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Neuro-Bionic Multi-Directional ARM Prostheses

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***Abstract*—Oodles of people in this world suffer every day from some form of amputation. However ample the prosthetics development, there is always a great demand for prosthetics proper for more robust everyday activities. The functions accomplished by central nervous system during real-time hand movement could be replicated using Brain Control Interface. This innovative process of design and fabrication of a brain controlled bionic arm would permit amputees to perform their everyday activities without others help. The initial development of the neuro-prosthetic arm encompasses research in existing prosthetic designs, the various anatomical facets of biological arm motion in all natural directions, the acquisition of human neural signals from motor cortex of the brain, and the use of appropriate raw brain signal processing techniques for enhanced data interpretation. The developed inexpensive non-invasive brain controlled neuro-prosthetic arm could evidently eliminate the high cost and invasive methods used in commercial prosthetic arm development. The implementation of Neurosky's Neuroheadset for acquisition of Electroencephalography (EEG) data from Frontal Parietal (FP-1) point resulted development of a fully functional neuro-prosthetic arm with fewer number of non-invasive electrodes. The augmented use of Neurosky's Neuroheadset alongside Matlab programming platform and Arduino microcontroller resulted in the development of a low cost neuro-prosthetic arm. This work resulted in development of an assistive bionic arm which seamlessly integrates the amputee's musculoskeletal structure with central nervous system (CNS).**

Keywords*— Arduino Microcontroller; Bionic; ThinkGear; Electroencephalograph (EEG); Mind Machine Interface (MMI); Neuroheadset; Brain Control Interface (BCI).

I. INTRODUCTION

Prosthetics were used since 900 BC to substitute various body parts. Modern research on brain controlled prosthetics focused mainly on mimicking recorded hand activity data from brain motor cortical areas to control the prosthetic arm. For hundreds of years the contemporary prosthetics were primitive with no robotic actuation. The word bionics means enhancement or replacement of biological organs or body parts by power-driven versions. Bionic human implants vary from ordinary prostheses to sophisticated systems which mimic natural biological function. All the technological know-hows of these times made possible the rapid advancements in human prosthetics, but the most solutions are still basic designs only. Most historic human prosthetics were made of metal and wood manufactured by tradesmen and blacksmiths which were esthetic pieces and not functional tools. Nowadays human anatomy is studied for more bio-inspired limb design. Technology nowadays has progressed where biomimetic prosthetics has begun challenging their natural counterparts.

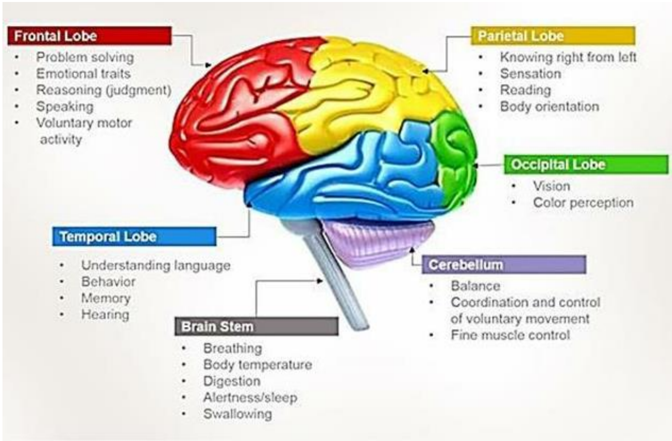

Fig. 1. Anatomy of the human brain

Biological limb motion originates naturally from within a vast network of human spinal interneurons called central pattern generator (CPG) which also modulate primary locomotor patterns. Biomimetics, is the notion in which a fabricated artificial mechanical device efficiently mimics the various functional, structural, and natural properties of biological entity which the device is modeled after. On the other hand, anthropomorphic devices mimic the various physiognomies of the biological human limb with its physical look, feel, and a textured human skin-like material on the surface. These models in prosthetic limb design are facilitated by various control systems, sensors, actuator designs, and biomechanical insights. These developments have steered to functional robotic exoskeletons, allowing paralyzed individuals movement for the affected limb. Appropriately leveraging these new technologies requires subjective examination of the device user and detailed study of current progress in brain controlled research and development.

In this work, the design, fabrication and testing of a brain controlled assistive prosthetic arm using latest developments in Brain Control Interface is detailed. Raw human brainwave data signals were acquired from the brain using Electroencephalograph for neural prosthetic arm control applications. Present work indicate that high level cognitive signal actuation can potentially improve the capability of paralyzed individuals to interact with the outside world using brain controlled bionic arm. Results show that various local field potentials from motor cortex of human brain provide real-time cognitive states of the user's Electroencephalograph activity for seamless mind machine interface in the future.

In the mean time employment of new brain controlled technologies will permit Electroencephalograph recording electrodes to automatically filter the best raw brain signals for decoding cognitive signals to execute complex gesticulations.

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II. METHODOLOGY

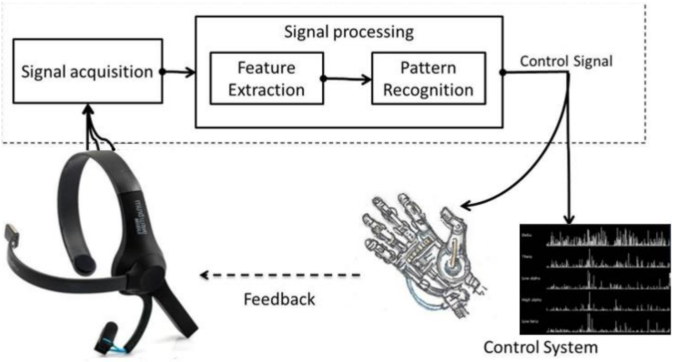

Fig. 2. Block diagram of the system

The complete block diagram of the system presented in Fig.2 is made of a brain controlled bionic hand, a Neurosky Mindwave headset which is an Electroencephalograph headset and Matlab Software platform combined with an Arduino board embedded platform. The direct bionic hand movement is controlled by Brain Control Interface which translates Electroencephalograph signals into real-time motion commands facilitating direct control of bionic hand extension and flexion movement. The bionic hand movements are controlled by real-time gesticulation commands translated directly from user's raw brainwave signals which are generated while imagining forearm or wrist movements. In this section the various hardware and software platforms are presented and their usage discussed; basic underlying information of brain controlled bionic hand operation will be presented in detail.

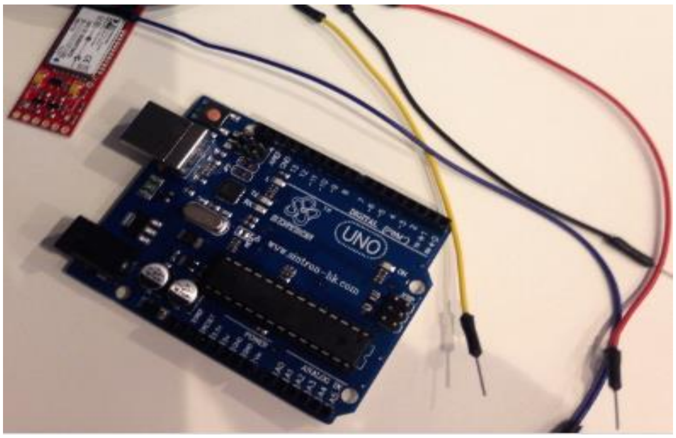

Fig. 3. Photo of Arduino Uno microcontroller

In Fig.3, Arduino microcontroller is basically an open source electronics platform used widely for engineering electronics projects. Arduino microcontroller board are fully programmable using Integrated Development Environment (IDE) software which is basically an integrated microcontroller development Platform with which the programmer develops and runs code before finally uploading the control code to the board through a computer. The Arduino Uno microcontroller is powered by a +5V DC supplied by an onboard battery pack. It contains eight analog pins, ten digital pins, four reference pins, six pulse modulation pins and six digital pins. It has three red light indications for receive, transmit and power. The brain controlled bionic hand is designed with an Arduino Uno microcontroller because of the ease to load the code to it.

Arduino microcontroller is used to receive inputs in real-time from the Serial Monitor window linked to the Matlab Software to send a flexion movement signal to the Hitec Hs-422 servo motors in the interior the robotic bionic hand for performing a motion. Arduino microcontroller is a micro-computer used for real-time motion control. The Arduino software was completely programmed from scratch with the use of Arduino Integrated Development Environment software.

Fig. 4. Photo of Neurosky Mindwave Headset

The principal hardware used for raw brainwave signal acquisition for the working of brain controlled bionic hand is the Neurosky Mindwave headset. The headset securely measures raw brain waves and delivers the EEG output signal as power spectrum. The EEG power spectrum mainly consists of alpha, theta, beta, delta, gamma brainwaves. The headset also delivers parameters like eSense attention and meditation signals including eye blinks. The core hardware module of the headset consists an EEG sensor arm and a reference ear clip electrode. The sensor arm contains an EEG electrode and ear clip is the headset's reference electrode and ground electrode. The sensor arm electrode is intended to rest on the user's forehead region directly above the eyes. The output headset preconfigured data packets are transmitted via HC-05 Bluetooth module. One +1.5V AAA battery power the headset.

III. IMPLEMENTATION

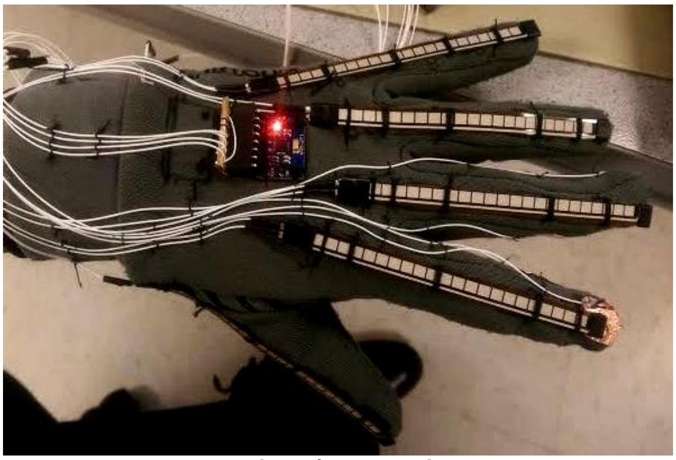

Fig. 5. Photo of Bionic Hand Prototype

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Arduino Uno microcontroller is +5V powered but the servo motors used in the brain controlled bionic hand require more power from extra +9V battery pack. When the Arduino Integrated Development serial output monitor is opened in the computer, the red LED on the board will turned on and system initialization commences. The brain controlled bionic hand servo motor feedback will be displayed on the Arduino serial monitor in real-time. The bionic hand control system executes two wrist motion to control extension and flexion based on the user's brain attention and meditation levels. FP1 EEG dry electrode is employed for raw brainwave acquisition, and after signal amplification and rectification the smoothed myoelectric brain signal is processed further by TGAM chip and send to Arduino Uno microcontroller to operate relays for controlling the +9V battery operated Hitec Hs-422 servo motors. The brain signals will be transferred in real-time to Arduino Uno microcontroller for seamless operation of the brain controlled bionic hand. The HC-05 Bluetooth transmitter module in the headset, is power using +1.5V AAA battery.

The raw brainwave data transmitted from the Neurosky Mindwave mobile headset is received wirelessly by Computer's Bluetooth receiver module. And the brain signal data analysis and further signal processing is done in Matlab Software platform. The Matlab Software platform will extract usable brain signal data and eye blinks for complex servo motor control and send it to the Arduino Uno microcontroller. The Matlab Software platform use Arduino microcontroller port pin for data transmission. The two types of brain signal data measured by the Neurosky Mindwave headset brain sensor are Meditation level and Attention level which are sent in real time to onboard Arduino microcontroller to execute simple extension and flexion arm motion by the bionic hand. The Attention levels received by Arduino microcontroller will execute preprogrammed control commands for Hitec Hs-422 servo motor actuation for bionic arm motion control in real time. The Arduino microcontroller continuously analyze all incoming raw brainwaves and by mapping them to execute preprogrammed control commands initiates appropriate wrist motion. The intensity of attention level and eye blink parameter control all the different wrist motion of the brain controlled bionic hand. These attention level values are classified into different intensity levels. For each raw brainwave intensity level, a specific wrist motion is allocated to the microcontroller to be executed. Five Hitec Hs-422 servo motors control extension and flexion of the the brain controlled bionic hand. The Arduino microcontroller drives all the Hitec Hs-422 servo motors based on the EEG spectrum. Servo motors with high torque, accurate rotation and fast response used for arms/legs control were opted. The Arduino microcontroller sends pulse width modulation (PWM) signals to the servos. A potentiometer in the servomechanism provides real-time analogical signals to indicate bionic hand position and an encoder provide wrist motion speed feedback. A PID controller is used for precision control of position and to stablise bionic hand position. The brain controlled bionic hand data transfer is controlled via HC-05 Bluetooth module. This Bluetooth technology use Serial Port Protocol to configure and setup a wireless realtime serial communication. HC-05 Bluetooth module works in 2.4GHz ISM band and is configured using Gaussian Shift modulation technique.

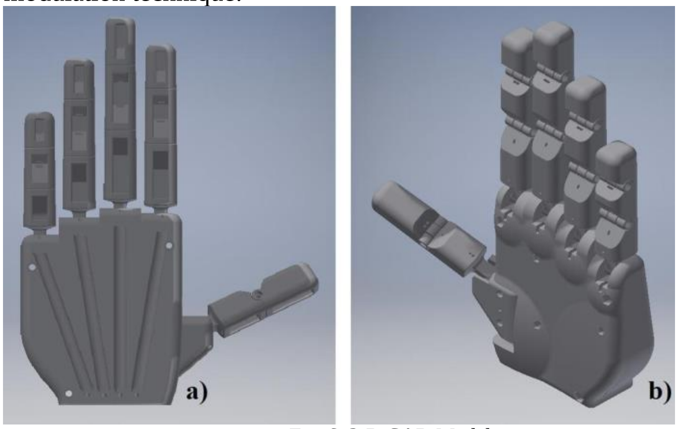

Fig. 6. 3-D CAD Model

IV. RESULT AND DISCUSSION

Table- I: Experimental Data

Action	Range	Actuation
Long Blink	40-60	Forward
Quick Blink	Normal Blink	Backward
Stress Blink	>100	Stop
Blink (twice)	40-70	Move Left
Stress Blink (twice)	90-255	Move Right
Attention 1	40-60	Pick
Attention 2	70-100	Place

The Attention brainwaves are extracted from raw eSense data packets received from Neurosky Mindwave headset along with eye blink values to control all the electric servo motors. The verification procedure for experiments is:
1. Link the Uno microcontroller in the bionic hand setup to a computer via HC-05 Bluetooth module and run the Arduino Integrated Development Environment (IDE) software.
2. Wear the Neurosky Mindwave headset and power it on.
3. Power on the bionic hand with its fingers perpendicular to a flat ground surface.
4. Open the serial output monitor in Arduino IDE software and monitor the bionic hand feedback.
5. Control the motion of bionic hand in real-time using Attention brainwaves to confirm extension and flexion movement of the fingers'.
6. Repeat the Experiment to initiate the various bionic hand motion and perform feedback analysis to confirm the output results.

The Experimental results are verified from the Arduino IDE serial output monitor feedback and the present finger positions of the bionic hand setup. When the result of the programs is satisfactory, this indicates that the new control system complies with expectations.

The FP1 EEG dry electrode sensor of Neurosky Mindwave headset gives up to 95% accuracy of user's brain waves. Still greater complexity of bionic hand extension and flexion may be achieved using Matlab toolbox (EEGLAB).

EEGLAB contains powerful tools for the processing and analysis of event-related Electroencephalograph brainwave filtering, raw artifact rejection, averaging and epoch selection.

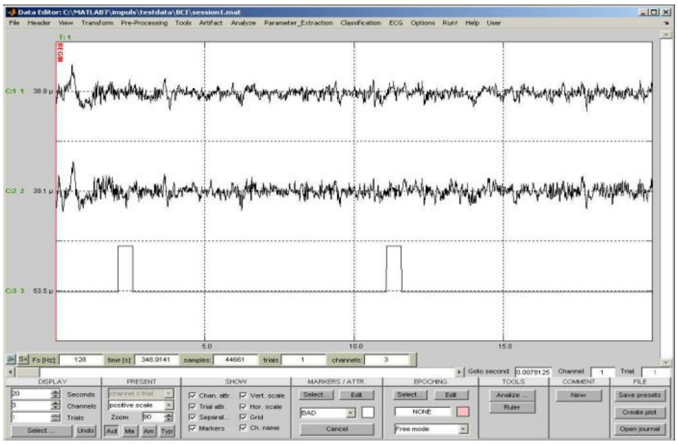

Fig. 7. EEG analysis of Matlab EEGLAB Toolbox

Matlab independent component analysis (ICA) was used for analysis of statistical event-related EEG data visualization, scalp mapping and event-related multi-trial potentials. The Matlab command window for acquiring raw human brainwaves shows real-time attention values sensed by the Neurosky Mindwave headset after linking the headset with PC via Bluetooth. After processing the attention brainwaves and eye blinks, a graph as shown in Fig.7, will be generated. These signals are then transmitted to the bionic hand setup through Bluetooth wireless transmission, the Arduino microcontroller receives command signals and actuates the servo motors to execute the predefined bionic hand movements. Thus complex bionic hand movements are voluntarily achieved using brainwaves only.

Brain signal acquisition, analyses and subsequent classification in various situations enabled successful command signal generation for controlling the bionic hand movements. The present work resulted in bio-algorithms which could be modified to generate command signals for a large number of electrophysiological bionic application.

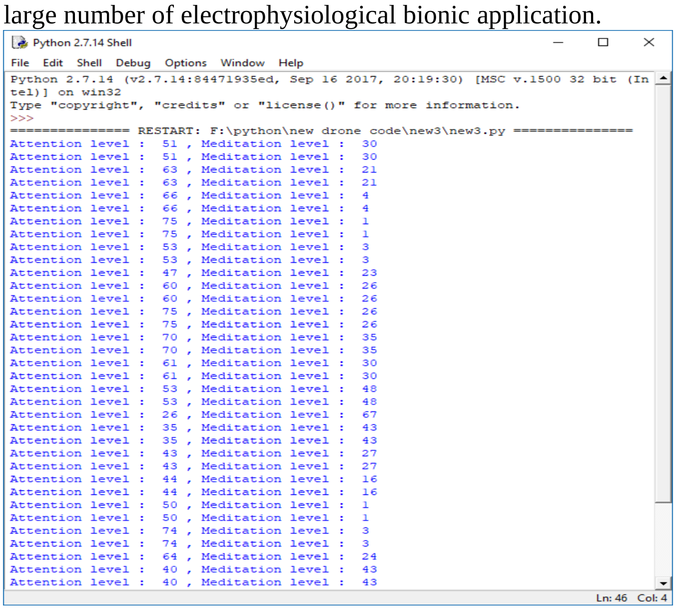

Fig. 8. EEG Readings

V. CONCLUSION AND FUTURE WORK

In present work, the research and development of brain-controlled bionic hand has revealed tremendous potential to improve the life quality of differently-abled people.

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