A Cost Effective Approach for the Practical Realisation of A Demonstration Platform for Brain Machine Interface

Elham Zareian, Vaibhav Kathpalia, Jun Chen, Tim Smith

Abstract— Over the last two decades, human brain functions have attracted a significant attention among researchers across a broad engineering spectrum. The most important field among the others, is Brain Computer Interface (BCI) which is a direct functional interaction between a human brain and external devices. In the past, the set-up for BCI research is costly and complex. In this paper, a cost effective way of implementing and designing a demonstration platform for BCI research is presented, featuring a low-cost hardware implementation based on an open-source electronics platform Arduino® with the view of being compatible with MATLAB® and Simulink®, and a commercial non-invasive electroencephalogram (EEG) recording device, Emotive®. Due to the compatibility with MATLAB® and Simulink®, and the chosen EEG logging device, the developed hardware and software platform can work seamlessly with several widely accepted BCI and EEG signal processing open-source software within the BCI research community, such as EEGLAB and OpenViBE. With the two-way communication and hardware-in-the-loop concept embedded within the design process, the developed platform can be tuned in an online fashion, which bears the long-term objective of investigating a holistic human-in-the-loop feedback control mechanism so that human and machines can collaborate in a more intelligent and natural way. The presented approach can be beneficial for BCI practitioners to set up their first inexpensive test rig and carry out fast prototyping in related activities.

Keywords—Brain Computer Interface, low-cost demonstration platform, open-source electronics, human-in-the-loop feedback control mechanism, fast prototyping.

I.   Introduction

Over the last two decades, human brain functions have attracted a significant attention among researchers in all related science fields. The most important field among the others, is Brain Computer Interface (BCI), which is a direct functional interaction between a human brain and external devices. BCI's capability in terms of translating the produced pattern of brain activity into corresponding commands to communicate with the external world, without using any motor skills, lends itself as an ideal technique for many applications across a broad range of areas [1]. For example, in medical related applications, assistive care can be provided for those who have severed motor disabilities [2]. Other emerging application fields include, but are not limited to, providing

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additional control channels or hands free control for the benefit of drivers, pilots and astronauts whose hands are constantly occupied in controlling devices, and subject state monitoring which is based on observing and anticipating subject's intentions and states so that for example an alert could be initiated to a sleepy driver [3].

Among many techniques, Electroencephalogram (EEG), is one of the most feasible and extensively investigated approaches for measuring the brain activities [4, 5]. Its simplicity, good time resolution, and being able to be measured via non-invasiveness methods have made it an outstanding and economical approach compared to other brain activity recording techniques, such as functional positron emission tomography (PET), magentoencephalography systems, etc. Despite its distinctive features, in the past, the set-up for EEG and BCI research is costly and complex, involving accurate placement of the expensive medical type of wet cap on subjects' scalp, together with gel injection into electrodes for the purpose of getting the right impedance values. Subjects will have to wash their heads after removal of the cap. Furthermore, medical type EEG devices normally come with dedicated acquisition software which, more often than not, lacks the support from EEG signal processing Open-source software. Extra efforts in programming and interfacing are required in such a case. Therefore, the whole process is time consuming and tedious, requiring professional training before designing and setting up any research endeavour in this area. This inevitably hinders researchers from non-psychological and/or medical background from entering the field.

In light of this, in this paper, the implementation and design aspects of a low-cost demonstration platform for BCI research are presented, consisting of a suitable human machine interface through a bespoke design of a Power Unit, Control Unit, Communication Unit and Sensing Unit. The hardware is based on an open-source electronics platform Arduino® with the view of being compatible with MATLAB® and Simulink®, and a commercial non-invasive dry EEG recording device, Emotive®. With a master and slave operational mode facilitated by two Arduino® Mega 2560 developments boards [6], and two XBee [7] wireless Receivers/Transmitters mounted on top of the Arduino®, a two-way communication link between the host computer and the demonstration platform is established. Due to the fact that Arduino® Mega 2560 is supported by MATLAB® and can also be run in an external mode in Simulink®, a low cost 'hardware-in-the-loop' mechanism is achieved. This feature bears the long-term objective of investigating, in the future, a holistic human-in-the-loop feedback control mechanism so that human and machine can collaborate in a more intelligent and nature way.

Attributed to compatibility of the chosen development board and EEG lodging devices with MATLAB® and Simulink®, the presented approach can, in the future, be extended to work seamlessly with several widely accepted BCI and EEG signal processing open-source software within the BCI research community, such as EEGLAB [8] and OpenViBE [9]. Such ability will be beneficial for BCI practitioners, especially those who are not from psychological and medical background, to set up their first inexpensive test rig and carryout fast prototyping in related activities.

The rest of the paper is organised as follows: Section II will start with some existing implementations for BCI research, then implementation and design, which is divided to hardware design and software design, will be presented; testing and results will be given in Section III; and finally, conclusion and future works will be included in Section IV.

II.   Implementation and Design

In the following, some existing examples similar to the developed demonstration platform are first given, followed by the presentation of both hardware and software implementation of the designed demonstration platform.

A.   *Some Existing Examples*

In [10], an Internet-based Teleportation platform with Brain-Computer Interface, consisting of two hardware and 4 software parts, is developed. In hardware part, the Master-Slave design was used, in which the slave part consists of a commercial three-wheel robot, i.e. pioneer P3-DX, as a remote platform, sensors and a server computer. Master part consists of computer connecting with different interfaces, such as BCI or joystick. The environmental information is provided to the operators by video or sound. Moreover, master and slave parts are communicating with each other via local Area Network or Internet. Software design consists of motion control module, video module, Data processing and communication module. Regarding the BCI, NeuroScan with a brain-cap were used to acquire the operator's brain wave signal.

In [11], the Lynxmotion AL5D Robot Arm is controlled through an inexpensive EEG recording system, the same as the one used in this paper. However, both implementations relied on existing commercial robot platforms as the base which, although saving time in developing hardware, increases the cost of BCI related research and restricts platform's expandability for future bespoke functionality, such as human-in-the-loop concept, as their research evolves. Therefore, in the following sections, a demonstration platform is designed with the view of its expandability for future use with MATLAB® and Simulink®, and some widely accepted open-source EEG signal processing software. It is worth mentioning that the mechanical design of the platform could be replaced by any other designs suitable for specific application purposes, while the implementations of the control unit and communication unit are more general, applicable to different applications.

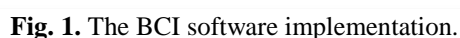### B.   *BCI Software Implementation*

In order to demonstrate the functionality of the designed demonstration platform, a cross-platform software environment is set up, which includes the following.

Firstly, Arduino IDE is used as programming platform and all the mentioned sensors are programmed in this environment in order to make them integrated with Arduino® and provide the required information. Environmental information is collected through sensors, such as IR distance sensor and Gyro sensor, which provides feedback for better operation of the platform.

Secondly, in order to control the movement of the platform by mind, Emotive® headset is used to acquire the subject's brain wave. The acquired signal will be passed to Emotive Cognitive Suite (ECS) [12], will continually process the signal and match them to the patterns of trained thought. Emotive Cognitive suite relies on Event Related Desynchronisation (ERD), and is designed to be most effective for thoughts directly relating to imagined motor movements. In order to start the training process, subjects need to be in the neutral state, which is related the relaxed state. Training will then start with thinking about different physical actions. ECS contains a virtual cube which animates the applied actions during the training and also when the engine detects the thinking pattern in real time. The training for each action should last for 8 seconds, during which the user must try to think a consistent thought. In order to obtain the higher online detection accuracy more training needs to be given to the system. In this work, for the demonstration purpose, only two actions, namely 'Push' and 'Pull', have been trained, which makes the platform move forward and backward respectively.

Finally, the detected actions need to be transformed into control commands to move the demonstration platform. For this purpose, Emokey [13], a tool provided by Emotive® SDK, is used to emulate the keystroke based on the combination of thoughts. A few things need to be considered before Emokey is applied: a) the actions which are generated in cognitive suite by thinking are animating the virtual cube movement; therefore, one keystroke related to one specific action need to be assigned; in this paper, 'f' is related to the action 'Push' representing 'forward', and 'b' is related to the action 'Pull' representing 'backward'; b) a target application is needed for sending the generated keystroke; in this paper, Processing [14] is used, which is free and open-source programming and development environment, widely used by students and professionals to visually depict a collection of data; and c) a threshold indicating the level of the right 'thinking' need to be defined.

Regarding the communication between the above mentioned applications and Arduino® on the slave side (mounted on the platform), an Arduino® board on the master side is connected to the PC, so that the generated command can be sent to the slave Arduino® on the demonstration platform via XBee wireless connection and make the platform moves based on the subject's intension. Fig. 1 shows the schematic diagram of the BCI software implementation.

Fig. 1. The BCI software implementation.

C. *Hardware Implementation*

The mechanical platform used in this demonstration is a circular wood based unit, having a circumstance of $(2 \times 3.14 \times 29.50)185\ cm$ approximately. The platform is supplied with a set of ball castors attached on its downside, in order to facilitate the movement in a lab testing environment and reduce friction. The platform is made up of a number of components, which facilitate a smooth operational process and as, a secondary function, provide environmental information (feedback) to the user. The platform has a total weight of $1.1\ KGs$ after mounting all the components on it.

Power Unit: A Lipo Battery is used to power up all the units, with specification of 4S-2200 mAh and 14.8 Volts which is mainly designed for RC planes or hobby purposes. Another important component of this unit is the Kill switch. It is a small box designed by the user, which comprises of a couple of mechanical relays, two-way switches, push to make and break buttons, and a kill switch circuit. This component is basically responsible to act in unprecedented situations. Moreover, it helps to protect any flow of current from improper battery connections to the user.

Control Unit: The unit is responsible for all functional and operational tasks required in the demonstration. Control unit includes: A set of Arduino® microcontroller boards which are ideal for small scale projects; a set of Brushless Electronic Speed Controller (ESC) and motor, and a RC servo, which help translate commands into operational activities. Arduino® is an open source prototyping platform which opposes all the microcontroller capabilities, convenient programming environment and user friendly interface. In this work, we have used two Arduino® boards in order to set up a master-slave connection; one on the PC side (master) and the other one mounted on the platform side (slave). The master one is programmed using Processing in order to transmit data to the platform, as well as receiving and plotting such information in real time. On the other hand, the slave side is programmed in Arduino Integrated Development Environment (IDE). The code is written to operate the Brushless ESC on pin 8 by receiving the speed input, while it operates the RC servo on pin 6 by receiving the angular input. Regarding the feedback task, the involved sensors (IR distance and gyro) keep sending environmental feedback information to the master.

The novel feature in the design of this demonstration platform and its control unit lies in the thrust vectoring system which is known as Aerial Coanda High Efficiency Orienting-jet Nozzle (ACHEON). ACHEON is a novel propulsion concept which aims to produce radically new aircraft propulsion systems (and possibly aircraft). It aims to verify a novel propulsion system with thrust vectoring capabilities known as High-speed Orienting Momentum with Enhanced reversibility (HOMER) and recently patented by the University of Modena and Reggio Emilia in Italy, together with a smart and effective active control system based on Plasma Enhanced Actuator for Coanda Effect (PEACE) devised by the Universidad de Beira Interior in Portugal [15-17]. .A number of studies have recently been performed regarding Thrust Vectoring Control (TVC) for civil aircraft [18-22], mainly as a means of emergency control for use in failure situations. There are also proposals to use TVC combined with the more traditional aerodynamic control surfaces during normal flight. The benefits may be: reduced trim drag (less fuel consumption); reduced aircraft weight; shorter take-off and landing; reduced noise around airfields and improved ability to handle adverse weather and flight conditions. The potential drawbacks include possible increases in engine weight and complexity. The use of thrust vectoring to augment vehicle control requires an increase in the number of physical control inputs to the control systems (i.e. the current interface uses hands and feet). In this work, the effective integration of EEG into the more conventional methods of control and Man Machine Interfaces (MMI) is investigated. It is also important that non specialist operators can also control sophisticated vehicles utilizing more conventional MMI and EEG may provide a mean to allow control of sophisticated drones with minimal training and simplified MMI. Another part in control unit is RC servo, which is an actuating device used in various mechanical

systems. In our work, a continuous RC servo is used which can rotate a complete circle and does not have a limitation in terms of travel angle. The aim of including a RC servo in this work is to implement a form of thrust vectoring into the working mechanism. The thrust to the platform is provided by Brushless motor and helps the platform travel from one place to another, while the RC servo is used to vector this thrust on its own axis. Therefore, the RC servo is placed in the center of the platform's base with a motor mounted on top of it. For instance, if the platform needs to be moved with 60% speed in the north east direction (135 degrees), then an input needs to be provided to the servo in order to rotate 135 degrees and finally an input is given to the motor so it operates at 60% of speed for a couple of seconds and moves the platform to the desired position. The next component in Control Unit is ESC, which controls the speed of the motor in a much smoother and efficient way compares to control a motor directly. This type depends on electronics unlike the traditional mechanical type resistive coils which used in the past to perform a similar function. In our work, a brushless ESC is used which is connected to the motor on one side and to the battery on the other side. Regarding the servo connections it has three cables, power (5 Volts) pin, ground (GND) pin and digital pin (8). Therefore, when the ESC receives an input in terms of Pulse-width Modulation (PMW) from Arduino board, it converts it into a speed value and sends it directly to the motor.

The chosen brushless Electric DC motor is a synchronous motor with permanent magnets on the rotor and the electromagnets on the stator. The motor is connected to the ESC, which receives any input signals sent to it and operates the fan accordingly. Moreover, it is placed on top of the RC servo via a wooden base, to translate the produced thrust to the RC servo and the platform itself.

Sensing Unit: several sensors are installed in order to provide feedback information to the user. Gyro sensor provides orientation data of the platform. It is a 2-axis orientation sensor. In order to read its data, analogue pins A1 and A2 of Arduino® board (Slave side) are used. The sensed analogue value (in terms of volts) needs to be converted into an angular roll and pitch value before sending them back to the other end. IR distance sensor provides information regarding the space around the platform during its traversing. It measures the distance around the surroundings of the platform in one direction, by sending out IR waves in that direction, and then getting them reflected back after touching any object. In order to read the data analogue pin A0 of Arduino® board (Slave-side) is used. The received analogue data is then converted into a distance value in centimetres. Finally, all the collected data is sent back to the host PC every second in order to provides the user with the accurate and updated position coordinates of the platform at a given time.

Communication Unit: this unit is responsible for communication between the brain control device (EEG device) and the platform via two types of communication means. First one is Bluetooth USB connection for connecting the EEG device to the host PC, while the second one involves a pair of XBees, which are mounted on top of the both Arduino® boards to allow the master (computer) and slave (platform) interacts with each other. XBee is a small Radio Frequency (RF) links that offer bi-directional communication at a very low cost. In this work, they are placed on top of the Arduino® via wireless proto shield. The hardware design has been shown in Fig. 2.

III. Testing and Results

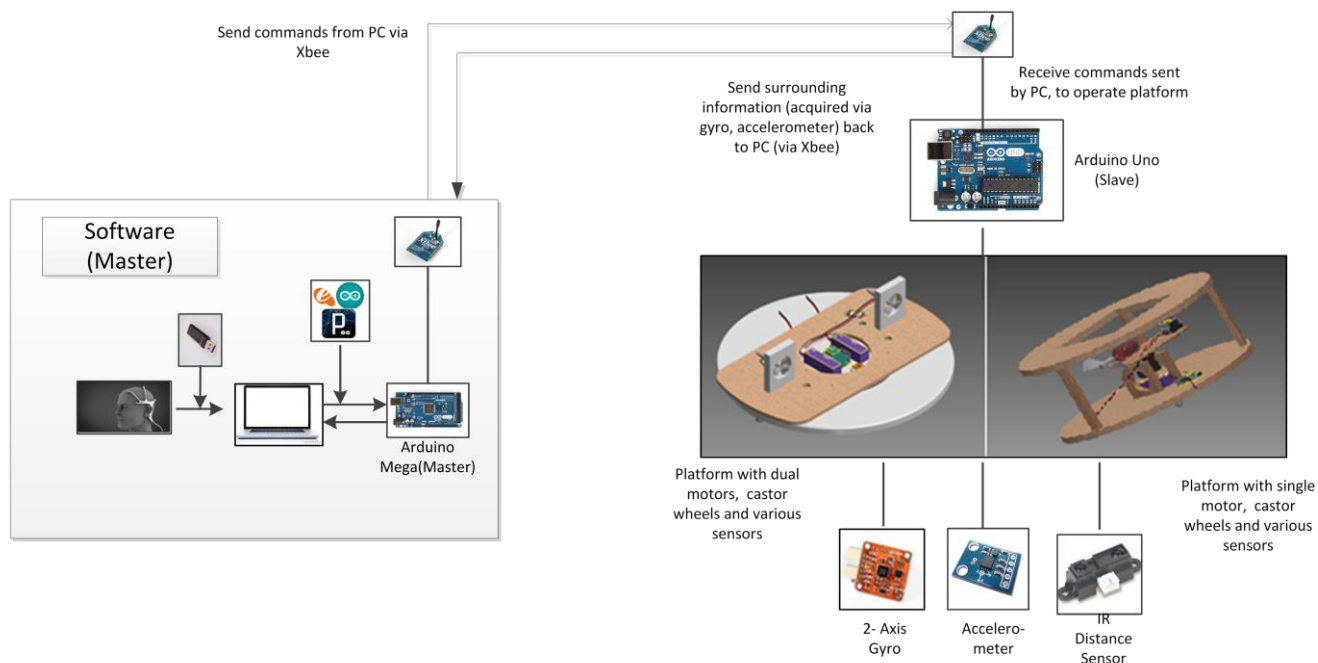For testing purpose, the platform is controlled using the

Fig. 2. Hardware implementation.

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paradigm discussed previously. Codes have been downloaded onto both Arduino® boards. Two commands, namely, backward and forward have been tested via brain patterns trained. In the following sections, we first show how environmental information can be monitored in real-time through wireless communication. Then, a two-way communication involving brained initiated commands are demonstrated.

A. IR distance sensor

Feedback from the IR distance sensor is acquired from the slave board on the platform, and sent back through wireless connection to the master board and the host computer in real-time. The feedback information is received in Processing environment and plotted it in real time. Fig. 3. depicts the obtained result.
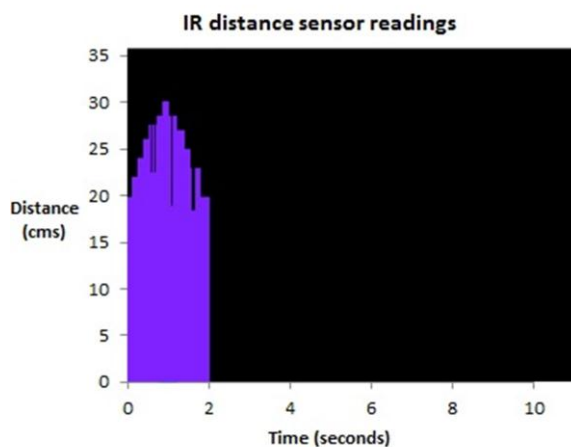
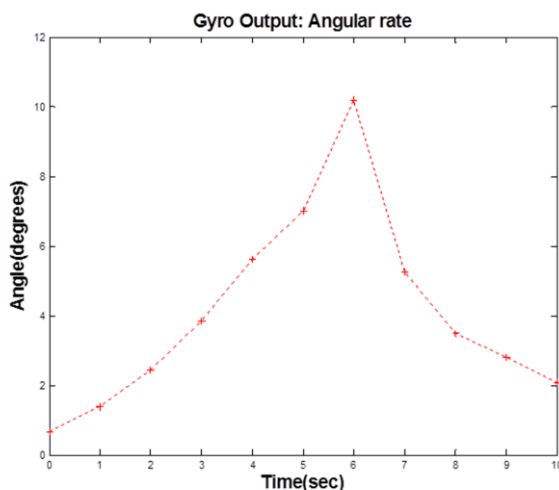**Fig. 3.** Feedback information from IR distance sensor.

Fig. 4. Results of the Gyro Sensor.

B. Gyro Sensor

Gyro sensor is placed on top of the servo motor. In order to test the angular feedback information from the platform, the servo motor has been given a command of rotating 10 degrees, which rotates the wooden platform the gyro has been placed on. The result of the Gyro sensor is also plotted in figure 4.

C. Testing of BCI

Finally, in order to test the proposed integrated software and hardware system, the complete procedure has been carried out as depicted in Fig. 5. Again, gyro has been placed on the wooden base, which was mounted on the servo. The rest of the connections remained same. An angular input (20 degrees) is initiated by Emoky® once an 'f' has been detected using the measured EEG signals. Next the command is mapped into 20 degrees and given to the servo. The feedback from the gyro is taken, on its measurement that it detected for the angular change. Finally, the result was noted down, and plotted in MATLAB® which is shown in Fig. 6. In this graph, the blue line represents the servo input, while the green-blue-dashed line represents the gyro readings. The discrepancy of the two is due to the measurement error and the code transferring the measured data into the angular data.
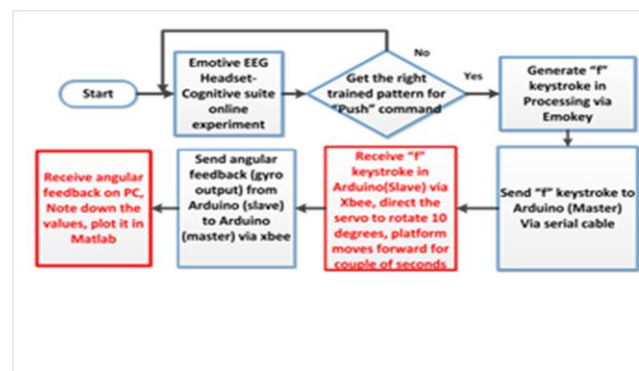

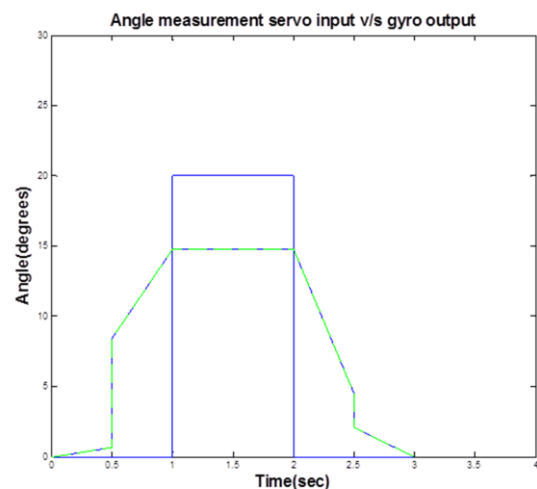***Fig. 5.*** Flowchart of steps obtaining angular feedback.

Fig. 6. Graph shows comparison of the angular input sent to the servo and the angle detected as output by the gyro.

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IV. Conclusions and future works

The overarching objective of the paper is to investigate an inexpensive and fast prototyping approach for the benefit of BCI research. The successful testing of the platform proved a cost effective way of implementing a two-way real-time communication interface, which facilities BCI and future human-in-loop control. Hardware-in-the-loop concept could also be achieved if the master board is run within the Simulink® environment in the external mode. Apart from the fulfilment of these objectives, the demonstration also showcases a simplified approach to a form of thrust vectoring, which was embedded in the control mechanism of the platform. Therefore, the proposed platform could be a suitable test bed for the investigated control mechanism for future research in this area

Acknowledgment

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