A Wearable AR-based BCI for Robot Control in ADHD Treatment: Preliminary Evaluation of Adherence to Therapy

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A Wearable AR-based BCI for Robot Control in ADHD Treatment: Preliminary Evaluation of Adherence to Therapy

Pasquale Arpaia, Sabatina Criscuolo, Egidio De Benedetto, Nicola Donato, and Luigi Duraccio

***Abstract*—A wearable, single-channel Brain-Computer Interface (BCI) based on Augmented Reality (AR) and Steady-State Visually Evoked Potentials (SSVEPs) for robot control is proposed as an innovative therapy for robot-based Attention Deficit Hyperactivity Disorder (ADHD) rehabilitation of children. The system manages to overcome the challenges regarding immersivity and wearability, providing a direct path between human brain and social robots, already successfully employed for ADHD treatment. Through the proposed system, even without training, the user can drive a robot, in real-time, by brain signals. A preliminary evaluation of the children adherence to the therapy was conducted as a case study on 18 subjects, at an accredited rehabilitation center. After investigating the children acceptance of the proposed system, different tasks were assigned to the volunteers aiming to observe their level of involvement. The experimental activity showed encouraging results, where almost all the participants were satisfied with the experience and keen to repeat it again in the future**

***Keywords* — ADHD Therapies, Augmented Reality, Brain-Computer Interfaces, Health 4.0, Robot-Assisted Therapies, Wearable Systems**

I. Introduction

Attention-Deficit Hyperactivity Disorder (ADHD) is a childhood-onset neurodevelopmental disorder, recognized as a medical condition in 1902. In 2013, a prevalence in children of 5% was stated [1], although more recent studies [2] estimated a significant increase (over 10% only in USA), which makes ADHD the most common psychiatric disorder of childhood, often persisting into adulthood and old age [3]. Describing the characteristics of children with ADHD is still a difficult task [4]. The key symptoms of this condition are inattention, distractibility, hyperactivity, and impulsivity. While hyperactivity and impulsivity may not be encountered, inattention and distractibility are always present. For this reason, ADHD is considered a heterogeneous disorder with different sub-types resulting from different combinations of concurrent risk factors (biological, dietary, psychosocial). Among the existing treatments of children with ADHD, different approaches are adopted: pharmacological, behavioral, occupational, cognitive, and psychological [5]. Typically, non-pharmacological therapies rely on teaching the children strategies to stay organized and focused, or to reduce the disruptive behaviors that can affect children at school and in their daily routine. As for non-pharmacological methods, the focus on this work is on behavioral therapies, which aim to improve children academic and social skills, and the relationship with parents and teachers. In combination with the standard treatment plan, a large variety of technological tools has been recently implemented, such as, for example, social robots. According to the definition given in [6], a social robot constitutes "a physical entity embodied in a complex, dynamic, and social environment sufficiently empowered to behave in a manner conducive to its own goals and those of its community". In [7], it was demonstrated an increase of the effectiveness of the same rehabilitative activity when involving a robot. Another interesting approach for both detection [8] and treatment of ADHD, [9], [10] is constituted by Brain-Computer Interfaces (BCIs), a powerful tool which translates electrical brainwaves into information, useful for sending commands to devices. The idea at the basis of this work is to propose an innovative ADHD treatment, by merging the adoption of wearable, single-channel BCIs and Social Robotics for developing a system to drive a robot by means of brain-signals [11]. Among the different BCI paradigms, Steady-State Visually Evoked Potential (SSVEPs) allow an easier detection, even with single-channel configurations and in conditions of significant noise [12], [13]. SSVEPs are exogenous potentials, triggered when a person is exposed to a flickering visual stimulus at a given frequency [14]. In this way, a corresponding cerebral potential is elicited in the occipital area and preserves the same frequency of the observed stimulus. With the SSVEP detection it is possible for the user to send to the robot a set of commands such as *Move left* or *Move right*, by simply observing the corresponding flickering icon and without training. In this case, it is important for the user to maintain relationship with the environment, by looking at the same time the robot movements and the light sources necessary to the SSVEP elicitation. For this reason, the flickering stimuli are rendered through a set of AR smart glasses, which superimpose the flickering stimuli onto the real world, thus allowing the user to have immediate feedback regarding the

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robot movements when the selected stimulus is observed. In fact, with respect the traditional ways to render the flickering stimuli, such as Computer Screen (CS), Augmented Reality (AR) is a promising technology to ensure greater immersivity, wearability, and portability [15]. On the basis on these considerations, a wearable, single-channel, SSVEP-based system was proposed in [11] for robot-based ADHD rehabilitation. The aim of the current work is to carry out a preliminary evaluation of the adherence to therapy, taking into account a larger group of children of different ages and diagnosis. The paper is organized as follows. Section II describes the design of the system, while the experimental results obtained are discussed in Section III. Therefore, in Section IV, the adherence to therapy is preliminary investigated at an accredited rehabilitation center. Finally, in Section V, conclusions are drawn

II. Design and Implementation

In this section, the design of the system is described in detail, from the system architecture to the operation, and the selected hardware.

A. Architecture

The architecture of the system is shown in Fig. 1. The user EEG is captured from the scalp by two active electrodes placed in *Oz* and *Fz* positions, according to the 10-20 International System [11], for a single-channel, differential configuration. A third, passive electrode is placed on the user earlobe (*A2*) and acts as a reference. The Electrodes are connected to an EEG portable Acquisition Unit, which sends the digitized signal to a portable Processing Unit over USB. After the signal processing, the corresponding command is sent to the Robot via TCP/IP. The robot movements constitute also a visual feedback for the user, who can notice if the desired choice has been actuated.

B. Operation

The system operation for moving the robot is based both on SSVEP and eye-blink artifacts detections [11], as shown in Fig. 2. Before to start, the user wears the AR-BCI equipment. The AR Glasses render two flickering stimuli at 10 Hz and12 Hz, corresponding respectively to *Move to right* and *Move to left* command. Furthermore, the number of commands is increased by voluntary eye-blinks, which act as *Start* & *Stop* commands. Initially, the robot is in *idle* state. The user, by a first eye-blink, takes the Robot into *select direction* State. At this point, by focusing his attention to the desired stimulus, the user is able to move the Robot to left or to right. With a second eye-blink, the robot *goes forward*. Finally, a third eye-blink stops the robot, taking it back to the idle state.

C. Hardware

The hardware of the proposed system includes the following pieces of equipment: an acquisition unit; a processing unit; a set of AR glasses; and the robot.

Acquisition Unit: The user EEG signals were digitized using the Olimex EEG-SMT, a 10-bit, 256 S/s, differential input Analog-Digital Converter (ADC) [16].

Processing Unit: A single-board computer Raspberry Pi 3 was used as processing unit with the aim (i) to process the signal received via USB from the Olimex, and (ii) to send the related command to the robot via TCP/IP.

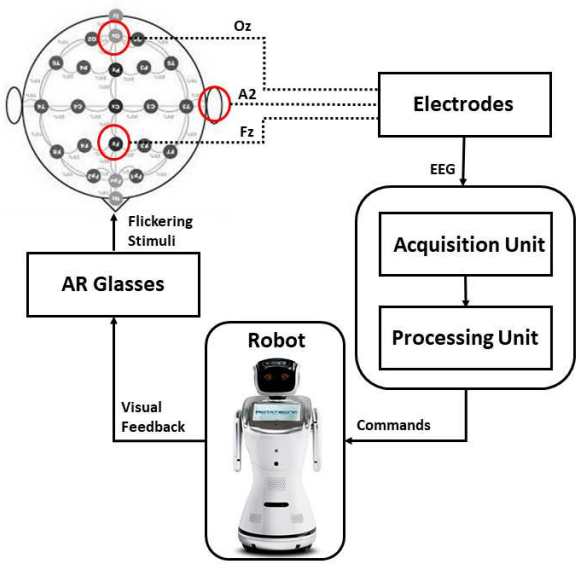

Fig. 1. System architecture

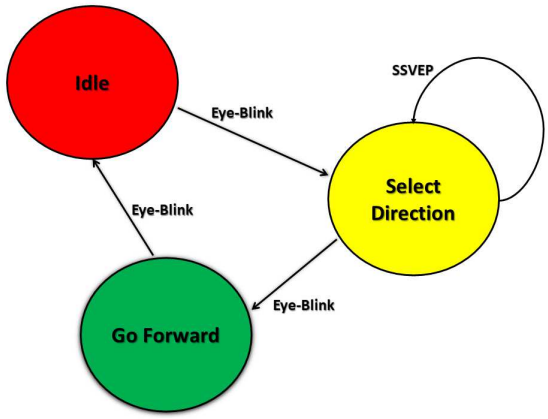

Fig. 2. State machine for moving the robot.

AR Glasses: The AR Glasses chosen were Moverio BT-200[17], with a 60 Hz refresh rate, a diagonal field of view of 23°, and a perceived screen size of 2 m at 5 m projected distance.

Robot: The social robot chosen for this application was a SanBot Elf [18], connected through Wi-Fi to the Raspberry Pi, retrieving information via TCP/IP.

III. Preliminary Experimental Results

Before proceeding with the case study, an evaluation of the classification accuracy of the proposed system was carried out on 10 healthy adult volunteers in [11], by means of a Java application which simulates the robot behavior. As shown in Fig. 3, the subjects were asked to move a pink arrow through a maze, trying to bring it to a destination, represented by the yellow point. The results in terms of accuracy, time spent to move the arrow, and number of commands sent are shown in Table I. This experimental campaign showed encouraging result by achieving an overall accuracy of about 83%.

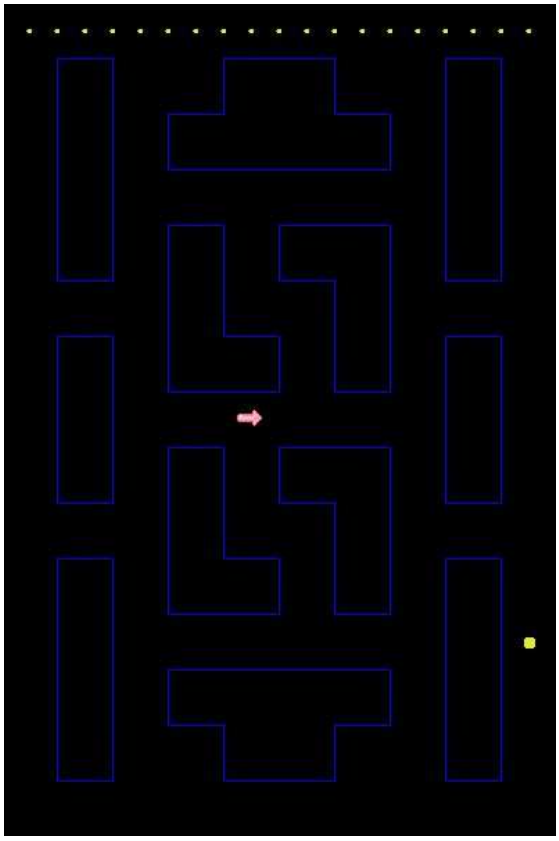

Fig. 3. Java application to simulate the robot.

TABLE I
PERFORMANCE OF SSVEP/EYE-BLINK DETECTION

Volunteer	Time (s)	Commands	Errors	Accuracy (%)
#1	124.91	30	5	83.3
#2	217.76	57	12	78.9
#3	107.44	33	6	81.8
#4	94.67	23	5	78.2
#5	102.98	33	5	84.8
#6	195.53	51	11	78.4
#7	59.23	16	2	87.5
#8	95.04	26	2	92.3
#9	104.34	32	4	87.5
#10	142.55	41	7	82.9
Average	124.44 ± 30.72	34 ± 8	6 ± 2	83.5 ± 2,9

IV. CASE STUDY

After a previous investigation about the system acceptance conducted in [11], which verified the usability of the device, a preliminary evaluation of adherence to therapy was carried out on 18 untrained children, from 6 to 10 years old, with different diagnosis always including ADHD. The on-field case study was conducted at an accredited rehabilitation center to (i) confirm the overall acceptance of the device by children, and mainly (ii) evaluate their adherence to therapy. To this purpose, 18 children between 5 and 10 years, with different diagnosis (always including ADHD), were asked to wear the system and perform the task indicated by their therapists. The task assigned to the children was to drive the robot according to the indication provided, aiming to achieve different objectives in a time interval of about 10 min. Every child accepted to wear the equipment and most of all completed the task assigned by their therapist. A summary of the experiment results is shown in Table II. As visible, all the children between 8 and 10 years completed the activities without difficulties and resulted very satisfied by the experience conducted. On the other hand, some children from 5 to 7 years had some issues related to devices ergonomics and, furthermore, in some cases they did not perform the task because of their lack of attention during the explanation of the activity to conduct.

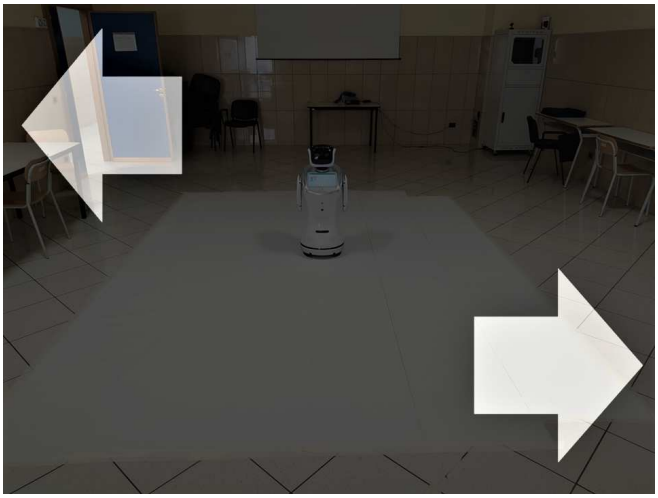

Fig. 4. User view during the task.

TABLE II
RESULTS OF THE EXPERIMENTAL ADHD CASE STUDY

Subject	Age (years)	Initial reluctance	Tasks completed
#1	10	no	yes
#2	6	no	no
#3	10	no	yes
#4	9	no	yes
#5	9	no	yes
#6	8	no	yes
#7	8	partially	yes
#8	10	no	yes
#9	5	yes	no
#10	8	no	yes
#11	10	no	yes
#12	9	no	yes
#13	6	no	no
#14	5	no	no
#15	7	yes	no
#16	7	no	no
#17	10	no	yes
#18	8	partially	yes

V. CONCLUSIONS

A system based on the integration of Augmented Reality Glasses with a non-invasive, single-channel Brain-Computer Interface detecting SSVEP and voluntary eye-blinks is proposed for children ADHD treatment. The proposal is based on the development of a wearable equipment to move asocial robot by brain signals without any training. The AR technology allows to see the visual stimuli while, at the same time, looking at robot movements. Previous experimental campaigns on 10 healthy adult volunteers showed encouraging results, by achieving an overall accuracy of about

83%. Then, the on-field case study was conducted on 18 children aged 5 to 10 years to confirm the general acceptance of the device and assess their adherence to therapy. Every child aged 8 to 10 years successfully completed the tasks, while some younger children showed problems related to the ergonomics of the devices and low levels of attention during the explanation of the operation. Further work will be dedicated to continuing the experimental activities in order to evaluate the effectiveness of the proposed therapy over time.

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