2022 IEEE 5th International Conference on Electronics Technology (ICET)

The Mind Commands You: Combining Brain-Computer Interactions with Augmented Reality to Control Internet of Things (IoT) Tools, and Robotic Platforms

Wang Haohong
SWJTU-Leeds Joint School and
Maker Association
South West Jiaotong University
Chengdu, China
eereer@163.com

Gao Shenghao,
Zhao Yimin,
Song Maojia
SWJTU-Leeds Joint School
South West Jiaotong University
Chengdu, China
974780149@qq.com,
smj812855@163.com,sc19yz3@163.com

Wang Heng
Engineering Training Center
South West Jiaotong University
Chengdu, China
877122485@qq.com

Damien Constantine Rompapas
Brewed Engagement Extended Reality Labs.
Adelaide
South Australia, Australia
dr-damo@beer-labs.net

2022 IEEE 5th International Conference on Electronics Technology (ICET) | 978-1-6654-8508-1/22/$31.00 ©2022 IEEE | DOI: 10.1109/ICET55676.2022.9824583

***Abstract*—Many researchers are exploring the use of Brain Computer Interfaces (BCI) in combination with Internet of Things (IoT) tools, and robotic control. However, the training and application process for BCI controls can be difficult to achieve partially due to the required double-attention of both the target matter, and the on screen feedback loop used during training. Enter Augmented Reality (AR), a technique for embedding computer generated content (CG) in the user's view of the environment. In this research, we describe a system that explores the combination of a BCI training environment with AR technologies for both training and run time usage. We show the key advantage of this combination, allowing the user to focus directly on the subject matter. While our work is in the prototype phase, we show that this combination of AR and BCI has the potential to be effective in the training and usage of BCI interfaces.**

***Index Terms*—Robotics, Brain-computer Interface, Mixed Reality, Augmented Reality IoT, Human-Computer Interaction**

I. Introduction

Brain Computer Interface (BCI) technology is the application of using Electroencephalography (EEG) as a method to record an electrogram of the electrical activity on the scalp, representing the macroscopic activity of the surface layer of the brain underneath. It is possible that with some prior training, brain-computer interface technology(BCI)[1] can be used to control IoT applications or robotic platform. When applying the technology 9in such a way, the User is able to deliver instructions to the target object when both hands are occupied or not available, allowing the user to accomplish other tasks in parallel. Research on implementing BCI into Internet of Things(IoT) and robotics has been proposed using BCI2000 and virtual reality environments to control virtual subjects[2]. BCI has also been used to control Lego robot platforms[3] using a combination of Cognitive Functions and Expressive functions[4]. Overall, the training and application of Brain-Computer Interfaces is notoriously difficult[5]. The typical approach, Steady State Visual Evoked Potential (SSVEP)[6], requires the subject to not only has to focus on the target for control, but also pay attention to the visual output of the training system simultaneously[1]. This division of attention can cause errors when providing input, making the technique impractical in industrial, transportation or civil service application with IoT and Robotics.

Note: The first four authors contributed equally on this article

Enter Augmented Reality (AR), a technology that embeds Computer Graphics (CG) content into a user's view of the real world. A key advantage of AR is the ability to embed content directly related to the physical component the data relates to. One of the more common variations of AR technology is Video See Through AR (VST AR), which augments the user's view of the environment by embedding content over a video image captured by a camera. VST AR is commonly used in Modern handheld Smartphone technology, allowing expansion of content into 3D spaces, which is ideal for learning using a spatial approach, however using VST AR either requires the user's hand to be holding an additional tool (Thereby limiting potential interactions) or usage of a device that can completely occlude the user's view of the real world . AR Technology is a platform that, when designed correctly, allows the user to focus better on the subject matter when performing the BCI training [7].

In this work, we present a combination of open source AR hardware and BCI technologies in order to achieve an in-situ interface, allowing a user to focus entirely on the target matter while keeping their hands free to perform other maintenance tasks. First we present the requirements of the target industry and application, then we show a system design schematic for integrating BCI technology into the open source platform, and finally we discuss the potential capabilities of this technology. We hope that this is a stepping stone for hands-free interactions between multiple robotics and IoT platforms, and are keen to investigate the freedoms that our new system will provide.

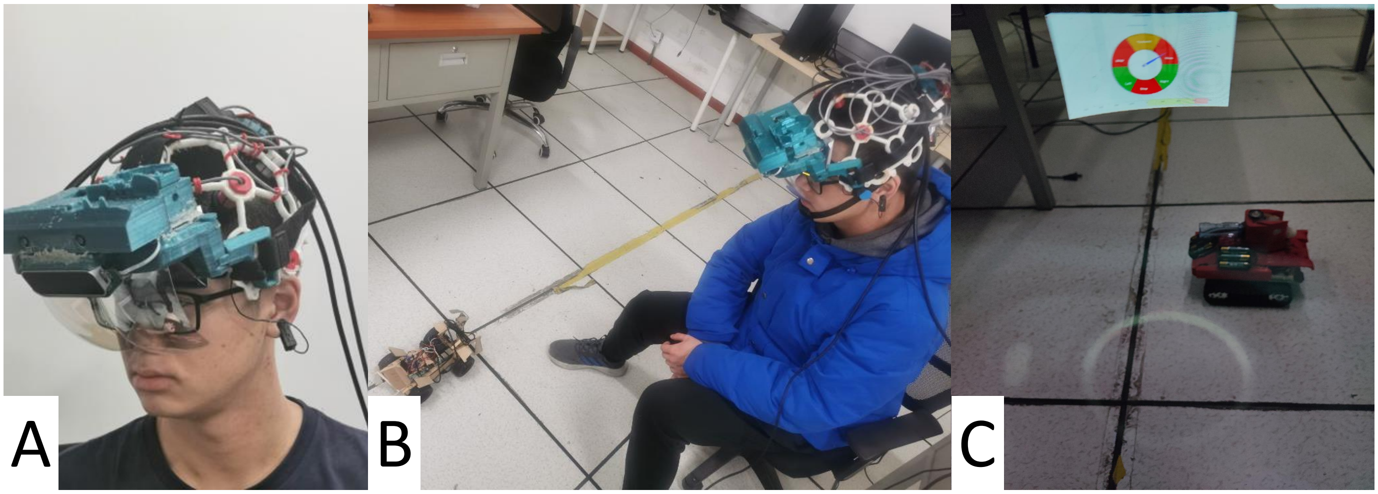

Fig. 1. We present a system that combines an Augmented Reality device with Brain-Computer Interface technology, in order to make the training process of reading BCI for robitics control easier for the user. A) A user wearing a custom AR headset with built in EEG functions allows a wearer to control a robot. C) The first person view of the wearer. By using the headset to overlay the training software and controls on the target matter, we aim to allow faster training and control cycles with robotic platforms.

II. Requirements and System Design

Our target environment for applying BCI for IoT and robotic platform control is in industrial sectors that can typically be noisy, with vast amounts of visual pollution. In order to deploy BCI in robotics or IoT in these environments, we need to ensure that:

- We can allow the user to gain the information of the interfacing subjects when delivering command, which is usually directly from visual observation on the device.
- The user to deliver commands to the device in a hands-free matter, so that their hands can be used to handle important tools.
- The system should have acceptable accuracy and latency for its application when delivering commands for maximum safety and efficiency during operation.
- The system must be workable in industrial environments.

Overall, there are two critical components that need to be addressed in order to meet these requirements, the hardware platforms and the software to power the hardware.

III. Hardware Design

Ultimately, there are two key factors for hardware that need to be considered when building our platform, the AR head worn device that is used to display content within our environment, and the hardware for capturing the user's thought processes. In order to address the hands free requirement for controlling the target devices, we look towards options for BCI technology. In addition, to achieve maximum efficiency we look towards Augmented/Mixed Reality headsets. Rompapas Et. Al [8] has shown that AR is ideal for directly overlaying information into the user's view of the environment. There are several Headset designs that have combined BCI technology with Virtual/Augmented Reality. One commonly known device, Project Geala, aims to implement BCI into VR gaming, by gathering user information to enhance gaming experience. However it's gaming focus design indicates it's not suitable for implementation in IoT or robotics[9].

Alternatively for visual output, one can apply SSVEP[6] with Augmented Reality. This research shows the potential for using BCI in industrial applications. However SSVEP prevents the user from observing the interacting objects as their attention is taken by the training and interaction interface, which can prevent the user from observing any erroneous behaviour of IoT devices or robots. This puts both the user, and other nearby workers in considerable risk [10]. To address these limitations, we developed a system using motor imaginary, a "disk" with quantized graduations. We include an AR Heads Up Display showing analog motor indicators to control the pointer of the "disk" which corresponds to the action the robot takes. Further detail will be provided in the next section. For AR hardware, there are a plethora of both commercial options, and open source solutions. In the commercial space, the Microsoft HoloLens[11] and HoloLens 2 [12] devices are known to provide the highest fidelity in regards to content registration. The magic leap one[13] is also good for this purpose. However, the cost of the devices are high, making them unsuitable for wide spread industry usage. Furthermore the headset design will require adaptability, as the head straps are incapable of integration with a BCI helmet. The open source market is more favourable in both aspects, with Project North Star [14] being a low cost alternative. However it's display arrangement blocks peripheral, making it unsuitable for industry application. Project Ariel [15] becomes the more suitable alternative at a lower fidelity due to the screen placement. The open source design made it a simple matter to create an adapter for an OpenBCI build. The result is our new headset, dubbed the Ariel Supremacy (See Figure 4), directly combining an OpenBCI[16] build with several EEG sensors within the helmet harness. In addition to the BCI harness, it

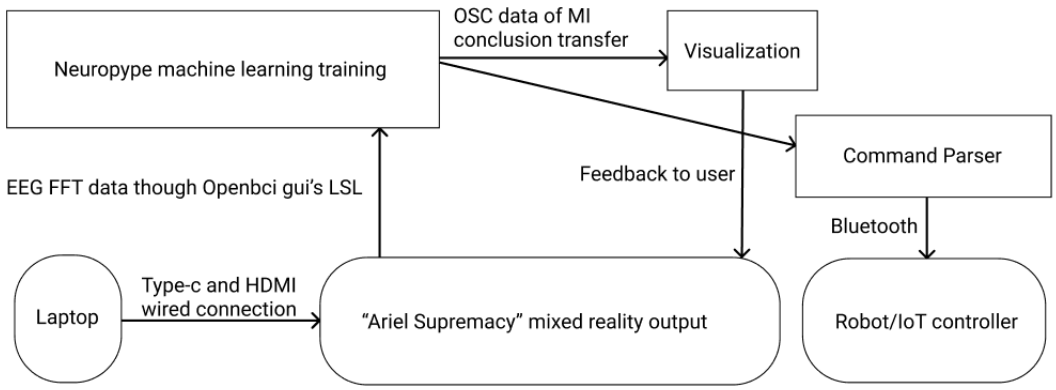

Fig. 2. The core system schematic for the hardware used within the system, including the Disk communications. It requires custom made software and hardware like the Ariel Supremacy headset to control robots or IoT.

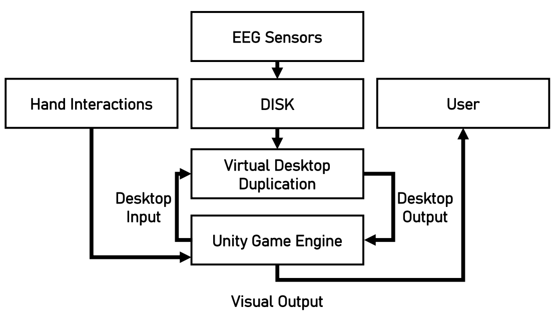

Fig. 3. A general software design schematic for the combination of BCI with AR functions provided by the Ariel Supremacy.

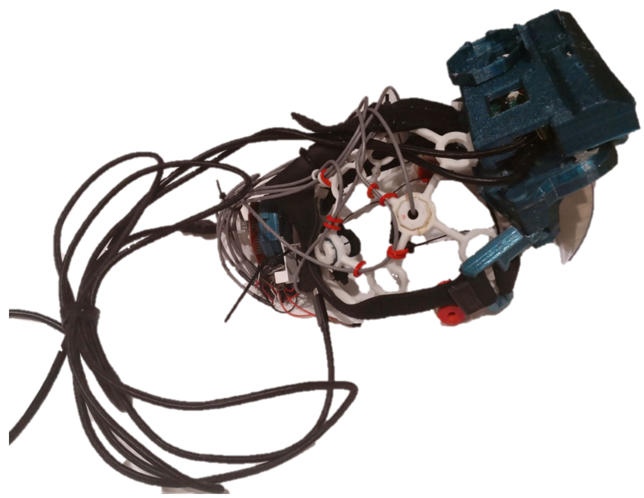

Fig. 4. The hardware design, dubbed Ariel Supremacy is our open source, low cost Brain-computer Interface and Mixed Reality headset. This allows EEG sensors to be accessed within the Mixed Reality Environment the original Project Ariel headset allows.

features the same function as the original Project Ariel headset, with hand tracking for user input, and six degrees of freedom head tracking (3 translation, 3 rotation). This allows us direct input, while embedding content within the user's view of the environment. Figure 4 shows a completed build of the headset. And the Teaser image shows how it is worn on the user.

We use a desktop pc with the following specifications for experimentation:

- CPU: AMD Ryzen 7 4800H
- GPU: Nvidia RTX 2060
- RAM: 32gb DDR4

Figure 2 shows the overall hardware communication, many software components are used to power the hardware, and are discussed in the next subsection.

IV. Software Design

The core of our hardware design requires we utilize the raw EEG readings from the helmet. We also need to render the images into the user's view of the real world.

In order to read the EEG Readings, we use Neuropype [17] to develop a training and usage pipeline for a neural network. The Neuropype Pipeline is used to to train and predict the neuro activities, with pyqt5 and python as front end and back end, respectively. Figure 5 shows the layout used within our Neuropype pipeline setup.

Imaginary prediction with CSP by Lab Streaming Layer(LSL) output. The prediction will then sent to the "disk" python script using Open Sound Control(OSC) output. Python script will then do the integral calculation of user's motor imaginary focus and deliver command to the interacting subject when reached threshold. The Esky mixed reality program will shows the system's feedback from the Mixed Reality using a virtual desktop. The main function of LSL in this system is to connect OpenBCI GUI to the neuropype which could analyse, record and operate the data. It is a bridge to transport the stream connect from OpenBCI GUI. Stream refers to a set of data consists of sample data, which is collected by the device, and Metadata, which contains the stream information. The LSL protocol handles both sides of the link to the network and access the device system in real time and the sample data transported by it are marked in order to make data can be mutually synchronized. Another important reason of choosing it is because LSL has a core transport library “liblsl” that supports multiple language interfaces, which is key to a project that utilises multiple languages and platforms.

Once the data has been recorded and processed by neuropype, the data is classified into two different signals, left and right motions. The python script receives the signal provided by neuropype and responds to them on the front end. To connect the python functionality with neuropype, we utilize the OSC protocol. OSC is open, transport-independent, message-based protocol and as long as receiving device that is on the same network as the sending device and listening on the same port will receive any form of messages. Another reason for choosing OSC was its high accuracy and the ability to interpolate high resolution temporal features between messages in a similar way to LSL to achieve accurate temporal coordination, hence with the help of this protocol, scripts and neropype could change data in real-time, and there is no significant delay between the response of the python front-end and the activity of the human brain.

The common spatial pattern (CSP) is an airspace filter feature extraction algorithm for two classification tasks, which can extract the spatial distribution components of each class from multi-channel brain-computer interface data. We aims to design a spatial filter so that the difference in variance value is maximized after the two sets of EEG space-time signal matrix filtering, so as to obtain a feature vector with high differentiation Used in the next step to feed the eigenvectors into the classifier for classification. Using the airspace filter feature extraction algorithm under the two classification tasks, the spatial distribution components of each class can be extracted from the multi-channel brain-computer interface data. The basic principle of the common spatial mode algorithm is to use the diagonalization of the matrix to find an optimal set of spatial filters for projection, and as our design target, feature vector into a high degree of differentiation is accomplished as the variance difference between the two types of signals is maximized.Therefore, based on spacial feature we extracted, left-hand and right-hand mode can be distinguished.

The Linear Discriminant Analysis (LDA) is a method used in statistics and pattern recognition to characterize two or more classes of data by finding a linear combination of specific features. We classify raw data using LDA to give maximised difference between two modes. To be more specific, we maximise the inter class mean and minimize the variance within the class: On account of complicated extracted Feature from CSP, we can project data on a low dimension, and the projection points of the same category of data are as close as possible after projection. The center point of the projection points of different categories of data is as far away as possible. Overall, determination modes from LDA can be used as instant judgement of users’ input, known as immediate ’MI’ vector.

The results of this information processing is then simplified and translated to a simple state machine, which correlates to the options of device control shown on the Disk system, to an WebAPI and bluetooth hardware layer, directly communication with the device in question over either Bluetooth Low Energy (BLE) serial communication, or WebAPI interfaces. In the example used on the Teaser image, the disk shows four possible movement commands. Left, Right, forward and stop. For safety reasons, the stop function is more utilized over the disk area. More importantly, allowing us to minimize the amount of erroneous input.

To visualize the output of the disk within the user’s view of the environment and more importantly, the target matter, we utilize Project Esky. Project Esky is an open-source Augmented Reality modular software platform. It combines the plugins within the Unity Game Engine, within Microsoft’s Mixed Reality Toolkit[18]. We installed the uDesktopDuplication library in Esky and used together with MRTK as a simple solution to integrate the ”Disk”. With this, the user is then able to know the current status of ”Disk”’s instruction delivery and signal quality of EEG FFT. To provide forced commands, the user is able to manipulate a series of sliders within their view, much like a physical joystick.

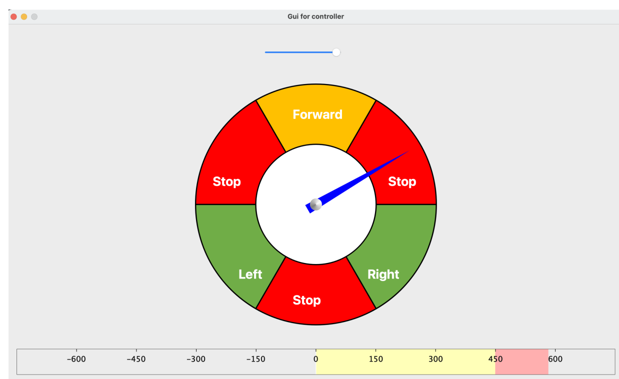

Fig. 6. The Disk: A software solution that translates the visual output of the training, along with corresponding decisions to IoT actions. The disk system is displayed on the target for interactions via. the Ariel Supremacy.

V. Conclusions

In this paper, we present a unique combination of open source BCI with AR in order to directly visualize the results of BCI usage when translated to controls for robotics and IoT manipulations. The result, Ariel Supremacy, when combined with our Disk system, allows an operator to directly manipulate and control either a Robotic device, or IoT tool. This project has many applications in the age of the Internet of Things and have great potential for civil and industrial applications. For instance, in civil application fields With the help of the BCI the chef can control the heat without stopping the cooking and the robot can be controlled by off-hand remote control to help deliver relief supplies in complex

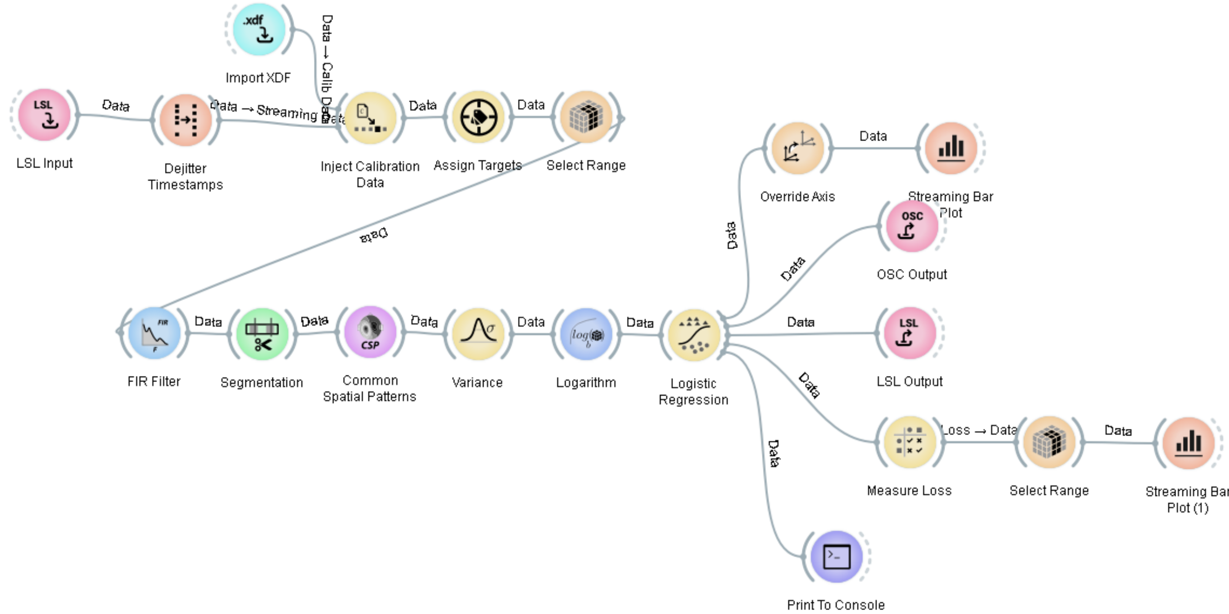

Fig. 5. The layout used as our Neuropype Pipeline training and processing units using the raw EEG data we receive from the Ariel Supremacy.

terrain. BCI could be applied to enhance game immersion and help the injured people to relieve their pain by enabling BCI and MR devices to play games. The system can be used to create interface shortcuts in MR device controls, for example controlling screen brightness.This system could be used to in art creation, like modify the color and painting tools while painting with MR. In industrial application, workers on the flow line can use the system to command the platform robots to move the finished goods while they control the equipment (control boom) with both hands. BCI system can realise the robots support human goods transit in the logistics sector, where workers can control the robot while handling. In the medical field, this system could help doctors to control the brightness and angle of the shadow-less lamp during surgery. This project has some limitation and potential power that has not been developed yet. First, this system has functional overlap with voice control in quiet working environments. Second, the headset used in the system is relatively heavy (Ariel Supremacy headset) and may also suffer from poor contact if wear it for a long time. Third, this system would perform low accuracy when works in the area with high EMF pollution.The level of software and hardware integration of the system is low, still room for improvement. Finally, the delay time between the command produced in user's brain and the robot execute the order is over 1 seconds and this time need to be reduced.

REFERENCES

[1] B. Z. Allison, S. Dunne, R. Leeb, J. D. R. Millán, and A. Nijholt, "Recent and upcoming bci progress: Overview, analysis, and recommendations," *Towards Practical Brain-Computer Interfaces Biological and Medical Physics, Biomedical Engineering*, p. 1–13, 2012.

[2] C. G. Coogan and B. He, "Brain-computer interface control in a virtual reality environment and applications for the internet of things," *IEEE Access*, vol. 6, pp. 10 840–10 849, 2018.

[3] A. Vourvopoulos and F. Liarokapis, "Robot navigation using brain-computer interfaces," in *2012 IEEE 11th International Conference on Trust, Security and Privacy in Computing and Communications*, 2012, pp. 1785–1792.

[4] ——, "Brain-controlled nxt robot: Tele-operating a robot through brain electrical activity," *2011 Third International Conference on Games and Virtual Worlds for Serious Applications*, 2011.

[5] D. C. Irimia, R. Ortner, M. S. Poboroniuc, B. E. Ignat, and C. Guger, "High classification accuracy of a motor imagery based brain-computer interface for stroke rehabilitation training," *Frontiers in Robotics and AI*, vol. 5, 2018.

[6] H. Segers, A. Combaz, N. V. Manyakov, N. Chumerin, K. Vanderperren, S. V. Huffel, and M. M. V. Hulle, "Steady state visual evoked potential (ssvep) - based brain spelling system with synchronous and asynchronous typing modes," *IFMBE Proceedings 15th Nordic-Baltic Conference on Biomedical Engineering and Medical Physics (NBC 2011)*, p. 164–167, 2011.

[7] H. Si-Mohammed, J. Petit, C. Jeunet, F. Argelaguet, F. Spindler, A. Evain, N. Roussel, G. Casiez, and A. Lécuyer, "Towards bci-based interfaces for augmented reality: feasibility, design and evaluation," *IEEE transactions on visualization and computer graphics*, vol. 26, no. 3, pp. 1608–1621, 2018.

[8] D. C. Rompapas, C. Sandor, A. Plopski, D. Saakes, J. Shin, T. Taketomi, and H. Kato, "Towards large scale high fidelity collaborative augmented reality," *Computers Graphics*, vol. 84, pp. 24–41, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0097849319301359

[9] . b. n. . Posted November 19, "Introducing: Galea," Jan 2021. [Online]. Available: https://openbci.com/community/introducing-galea-bci-hmd-biosensing/

[10] L. Angrisani, P. Arpaia, A. Esposito, and N. Moccaldi, "A wearable brain–computer interface instrument for augmented reality-based inspection in industry 4.0," *IEEE Transactions on Instrumentation and Measurement*, vol. 69, no. 4, pp. 1530–1539, 2020.

[11] Microsoft, "Microsoft hololens." [Online]. Available: https://docs.microsoft.com/en-us/hololens/

[12] ——, "Microsoft hololens 2," Last Accessed 2021, Feb. [Online]. Available: https://en.wikipedia.org/wiki/HoloLens_2

[13] M. L. Company, “Magic leap,” Last Accessed 2021, Feb. [Online]. Available: https://www.magicleap.com/en-us

[14] Ultraleap, “Project north star,” Last Accessed 2021, Feb. [Online]. Available: https://project-north-star.gitbook.io/project-north-star/

[15] C. James, T. Vincent, C. Alvaro, and C. R. Damien, “Project ariel: An open source augmented reality headset for industrial applications,” in *International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2021 ACM International Symposium on Wearable Computers (UbiComp-ISWC ’21 Adjunct))*, ser. ISCW ’21. Association for Computing Machinery, 2021.

[16] . b. R. C. J. . Posted October 5, “Use your imagination power to control robots and devices,” Oct 2020. [Online]. Available: https://openbci.com/community/use-your-imagination-power-to-control-robots-and-devices/

[17] ——, “Use your imagination power to control robots and devices,” Oct 2020. [Online]. Available: https://openbci.com/community/use-your-imagination-power-to-control-robots-and-devices/

[18] D. Rompapas, C. Rodda, B. C. Brown, N. B. Zerkin, and A. Cassinelli, “Project esky: An open source software framework for high fidelity extended reality,” *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*, 2021.