DEVELOPMENT OF A BCI VIDEO GAME FOR MENTAL STATE RECOGNITION

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Abstract: This paper explores the applications of BCI technology in video games, ranging from medical to innovative gaming experiences. The research considers neurogaming platforms combining BCI and EEG for real-time insight into the cognitive state of players. Additionally, it investigates the use of EEG for emotion classification in gaming contexts. In this paper we develop a video game based on BCI that studies the influence of alpha and beta waves in installing the emotional state of happiness, together with normal state and relaxing state. As a solution to capture EEG signals, we propose to use a neural headset with a single detection electrode that was originally developed for an entertainment game, being augmented with a development board for signal extraction.

Key words: BCI, EEG, low alpha waves, low beta waves, happy.

1. INTRODUCTION

BCIs facilitate direct interaction between the human cortex and external devices, enabling individuals to control technology through thought. This technology is particularly beneficial for persons with severe motor impairments, such as those caused by diseases such as spinal cord injury or amyotrophic lateral sclerosis (ALS).

BCIs generally capture brain signals using methods like electroencephalography, which analyzes brain's electrical activity via electrodes placed on the surface of the scalp. Ensuring accurate signal acquisition and processing remains a significant hurdle due to noise and artifacts in the data.

Brain-Computer Interface (BCI) technology has made significant strides in its application to video games over the years, offering innovative ways for players to interact with virtual environments using their thoughts.

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We present a brief history of BCI's integration into gaming. In the early stages, BCI technology was primarily focused on medical applications and research. However, as the technology advanced, researchers and developers began to explore its potential in the gaming industry. The use of BCI in gaming started to gain traction in the early 2000s. Researchers began experimenting with EEG-based systems to control simple game elements, laying the groundwork for more complex applications [1].

The development of consumer-grade EEG headsets, such as the Emotiv EPOC+, played a crucial role in making BCI technology more accessible to game developers and players [2]. These devices allowed for easier integration of brain signals in gaming experiences.

As BCI technology improved, it found applications in serious games designed for training and rehabilitation purposes. For example, in 2019, the serious game PROEZA was developed to train users in controlling a hand prosthesis using BCI. This game integrated EEG signals captured by an Emotiv Epoc+ headband with the Unity game engine [3]. Researchers have also explored using BCI-enabled video games to enhance cognitive skills like attention and concentration. Studies have shown that mental training through BCI applications can improve these abilities over time [2].

In recent years, BCI technology in gaming has seen further advancements: the development of more sophisticated algorithms and machine learning techniques has improved the accuracy and responsiveness of BCI systems in gaming contexts; there's been an increased focus on creating immersive gaming experiences that incorporate BCI technology, enabling players to control game elements with their thoughts more seamlessly [4]. The combination of BCI with augmented reality and virtual reality technologies provide new opportunities for creative gaming experiences [5].

As BCI technology continues to evolve, its potential in gaming is expanding. Researchers are exploring ways to use BCI for enhancing player engagement and immersion in games, creating adaptive gameplay experiences based on a player's cognitive state, and developing new genres of games that are specifically designed around BCI interaction.

While BCI in gaming is still a developing field, it has enormous potential for altering how we interact with video games in the future [1].

2. Neurogaming platforms

Neurogaming platforms combine Brain-Computer Interfaces and EEG with video games, enabling the examination of the cognitive state of players in real time by linking brain activity with game actions. Brain-Computer Interface EEG data during gaming provide a continuous objective measurement of the player's cognitive state without interrupting gameplay and offer deeper insights into gaming experiences. While it is common to use this approach for assessing task engagement and arousal, a standard method has not been brought into being yet [6].

A study conducted by McMahan, Parsons, and Parberry demonstrated the effectiveness of EEG in assessing cognitive workload during video game play. The researchers used an off-the-shelf EEG device, the Emotiv EPOC headset, to analyze brain activity during different gaming [7].

Dehais et al. proposed a neuroergonomics framework that maps undesirable neurocognitive states within a two-dimensional space of task engagement and arousal, which can be applied to understanding gaming performance. The framework identifies specific mental states like mind wandering and effort withdrawal, which could be used to analyze how game elements influence players' cognitive states and performance [8].

A recent study evaluated cognitive attention levels of subjects using EEG data while they played three distinct genres of VR video games: Exergames, Challenging Puzzlers, and Casual Games [9]. The researchers studied the brain's activity in the alpha band, comparing IAF - individual alpha frequency and PSD - power spectral density values to detect changes indicating concentration states. Additionally, they examined FAA - frontal alpha asymmetry from the left and the right brain hemispheres [9].

EEG-based neurogaming platforms have shown potential in detecting cognitive decline. A study using a single-channel EEG system with an interactive assessment tool demonstrated the potential for extracting cognitive decline biomarkers in seniors at various clinical phases of cognitive impairment [10]. This approach could potentially aid in an early diagnosis of conditions like Alzheimer's disease.

3. EEG FOR ESTABLISHING HUMAN EMOTION

Combining features from the EEG dataset obtained from both time-domain, frequency-domain, and time-frequency analysis using the Discrete Wavelet Transform (DWT) through a hybrid domain can affect the decision-making process of emotion classification. The emotions in the EEG data set are often divided into four types based on model arousal-valences: those with positive valences with high arousal represented as happy and relaxed, and those with negative valences with low arousal represented by bored and stressed [11], [12], [13].

Most neurophysiological studies correlate emotional activity with the structure of the amygdala as part of the temporal lobe but also with the frontal lobe. Also, happy emotion phenomena can be correlated with brainwave power distribution estimation in the Alpha and Beta bands [14], [15].

An increased presence of low alpha waves (8-10 Hz) located in the frontal lobe may be closely aligned with the state of relaxation induced by mindfulness-based meditation, while increases in beta power together with increased lower alpha reflect networks involved in specific feelings and thoughts related to compassion and gratitude [16], [17].

4. APPROACHED METHOD TO MEASURING EEG SIGNAL

To measure the user's EEG signals, we chose a MindFlex neural headset equipped with a dry metallic detection electrode placed on the forehead at the location of the frontal pole of the brain (FP1) and two reference electrodes placed on the earlobes.

We choose this solution because it offers an inbox circuit-level processing in addition to amplification and digitization. This approach allows data processing based on Fast Fourier Transform (FFT) to generate power values in the spectrum of different brain wave patterns. This headset transmits the ThinkGear Data Values encapsulated in ThinkGear packets, represented as a sequential stream of bytes. In addition to signal strength values, it can transmit values related to the level of attention and meditation but also to all major frequency bands of the brain [18].

To be able to extract the signals directly from the MindFlex headset circuit data flow via a USB port, we implemented a hardware connection based on the Arduino nano V3 development board, as presented in Fig. 1.

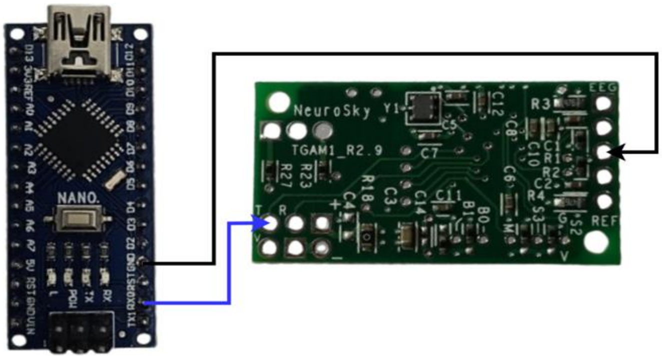

Fig.1. Hardware diagram Arduino Nano V3–Neurosky TGAM1 board

As shown in Fig. 1, we connected the Rx receiver pin of the Arduino to the T transmitter pin of the MindFlex board to enable the UART (Universal Asynchronous Receiver-Transmitter) hardware serial communication protocol between the boards.

The result of MindFlex neural headset integration with the development board is presented in Fig. 2.

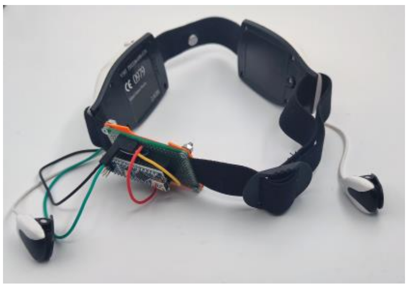

Fig.2. MindFlex neural headsets after hardware upgrades

Next, we implemented a code in the Arduino Integrated Development Environment (IDE) that uses the <Brain.h> library (https://github.com/kitschpatrol/Brain), available by the General Public License (GNU), for parsing the data. We aimed to obtain processed data every second at the Neurosky TGAM1 chip baud rate, related to signal EEG quality, attention, low alpha waves that it associated with relaxation and meditation, and low beta waves that it associated with active thinking and focus. Each data point is then transmitted over the serial interface in CSV (Comma-Separated Values) format to be used as input to trigger a specific action in a BCI video game.

5. THE IMPLEMENTATION OF BCI VIDEO GAME

To be able to decode the user's emotional state, we developed a BCI-based video game based on a five-step algorithm, presented in Fig. 3, which we implemented in the Java-based Processing high-level programming language through the open-source sketchbook software, Processing 4.

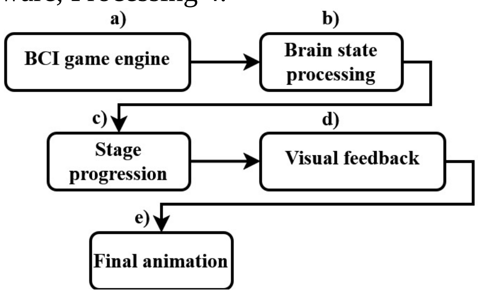

Fig.3. The implementation of emotional state decoding BCI video-game

The first step has the role of implementing the game variables that manage the number of stages set to three, to the current stage, but also the target brain state tracked from three target states that are chosen pseudorandomly. It also sets a series of timers, both to measure the user's performance and to trigger the closed or open state of a padlock animation generated as a reward based on the state reached by the user.

The second step aims to update the user's brain state in the category of normal state or emotion, such as relaxed or happy, by comparing the low alpha and low beta wave values obtained from the processed data as a result of reading the brain signals received from the Arduino board through the serial port. This classification is obtained by comparing the read values with a set of predefined minimum and maximum thresholds proposed by Hadi et al. in the domain of the tracked brain waves, presented in Table 1.

Table. 1. ***The threshold value for low alpha and low beta waves [19]***

Mental condition	α (Min– Max)	β (Min – Max)
Normal	11000 − 150000	13000 − 150000
Happy	50000 − 150000	150000 − 300000
Relax	150000 − 260000	150000 − 250000

The third step verifies each step's completion by marking the current state as successful if it matches a target of 2 seconds in which the user focused and maintained the set emotion or normal state as appropriate. At the same time, it imposes a time limit of sixty seconds within which the imposed state must be reached; otherwise, the stage is counted as a failure. In case of success, a countdown is initialized, which will be displayed in the form of a numerical animation, marking a three-second countdown between stages. The implementation of the third step with open padlock state animation is presented in Fig. 4.

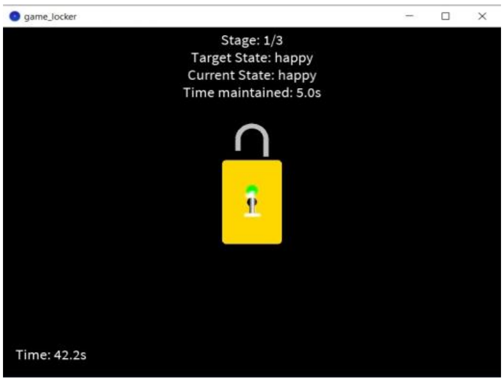

Fig.4 The first stage of BCI game with happy state recognition

The fourth step implements a series of animations to improve the user's perception of game dynamics offered as a reward to the action performed from rendering a closed padlock shown in Fig. 5. a), marked by a green pulsating indicator whose intensity is marked by the power developed by the user feeling experience. At the same time, a render of an open padlock, shown in Fig. 5. b), may or may not be marked by the pulsating indicator, depending on the presence or absence of maintaining the emotion, but it is certainly marked by the numerical animation of the three-second countdown.

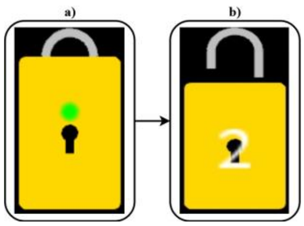

Fig.5 The interstage animation of paddlock

The last step represents the completion of all stages and aims to display an animation of total stars accumulated by the user as a result of accomplishing the imposed state. Along with the number of accumulated stars, represented between two and five, each user is being rewarded with one star for fulfilling the condition of the stage, displaying the related message, the completion times, and the achieved states for each stage. The final scene result of the BCI video game is presented in Fig. 6.

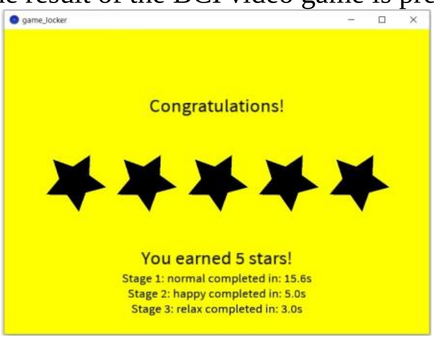

Fig.6 The final scene of BCI video game

6. CONCLUSIONS

BCI technology in gaming aims to change the way players engage, the mode of interaction based on immersive experiences, with the role of unlocking experiences between cognitive health and emotional well-being.

Through this study we found that the analysis of low alpha and low beta waves obtained as a result of preprocessing EEG signals at the circuit level by the MindFlex neural headset produces optimal results in the detection of the emotional state of happiness. This is influenced by the user's imagined experiences and produces better results in the case of imagining a scenario in which he associates the emotion with seeing a close person again, as shown in Fig. 4 reported to the time of maintaining the state. Also, we found that relaxation can be improved when the user was focused on his breath and maintained a defocused eye gaze.

Further, we want to extend the study to the gamma waves in the frontal lobe, as it is known this phenomenon can produce a decrease in the power spectrum related to responses to videos that evoke happiness.

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