ATVR: An Attention Training System using Multitasking and Neurofeedback on Virtual Reality Platform

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***Abstract*—We present an attention training system based on the principles of multitasking training scenario and neurofeedback, which can be targeted on PCs and VR platforms. Our training system is a video game following the principle of multitasking training, which is designed for all ages. It adopts a non-invasive Electroencephalography (EEG) device Emotiv EPOC+ to collect EEG. Then wavelet package transformation(WPT) is applied to extract specific components of EEG signals. We then build a multi-class supporting vector machine(SVM) to classify different attention levels. The training system is built with the Unity game engine, which can be targeted on both desktops and Oculus VR headsets. We also launched an experiment by applying the system to preliminarily evaluate the effectiveness of our system. The results show that our system can generally improve users' abilities of multitasking and attention level.**

***Index Terms*—Multitasking, Neurofeedback, Attention Training, Virtual Reality**

I. Introduction

Attention training is an efficacious neurobehavioral therapy for the emotional disorder, and is considered to be the standard interventions for these disorders [1]. Unfortunately, attention training is not always easy to apply because the training system should be both theoretical supported and have the objective evaluation properties.

To solve these problems, biometric information such as electroencephalogram(EEG) [2] is applied as a reference to evaluate the attention level [3]. Cognitive training uses on-going computer feedback to reinforce correct responses, thus training attention and working memory and decreasing impulsivity [4]. Neurofeedback provides immediate feedback on any change of brainwave patterns, which represents the attention level, back to the training process. Such a technique is used clinically as auxiliary treatments of insomnia, pain, Attention deficit hyperactivity disorder (ADHD) and other diseases. [5] [6] [4] The basic working principle of neurofeedback training technology consists of recording the brain activity, decoding or identifying the brain patterns of interest, and providing users with relevant feedback stimuli based on the current/required working levels of their brain rhythms [7]. For our system specifically, it monitors a user's attention while collects the game performance in real time. It further improves the user's performance as well as attention level by training multiple times. Moreover, the virtual reality(VR) devices provide not only more immersive experience but also enhance biofeedback effects because the visual system is one of the factors influencing EEG activity and attention [8].

II. Related Work

The state-of-the-art researches show that just one hour of gaming may improve attention [9]. Attention training and cognitive enhancement through the video game are expected to be an efficient and easy practical way [10]. The relationship between video games and human social, political, mental, physical, and even creative variables has been studied [11]. Llorens et al [12] investigated video games as a therapeutic tool for cognitive behavioral therapy(CBT) during treatments for clients with bulimia nervosa. They looked at how CBT coupled with a serious video game can address a clients emotional dysregulation and demonstrated that CBT coupled with video games is a good tool to use. Similarly, studies also conduced by Rernandez-Aranda [13] and Chang [14], which shed some light on the possibilities of using video games in counseling and psychotherapy. Meanwhile, For a long time, immersive VR with cognitive training is effective for attention enhancement [15].

Neurofeedback techniques were introduced in psychotherapy studies. Steiner et al [16] fit the training methods to the treatment of attention deficit hyperactivity disorder, relying on the patients' self-conscious to strengthen some particular brain waves and applied the feedback to help therapy. However, this treatment is clinically unstable, especially for those special clinics with poor compliance towards the treatment, resulting in poor neurofeedback. Anguera et al [17] also developed a cognitive control system to train the elderly through multitasking training. This therapy scheme achieved very good results. But the game itself was not embedded with reaction to users' performance and neurofeedback.

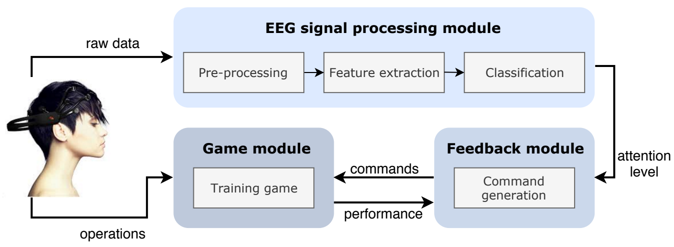


Fig. 1: Work flow of our attention training system

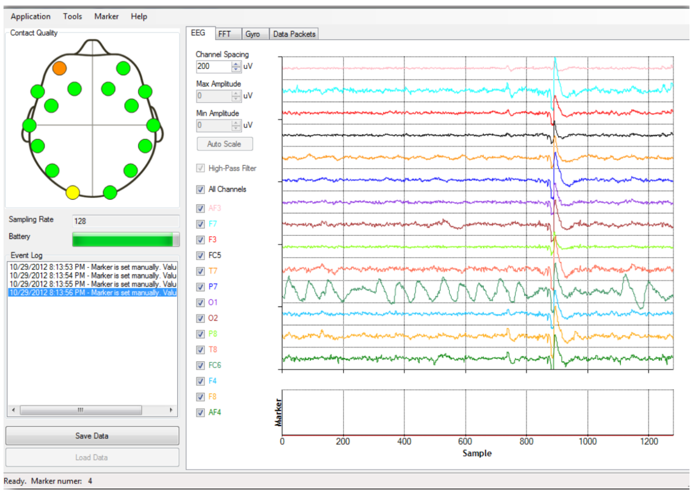


Fig. 2: Emotiv EPOC+ TestBench EEG Signal Collection

III. Methods

Figure 1 shows the workflow of our system. Firstly, the data are collected using a noninvasive method of the EEG signal measurement using EMOTIV EPOC+ 14-Channel Wireless EEG Headset. The data from the process of data acquisition were registered using Emotiv TestBench software. Secondly, we use Wavelet Packet Decomposition(WPD) to extract features of EEG signals and use Support Vector Machine(SVM) to build the classifier. The following step comes to generate game commands based on the decoded attention level from neuro-information. Those commands are fused to the adjust attention training system on the fly. Therefore, parameters of the training system are tuned based both on the post-processed neuro-information and behavior of users.

A. EEG Signal Processing Module

Emotiv SDK provides TestBench to show the device connection status and report real-time changes of brainwave signals gathered from 14 channels(AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4). Fig. 2 shows the positions of electrodes and the raw data collected from Emotiv TestBench. We record the frontal lobe electrode (F3, F4, F7, F8, FP1, FP2) with 128Hz sampling frequency because the rapid processing of the frontal lobe information is one of the most important features of the brain multitasking capabilities [18].

The pre-processing stage removes the noise of raw data coming from eyelids movement, blinking, and teeth clenching, etc. Those noises can be clearly seen that all the electrodes registered a considerable change of the EEG signal. The main components of EEG signal are concentrated in the 0.5-30Hz, and the frequency of interference EMG signal usually exceeds 100Hz. In the pre-processing, we applied pre-filter to the original signal with bandpass 0.5Hz-63.5Hz to get only useful information.

Feature extraction techniques such as time domain, frequency domain, and time-frequency domain methods [19]. Due to the non-stationary property of EEG signals, the wavelet packet transform (WPT) is considered to be one of the most suitable choices to use time-frequency domain methods. Wavelet Packet Decomposition (WPD) decomposes the EEG data into a mutually orthogonal set of wavelets. Both detail and approximation coefficients are decomposed to create the full binary tree. The energy of special sub-bands and corresponding coefficients of wavelet packet decomposition is selected as features that satisfy maximal separability according to the Fisher distance criterion.

In this work, we adopted Daubechies 4(db4) wavelet because its smoothing feature is suitable for detecting changes in EEG signals. The number of decomposition levels is chosen based on the frequency sub-bands we are interested, which are listed in Table I. We obtain four types of signal δ, θ, α and β from 6

Decomposed Signals	Frequency Bands(Hz)	Decomposition Level
D1	43.4-86.8	1(noise)
D2	21.7-43.4	2(γ)
D3	10.8-21.7	3(β)
D4	5.40-10.8	4(α)
D5	2.70-5.40	5(θ)
A5	0.0-2.7	5(θ)

TABLE I: Frequency Bands Corresponding to Different Decomposition

electrons and then calculated their energy separately to build the feature vector. For the EEG signal with length N, the energy is computed as

$$E(x) = \sigma_{n=0}^{N-1}|x(n)|^2 \tag{1}$$

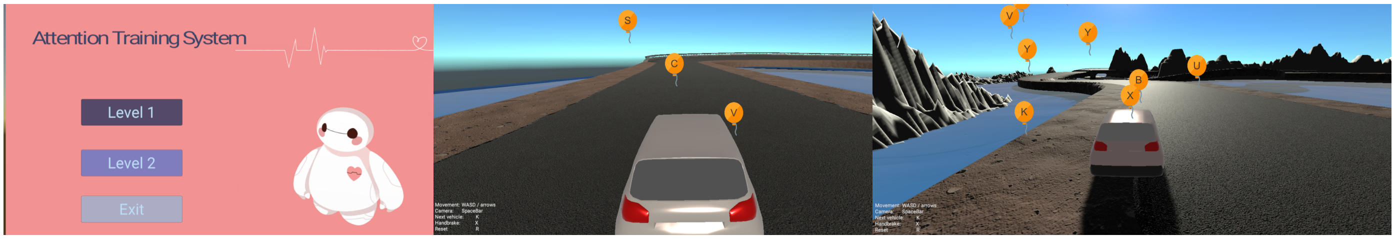
Then for the 4 selected signals, the energy for each or them is:

$$E(i) = \frac{E(x_i)}{\Sigma_{i=1}^{4} E(x_i)} \quad where \quad i = 1, 2, 3, 4 \tag{2}$$

Classification can be done with Support Vector Machine (SVM), which is a supervised learning method to analyze data and distinguish patterns.

Inspired by the previous works that either construct a single hyper-plane to divide EEG data into attention/in-attention modes or use multi-class SVM to distinguish different activities, we build a multi-class SVM to differentiate multi-level attention.

During the training stage, we collect the EEG data from 20 users while they are in the resting state or playing different game levels of our training system. There are four states: resting, game level 1, game level 2, and game level 2 with



(a) Main Page (b) L1 screen shot (c) L2 screen shot

Fig. 3: Screen shots of the attention training game

multi-tasking, which are labeled accordingly. For each user, we collect 3 pieces of data twice for each state. Then an SVM library, LIBSVM, is used to train a multi-calss SVM. Given the training dataset of n points of form $(\vec{x_1}, y_1), ...(\vec{x_n}, y_n)$ can be mapped into high-dimensional feature space as separable samples$\Phi_1(x), \Phi_2(x)...$ with labels.
Compared to the classifier based on the hot topic neural network, this straightforward method is less likely to become overfitting, which is a common case in learning-based solution.

B. Video Game of Attention Training in VR

The screen shots of our system are shown in Fig. 3. We adopt the multitasking training technique and transformed this technique into a video game. Our game is a combination of a racing game and a balloon shooting game, which requests the users to drive while reacting to the spawned balloons with characters.
In the racing game, a player uses the keyboard to control the direction of the car to finish the routes while avoiding obstacles. Different levels come with different difficulties with driving routes. The balloon shooting game is that the player reacts to the spawned balloons with characters as soon as possible before they flow up to the end. The system will check the game status every 10 seconds to adjust the speed of both the car and the balloon generation(higher speed for better performance). Game scores consist of car speed, average reaction time, and reaction accuracy. Each item with full mark 5 is evaluated and finally added up together with full mark 15.
Before the assessment of multitasking costs, an adaptive staircase algorithm was used to determine the difficulty levels of the game based on the scores each participant performed in the car-racing-only task.

IV. Experiments

A. Experiment Design

The experiment participators are divided to the experimental group and the control group. Participants are required to do a stress evaluation questionnaire first to decide which group they are in. Clients with obvious high-stress level are assigned to the experimental group, also 16 clients in the group are diagnosed as generalized anxiety disorder(GAD) patients. Other participants with low-level stress are in the control group. The experiment procedure is:

Name	Age	Gender	GAD history
GAD level	Medicine history	Game training	video game

TABLE II: Participator Self-evaluation Form

Level	Control Group	Experimental Group
L1	12.12	10.51
L2	11.76	9.89

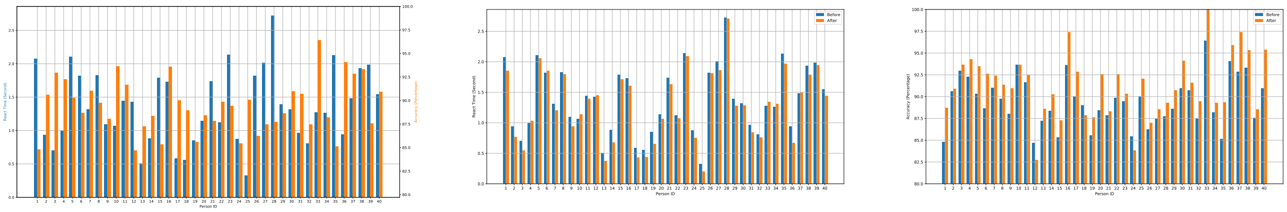
TABLE III: The average game scores in the training stage

- Step 1: Before training stage: do a self-evaluation by completing the form as Table II.
- Step 2: Pre-training stage: do the car racing task to assign each of the participators an initial difficulty level.
- Step 3: Resting stage 1: relax for 5 minutes and record EEG data as resting-state data.
- Step 4: Training stage: do multitasking experiment for 15-20 minutes, recording their performance.
- Step 5: Resting stage 2: relax again for 5 minutes and record EEG data again.
- Step 6: Testing stage: relax for 15 minutes and do the multitasking experiment for another 5 minutes.

B. Results

We record the game performance as the effectiveness measurements of our system. In the pre-training stage, the system assigns each user a difficulty level for the following training stage according to his/her game performance(car racing). This is done because the performances vary a lot for the users with different backgrounds of the individuals. For example, Figure 5 shows the records of the experimental group in the pre-training stage.

In the training stage, participants are required to do the multitasking game challenge. Table III presents the average game scores gained by both groups after that. Figures 4b and 4c compare the performance gathered from the training stage and testing stage, demonstrating the reaction time and reaction accuracy. From the results, we see that the accuracy of multitasking improves a lot while the reaction time declines as well overall. Therefore, we conclude that our system could improve users' reaction speed and multitasking performance to some degree which means the improvement of attention.



(a) Performance in the training stage

(b) Reaction time in the training and testing stage

(c) Reaction accuracy in the training and testing stage

Fig. 4: Task performance of experimental group

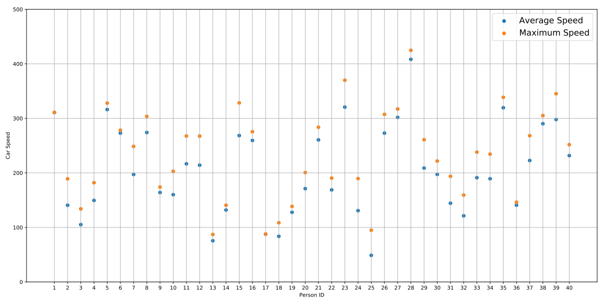


Fig. 5: Average speed and peek speed of clients in the experimental group in pre-training stage

V. Conclusions

In this paper, we choose an attention training scheme that is widely applied and transform it into a video game that can be played both on PC and in the virtual reality environment. We then augment this video game as a neurofeedback BCI system with gathering and analyzing users' EEG signals. For the training system, a feedback module, which contains neurofeedback and game performance feedbacks is designed with classifying EEG data into multiple attention levels. We finally conducted experiments to preliminarily evaluate the effectiveness of our system. The system itself is user-friendly, extensible, and with good reliability. From the experiments, we could say this system played a role in attention level improvement and helped to decrease the anxiety level.

However, our work focus on the system architecture and there are many aspects in the application that are waiting to be tested accurately.

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