Wearable Mind Thoughts Controlled Open Source 3D Printed Arm with Embedded Sensor Feedback System

S. Hasan, K. Al-Kandari, E. Al-Awadhi, A. Jaafar, B. Al-Farhan, M. Hassan, S. Said and S. AlKork
College of Engineering and Technology, American University of the Middle East, Kuwait

Keywords: Robotic Arm, 3D Printer, EEG, Emotiv, Arduino, Inmoov, Prosthetic Arm, Mind Controlled.

Abstract: Number of amputees are increasing every year due to may causes such as vascular disease (54%) including diabetes and peripheral arterial disease, trauma (45%), and cancer (less than 2%). The fields of brain controlled and Medical applications for 3D printing are expanding rapidly and are gradually revolutionizing the delivery of health care. Based on these two technologies, we set out to find the feasibility of a low-cost wearable 3D printed arm to address the problem of amputation. This paper presents mind-controlled 3D printed arm with embedded sensor feedback system. The aim of this project is to come up with a light-weighted wireless 3D arm which can be portable, wearable and controlled using EEG headset. The given criteria were set to be based on 3 factors: Weight, Cost and Battery Life. An open source 3D arm was printed and controlled using an EEG headset to test the arms flexibility. The results show that the printed arm weighs almost half of an average male arm (1.53KG). More over the Cost of the arm was considerably lower than a surgical, prosthetic or static procedure with the deviation reaching up to a massive 8000% in the favour of the robotic arm. The battery life is estimated to be about 0.5 to 1 day considering normal usage. Given that all three factors fall in a reasonable range, it could be concluded that the future of 3D printed arms for amputees is much bright, with more work to be done in the portability and mechanical design.

1 INTRODUCTION

Millions of people are suffering from disability which prevents them from doing basic things that we take for granted. Studies show that about 15% of the world's population suffers from some form of disability (Hawking, 2011). Around 10 million of the world's population are amputees, and 30% of them are arm amputees (LeBlance, 2011). Moreover, due to many political, economic, and scientific reasons, the overall rates of amputees and limb dysfunction patients are increasing (NBC, 2010). People who are suffering from amputation have difficulty to do their daily life routine by themselves and they need assist from others. There is a great way to help the amputees, but they are either being incredibly expensive and not everyone can afford, hard to install and maintain, or it may require surgical procedures in this case it relies on the nerves which in some cases might be damaged. A lot of work is being done on the lower body exoskeletons (Li, *et al*., 2016) (A. Bennett, 2002). but this project focuses more on the upper body. There has been a research done on development of robotic arms such as the one developed by the team in John Hopkin University (Jeong, *et al.*, 2000), but most of them are more focused on the functionality rather than the real world feasibility. The mind controlled 3D printed arm has the potential to help amputees to preform many of their daily activities normally (Beyrouthy, *et al*., 2017), provide a better life, and improve the quality of life. Also, it helps amputees to regain functionality with natural control via brain waves. There are several existing solutions such as surgical arm, myoelectric-controlled arm, cosmetic restoration, and bionic arm and each type has advantages and disadvantages. One of the solutions for amputees is having a prosthetic arm. Prosthetic arm needs to be measured and specified to the patient needs. The second solution is the surgical limbs, where the patient will have a surgical operation to have a new arm. The surgical method is considered to be very costly. There are some problems that may happen due to the surgical arm. For example, sometimes the nerves may cause problem when they are damaged totally, which could make it hard to perform surgery. Also, the surgical method causes heart disease and back pain in some patients. The amputees face

Hasan, S., Al-Kandari, K., Al-Awadhi, E., Jaafar, A., Al-Farhan, B., Hassan, M., Said, S. and AlKork, S.
Wearable Mind Thoughts Controlled Open Source 3D Printed Arm with Embedded Sensor Feedback System.
DOI: 10.5220/0006929701410149
In *Proceedings of the 2nd International Conference on Computer-Human Interaction Research and Applications (CHIRA 2018)*, pages 141-149
ISBN: 978-989-758-328-5

nociceptive and neuropathic pain, due to bone and soft tissue injury. On the other hand, the prosthetic arm has less problems when compared to the surgical arm. Prosthetic arm avoids many medical issues that may happen. Table 1 shows comparison between different arm types:

There are many techniques to control a robotic arm. First method is to use an EEG device. The EEG is a headset which records the brain waves when the person is thinking of an action or implementing a facial expression. The EEG will read signals and then convert them to commands, to send them to the arm. The second method is to have surgical implantation for the person. In this method, the arm will be connected to the person's torso by performing surgery. The aim of connecting the arm to the nerves is to read the signals and then convert them to commands. The last method is using sensors. The sensors will be connected directly to the arm, and would take the readings from the surroundings. Some examples of such sensors would be EMG, gyroscope, and accelerometer.

The objective was to implement a wireless mind controlled 3D printed arm that can be controlled by brain signals using an EEG headset. The EEG headset is not only cost effective but accurate as well (Beyrouthy, *et al.*, 2016).In addition, the material for building the arm had to be light-weight and high-strength which could handle high impact while being comfortable, as studies have shown that 64 % of the amputees rate the comfort level of the prostheses as fair or not acceptable (Davidson, 2002). Moreover, the goal was to minimize the number of sensors used i.e. to use the most important ones for preforming normal hand activities. Also, making the 3D printed arm wearable (Said S. *et al, 2017*), secure, light-weighted, affordable, user friendly and easy to wear and to take off. The arm was controlled via brain signals obtained from EEG headset which is Emotiv EPOC headset (Sayegh, F. *et al, 2017*). Different mind states are captured and encoded to allow the arm to react and execute pre-programmed series of actions in specific cases.

Table 1: Comparison between different arm types.

Arm Type	Cost	Potential	Flexibility	Resistance
Bionic	Might cost $36,000	Good potential especially with the microprocessor revolution	Depends on the surroundings analyzing of the processor	Optimum resistance as it aware of its surroundings
Robotic	Might cost $1150 - $1300	High potential with the rise of 3D printers	Depends on the motors, material and design	High resistance depends on the motors
Surgical	Might cost $10,000 - $120,000	Very high potential	Depends on the training and the physiotherapy	Different depending on each case
Static	Might cost $3,000 -$5,000	No potential	Not flexible	Low resistance
Prosthetic	Might cost $10,000	Might be overshadowed by the surgical and the robotic limbs	Very high flexibility because it is custom made for each person with exact measurements	Need less work to ensure the best result

Table 2: Comparison between Different Arm Amputation Solutions.

Type	Accuracy	Cost	Installation	Degree of Control
EEG	Accurate	$100 750	Detachable	Complete Control
Surgical	Very Accurate	$10000- 120000	Permanent	Complete Control
Sensors	Accurate	Under $100	Detachable	Limited

2 STATE OF THE ART

The prosthetic technology is growing and getting more advanced for the past years. Many companies are developing 3D printed arms, such as Inmoov, Open Bionics, Create O&P and e-nable.

Inmoov (Langevin, 2012) is one of the most popular Open Source prosthetic arm, which contains the parts for building a full robot. Building a full arm does not require particular skills since it is easy to learn and all the STL files are free to download. It is also possible to adjust some parts to make it fit the design. Inmoov requires 3D printer with at least 12 x 12 x 12 volume of printing, and filament either ABS or PLA. Create O&P is a medical- technology company in the orthotic and prosthetic industry (Create O&P,2018). Create O&P arm is attractive, light in weight, low-cost, and custom-made for each patient. The arm is attached by using silicone suspension sleeve. Open Bionics (Open Bionics, 2018) is a bionic company that developed an assistive device which improve the human body. Open Bionic is one of the most affordable bionic arms in the market. Each arm is custom-built for patients that are as young as nine. The arm is light-weighted, comfortable, and breathable. The Open Bionics arm has special sensors that detect muscle movements, and the patient will effortlessly control it.

3 SYSTEM MODULES

The design consists of four modules: EEG Module. Electromechanical Module, 3D Printed Arm Module and Feedback Module.

3.1 EEG Module

First, Emotiv EPOC headset (Andrew, 2012.) reads the signals from the brain and sends them (using wireless communication) to USB dongle, which connects to a PC. These signals are read by the Emotiv Xavier software which are mapped to an event into any combination of keystrokes. Apart from that, a significant amount of training for different set of actions like opening and closing hand, rotating the wrist etc. was done which was then connected to the keystrokes. These keystrokes are then sent to the second module which is the electromechanical module.

3.2 Electromechanical Module

In this module, we have XBee communication between the PC and the Arduino UNO. We used two XBee modules, one of them was attached to the PC using XBee USB adapter, and the other one was connected to the Arduino using XBee shield. Both of the XBee modules are capable of sending and receiving data. The first XBee module which was connected to the PC sends the values to the XBee module that is connected to the Arduino to perform the movement. Based on this data, a certain arm

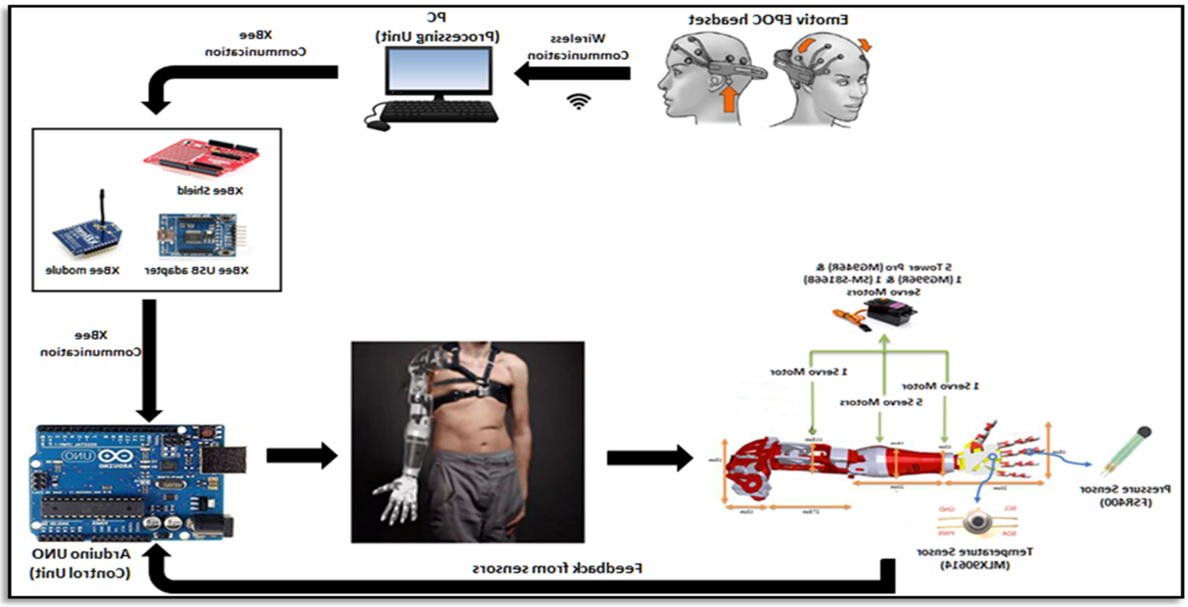

Figure 1: Mind Controlled 3D Printed Arm Design.

movement occurs. The XBee module that was connected to the Arduino sends the sensor feedback readings to the XBee module that was attached to the PC to be printed on the terminal.

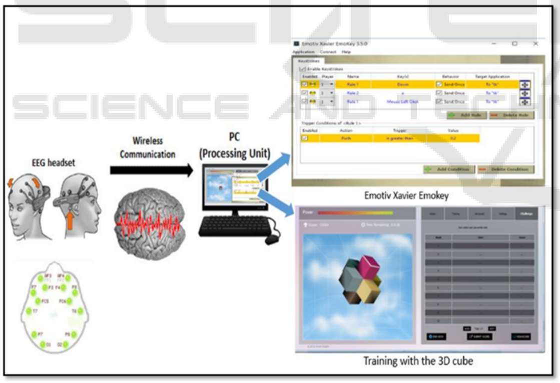

Figure 2: EEG Module.

3.3 3D Printed Arm Module

The third module is the 3D printed arm. In order to create the full 3D printed arm, the open source Inmoov design was used (Langevin, 2012). For the testing purposes only the files for the right arm were used Figure 4.

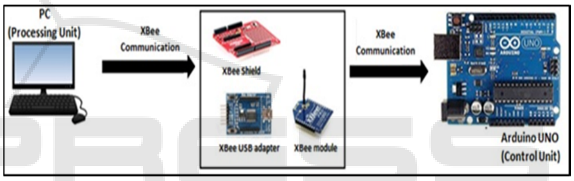

Figure 3: Electromechanical Module.

All the relevant parts were printed using PLA filament and assembled with bolts, nuts and screws. The final 3D printed arm is shown on figure 4. The arm was designed in such a way that it remains light-weight while maintaining high-strength. This was important as the arm has able to handle several types of objects with different weights.

3.4 Feedback Module

The last module is the feedback module, where the sensors are connected to Arduino. Both the temperature and pressure sensor were placed on the fingers which were connected to the analog pins of Arduino. This feedback system is important as the person who using the arm will not have the sense of feeling, this would help avoid any damages to the arm from the surroundings. For the arm movements, 7 servomotors were used, 5 for the fingers, 1 for the wrist and 1 for the elbow. All of them were connected to the digital pins of Arduino.

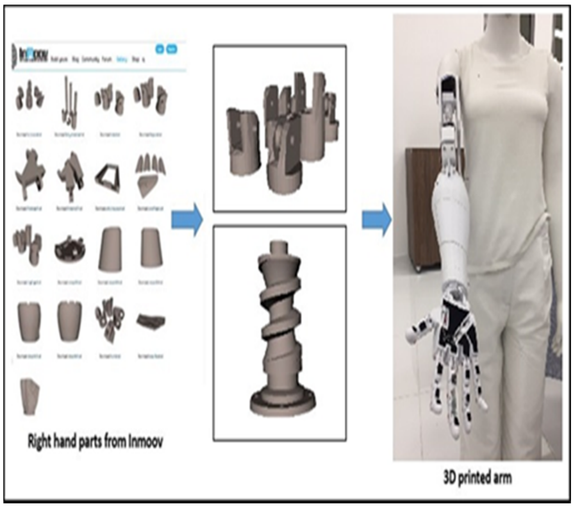

Figure 4: 3D Printed Arm Module.

The communication between the sensors and Arduino helps the arm to have the ability to respond to the surroundings. The respond occurs when the arm faces any objects. For example, if the arm wants to hold something that is very hot, the temperature sensor will avoid holding the object and the hand would open. In the other case if delicate object is being grabbed the pressure sensor would make sure to avoid breaking the object as well as the finger mechanism.

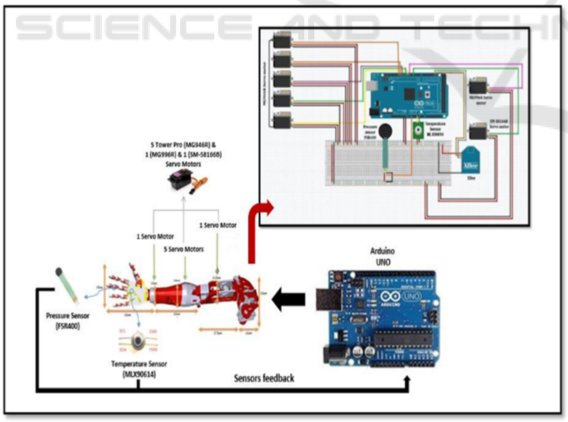

Figure 5: Feedback Module.

4 TECHNICAL SPECIFICATION

4.1 Hardware Overview

Using Emotiv EPOC headset, the user initiates brain commands to control the arm. After the thinking process, the headset will send the brain signals to the PC, which then compares them to the training in the Emotiv Xavier program. By using EmoKey each signal is mapped to have its own keystroke that is pressed while thinking of a certain action such as push, pull, rotate. Using Arduino Ide, the signal is processed that initiates a corresponding action by controlling the servo motors. This data is sent to Arduino UNO using XBee communication. Based on certain values of the keystroke, motors are activated. Since the user does not have the sense of feeling, a feedback system which includes temperature sensor and pressure sensor was added.

The temperature sensor is embedded on the finger, so that while holding the object, the temperature sensor will measure the temperature (at every angle). If the temperature reading is too high for the human skin or for the material to handle, an action will occur to open the hand. After checking the temperature, if it was not high then the pressure sensor checks the pressure while holding the object. This allows the fingers to stop at a redefined pressure. If both the temperature and the pressure readings are safe, the action of holding an object occurs.

Table 3: Main Hardware Components.

Component	Input/output	Analog/Digital
Temperature Sensor MLX90614	Input	Analog
Pressure Sensor FSR400	Input	Analog
Tower-Pro MG946R Servo Motor	Output	Digital
SM-S8166B Servo Motor	Output	Digital
XBee Module	Input Output	Analog
EEG headset (Emotiv EPOC)	Input	Analog

4.2 Power Consumption

The Emotiv EPOC headset uses a lithium (Li) battery that can be used for up to 12 hours continuously when fully charged. If the headset is fully discharged it will take 4 hours to be fully charged.

Thus, mind controlled 3D printed arm needs batteries that can make the arm operate for about 7 to 8 hours of continues usage. Furthermore, the arm weight should be suitable for the person and comfortable. Two lead Acid batteries are used separately in order to let the arm operate for longer time, one of them is 6V with an output current of 7Ah, and the other one is 6V with output current 4.5Ah. Given the table below the total ampere required to operate the arm is added to be 3.92A. With this usage, the arm will operate for about 2 continuous hours. Since a person moves their arm for about 1 to 3 hours per day on an average depending on the activity performed, the system can work for approximately 0.5 to 1 day. We calculated the power consumption for each component as shown in Table 4 using Equation 1

$$Power\left(\frac{W}{h}\right) = Voltage\ (V) * Current\ (I) \quad (1)$$

Table 4: Power Consumption Calculation.

Component	Power Consumption
Arduino UNO	5V * 0.05A = 0.25 W/h
MG996R Servo Motor	5V * 0.9A = 4.5 W/h
MG946R Servo Motor	5V * 0.95A = 4.75 W/h
SM-S8166B Servo Motor	5V * 2A = 10 W/h
FSR400 Pressure Sensor	5V * 0.01A = 0.05 W/h
MLX90614 Temperature Sensor	5V * 0.01A = 0.05 W/h

5 SYSTEM FLOWCHART

5.1 Flowchart Scenario

Step 1: The user will have the ability to initiate brain commands to control the arm, after the thinking process, the headset will read the signals then compare it to the database of the Emotiv Xavier. After that, signal processing will be performed to obtain a corresponding action. Finally, the data will be sent to Arduino and based on the XBee values servo motors will be active.

Step 2: If the value of the XBee equals to 1, then "Action 1" command occurs; thus, the user will be able to open the hand.

Figure 6: Open Action 1.

Step 3: If the value from the XBee equals to 2, then "Action 2" command occurs, the servo motor in the bicep that controls the fingers will close to a certain degree which will make the hand closes and will help in holding the object.

Step 4: The temperature sensor is embedded on the hand palm so that while holding the object, the temperature sensor will measure the temperature. If the temperature sensor reading is too high for the human skin or for the material to handle, "Action 1" will occur and this will open the hand.

Figure 7: Close Action 2.

Step 5: If the temperature was not high then the pressure sensor will check the pressure of holding the object, if pressure was detected, the servo motors will stop at that position.

Step 6: If the result of both the temperature and the pressure sensors are safe and the value of the XBee equals to 3, "Action 3" will occur which will make the hand rotate to a certain angle then "Action 1" will occur to open the hand and throw the object. Finally, we will have a delay and after the delay "Action 4" will occur and the hand will rotate back to the initial position.

Figure 8: Rotate Action 3.

6 DESIGN CONSTRUCTION, TESTING AND IMPROVEMENT

The construction of the arm started with fingers. The fingers were attached and connected to the servo motors (MG946R). The hand was tested with the temperature and pressure sensors. For the wrist the MG9996R servo motor was used. The hand and the wrist were tested with the headset with four actions, which were close hand, open hand, rotate wrist right, and rotate wrist left. Emokey was used to map the signals with different keystrokes and send it to Arduino.

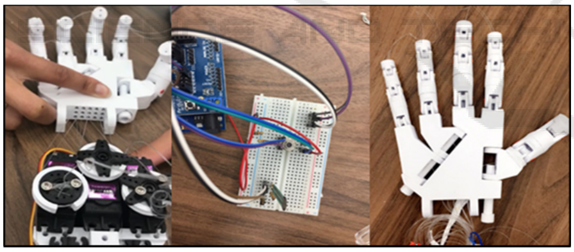

Figure 9: Testing fingers' Movements with sensors

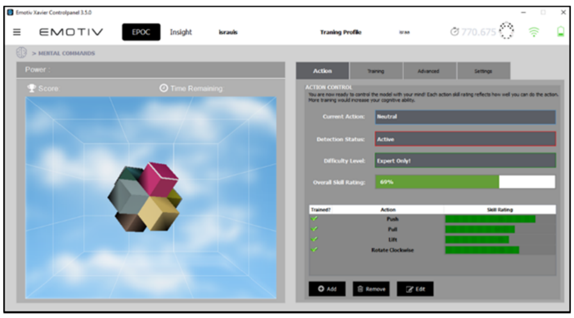

Figure 10: Emotiv Headset Training (Xavier Control Panel).

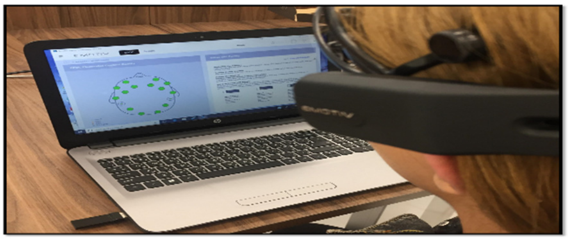

Figure 11: EPOC Headset Testing.

The strings were re-adjusted (of the fingers) to make sure that they move in a synchronized motion. After completing the hand, wrist, and forearm, the sensors were attached to the hand.

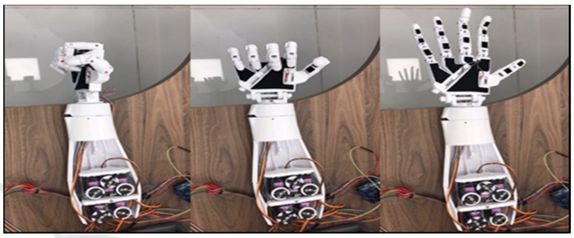

Figure 12: Testing the Arm Actions.

For the wireless communication the XBee module was added. The XCTU program was used to start the communication between two XBee modules, one of the modules was attached to XBee adapter and connected to the PC, and the other module was attached to XBee shield that was connected to Arduino. Both of XBee modules act as TX (sender) and RT (receiver).

The final step was assembling the elbow and the bicep. The SM-S8166b servo motor was used for the elbow. The servo motor had some fitting issues, as the Inmoov used different servo motor, which were fixed. However, it worked fine at the end. Figure 13 shows the final implementation of the project. After completion of the hardware the total weight of the arm without the battery and electronics was measured which came out to be 1.53 KG.

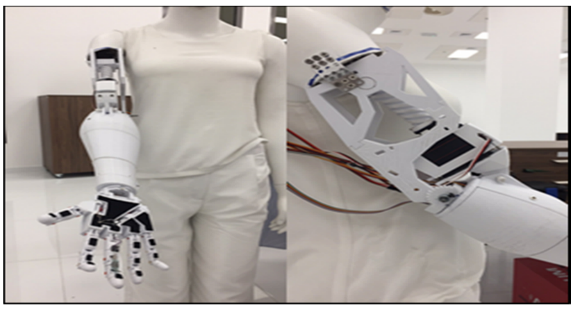

Figure 13: Attaching the Arm to Mannequin.

7 PROJECT COST

The cost of the project is divided into two parts which are the components (servo motors, sensors, XBee, Arduino UNO and Emotiv EPOC headset, two Lead Acid batteries), and the 3D printing cost. All the required components are relatively inexpensive. The total cost of the design is estimated to be around $1451 as shown in Table 5.

Table 5: List of Main Components.

Components	Cost
Emotiv EPOC Headset	$840
Servo Motors	$88
Sensors	$66
3D Arm	$233
Arduino UNO Microcontroller	$39
XBee Communication	$123
Batteries	$62
Total	$1451

8 CONCLUSION AND FUTURE WORK

At the completion of building the 3D printed arm and assembling the needed sensors, the arm movements controlled successfully using EEG headset. Thus, the technology of brain controlled and printing 3D materials lead up to create a wearable light-weighted affordable arm that has feedback system. Despite getting good results there is a lot of work still to be done in order to make the 3D printed arm a reality. One area to be explored is to control the arm using facial expressions in addition to the mind control. Facial expressions can be an alternative option for the amputee when his mind signals cannot be detected easily because of noises or if the user is not relaxed and does not act normally, so the needed signals which are muscles sensors will be detected using his facial expressions such as smiling, blinking, looking right and left, clenching, laughing, etc. Moreover, Raspberry Pi as a processing unit instead of PC could be added in order to get portable arm. Some small additions like attaching LCD screen to the arm to show the sensors readings could also improve the overall user experience. Another aspect in the improvement is the appearance of the arm which could be greatly improved by adding silicon giving it a more natural look.

In conclusion, the number of amputees is increasing year by year in the world due to several reasons such as cancer, trauma, explosions, and diabetes. As a result, amputation prevents people from doing their daily life activities and leads them to depend on others. Actually, there are many solutions in the market but they are either incredibly expensive or require surgical procedures that relies on nerves which in some cases might be damaged. Thus, in this project we came up with an affordable design that can help amputees to depend on themselves by performing their daily routine which helps them to raise their self-esteem and provide them with a better life. A 3D printed arm that is controlled by brain signals using EEG headset and equipped with most important sensors that gives a feedback and avoid any damaging or breaking in the arm.

Results show that the printed arm weighs almost half of an average male arm (1.53KG). More over the cost of the arm was considerably lower than a surgical, prosthetic or static procedure with the deviation reaching up to a massive 8000% in the favour of the robotic arm. The battery life is estimated to be about 0.5 to 1 day considering normal usage. Given that all three factors fall in a reasonable range, it could be concluded that the future of 3d printed arms for amputees is much bright, with more work to be done in the portability and mechanical design.

ACKNOWLEDGEMENTS

We would like to thank the American University of the Middle East that gave us the opportunity to carry out our research. We would also like to thank the Robotics Research center for funding the project providing us such great facilities and assistance throughout our research.

REFERENCES

Beyrouthy, T., K Al Kork, S., Akl Korbane, J. & Abdulmonem, A., 2016. *EEG Mind controlled Smart Prosthetic Arm.* Balaclava, Emerging Technologies and Innovative Business Practices for the Transformation of Societies (EmergiTech), IEEE International.

A. Bennett Wilson, J., 2002. History of Amputation Surgery and Prosthetics. [Online]

Andrew, 2012. Neourosky Mindwave Mobile Rewiew. [Online] Available at: https://neurogadget.net/2012/12/20/neurosky-mindwave-mobile-review/6611.

Davidson, J., 2002. A survey of the satisfaction of upper limb amputees with their prostheses, their lifestyles, and their abilities. *Journal of Hand Therapy, pp. 62-70*.

Hawking, S. W., 2011. World Report on disability, Geneva: *World Health organization*.

NBC, 2010. Limb loss a grim, growing global crisis. [Online] Available at: http://haitiamputees.nbcnews.com/_news/2010/03/19/4040341-limb-loss-a-grim-growing-global-crisis

LeBlance, M., 2011. Give Hope - Give a Hand. [Online] Available at: Available: https://web.stanford.edu/class/engr110/Newsletter/lecture03a-2011.html

Jeong, Y., Lee, D., Kim, K. & Park, J., 2000. A wearable robotic arm with high for reflection capability. Osaka, *9th IEEE International Workshop on Robot and Human Interactive Communication, pp. 411-416*.

Langevin, G., 2012. Build Yours InMoov. [Online] Available at: http://inmoov.fr/build-yours/

Li, J. et al., 2016. A Robotic Knee Exoskeleton for Walking Assistance and Connectivity Topology Exploration in EEG Signal. UTown, *6th IEEE RAS/EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob)*.

Said, S., AlKork, S., Beyrouthy, T. & Abdrabbo, M. F., 2017. Wearable Bio-Sensors Bracelet for Driver's Health Emergency. Paris, *Bio-engineering for Smart Technologies (BioSMART),IEEE*.

Sayegh, F. et al., 2017. A Wearable Rehabilitation Device for Paralysis. Paris, *Emerging Technologies and Innovative Business Practices for the Transformation of Societies (EmergiTech), IEEE International*

Open Bionics. (2018). Hero Arm - an affordable, advanced and intuitive bionic arm. [online] Available at: https://openbionics.com/hero-arm

Create O & P. (2018). Create Prosthetics. [online] Available at: https://www.createoandp.

S. K. A. Kork, I. Gowthami, X. Savatier, T. Beyrouthy, J. A. Korbane and S. Roshdi, "Biometric database for human gait recognition using wearable sensors and a smartphone*," 2017 2nd International Conference on Bio-engineering for Smart Technologies (BioSMART), Paris, 2017, pp. 1-4*.

Taha Beyrouthy, Samer Al. Kork, J. Korbane, M. Abouelela, "EEG Mind Controlled Smart Prosthetic Arm – A Comprehensive Study", *Advances in Science, Technology and Engineering Systems Journal, vol. 2, no. 3, pp. 891-899 (2017).*