Neural Interface Emotiv EPOC and Arduino: Brain-Computer Interaction in a Proof of Concept

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Abstract. This study aims to demonstrate the interaction between the human being and the machine through a neural pattern recognizing interface, namely Emotiv EPOC, and a robotic device made by Arduino. The union of these technologies is assessed in specific tests, seeking a usable and stable binding with the smallest possible rate of error, based on a study of how the human electrical synapses are produced and captured by the electroencephalogram device, through examples of projects that achieved success using these technologies. In this study, the whole configuration of the software used to bind these technologies, as well as how they work, is explained, and the result of the experiments through an analysis of the tests performed is addressed. The difference in the results between genders and the influence of user feedback, as well as the accuracy of the technologies, are explained during the analysis of the data captured.

Keywords: Emotiv EPOC. Arduino. Brain-Computer Interface. Interaction. Electroencephalogram.

1 Introduction

According to the French philosopher Pierre Lévy, social and economic changes of the 21st century came to establish a new paradigm of social life in the contemporary society. Such abrupt change of paradigm is what sociologists of current technology come to call “The Technological Revolution”. In his book “O que é virtual?” (Becoming Virtual: Reality in the Digital Age) (1996), Lévy sets and demonstrates how the virtual abstraction of information has an impact both on everyday life and on more complex business processes, science and even contemporary human thought.

As well pointed out by Levy, the development of the very scientific method is already conditioned to the use of digital technology and information technology. Medicine and neuroscience, through digital image modeling for diagnostics, establish a pattern of work, making use of resources which, for simple clinical psychology, seemed unreachable.

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It is with this intention that Emotiv EPOC, a helmet which consists of a complex portable noninvasive electroencephalogram apparatus produced by Emotiv, is presented in this study.

In addition to the Emotiv EPOC, other technologies, such as robotics (e.g. through Arduino), are easily falling into the hands of ordinary people. One can buy the Arduino Starter Kit for an affordable price and this is a very easy platform to work on.

The Emotiv EPOC, as well as his brother, the Electroencephalogram (EGG), use a set of fourteen sensors and two references to tune the electrical signals produced by the brain in order to detect patterns of thought, feelings and expressions in real time (EMOTIV, 2013), and based on the assumption that the device can receive such information, it is possible to use them for any purpose; from playing a specific game for this interface or controlling common actions in any application on your computer without using a mouse or a keyboard, to performing physical actions through the use of Robotics in conjunction with the EPOC, everything is defined by how the device is used and how the information captured will be treated and used.

An idea to make use of these data is, precisely, its combination with robotic interfaces, such as the Arduino, to create prototypes and test the concept of functionality, thus expanding the horizon of utilization for larger applications and having a greater influence on the scientific and commercial environment.

According to McRoberts (2011, p. 22), the Arduino is a micro single-board controller and a set of software to program it. In practical terms, it is a small computer that you can program to process inputs and outputs from the unit and the external components connected to it.

Based on the assumption of using the EPOC as the data input device, and the Arduino as the output device, this study intends to unite the two technologies and develop an interface (software), with the purpose of demonstrating the functional visibility of neural reading for robotic control.

Through this project, the idea that the link between the EPOC and the Arduino is really possible will be proven, thus generating new possibilities far greater than four simple lamps lighting up controlled by the power of the brain.

2 Electrical synapses and the EEG study

The nervous system "is the basis of our capacity for perception, adaptation and interaction with the world in which we live" (GAZZANIGA, 2000 Apud STERNBERG, 2008, p. 43) and "through this system we receive, process and then respond to the information that come from the environment" (RUGG, 1997 Apud STERNBERG, 2008, p. 43).

Through devices such as the EEG and study areas such as the neuroscience an important objective of the work and study of the brain can be attained, locating the areas responsible for a given function or behavior (STERNBERG, 2008, p. 42).

Everything that happens in the brain and, consequently, in other parts of the body occurs due to the synapses. Lent (2005, p. 99) refers to the synapse as "a biological chip, because the computations that the neural circuits are capable happen in them".

Among all the 1,000 synapses formed and the 10,000 received by a neuron, the majority consists of chemical synapses, conducted through the neurotransmitters. The rest occurs by electrical impulses through the presynaptic membrane and through the channels that bind presynaptic and postsynaptic cells (KANDEL & SIEGELBAUM, 1995 Apud MONTENEGRO, 2012, p. 01), and these impulses are called electrical synapses, responsible for the transmission of information between neurons, which are picked up by EEG devices.

The whole process of capturing the electrical signals from the brain by the EEG device depends on the existing electric current of the brain, but this in itself has no power. For the electrical current to flow a conductive bridge connected to the brain is necessary – considered, in this case, as the source of energy – thus creating a circuit. This "brain circuit" is formed as any other electric circuit, and the science of electricity works the same way.

Simply put, the electroencephalographic record consists of capturing the cerebral electrical using electrodes, transmitting to the electrode box and then to the amplifiers of the EEG device. Then, the record is made. The breadth and width of each wave are based on the voltage and the frequency of the electrical current captured by the electrodes.

According to Montenegro (2012, p. 8), the electrodes are the metallic medium where the signals will be received. Directly applied to the patient's scalp according to the international 10-20 system, which consists of an internationally recognized method to describe and apply the location of electrodes on the scalp, the conductors register the electrical currents that will be forwarded to the amplifiers. The current passes from scalp to the electrode through the current created by the ions present in the solution, which is a conductive gel, a paste or even a liquid. An electrochemical phenomenon occurs on the link between the scalp and the electrode, turning the ionic current in an electron flow, which generates an electrical current capable of being transmitted to the EEG amplifiers which increase 1500 times the voltage picked up in order to be able to record the electrical activity of the brain.

The technique of electrodes on the scalp is widely used, since it is not intrusive, however, it has many limitations, mainly by suffering influence of the skull itself.

3 Studied Technologies and Its Limitations

The interaction of human thought and a given software or hardware goes into test when tools that allow it to happen reach the market. The studied union is made possible through the interaction between the Emotiv EPOC neural interface and the Arduino.

The Emotiv EPOC, despite being relatively new in the market, makes use of EEG technology to perform actions on digital media through a headset, but it's not a novelty that brain patterns are used to control digital actions in the field of robotics.

Thus, some projects using portable EEG headsets are emerging. Improving accessibility has been a much aimed target in current studies in different areas, which leads most of these studies to be directed to the field of disabled people in order to facilitate their lives.

For example, the University of Zaragoza, Spain, has been studying, in recent years, the possibility of creating a wheelchair commanded by thought captured by an EEG machine.

Through sensors installed in the chair, a scenario is assembled by a software and options are given to the user, who makes the choice of where to go only by thinking. After the path is designed, the user can rest and the chair calmly goes through the path created earlier, decreasing the mental exhaustion present in interactions that require concentration to achieve the desired action.

Although the Spanish project is revolutionary, it was not the only one to be created in order to improve the lives of wheelchair users. Shortly after the creation of the Spanish project, a team of researchers at the Federal Polytechnic School of Lousana (EPFL), Switzerland, also created a project for wheelchair users driven by electrical signals detected by EEG, also adding augmented reality to the set of technologies involved.

In this project, two cameras are positioned in front of the chair to detect and recognize close objects on real-time, avoiding, in a relatively simply fashion, possible collisions and accidents that may occur involving the chair and the rest of the environment in which it lies. Using software developed for this project, the user controls the wheelchair through defined movements, for example, the simulation of movements of the right hand to move the chair to the right and of the left hand to move it to the left.

Besides the two aforementioned projects, the Emotiv EPOC is being used at the University Center of Pará (CESUPA), in Brazil, to control a simple wheelchair, built on Arduino. Being simpler than those cited above, this project makes use of a regular wheel chair, fitted with motors and a laptop. The signals are sent to the computer wirelessly and it issues specific commands to the chair, making it to move.

Projects in this area do not cease to be created, which clearly demands further study of these technologies.

3.1 Emotiv EPOC Neuroheadset

According to the institutional site of Emotiv (2013), the neuroheadset EPOC is a personal interface for human interaction with the computer through the acquisition of electrical signals produced by the brain, through techniques of electroencephalography (EEG), in order to identify thoughts, feelings and expressions in real time.

Fig. 1. Emotiv EPOC Neuroheadset

Through 14 sensors and 2 references that offer optimal positioning for accurate spatial resolution, brain patterns are obtained for certain functions, in addition to reactions such as eye blinking and smile, and movements such as lifting or lowering the head and turn it to the right or left.

Along with the neuroheadset, accompanies an interface for training where 13 actions can be trained and patterns of each user for these actions are recorded so that when played, are identified correctly. These actions are: move right, move left, up, down, push, pull, rotate clockwise, counterclockwise, rotate left, right, front and back.

3.2 The Choice of Arduino as Platform for Application of Concept

According to McRoberts (2011, p. 22), “Arduino is a small computer that you can program to process inputs and outputs between the device and external components connected to it”.

The Arduino has numerous components that can be connected to it as LEDs, dot matrix displays, buttons, motors, switches, temperature sensors, pressure, distance, GPS receivers, Ethernet modules or any other device that transmits data (MCROBERTS, 2011, p. 22), and, depending on the Arduino, USB ports that enable connection to PC or Mac to exchange information.

A free development platform allows software, or sketches, to be created in a C-based language, which Arduino understands, and as these are open source as well as the hardware, have full compatibility with each other. These sketches are loaded into the Arduino board allowing it to interact with the components connected to it and to the environment.

The ease of creating and by its recognition for exercising its role, the Arduino was considered one of the best choices for use in proving the concept of usability of Emotiv EPOC connected to an independent hardware platform.

4 Project, Development and Research Application

The interaction between these technologies is presented in this project. The idea of uniting the brain activities of a subject to a robotics interface is the main focus of this scientific work.

The information used in this paper comes through observation of LEDs on an Arduino board. This board is connected to the computer via USB cable and receives specific data sent to it by software that was developed on Windows platform, which in turn receives data from EmoKey software and the Control Panel EPOC, as can be seen in the representation follow.

Solely the union of the technologies presented in this project does not prove its usability. It can run as expected and technologies communicate through the software mentioned, as shown in Figure 2, however, if the error rate and / or difficulty of controlling these technologies are very large, the way which is being made this combination is no longer useful.

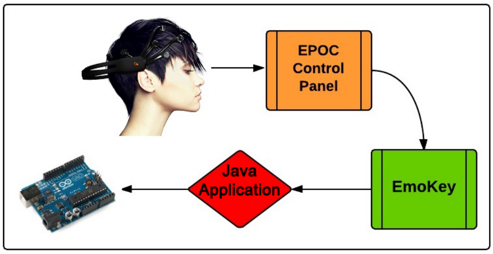

Fig. 2. Representation of the interaction between technologies

Given this thought a series of tests for a total of 10 people is proposed, which are divided between males and females in equal percentage, in order to assess the usability and the percentage of hits and misses on a range of small assisted tests.

The first and most important step of the whole process of testing is the calibration and training of movements and thoughts in Emotiv EPOC Control Panel. In this step the user wears the EPOC, each sensor is properly positioned at the correct point of the head based on the International 10-20 system and the signal of each sensor is checked through the existing representation on the display.

After all sensors are sending signal, ranging medium to good, the next step is the training of thoughts or movements in "Cognitiv Suite" tab of the Control Panel where the five thought patterns are recorded individually, "Neutral" , "Left" , "Right", "Lift" and "Down". Each of these can be trained as often as necessary according the ability of each user to focus.

The first pattern to be recorded is obviously the "Neutral" because this is the basis of comparison for all other movements that are trained later. For this pattern the user is oriented to relax and try to keep the mind free of thoughts, or simply do not focus on any particular thought, so that electrical signals are captured from a peaceful mind without defined patterns of thought. For 8 seconds this pattern is recorded, process that can be repeated until the user considered that was, in fact, relaxed and was not focused on anything.

The order of recording after the "Neutral" standard be recorded is irrelevant, because the training is done individually for each motion, and the order is not important. The only point that one should take care on this step is that the user is calm and aware of what he/she is doing. They should know that their goal is to focus their thinking on the proposed motion and taking care not to record the same patterns in different movements, so they are oriented thinking is quite distinct from one another and that during training the user has the greatest focus on activity.

After The patterns are all recorded the next step is the configuration of the second software used, EmoKey, whose function is to interpret the signal recorded by the Control Panel and play a pre-programmed action.

The EmoKey works from rules and for each of these is identified and enabled each one receives one or more Trigger Conditions which when executed triggers the rule.

For execution of the proposed battery of tests, four (4) specific, simple rules are created, each having a unique action and well-defined conditions trigger. The target

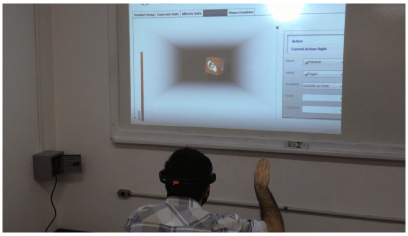

Fig. 3. User being training in EPOC Control Panel

application of all rules is in focus on the screen and is the third software that should be working to achieve these tests, as shown in Figure 2, the Java application.

The rule for “Right” receives a key that consists of writing the number one (1) and simulate an “Enter” on the keyboard. The condition for this rule to be performed is that thought “Right” is played and is consistent.

Each of the other three rules, “Left”, “Above” and “Below”, follows the same pattern of the “Right” rule, only changing its action for the respective thought and the value that is written and sent to the Arduino.

The third software used, the Java application was developed with the Swing graphics library used for visual programming. Through this library a simple window with a field for entering text and two buttons “OK” and “Cancel” is created, precisely to receive the value passed by EmoKey.

The rule in EmoKey is set to write the command for the thought reproduced by the user and simulate a click on the “Enter” key on the keyboard, i.e. confirm the submission of this information. When confirmed, the value is captured by the Java application and sent to the Arduino which should light up the corresponding LED.

The sketch written in Arduino is used to interpret the signal sent by the Java application through the use of the RXTX API, which connects via serial port the computer and Arduino. In this sketch are configured, very simply, the rules to light up each LED when it receives the expected value, keeping it lit for one (1) second and then deletes them.

The Java application receives the value written by EmoKey previously configured, and sends it to the Arduino, which turns on a light for each value (Figure 4) as follows:

- Thought “Right”: send the value 1 and turns on the green LED;
- Thought “Left”: send the value 2 and turns on the red LED;
- Thought “Up”: send the value 3 and turns on the white LED;
- Thought “Down”: sends the value 4 and turns on the yellow LED.

The Java application is terminated when the user cancels, using the existing button in the window, the application without sending any data to the Arduino.

After all patterns are trained in the Control Panel, the Java application is properly working, the sketch is recording in Arduino and the rules are set in EmoKey, testing can begin effectively. Each user goes through four (4) test sessions, on the first session only a standard is tested and on the fourth session all standards and rules are in test.

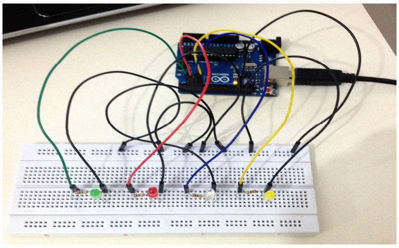

Fig. 4. LEDs on Arduino

Individually, each session is divided into two parts. The first consists of fifteen (15) replicates composed of green arrows pointing in a certain position among the four existing. The user should reproduce the thought relative to the direction shown by the arrow at each repetition and the results are captured by Arduino are registered in a specific table. This part of the session can be seen in Figure 5, where the user has no access to the Arduino.

Fig. 5. Test without user feedback and results being captured

The second part is nothing more than a repetition of the first part, that is, the user is challenged to play a specific oriented thinking shown by the arrows, but the Arduino is in field of vision allowing the user to monitor in real time if their thoughts are executing the proposed action. With that he/she can focus more attention on the proposed standard aiming at turning on the LED.

Each repetition takes six (6) seconds to happen, and during half the time (3 seconds) the arrow appears and during the other half of the time the screen turns white, giving the user time to relax and clear his mind to run the next thought when the next arrow is displayed.

After all testing sessions were conducted and all data is properly captured the users were able to describe how they felt during the testings and how they evaluate it.

Records containing tables of hits, wrongs and feedbacks of users were analyzed, and some results were obtained from them in order to improve the view on the technologies presented.

5 Data Analysis

The analysis of the data captured during the tests intended to check the accuracy of the union of the technologies presented, and it was confirmed that the stimulus produced by the user's brain reaches the Arduino and turns on the LED as proposed.

To analyze this accuracy, ten (10) people aged between twenty (20) to twenty nine (29) years, invited by the author were used in the tests previously discussed. Without following any particular order, five (5) users of male gender and sex, four (4) users of female sex and gender and one (1) user of male sex and female gender were tested individually.

One of the issues discussed was to seek to know the relevance of the user to be aware whether or not he was lighting the LED as proposed. Each session had two tests, one without the user seeing the Arduino board and the other user could check in real time if the LED which should light up or was not responding. It was expected that when receiving feedback via the Arduino, the user could increase his/her level of hits, assuming that one could focus more thought in the proposed action, but as we can see in the table below the difference between the first test and the second one not was very large, and we can assume that the way the feedback was passed was not as efficient as expected.

Table 1. Difference of feedback to the user

Result	Without feedback	%	With feedback	%	Total	%
Hit	302	51%	314	52%	616	51%
Wrong	50	8%	46	8%	96	8%
Opposite	61	10%	66	11%	127	11%
Without answer	187	31%	174	29%	361	30%
Total	600	100%	600	100%	1200	100%

The entire analysis was based on four (4) possibilities to be able to get the most accurate results. Each stimulus passed to users could result in:

• Hit: when the respective LED lit according to the passed stimulus;

• Wrong: when the result had no relationship with the stimulus, for example, we obtained the result “up” with the “left” stimulus;

• Opposite: when the result is the opposite of stimulus, for example, we obtained the result “left” with “right” stimulus;

• Without Answer: When no LED lit during the stimulus.

As proposed, and judging from the way of selecting users to be tested, a relationship between males and females users was created. From the users it was possible to see a greater focus and attention of male users when compared to females. As can be seen in the table below, there is no significant difference in the results regarding the gender of users.

During the tests, and even through the opinions of the users tested, there is a clear relationship regarding the difficulty when a new thought pattern was added. The first test was with only one thought pattern and at each new test a pattern was added.

Table 2. Differentiation between Genres

Result	Male	%	Female	%	Total	%
Hit	318	53%	298	50%	616	51%
Wrong	50	8%	46	8%	96	8%
Opposite	58	10%	69	11%	127	11%
Without answer	174	29%	187	31%	361	30%
Total	600	100%	600	100%	1200	100%

At each test performed hits decreases and the amount of different than correct results increases, as it requires greater concentration of the user and thoughts that were not well recorded end up being forgotten and reproduction of these is almost impossible.

After all tests and some relevant information have been drawn from these data, there is still a relationship that becomes necessary. The overall ratio of successes, failures, opposite results and lack of physical response through the Arduino not caring about which test resulted that information. The table below shows these results.

Table 3. Relationship between Test Analysis and General Analysis

	Test 1	%	Test 2	%	Test 3	%	Test 4	%	Total	%
Hit	244	81%	182	61%	116	39%	74	25%	616	51%
Wrong	56	19%	51	17%	105	35%	149	49%	361	30%
Opposite			67	22%	27	9%	33	11%	127	11%
Without answer					52	17%	44	15%	96	8%
Total	300	100%	300	100%	300	100%	300	100%	1200	100%

It is noteworthy that the second larger part of the data, which represent the tests "Without Answer" does not indicate that the user was not able to perform the movement correctly, but the thought pattern was not concise enough to trigger the rule set in EmoKey to light the LED on the Arduino, because during the testing sessions it was observed in the EPOC Control Panel where the cube used for training suffered an effect according the user's thinking.

Based on this information, it is worth restating that the percentage of correct responses and accuracy of movements may prove to be augmented with a greater amount of training and with individual settings for each user at EmoKey in the same way it was done in the Control Panel during the training of thought standards.

6 Final Remarks

This work demonstrates and reaffirms that the technology of reading patterns of neural waves is existing and can be viable and affordable. The devices used in this study are publicly available outside the academic community. Once object of scientific projects feasible only for medical systems or high-precision and criticality, technology presented here is available to commercial developer and student, so it's only a matter of time and market so they can reach the software industry and information technology solutions.

The tests performed and the results achieved in this work are from people without any disabilities, which may have uninterested them, making it difficult to perform the tests. Bringing these technologies for people with special needs, who see this as a change in their lives, totally change the paradigm and likely achievements.

After all tests, even requiring more precise technologies, it has been proven that there is no randomness in the project and that at least one pattern of thought possessed great hit percentage, which indicates a valid union and that with well-defined training and development of higher level software and hardware the paradigm we live in today may be changed.

The LED lamps the Arduino board turning on as each thought pattern recorded by EPOC and projects already undertaken, such as wheelchair controlled by thought and the tractor moved by brain signals, show that simple designs can evolve and become major innovations, as we see in studies in the area of augmented reality, or even the Google Glass project, for example, that have evolved in recent years and may even be used in sets with techniques using brain-machine interfaces.

The results of data analysis indicate that a lot of training and skill to achieve a positive result is required. This suggests that there is need for research in psychology and sensory medicine that will contribute to the development of technology.

From a systems analysis approach, the default robotic control to light small LED lamps may not mean a great advance itself beyond the technology and the physical principles applied in electronic devices offer. However, the integration of these two technologies is what we hope to be inserted at the forefront of technological trends in contemporary society. The virtual world and human communication, through the branch of affective computing hitherto presupposed communication interfaces with visual and tactile-motor sensory interactions. The paradigm of capturing user intentions directly from its source, for us, includes a bright future for the development of information technology.

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