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The Effectiveness of Brain-computer Interface Technology in the Metaverse

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Abstract: The rapid rise and development of the metaverse has brought people's desire for immersive virtual experience. However, the fully virtual environment and highly interactive metaverse experience still face many challenges. The traditional human-computer interaction mode is limited by the keyboard, mouse and other devices, which cannot meet the needs of users for natural and intuitive interaction. Therefore, the introduction of brain-computer interface technology (BCI) provides new possibilities to solve this problem. In this paper, through literature review and case analysis, it summarizes the existing knowledge about the interaction between BCI technology and meta-universe, explores the application potential of BCI technology in meta-universe, reviews its existing problems, and makes prospects for its future improvement and development. Through the review, this paper will prove that the application of brain-computer interface technology in the metaverse has great potential, which provides ideas and theoretical basis for further research and development of innovative metaverse applications.

1. Introduction

With the rapid development of science and technology, human beings have entered a new digital era, and the metaverse, as an emerging concept in the digital field, is attracting people's attention and participation at an amazing speed. As the intersection point of virtual reality and the real world, the meta-universe has brought unprecedented opportunities and challenges to human beings [1]. A striking feature of the metaverse is that the individual is the central figure, known as the digital body, all the activities and events in the virtual world. In addition to communicating and interacting with each other, individuals can also create digital objects in this virtual environment. However, the real-time reproduction of people's activities in the metaverse poses a major challenge to metaverse development. The main reason is that creating virtual objects often requires a large number of sensors and cameras to accurately capture human movements in the real world, so as to realize the interaction between people and the metaverse [2]. Therefore, how to better capture such activities to realize the interaction between human and the metaverse has become a key problem.

In view of this problem, the traditional interaction mode is limited by the keyboard, mouse, controller and other devices, which cannot meet the needs of users for an intuitive interaction. Therefore, in some articles gives a different solution from the traditional solution of brain-computer interface technology [2-7]. And, the authors point out to brain-computer interfaces as an innovative technology that establishes a direct connection between the human brain and the computer [3], allowing humans to interact with the virtual environment through pure EEG signals. Using brain-computer interface technology, users can control the actions of virtual characters, operate virtual objects, or communicate with other users through thinking instructions. Those authors point out that brain-computer interface technology offers exciting applications for the meta-universe, further deepening the virtual world and revolutionizing people in gaming, education, health care, and social networking [4, 5]. In response to the feasibility of the technology, the research team at Murcia University evaluated the use of brain-computer interface technology in the educational driving environment and verified it in the metaverse. The experimental results are shown in Figure 1. It can be seen that the accuracy has reached 90%-100% [6]. However, despite some breakthroughs, the use of brain-computer interfaces in the metaverse still faces many challenges and limitations, such as the safety and reliability of the technology. In addition, the application of brain-computer interfaces in the metaverse needs to consider multiple dimensions, including ethical, legal and social implications [7, 8].

This paper will conduct a literature review on the practical application, existing problems and future development of brain-computer interface technology in the meta-universe, and further supplement its application field and existing problems, and predict its future development trend. By reviewing the application of brain-computer interface technology in the universe, we are expected to provide strong support for the development and evolution of the future. Finally, the closer integration of human beings and the digital world will be realized, and the quality of people's life and creativity will be improved.

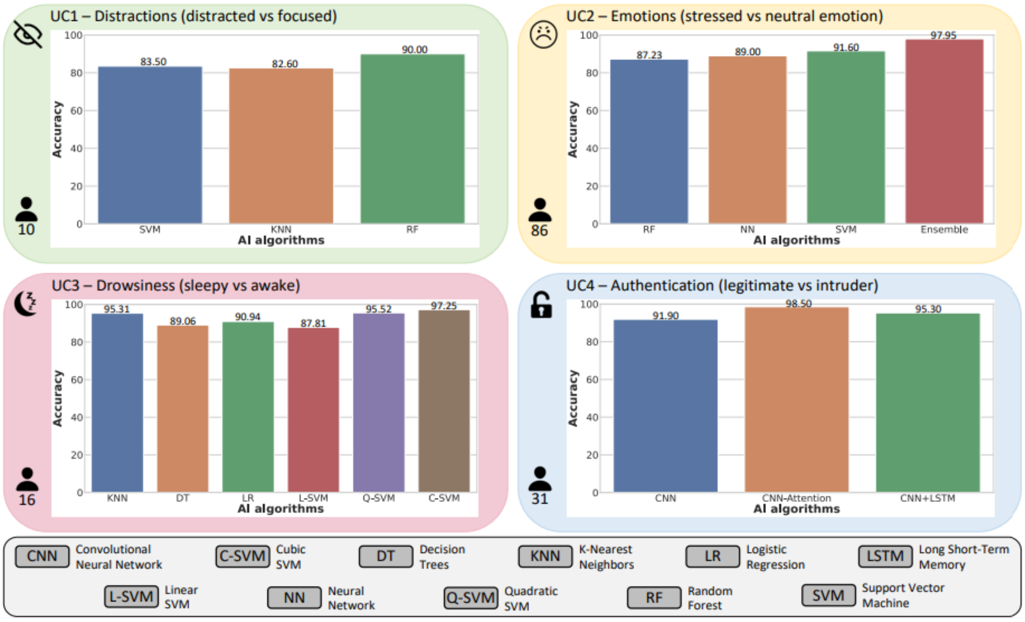

Figure 1: Using brain-computer interface technology to evaluate the user's optimal driving conditions in the educational driving environment [6].

2. Overview of BCI Techniques

2.1. Definition and Principle

The principle of BCI technology is based on the understanding of neural activity in the brain and signal processing techniques. The brain is composed of billions of neurons that communicate through electrochemical signals. These neural signals can be recorded and decoded, thereby providing information about brain activity. Brain-computer interface technology typically uses sensors to record brain signals. The sensor can be an implanted electrode, head-mounted sensor or other non-intrusive sensor. Implantable electrodes have access to nerve cells in the cerebral cortex and record neural signals by measuring their potential changes [9]. Head-mounted sensors can measure potential changes on the scalp or other physiological indicators of brain activity, such as electroencephalogram (EEG) and functional magnetic resonance imaging (fMRI). As shown in Figure 2, the BCI system also requires signal processing techniques to decode brain signals. These techniques often include pattern recognition algorithms, machine learning, and statistical analysis. By analysing and processing a large number of training data, the system can learn and identify different brain activity patterns, and then translate them into specific commands or intentions [4].

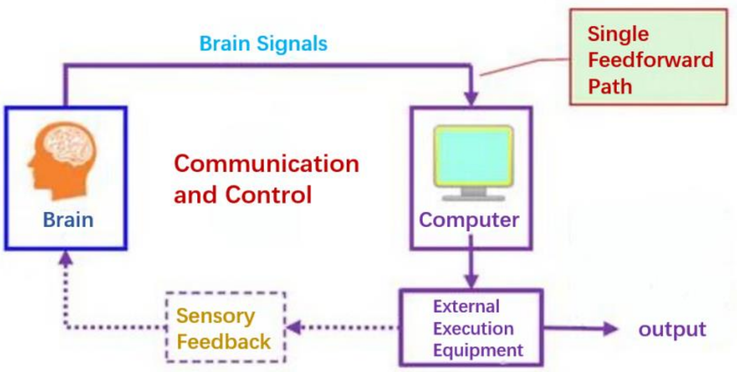

Figure 2: Schematic diagram of the BCI technical system [4]

2.2. Different types of BCI technologies

There are many ways of classifying brain-computer interface, which can be classified as Electrocorticography and Electroencephalogram [10]. Invasive brain-computer interfaces require electrodes directly into the cortex or neurons. Invasive brain-computer interfaces can provide high-resolution and stable EEG signals for accurate brain control. Non-invasive brain-computer interfaces, they do not require electrodes to be implanted, but rather collect EEG signals from external sensors. According to whether the user has voluntary control in use, the brain-computer interface is divided into dependent brain-computer interface and independent brain-computer interfaces need some degree of motion control, it can help people do things easier, such as control electric wheelchair; and the independent brain-computer interface does not need any control, such as severely disabled patients need independent brain-computer interface. According to the different direction of the information pathway between the brain and the computer, the brain-computer interface can also be divided into one-way brain-computer interface and bidirectional brain-computer interface. One-way brain-computer interface is the one-way technology to obtain some simple brain information; and the two-way interactive brain-computer interface technology, not only can receive the nervous system signals but also can stimulate the nervous system, is the future development direction [8].

2.3. Application cases of BCI in the real world

Brain-computer interface technology is widely used in the real world, bringing many amazing innovations and changes to people. An important application scenario is to help people who have lost limb function to restore their motor ability. Through invasive or non-invasive brain-computer interface technology, people can control external prosthetic limbs or mechanical devices. Another application scenario is the application of brain-computer interface technology in medical diagnosis and treatment [11, 12]. For example, in electroencephalogram (EEG) technology, brain-computer interfaces can monitor and interpret EEG signals to help doctors in brain function assessment, epilepsy diagnosis and sleep analysis [8]. In addition, when some patients have severe motor disorders, brain-computer interfaces can help them communicate through their thoughts in order to meet their basic needs and express their wishes. In addition, brain-computer interface technology plays an important role in virtual reality (VR) and augmented reality (AR). Through invasive or non-invasive brain-computer interface technology, users can explore and interact with the virtual world through their ideas [5]. The technology covers games, training, medical therapy and other fields, and provides users with a deeper and more immersive experience.

It can be seen that the application cases of brain-computer interface technology in the real world are diverse. Whether it is restoring limb function, medical diagnosis and treatment, or virtual reality experience, brain-computer interface technology provides people with a wider range of interaction and control methods. Therefore, it is very reasonable to apply this technology to the metaverse.

3. BCI Progress in the Metaverse

3.1. Metaverse Medicine

The researches hope you find the information in this template useful in the preparation of your submission. The concept of meta-cosmic medicine originated from telemedicine. Telemedicine is a medical service that uses information and communication technology to conduct diagnosis, treatment, monitoring and disease management over a long distance. It allows doctors and patients to communicate and interact with each other geographically apart. Change the form of telephone and video in telemedicine into a virtual platform. This technology can help patients to access more convenient, timely and high-quality medical services, while also enabling more effective allocation and utilization of medical resources. Telemedicine is widely used in remote areas, areas without medical resources, emergency situations, chronic disease management and other scenarios [13]. In 2018, Professor Chunxue Bai from Fudan University created the world's first clinical research of meta-cosmic medicine prototype, and led the team to develop the BRM all-in-one machine, in which doctors can use AR equipment to collect and view the holographic medical data of patients in the system, so as to achieve efficient and accurate diagnosis and treatment [5]. Through the brain-computer interface equipment, doctors can directly communicate with the patient's brain, monitor and interpret the brain electrical activity in real time, assess the patient's sensory and consciousness disorders, emotional and fatigue state, cognitive load, etc., so as to achieve a more accurate diagnosis [14]. In addition, through the realistic environment simulated in the meta-universe, patients are provided with rehabilitation environmental conditions that cannot be achieved in reality due to safety, time, cost and other factors. This technology can help patients in the treatment through brain-computer interface, the recovery effect can be used for the rehabilitation training, through active rehabilitation training to promote the motor cortex nerve plasticity, can also be used for muscle weakness and diseases such as spinal cord injury, improve the condition of neurological disease and spinal cord injury [15]. Patients can control the physical response in the virtual reality environment through their mind, and conduct rehabilitation training to enhance the function and adaptability of the nervous system.

In addition, the combination of brain-computer interfaces with the meta-universe is also widely used in the field of mental health. By interacting with the meta-universe, patients can gain support from emotion regulation and cognitive-behavioural therapy. Taking serious game therapy for autism spectrum disorders (ASDs) as an example, early intensive behavioural intervention (EIBI) is a relatively mature treatment method [16]. Through the interaction with the virtual characters, the patients can exercise social skills, correct attention defects, improve the terror mood, and improve the training effect of motor skill. Ordinary VR equipment, however, tend to design a social interaction scenario, will be measured head movement, eye gaze, gaze focus of non-verbal behaviour as a biomarker [17], but for good social skills and poor mental theory of social compensation ASDs, this diagnosis may fail, can use the brain computer interface acquisition μ frequency brain waves do further diagnosis, help doctors to better understand the patient's brain activity, in order to provide personalized treatment [5]. OpenBCI announced that it has launched a new product Galea in partnership with VR development company Varjo. Galea is a hardware and software platform that combines the next generation of brain-computer interface technology with head-mounted displays. Through the system shown in Figure 3， this product can further provides hardware support for ASDs' therapy.

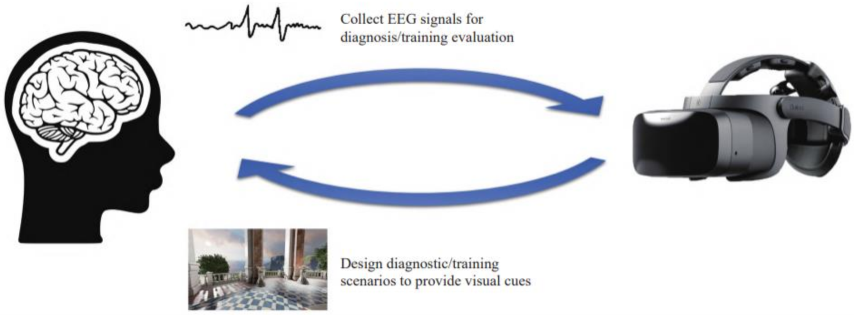

Figure 3: The ASDs training/diagnostic system based on the Galea equipment [5]

3.2. Metaverse Social

Face-to-face communication is considered as the most ideal form of social communication, but there are many obstacles to face-to-face communication due to multiple influences such as geographical time zone and cultural differences. Therefore, cosmic social came into being. Metaverse social can span time and space, but communication lacks "distortion" [18]. That is, users cannot feel each other's feelings and express their emotions through facial expressions and other ways. In response to this problem, Meta, in its Horizon Worlds platform, collects users' voice, judges and recognizes their emotions by AI, and then models the facial expressions of the virtual images in the universe [5]. However, the effect of this expression is very stiff and unnatural. In addition to single facial movements such as raising eyebrows, blinking and opening mouth, AI accuracy of human emotions is also very low.

There are two common methods to reproduce people's expressions. One is based on non-physiological signals such as sound signals and facial expression images used by Meta above, and the other is based on physiological signals such as EEG, EMG and ECG. In the first type of methods, facial image recognition has the best expression effect, collecting people's facial expressions through cameras and sensors on VR devices. But the device completely blocks the user's face, restricting the freedom to make various expressions. The second type of method is based on the user's physiological signal, which can get rid of the limitations of blocking face and binding expression of VR devices through the non-invasive brain-computer interface. In addition, in the judgment and collection of emotion recognition, EEG signals are also one of the most commonly used physiological signals, which can be directly captured from the cerebral cortex, which is conducive to reflecting the inner emotional state [19], and has higher recognition accuracy and user comfort.

3.3. Metaverse Art

Metaverse art is an extension of computer art, using digital media and virtual technology to create artistic works and provide artistic experiences. The 23rd "2021 Seoul Drum Festival" held in Korea in 2021 is typical of the metaverse Art Festival. Festival held in the form of online and offline, online is to use the universe platform ZEPETO, participants run ZEPETO application into the "world map" can participate in the Seoul drum festival, participants can also be in the universe visit the festival scene, with popular drummer attend fans meet, and photo area activities, etc. This form of art festival can break through the limitation of region and number of people, and can let more people who love drum art participate together [20].

Brain-computer interfaces in the field where meta-cosmic art meets lie in generative art. Generation art is an art form generated by computer programs, algorithms, or automated systems. It emphasizes the collaboration between artists and computers, through programming and algorithmic design to create unique, dynamic, and automatically generated works of art [21]. Through brain-computer interface technology, collect signals input to generate art devices. Due to the dynamics and uniqueness of EEG signals, different people produce different output results in different art installations at different times, thus creating a unique and dynamic art. In 2021, researchers have successfully designed the system shown in Figure 4, the subjects used the NeuroSky Brain Cube headset II as a signal acquisition tool. And then pass the collected brainwave data to the ThinkGear Connector program on the computer via Bluetooth. After that, it uses the user data reporting protocol (UDP) sends the data to the Unity engine. The Unity engine then performs an instant rendering based on the data. The resulting animation was synchronously projected to subjects wearing headphones. With the support of this system, the complex creation process of art can be greatly simplified and given a broader artistic creation process [5, 22].

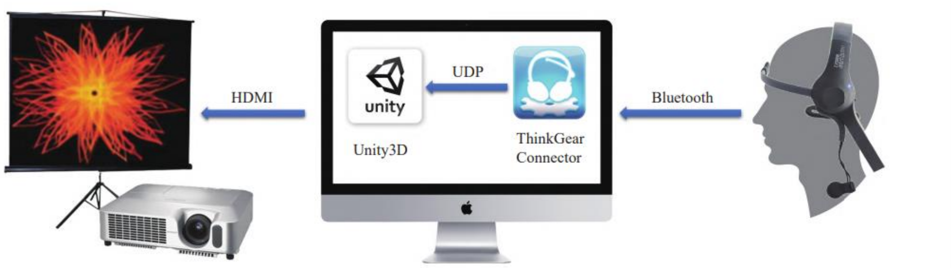

Figure 4: Example of the application of the generation art driven by EEG technology [5]

4. Discussion

4.1. Safety Issues

From the perspective of security, the brain-computer interface technology is still in the early stage of immature development, which may cause harm to the physical and psychological problems of users. This paper divided the problem into two aspects, one is the medical trauma problem, and the other is the nerve safety problem. The medical trauma problem mainly targets invasive brain-computer interfaces. Due to the obstruction of the skull, to obtain clear, stable and accurate brain signals, it generally need craniotomy implantation equipment. The implantable electrodes provide stable positioning, eliminating artifacts and having higher signal and noise (SNR) [11]. However, the implantation of electrodes in the brain may cause brain function damage and related sequelae. Even if it is attached to the meninges like EcoG, it will inevitably involve infection problems and the compatibility with the biological tissues of the human body [8]. Therefore, implanted devices can only be used more widely if they are small enough to be biocompatible. Neural safety issues refer to potential safety risks or risks in technologies or applications related to the nervous system. These problems involve direct or indirect interference, interference or attack on the human nervous system, which may affect the health, privacy and security of individuals. In 2021, Bernal et al. subdivided the functional cycle of bidirectional brain-computer interfaces into five links, and cycles in two directions [23]. In the two cycles of data acquisition and stimulation, the perpetrator may initiate an attack on the data tampering of the destructive neural device at each link. Such attacks may mislead the information obtained by the attacker, or seriously even damage the brain by stimulating the neurons, which may lead to neurodegenerative disease in the victim [24].

4.2. Technical Problems

There are still many technical problems to be solved before brain-computer interface technology is used in the metaverse. The first is the slow information processing and information conversion of brain-computer interfaces. The BCI interface system needs to process it after collecting it, and then it can be converted into computer language and accepted by the computer. In the process of using the BCI, it often needs multiple stimulation and feedback. Limited by the technology, the communication speed of brain-computer interfaces is still relatively low. At present, the maximum information conversion speed of the brain-computer interface based on P300 is 20-25bit / min, and the brain-induced interface is slightly higher, and its communication rate is only 60-100bit / min. Such information conversion efficiency is not at the level of normal communication [25]. Secondly, the recognition rate of brain-computer interface systems based on spontaneous EEG is low, only about 80% on average. Once the control command is long, the problem of low recognition rate makes the brain-computer interface system greatly limited in the practical application [26].

4.3. Ethics Issues

The ethical problems of brain-computer interface technology in the universe are mainly manifested in two aspects, one is the invasion of privacy, the other is the control of behaviour. Brain-computer interface technology requires reading and parsing personal brain activity data, from which you can extract private information, such as residence and bank card numbers [7]. In the process of building the meta-universe, it is necessary to extract a large amount of the collected information to ensure that the scene and virtual characters do not lack "distortion". How to protect such a large amount of data from leakage is a problem to be solved. The question of behaviour control refers to whether users entering the meta-universe through brain-computer interface devices will be affected or even lose their self-control. In general, the application of brain-computer interface technology is simply a simple transmission of brain thinking signals, which is an extension of human thinking. However, early stimulus tests proved that this signal can also be transmitted backwards, and the device can send signals to the brain according to external conditions, allowing people to change their original judgments and decisions. For example, Caldwell (Caldwell), and others have found that, "the imaging of neural activation patterns can reliably represent the interest in the type, brand, or political preferences of a product" [27]. If advertised in the meta-universe world, whether the user of the AD will amplify or even change the love of the product, and whether this behaviour goes against the personal will of the user, these questions remain to be verified.

4.4. Improvement and Innovation of Hardware Technical Problems

In order to solve the problems of brain-computer interface technology, which is usually heavy, inconvenient for long-term carrying and low communication speed and accuracy, combined with the current research, this paper believes that the following two hardware technologies have great potential and development space. The first type is a wireless implantable minimally invasive brain computer interface system as shown in Figure 5. Different from the traditional invasive brain-computer interface, the minimally invasive brain-computer interface system buries a coin-sized machine in the skull, adopts wireless power supply mode, smaller volume, epidural acquisition and stimulation, real-time transmission of all the EEG data; across skin and body map. The quality of no. 10, and did not destroy the dural brain injury and nerve cells, to solve the pain point of long-term implantation complications. The stable internal environment of the skull not only ensures the quality of the long-term and reliable collection of EEG signals, but also can realize the closed-loop feedback stimulation. It is a long-term, stable and reliable closed-loop bidirectional brain-computer interface [4]. The second type is the brain-computer interface technology for optical array input. The optical dot matrix pattern is used to illuminate the cortex, and the photoconversion device array attached to the cortex is used to convert the information of each independent point of light spot into electrical pulses, thermal pulses, mechanical displacement (pulses), etc., triggering the excitation of cortical neurons at different local depths, thus causing brain perception [8]. This technology can be truly non-invasive while achieving higher communication speed and higher-accuracy. It is worth noting that modern optical systems can reduce the diameter of the spot to 1 μ m, that is, 1 / 10 of the diameter of neuronal cells, and the spot intensity and light wavelength can be regulated in a large range. At present, photoelectric conversion devices have been realized in the liquid crystal-piezoelectric composite thin film system, and their application in the field of brain-computer interface is also imminent.

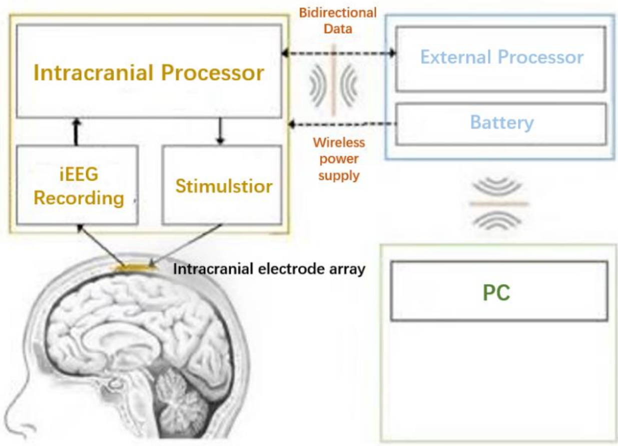

Figure 5: Wireless implantable minimally invasive brain-computer interface system [4]

4.5. Deeper Integration

The one-way data pathway from computer to human brain in the universe is the simulation of a series of senses such as smell, taste and touch. Today, the interaction between the meta-universe and the real world mainly depends on vision and hearing, and cannot capture and stimulate the sense of smell, taste and touch, so it has a certain "distortion". Therefore, in the future, the problem of the deeper integration of the brain-computer interface technology and the meta-Universe can be solved by optimizing the method of sensory capture. In the field of tactile simulation, in 2020, Ganzer and other used closed-loop de-multiplexing BCI to transform the subperceptual signal of the primary motor cortex into conscious perception through decoding [28], which almost completely restored the tactile sensation of patients with spinal cord injury. In the field of olfactory simulation, devices such as Taste the TV stimulate the trigeminal nerve by interacting with external devices to sense taste. It can be seen that in the near future, people can use specific electrical stimulation to the body to produce exactly the same feeling as the real life, giving people a realistic and immersive immersion in the exploration of the meta-universe.

5. Conclusion

In general, as a highly advanced human-computer interaction technology, brain-computer interface technology still has great application potential and prospect, although it still needs to pay attention to its security, technical nature, ethics and other issues. Through the above literature review, this paper make some supplements to the current application progress, and put forward several possible conjectures for its future development, this study hope this can provide some support for the subsequent application research in this aspect. It is foreseeable that in the near future, people will be able to achieve a more immersive metaverse experience through brain-computer interface technology, and will play its full role in the metaverse. It can be seen that in the near future, brain computer interface technology can be further applied and promoted in the metauniverse, creating richer and more real virtual experience and better life for mankind.

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