Brain Computer Interfacing with a Virtual Environment

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ABSTRACT

Virtual Reality (VR) applications constantly strive for more realism, immersion and intuitive user experiences. Traditional VR controllers can hinder full immersion, since they form an additional barrier between the user's thoughts or intentions and the virtual world. Brain computer interfaces (BCIs) have the potential to close this gap by enabling an immediate translation of human thoughts to commands that can be processed by a computer. This paper investigates the feasibility of employing an affordable commercial BCI device for VR interaction. In a preliminary study conducted in a Cave Automatic Virtual Environment (CAVE), we evaluate both the effectiveness and limitations of the popular BCI device *Emotiv Insight*.

Keywords

Brain Computer Interface, Virtual Reality, CAVE

1 INTRODUCTION

In recent years interest and popularity in virtual reality (VR) devices has increased drastically and has attracted the attention of the research world and consumers alike [1]. Today, VR experiences are more realistic and engaging than ever. Different input devices allow users to engage with their virtual environment and play an important role in increasing immersion [2]. Unlike traditional computers, where the interaction usually involves mouse and keyboard, VR applications use alternative input devices and aim for a more intuitive control. Besides input methods like gesture [2], or head-movement [32], brain computer interfaces (BCI) offer a promising alternative as a communication tool. These systems work by reading the user's brain signals, applying machine-learning algorithms to classify the brain state, and then based on the signal, trigger an action on the computer [11].

BCIs have the advantage that no muscular movements are needed, instead systems are only controlled by thoughts or emotion, which is why BCIs are often discussed as an alternative input device to help users with motion impairments to interact with a computer [26]. More recently BCIs have been explored as an additional input channel in video games and VR [22].

For noninvasive acquisition of brain activity, electroencephalography (EEG) [29] has been the most widely used method, due to its relatively low cost, high resolution and portability [21]. EEGs measure electrical activity resulting from current flows, which are produced when neurons are activated. Signals are read by electrodes that are placed on different regions of the skull [31]. The recorded brain activity can be seen as waves that can be categorized based on their frequency [31]. The dominance of each wave type is heavily influenced by the user's current emotional state and where the electrodes are placed [31].

In recent years, consumer-grade EEGs have found their way from research into real-world environments [22]. Despite limitations compared to medical-grade devices including lower sensor counts, accuracy and transfer rates, commercial EEG devices are still a popular choice for immersive experiences due to their affordable price and ease of use [22].

This paper presents an exploratory study on the applicability of BCIs in conjunction with virtual environments, aiming to test the technical feasibility of utilizing consumer-level BCIs for this purpose in a practical setting. We conducted experiments with the commercial and affordable EEG headset *Emotiv Insight 2.0* (shown in Figure 1) in order to evaluate, whether cost-efficient BCIs can be used as an intuitive input device for VR applications. We chose to utilize Emotiv Insight for our experiments due to the minimal setup time of 1

Figure 1: *Emotiv Insight*. Image taken from [4].

- 2 minutes, the seamless integration within the Unity game engine through Emotiv's API, and it's popularity in research. Emotiv offers a Pro license for 149$ per month that offers high-resolution performance metrics with a higher sampling rate than the free license. However, the Pro license would not have made an impact on the overall quality of the device, which is why we opted for the free license. Choosing the free license over the Pro license also ensured alignment with our goal of a low-cost interaction method [5]. To assess its applicability as an input device for VR we used the Emotiv headset to trigger different animations in a Cave Automatic Virtual Environment (CAVE).

All experiments were performed in the CAVE, a four sided, projection-based VR setup with lightweight LCD shutter glasses which offer improved wearing comfort compared to head-mounted displays, and minimise obstructions and interference between VR and BCI headsets.

2 RELATED WORK

Brain Computer Interfaces (BCI) have enabled many different possibilities over the years. Traditionally, BCI focused on medical applications, developing applications to allow patients to control and communicate with things in all aspects of life [22]. Research in this field has undergone major advances over the years, with BCI being used as an assistive technology to enable patients with a paralyzed body to communicate [15], to controllable wheelchairs [9] and many other applications.

Recently, BCIs have been introduced in the consumer market and new applications have been developed in particular for the entertainment/gaming area [22]. In this area, combining BCI devices and VR has led to promising results [22]. Friedman *et al.* [8] showed that BCIs can be suitable to interact with virtual environments. In their work, they used the Graz-BCI [25] to carry out different experiments with three subjects in different VR setups. The authors came to the conclusion that BCI has potential as an input device in VR. They also found that accuracy was the highest in a CAVE environment, which was also the preferred environment of all subjects. Leeb *et al.* [19] aimed to overcome the use of cue-based BCI and get closer to real world conditions. Therefore, the VR application must allow the users to freely decide, what they want to do. For their study, they built a freely explorable apartment and asked 10 test subjects to walk to a defined target room using EEG signals from only three channels. They concluded that also with a simple EEG setup of only three channels, the users could successfully navigate through the apartment. The study also showed that motivated users performed better than unmotivated ones, which indicates that motivation is an important factor during BCI training.

VR setups are also an ideal test environment for BCI research and for scenarios that would be too costly or dangerous under normal circumstances [18, 17]. Leeb *et al.* [18] showed that combining VR and BCIs can be a useful tool to control a wheelchair in VR. Guger *et al.* [10] demonstrated in a VR setup that BCI devices can be successfully used to control smart home devices and applications, such as opening doors.

In recent years, multiple studies have indicated that Virtual Reality can convey feedback to BCI users better than simpler 2D approaches [19]. Ron-Angevin and Díaz-Estrella [27] found in their research that receiving feedback through an immersive experience can have a positive impact on BCI accuracy. In this study, users, who performed BCI tasks in VR, demonstrated reduced error rates and also reported a motivational effect compared to a traditional 2D screens. This effect may arise from the increased immersion and realism in virtual scenes provided by VR that can lead to more distinct brain patterns, which can be better recognised by BCI devices [23].

Due to advancements in technology, EEG devices have recently entered the consumer market [22] and several commercial EEG devices have emerged. Examples include Emotiv Epoc, Emotiv Insight, Neurosky Mindwave, & the OpenBCI headsets, which vary in price & the amount of sensors. In their review on the use of consumer-level BCIs in research, Sabio et al. showed, that Emotiv devices were the most extensively utilized, followed by Neurosky Mindwave [28]. Neurosky Mindwave offers only one electrode and one reference electrode next to the ear, which might be the reason for it's low accuracy, as indicated by multiple works [22]. Other BCIs such as OpenBCI have received limited attention in research [28]. Zabcikova [33] investigated the quality of *Insight*'s EEG signals with the help of subjects that were exposed to visual and auditory stimuli. Other application where *Emotiv Insight* has been used include drone control [20] and controllable smart wheelchairs [6]. In combination with a head-mounted display, Fayed *et al.* [7] used *Emotiv*

Insight to create a cognitive training program to train focus. A cognitive approach was also taken in [12], where Hu and Roberts used an *Emotiv Insight* device with a VR setup to study the correlation between the emotional state and the built environment characters.

In this paper we employ the *Emotiv Insight* device to control VR scenes which surround the user in a CAVE. We chose this specific device due to it's widespread adoption in research and the acceptable count of five sensors. Aiming for affordability, Emotiv Insight additionally emerges as a cost-effective alternative compared to higher-priced products like Emotiv Epoc.

3 METHOD

This section provides insight into the input device, the test environment, as well as the animations that can be triggered by the EEG signals. Our proposed BCI-VR setup allows users to experience a changing environment that responds to the user's thoughts. A schematic model of our system is illustrated in Figure 2. The user's thoughts or mental commands, are picked up by the *Emotiv Insight* device and are used as an input for the VR Scene depicted in the CAVE.

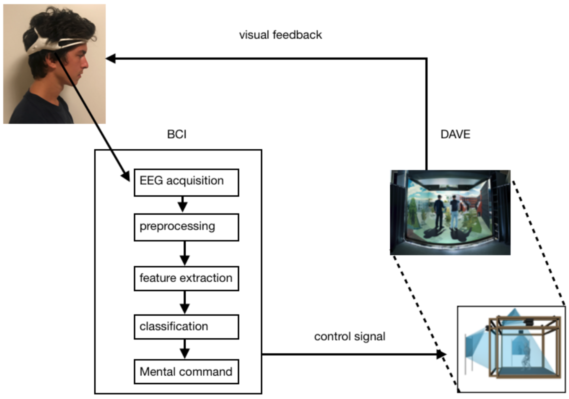

Figure 2: Schematic model of our *Emotiv Insight*-VR setup. EEG data is acquired by the Insight device, and processed to a *mental command*, which is subsequently used as an input for our VR system, which responds with visual feedback to the user.

3.1 The Virtual Environment

A CAVE offers an immersive experience and unlike head-mounted displays (HMD), also allows users to feel their presence in the virtual world [30]. In our case, the CAVE is a projection-based VR setup, which consists of four projection walls, four stereoscopic projectors and two standard hardware computers for each projection wall rendering the image for the left and the right eye respectively [16]. Additionally, users wear lightweight LCD shutter glasses, which can be comfortably worn together with the BCI. A schematic of our CAVE is shown in Figure 3.

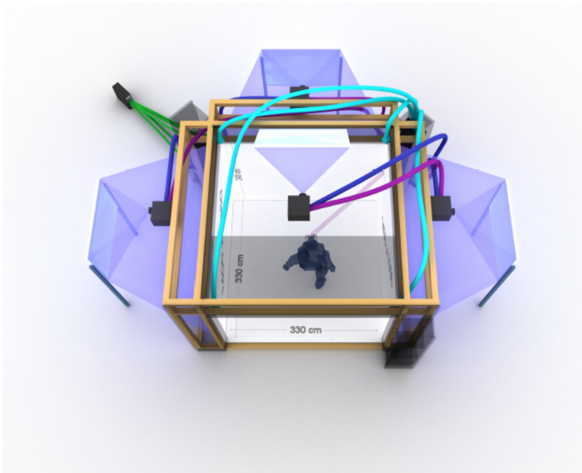

Figure 3: A schematic of the CAVE setup. Images are projected on the side walls from the back and on the floor from above. Mirrors are used to reduce spatial requirements.

3.2 The Brain Computer Interface

Emotiv Insight is a portable, consumer-grade EEG headset and is a cost efficient alternative to other EEG devices. The headset is designed for every day use and features 2 reference sensors and 5 channels which are located on the scalp according to the 10-20 electrode system [14] on positions AF3, AF4, T7, T8 and Pz. The connection between the computer that runs the CAVE application and the headset is established via Bluetooth. Communication with the headset is done with *Emotiv's Cortex API*, which is based on JSON and Websockets [3]. Additionally, the *Emotiv App* is also needed to authorize the application. The API can be used to obtain different data from the headset, namely *facial expressions, mental commands* and so called *performance metrics* that represent values of the user's current stress, relaxation, focus, excitement, interest and engagement levels. The data rate of the device is 128 Hz, which corresponds to 128 JSON messages per second for each opened data stream. Nevertheless, the actual data sampling rate heavily depends on the type of license. In this case, we used the free license, which allowed us to receive new *performance metrics* every 10 seconds. Since the use of such a device requires focus on the task, the time was used by applicants to really focus on the thought.

To trigger animations in VR we used *mental commands*. This functionality allows users to trigger events based on their thoughts and allowed us to receive data in real-time.Therefore, a profile must be trained with Emotiv's BCI software, which associates thoughts to specific events. Besides the *neutral* command, which represents a relaxed and calm state, this EEG headset is able to differentiate up to 4 different commands at a time, which are named as *push, pull, left, right*.

After sufficient training, we ensured that a good connection is established before we could use it in our CAVE application. For this, the Emotiv App indicates the EEG quality for each sensor with a color. Before usage, it is crucial that the headset fits firmly on the user's scalp and that the sensors are moisturized with contact lens fluid. Only if all sensors report a good EEG quality, high-quality *mental commands* can be received. In the API, *mental commands* come as string tuples that contain the *mental command's* name, the power, and the time. The current *mental command* and its power were then used, to trigger an animation. To sort out faulty and inaccurate *mental commands* that can be caused by bad EEG quality, we introduced a threshold on the power. The *mental command* was only used, if it exceeded the defined threshold. This allowed us to receive consistent data without the need of computationally intensive smoothing.

3.3 VR Animations

To assess the applicability of the commercial BCI input device for VR control, we used three animations which the user may control via a *mental command*. The experiments were carried out by a 22-year-old male participant. All animations where developed using Unity 3D.

3.3.1 Accelerating Sphere

In this animation, the user can accelerate a sphere and move it through hoops, Figure 4.

If the *mental command* is neutral, the sphere decelerates until it eventually comes to a standstill. If the user focuses on pushing the sphere through the hoops, the sphere accelerates and rolls through the hoops, much like a VR game of croquet.

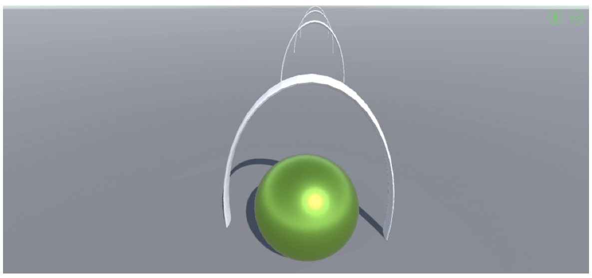

Figure 4: The sphere's acceleration is controlled by the power of the triggered *mental command*.

3.3.2 Terrain

A planar terrain, Figure 5, is modified by generating Perlin noise [24] using a users thoughts.

The hills increase in depth when the user starts to trigger a *mental command*. The longer the user holds on to the thought and the stronger the current command is picked up, the deeper the valleys and hills get. When users relaxes from the thought, the surface starts to get smoother, until it reaches a flat and even surface.

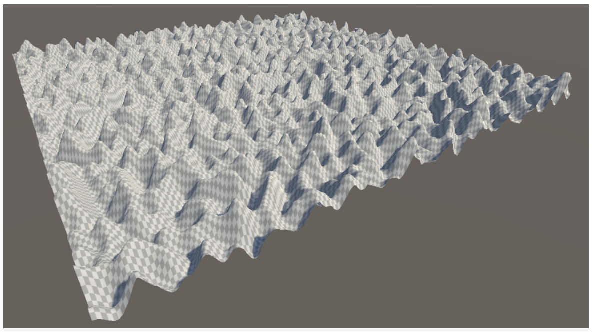

Figure 5: Generated terrain using *perlin noise*. The magnitude of the terrain is controlled by the duration and strength of the *mental command*.

3.3.3 Forrest Environment

Our third animation is a natural environment with rocks, trees, and grass that are waving in the wind, as illustrated in Figure 6. The user can transform this environment into a flower meadow with mushrooms, when triggering a *mental command*. As soon as the thought is relaxed, the flowers retreat into the ground.

Figure 6: Forrest environment with mushrooms and flowers.

4 RESULTS

Our results using this headset showed several issues with the device. Originally, we planned to use the *relaxation value* to control animations, but due to the low sampling rate and inconsistencies within the metrics this plan was discarded. To determine whether the *performance metrics* were a reliable input for our CAVE application, we tested its accuracy by recording our mental state over a time span of 28 minutes. During the test, a relaxation video ran in the background and we closed our eyes to enter a state of relaxation. As shown in Figure 7, the relaxation value increases over time. However, we also found a correlation between the *stress* and *relaxation* value in our test (see Figure 8). This finding is unexpected, since relaxation and stress are emotions that usually do not correlate with each other.

This correlation and the low sampling rate of 0.1 Hz were the reason, why we utilized *mental commands* instead. The *mental commands* capability has a higher sampling rate, which allowed us to receive roughly one data sample per second. Using a single command, we were able to control the animations successfully. However, using more than one command severely affected the accuracy and made the use infeasible. Additionally, the result depended heavily on the contact quality of the headset. All electrodes must at least indicate some contact with the scalp to receive any *mental commands*. In our testing, we experienced that even subtle movements could disrupt the signal quality, which affected the experience in the CAVE significantly.

While training a command, the users were asked to hold on a thought for eight seconds. After each training, the users receive feedback on how representative the measurement was and can then decide, whether the training session should be erased or not. In the beginning, a profile was only trained with a single command (*push*) with a training time of 3-4 hours.

After we had sufficient control over one command, we tried to train a profile with higher command counts, with limited results. Even after extensive prior training the majority of *mental commands* was detected incorrectly. This is on par with other works, like Khan & Laique [13], who experienced similar results. In their work, a profile was trained on an *Emotiv Epoc* headset for 11 hours with 4 different *mental commands*, which resulted in an accuracy of only 25% [13]. This led us to only use one single command in our animations.

Users also experienced physical discomfort after already 15 minutes of use, because *Emotiv Insight's* sensors press tightly against the skull.

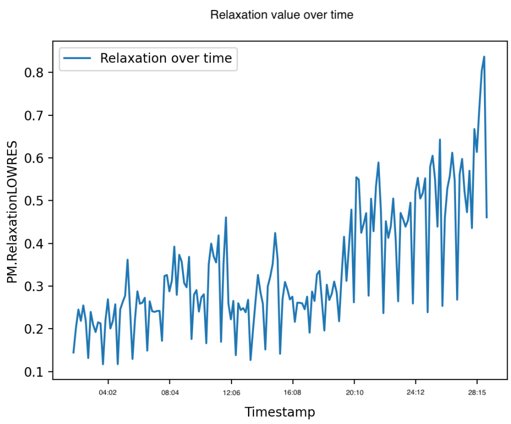

Figure 7: Relaxation value over a time span of 28 minutes.

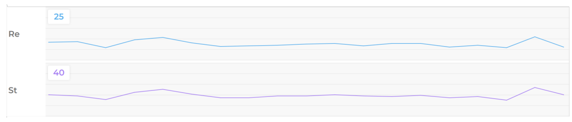

Figure 8: Line graph of the relaxation (Re, top) and stress (St, bottom) *performance metrics*. The figure indicates a correlation between the relaxation and stress value.

5 CONCLUSION AND DISCUSSION

In this preliminary study, we have investigated the use of the cost-efficient EEG device *Emotiv Insight* for VR control and tested the technical and practical feasibility of such a setup. We developed three different animations that react to the user's thoughts: A sphere, which can be accelerated, a procedurally generated terrain that forms valleys and hills and a forest environment, in which mushrooms and flowers are generated based on the user's brain activity.

Our experiments revealed a number of issues with the *Emotiv Insight* device. Severe reliability issues with the sensor data, the low sampling rate, as well as the physical discomfort of the device, led to the conclusion that *Emotiv Insight* is unsuitable as an input device for real-time applications. Our results further indicate a poor user experience, particularly due to reported headaches after only a brief period of wearing the BCI headset. Due to overwhelmingly negative feedback, a full evaluation of the setup involving this device was abandoned.

We also found that the initial training phase and the time-consuming task of adjusting the sensors make *Emotiv Insight* not suitable for applications in VR. Additionally, some important features of Emotiv's SDK, such as high-resolution *performance metrics* are restricted and require a costly monthly subscription.

We conclude that multiple improvements have to be made such that the *Emotiv Insight* becomes a viable alternative for controlling VR applications. Our suggestions include a more adjustable design, more sensors to improve accuracy, and overall a stronger focus on reliability. In the future, we will examine other BCI devices and conduct comparison experiments evaluating both usability and reliability. BCI devices are a promising technology, but need to overcome some shortcomings to be a practical input method for real-time interaction in VR environments.

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