IMMERSIVE NEUROFEEDBACK: A NEW PARADIGM

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Abstract: Healthcare organizations continue to pursue ways of offering higher-quality care to face the demand and expectations in promoting and maintaining health and in disease prevention. Currently, in neuroscience, there is an undergoing paradigm shift towards immersive neurofeedback mechanism. This will improve the user's (or patient's) ability to control brain activity, medical diagnoses, and rehabilitation of neurological or psychiatric disorders. Indeed, several psychological and medical studies have confirmed that virtual immersive activity is enjoyable, stimulating, and can have a healing effect. The new paradigm consists of an immersive room and three input devices: Emotiv headset (wireless non-invasive acquisition of brain waves), Kinect camera (gesture recognition), and wireless microphone (voice/speech recognition); towards immersive treatment and better quality health system in the near future.

1 INTRODUCTION

The electroencephalogram (EEG) was first recorded in 1924 by Hans Berger [1]. At that time, Berger studied and described for the first time the nature of EEG alterations in brain diseases such as epilepsy. Currently, EEG is a helpful tool in clinical neuroscience, with several applications such as:

- Monitor alertness, coma and brain death [2, 3]
- Locate areas of damage following head injuries [4, 5], stroke [6, 7] or brain haemorrhage [8, 9]
- Detect Alzheimer's disease [10-13] and brain tumour [14, 15]
- Investigate sleep disorders [16, 17] and epilepsy [18, 19]
- Monitor human brain development [20, 21]
- Measure the depth of anaesthesia [22]
- Test drug effects [23, 24]

Both the progressive developments in electrical engineering and the fascination with the human brain have attracted researchers from different background to investigate EEG recordings.

One of the interesting multidisciplinary applications of EEG is *sonification*, i.e., converting the brain waves into music. Several researchers [25-30] tried to generate sound from EEG signals; there are still many open questions and challenges, and plenty of opportunities especially after the recent advent of convenient wireless EEG headsets [31-35].

As far as we know, converting brain waves into combined representation (i.e. sounds, graphics, and haptics) in an immersive room has not been reported in literature. However, Elgendi *et al* [36] suggested transforming real-time EEG signals into multimodal tangible representation such as sounds (sonification) and graphics (visualization), to improve neurological diagnosis and neurofeedback.

In this paper we are providing a new paradigm that translates EEG signals, recorded from a wireless EEG headset, into sounds and graphics mapped in an immersive room.

Figure 1: A performer tries to control the sounds and the tunnel properties (i.e. colour and speed) generated from his EEG, by adjusting the mental states associated with the heard sound and shown graphics.

The immersive room offers a unique and powerful platform to represent brain waves in a tangible fashion. Although neural feedback has been investigated for quite some time now, it has never been implemented in an interactive and immersive room. Such novel representation of brain signals can be valuable for therapy, diagnosis, entertainment, and arts. Indeed, several psychological and medical studies have confirmed that virtual immersive activity is enjoyable, stimulating, and can have a healing effect. These studies have also shown that the effect is stronger with virtual reality (VR) feedback than with simple 2D feedback [37-40].

2 VISION

A visitor in the immersive room can see, hear and touch his brainwaves, as if he is standing in the middle of his own brain, as shown in Fig.1. Such intense neural feedback may for example be used to cure neurological diseases such as depression, epilepsy, bipolar disorder, cognitive impairment, migraines, and autism spectrum disorders; alternatively, it can be used to explore and investigate mental states (e.g., emotions, meditation).

3 METHODS

We map electroencephalogram (EEG) signals onto computer graphics, sounds, music, and haptic stimuli (vibrating gloves). Those different representations can be generated separately or simultaneously, resulting in a virtual reality (VR) that has been sculpted from EEG signals.

This virtual reality can be generated offline: that allows a medical doctor to screen EEG signals of patients in a retrospective fashion.

We are also developing a real-time implementation: the visitor then perceives his own brainwaves in real-time, which in turn will alter the brainwaves; such feedback system ("neurofeedback") may have a stabilizing effect on the brain [39], and has been shown to be an effective cure for a wide spectrum of neurological diseases [41].

A virtual human (VH) in the immersive room guides the visitor through different applications and types of neural feedback. The visitor can customize the demo in the immersive room on the fly: he can control certain parameters of the virtual reality (e.g., colors, speed, angle of view, zoom), by talking to the virtual human and by gestures.

4 SCENARIO

Different scenarios can be proposed, but in here we will explain the generic scenario. Once the visitor enters the room, the Virtual Human (VH) will operate as a host. First the VH will verify the identity of the user, and will check whether the visitor has access to the system. Then, the VH will ask the visitor whether he would like to use the system for real-time neural feedback or for offline analysis of recorded EEG signals. In the latter case, the VH will ask the EEG database to be processed;

in the former case, the VH will ask the visitor to wear the wireless EEG headset. In both cases, the VH will ask the visitor to select one of the applications, including Paint, MIDI-3D brain, Vortex, and Topoplot.

- **Paint:** Painting with your brain waves in 3D.
- **MIDI-3D brain**: Listening to the music generated by the brain waves in 3D, while watching a 3D artistic rendering of brain waves, and feeling the brain waves as vibrations in smart gloves.
- **Tunnel**: Monitoring and controlling the level of consciousness of the visitor through 3D tunnel, as shown in Fig. 1.
- **Topoplot:** A variety of research-oriented representations of the brain waves, including time-frequency maps, spatial distribution of power, EEG statistics such as synchrony and complexity.

The visitor can ask the VH to stop the system at any time.

5 SYSTEM DESIGN

Our system has three input devices: Emotiv headset (wireless non-invasive acquisition of brain waves), Kinect camera (gesture recognition), and wireless microphone (voice/speech recognition). These devices are connected to Processing (3d graphics mapping), Dolby surround system, topoplot (brain activity mapping), and SAPI5.4 (Speech Application Programming Interface).

The graphics output of these software packages will be projected on the screens in the immersive room, and the sound will be fed into the Dolby Surround System. As shown in Fig.2, the system is developed in different programming languages; the input devices are all processed in VC++, whereas the output devices are developed in Java, VC++, and Python.

We use multithreading technology and sockets to seamlessly integrate those different languages; the same technology also allows us to run multiple applications in parallel, and to connect and process additional sensors and input/output devices; information can even be transmitted and received through the world wide web, enabling various powerful extensions of our approach (e.g., multi-user applications for study of social interactions).

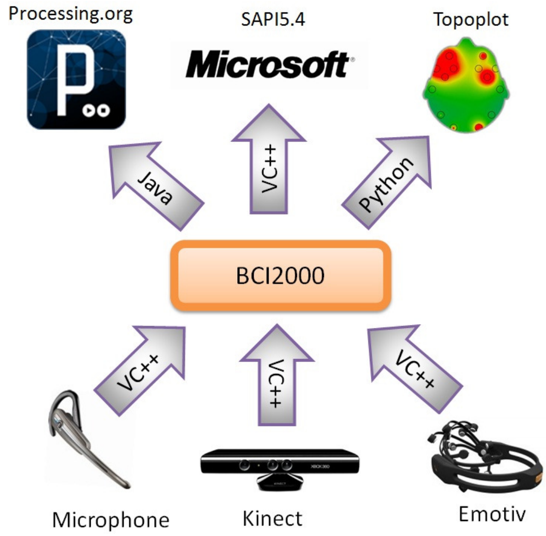

Fig. 2. Emotiv (wireless EEG headset), Kinect (gesture detection camera) and wireless microphone are connected to Processing.org software (graphical rendering), Topoplot (research-oriented visualizations), and Speech Application Programming Interface (SAPI5.4). The programming language used for each component is indicated on the arrows. The package BCI2000 serves as an interface between those different languages, and operates as a meta-platform.

5 CONCLUSION

A new healthcare model that shifts towards immersive neurofeedback has been introduced. Mapping brain signals in an immersive room can be valuable for therapy, diagnosis, entertainment, and art.

The committee on quality of health care in America Institute indicate that a radical transformation of health services supply process is required for the 21st century. Fully immersive real-time feedback of the users' mental state offers a potential for a new paradigm in future healthcare.

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