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Initial control of a sub-actuated robotic hand using Bluetooth-transmitted brain waves

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Abstract: *Sub-actuated robotic hands are increasing targets for studies and research on the biomedical engineering field, with several types of drives and degrees of freedom. Brain waves captured by EEG equipment have been used to prostheses control. The present work aims to study a initial new way of controlling bionic prostheses, by brain waves, and transmitted to the prostheses via Bluetooth, causing direct connections or other invasive methods to become expendable. For the control, the EEG device captures the frequencies and voltages of the brainwaves and transmits them to the Arduino board, after a filtering and calculation of these waves. The methods necessary for activation of specific parts of the brain are also commented on, based on neurological concepts about functional brain mapping. The tests results demonstrated that is possible to open and close a prototype hand in 3D printer using brain waves, presenting excellent control efficiency and drive response.*

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I. Introduction

Neuroscience is a science that studies the nervous system, addressing biological, anatomical, psychological and physiological aspects, being the target of researchers of diverse areas, such as education, computer science and engineering[1,2]. Central nervous system (CNS) is a term that brings together all the neural structures located inside the skull and spine[3], responsible for controlling all physical activities, conscious and unconscious, being formed by billions of nerve cells that capture information coming from inside and outside the body[4,5]. These nerve cells are called neurons, highly specialized, sensitive, and they have the function of capturing the stimuli, interpreting and recording them, giving order to the organic functioning and the emotional reactions[6]. With studies of Magnetic Resonance Imaging (MRI) over time, it has been possible to consider that each small part of the brain is responsible for a given task, but not in its entirety, since brain functions are the results of general motor and psychological actions that individuals perform[7]. In order to determine the brain regions most used to certain tasks, functional MRI was used, first verified by the researcher Ogawa et al.[8]. This technique is based on image analysis considering the level of oxygen present in the blood. The signal acquired from this test is called a signal on Blood Oxygen Level dependent. The results suggest that BOLD-contrast imaging can be used to provide in vivo mapping of blood oxygenation in the brain under normal physiological conditions[8]. Consequently, to the brain activity, the hand is one of the most important parts of the human body, since it allows the execution of a high number of functions, such as: prehension, perception, exploration, manipulation, being responsible for most man daily activities[9]. Sub-actuated hands are increasing targets of studies and researches on the biomedical engineering area, with several types of drives and degrees of freedom. They are classified as sub-actuated because the number of degrees of actuation is less than the number of actuators[10-12]. Currently, sub-actuated hand prostheses are controlled electromyographically, that is, with stimuli produced from a muscle or a group of them. This same type of control can also be achieved through to the use of brain waves captured by electroencephalogram (EEG) equipment. The present project approach the control of movements of a sub-actuated robotic hand using brain waves captured through an EEG device, aiming to acquire and decode data sent by a portable electroencephalogram equipment and, from this data, to control the "open and close" of the respective biomechanical prototype using Bluetooth communication. A Mindwave Mobile device has been used throughout the development of the study. The brain waves picked up by the device can be viewed by software called Brainwave Visualizer, which comes with the product. The data obtained includes the frequency of the waves and their respective voltages. From these data, it is possible to control several types of movements. In this way, it allows the development of new projects that capture the brain waves and control from simple servo motors to integrated systems much more complex.

The electroencephalogram or electroencephalography (EEG) is an examination that allows the study of the graphical register of spontaneous electrical currents developed in the brain through electrodes applied on the scalp[13-15]. The electrodes pick up the electrical changes recorded on the brain surface, which are caused by the ordered activity of a set of neurons. These electrical changes, in turn, must happen synchronously to generate electrical potentials capable of being registered[16]. When neurons fire asynchronously, the potentials can be overridden. For this reason, the amplitude of the EEG signal doesn't concern the total level of brain activity, but mainly the amount of neurons firing synchronously. The electrodes should be fixed using some type of adhesive, taking full advantage of the contact of the entire electrode area with the patient's skin. This allows the signal to be recorded with less interference from the disproportionate movement of the electrode, increasing signal quality[13,15]. The device to be used for capturing brain waves has a sensor located in position FP1 (located in the frontal lobe). The position was chosen because it is an area with a minimum of noise, offering better clarity of the signals and band[17]. According to Guyton & Hall[18], the electrical records of the brain surface and the head outer surface demonstrate that there is continuous electrical activity in the brain. The ripples in these electrical potentials are called brain waves, which are Alpha (8-12 Hz), Beta (12-30 Hz), Theta (4-7 Hz) and Delta (< 3.5 Hz). Alpha waves are found in the EEG of almost all adults awake in a state of calm and rest in the brain. Beta waves, because they have a higher frequency, are recorded mainly when activation of the parietal and frontal lobes occurs, indicating a state of alertness. Theta waves occur in adults during emotional stress, disappointment or frustration. Delta waves occur during the dreamless deep sleep state and in severe organic brain disease, which manifests in memory problems, behavioral changes and difficulties in communicating verbally[19,20]. An increasing number of researches have been carried out due to the magnitude of application of biomechanical prototypes using the brain waves control[21-23]. Saez[24] developed a functional prototype of a human-like robotic hand considering anthropomorphic characteristics. Image processing analysis was performed from computed tomography, generating a model for the synthesis of a four-bar sub-mechanism to grasp objects with different geometries considering the functionality, appearance and symmetry of the system for the human body. Lin, Wang and Jung[25] demonstrated the need to use EEG to monitor body signals and positions. The authors used EEG headset, consumer level, to analyze human movements during walking, decoding a system (SSVEP) based BCI. The results promoted the use of EEG headset for real-life applications. Astaras et al.[26] a robotic arm with six degrees of freedom, operated by an exoskeleton connected to a braincomputer interface (BCI headset). The system has been successfully tested, allowing the user to perform tasks with immersive control, speed and smooth movements.

The present work aims to study a new way of controlling bionic prostheses, restoring the ability to move limbs that no longer have a connection with the patient's nervous system. The control is realized by brain waves, which in turn are picked up by a portable electroencephalogram (EEG) device, and transmitted to the prostheses via Bluetooth, causing direct connections or other invasive methods to become expendable.

II. Materials And Methods

Mechanical structure

Figure 1a shows the mechanical hand used in this study. The model was provided by Faculdade de TecnologiaTermomecanica (CEFSA-FTT – Brazil), made by rapid prototyping, presenting good dexterity and anthropomorphism, making feasible the application of the project in real situations[27]. For the movement of the fingers were used servo motors model TowerPro SG-5010, as well as torsion springs, responsible for the return of the fingers to the resting position of the hand. Nylon lines were used to perform the finger movement from the servo motors. For a better utilization of the servo motor course, prototyped pulleys were adapted in 3D printer (Figure 1b).

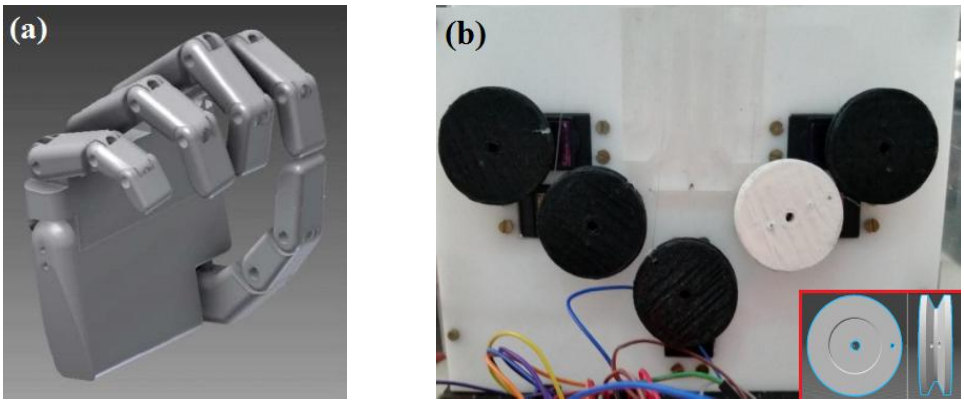

Figure 1: (a) Design representation of mechanical hand model. (b) Final pulley model with details of the model used.

Mind wave mobile

Developed by the Neurosky Company, the Mindwave Mobile relies on a low-cost brain waves reading device (EEG). The software that comes with the product is designed to identify brain wave frequencies captured by the helmet and control educational games through mobile applications. Even with only one electrode, the device is capable of reading and transmitting data from the delta and theta bands, as well as the low and high bands of alpha, beta and gamma waves. The data obtained include the waves frequency and their respective voltages. After reading the data, the EEG clears the ambient noise waves (other Bluetooth signals, electromagnetic interference, etc.) and, using its own algorithm, generates two types of signals that vary in a range from 0 to 100: attention e meditation[17]. These signs, however, don't necessarily indicate that the subject's attention or meditative state are elevated. By reason Mindwave acquires several types of waves and effectively measures the neural activity of the brain (especially the frontal lobe), this type of signal only indicates a high or low activity, and should not be taken as a basis for medical conclusions. For the control of the sub-actuated robotic hand, it was used a Mindwave helmet, shown in Figure 2. The device has a reading range of 3 to 100 Hz, sufficient to read most of the waves produced by the brain, and a signal amplitude of approximately 100 μV. It is compatible with values of 1200, 9600, 38400 and 57600 for baud rate, enabling a high data send rate and only the most significant bits, which are chosen according to the device itself. The Bluetooth signal strength of the device is classified as class 2 (it has a matching range of approximately 10 m). The Mindwave Visualizer 2015 software was used during the project, being an interactive applicative that graphically represents brain activity, presenting the six types of wave that the EEG acquires, its intensity, as well as the attention and meditation values. To stimulate the frontal lobe to produce greater brain activity, the Brain Functional Map. In this way, it was noticed that when touching a bubble plastic, performing simple mathematical calculations mentally, opening and closing hands, for example, there was a considerable increase in the level of attention produced by Mindwave. Based on the levels of attention that the Brainwave Visualizer displayed in stimulating the frontal lobe and the number of LEDs that indicated the attention value measured, the activation value of the servo motor was set to 60, on a scale of 0 to 100.

Figure2: Mind wave mobile equipment used as EEG sensor.

Development platform

Arduino is an open source electronic platform based on easy-to-use hardware and software capable of reading input signals and transforming them into output signals through a microcontroller built into the board itself. In this study, the Arduino UNO was used, due to the simplicity of the test design, where it was necessary to use ten digital ports as outputs, and the TX and RX pins for communication with the Bluetooth module. Transmission is done using a packet protocol within a master-slave structure. Bluetooth splits the transmitted data into packets and sends these packets to channels with 1 MHz of bandwidth. The master sets the send intervals and all slave devices share the same clock.

III. Results And Discussion

The test program shows the attention value using LEDs. Six LEDs were used, where, on a scale of 0 to 100 – value related to the attention data – each LED on represents a value of 10 on this scale. Due to the limited ports on the Arduino board, it wasn't possible to represent values from 0 to 100. This was taken into account later, choosing a value of 60 for servo motor activation. Figure 3 exhibits four LEDs on, which represents a value of 40 of the attention variables.

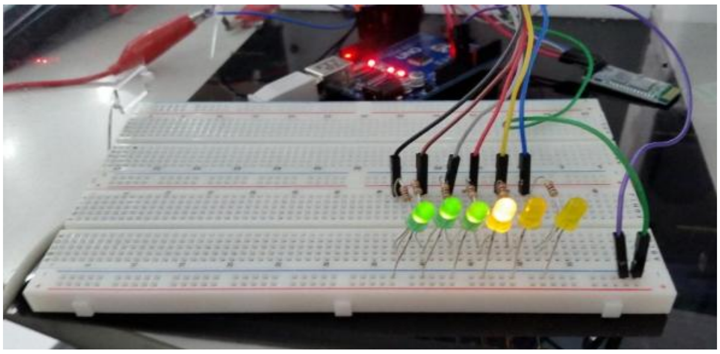

Figure3: LEDs indicating an attention value 40.

Mindwave has several types of commands for specific data, but only two of them have been used in programming: attention e meditation. Initially, there is the synchronization of the helmet baud rate with the Bluetooth module (38400 in this work). After pairing the helmet with the module, Mindwave looks for signals from the brain (the process may take a few seconds after the helmet is placed on brain), and constantly searches for the sync byte with the 0xAA value (170 in decimal values). Then there is a double check of the byte, ensuring that the received packet is valid. The PayLoad Length defines and limits the size of the data packet that can be used within the PayLoad Data variable, which is then loaded with the received packet bytes. After this step, there is a check of the values received in PayLoad Data through the checksum variable. The checksum is used to verify the integrity of the packet loaded in the PayLoad Data variable, and is defined by summing all bytes of the PayLoad Data variable, taking the least significant 8 bits of that account and completing one of those bits (inverting all 1 by 0, and vice versa). If the values match, an attention value and a meditation value are generated, as well as a Poor Signal value that measures the quality of Bluetooth communication. Mindwave generates new data every second, so a loop of repetition was used for constant data refresh. The project achieved satisfactory results, achieving its main and specific objectives, as shown in Figure 4. It was possible to perform the hand opening and closing using brain waves to control servo motors.

Figure4: Practical demonstration of the study partial result.

However, for a precise control of the hand opening and closing, a better signal processing must be performed, for this control with neural activity. The method of control of prostheses by EEG signal is the most used today, but it is necessary that the patient have control over these muscles, which in a paraplegic or tetraplegic person becomes impossible. By exploring brainwave control, a wide range of opportunities and applications open. The technology can also be applied to simpler tasks, such as lighting a lamp, answering a call or unlocking the cell phone screen, provided there is specific training for this. The opposite is also valid: activities more complex such as the entire hand control, muscle by muscle, can be performed (evidently that using EEG equipment with more electrodes, a specialized medical team and a larger study of this technology). As there isn't a brain part specifically responsible for the attention, some visual (color, for example) or sound stimulus could be used to open or close the hand. With complete EEG equipment, the procedure would be to study the main stimulated areas of the brain at certain times or pre-established tests with a large variety of patients, which was not possible in the project because of the short time available.

IV. Conclusion

Once the project was completed, it was possible to perceive the opportunities that a future approach to technology can offer. Further study on the subject can bring back the movement of people who could never walk or hold anything in their hands with the technologies currently available. When using Bluetooth communication, interference with the signal from the environment is perceivable. However, this is the only way that the Mindwave device can communicate, forcing us to work with this type of communication. In order to pursue the matter, it would be best to seek to know better, and if possible, personally, the rehabilitation in people who do not have the upper limbs. Since the main area responsible for the motility and planning of these movements is located between the frontal lobe and the parietal lobe, an electroencephalographic study of this area is extremely important, as well as how to stimulate this region in people who no longer have any limbs. Finally, the feasibility of future projects seems to be high, since the control technology itself by electromyographic signal is in itself very expensive, and still very widespread, which leaves our type of communication at a similar level in terms of cost.

Conflicts of Interest

The authors declares that there is no conflict of interest regarding the publication of this paper.

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