Misung Kim, and Minkyu Ahn. "Evaluation of consumer-grade wireless EEG systems for brain-computer interface applications." *Biomedical Engineering Letters* 14, no. 6 (2024): 1433-1443.

[5] Li, Hongbian, Hyonyoung Shin, Minsu Zhang, Andrew Yu, Heeyong Huh, Gubeum Kwon, Nicholas Riveira et al. "Hair-compatible sponge electrodes integrated on VR headset for electroencephalography." *Soft Science* 3, no. 3 (2023): N-A.

[6] López-Larraz, Eduardo, Carlos Escolano, Almudena Robledo-Menéndez, Leyre Morlas, Alexandra Alda, and Javier Minguez. "A garment that measures brain activity: proof of concept of an EEG sensor layer fully implemented with smart textiles." *Frontiers in Human Neuroscience* 17 (2023): 1135153.

[7] Mansi, Silvia Angela, Ilaria Pigliautile, Camillo Porcaro, Anna Laura Pisello, and Marco Arnesano. "Application of wearable EEG sensors for indoor thermal comfort measurements." *Acta Imeko* 10, no. 4 (2021): 214-220.

[8] Nargund, Avinash Ajit, Alejandro Aponte, Arthur Caetano, and Misha Sra. "ModBand: Design of a Modular Headband for Multimodal Data Collection and Inference." In *Adjunct Proceedings of the 36th Annual ACM Symposium on User Interface Software and Technology*, pp. 1-3. 2023.

[9] Parkin, Simon. 2021. "Oculus Rift." *MIT Technology Review*. MIT Technology Review. September 17. https://www.technologyreview.com/technology/oculus-rift/.

[10] Sofian Suhaimi, Nazmi, James Mountstephens, and Jason Teo. "Class-based analysis of Russell's four-quadrant emotion prediction in virtual reality using multi-layer feedforward ANNs." In *Proceedings of the 2021 10th International Conference on Software and Computer Applications*, pp. 155-161. 2021.

[11] Souza, Rhaíra Helena Caetano E., and Eduardo Lázaro Martins Naves. "Attention detection in virtual environments using EEG signals: a scoping review." *frontiers in physiology* 12 (2021): 727840.

[12] Tauscher, Jan-Philipp, Fabian Wolf Schottky, Steve Grogorick, Paul Maximilian Bittner, Maryam Mustafa, and Marcus Magnor. "Immersive EEG: evaluating electroencephalography in virtual reality." In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 1794-1800. IEEE, 2019.

[13] Van Goethem, Sander, Kimberly Adema, Britt van Bergen, Emilia Viaene, Eva Wenborn, and Stijn Verwulgen. "A test setting to compare spatial awareness on paper and in virtual reality using EEG signals." In *Advances in Neuroergonomics and Cognitive Engineering: Proceedings of the AHFE 2019 International Conference on Neuroergonomics and Cognitive Engineering, and the AHFE International Conference on Industrial Cognitive Ergonomics and Engineering Psychology, July 24-28, 2019, Washington DC, USA 10*, pp. 199-208. Springer International Publishing, 2020.

[14] Wang, Danyang, Jianhao Weng, Yongpan Zou, and Kaishun Wu. "EmoTracer: A wearable physiological and psychological monitoring system with multi-modal sensors." In *Adjunct Proceedings of the 2022 ACM International Joint Conference on Pervasive and Ubiquitous Computing and the 2022 ACM International Symposium on Wearable Computers*, pp. 444-449. 2022.