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Neuro-Robotic Unmanned Aerial Vehicle

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***Abstract*—Since time immemorial, human beings are continually experimenting with novel ways to interact with the environment to achieve high data transfer by touch, speech and gestures. A technology called Electroencephalography (EEG) enabled direct communication between man and machine for the first time. Here brain signal activity links us with technology. This cutting edge technology is employed to enable real-time control of an Ariel Vehicle by using raw brain signal data.**

The present work entails design, fabrication, and real-time testing of a semi-autonomous brain controlled quadrotor UAV or more specifically a Drone directly controlled using thought power only. Brain computer interfacing was solely developed four decades ago for enhancing and developing neuroprosthetics, in modern times the invention of non-invasive Neuroheadset technology is has instigated various applications like control, automation and vehicular control. The real-time flight control system was executed by Arduino IDE on-board quadrotor UAV. The prototype was tested in actual flight tests. The results indicate BCI system has potential application for the control of quadrotor Drone, which in the long run used to improve life of paralyzed people by maximizing their independence and communication capabilities.

Keywords*— *Arduino; Mind-Machine Interfaces; Quadcopter Drone; Neuroheadset; Fuzzy Proportional Derivative (FPD); Electroencephalograph.

I. INTRODUCTION

The earliest ever human brain recording of raw electrical activity was conducted in 1929 by Hans Berger using Electroencephalography (EEG). His focus was a boy who had a hole drilled into his skull for tumor treatment. Berger's toil was ridiculed by his contemporaries until 1934, when British electrophysiologists established his findings, and bestowed Berger the title "father of EEG". Brain controlled technology offer novel type of interaction between computer and human. "The usage of unmanned aerial vehicle is steadily growing in recent times owing to rapid technology advancement" [1]

In the last decades, Unmanned Ariel Vehicle employment grew considerably in the various federal agencies. Mind Machine Interfaces (MMI) capture and then analyze the raw brain signals on computers. Brain Computer Interfaces (BCIs) convert neuronal information from human brain into control commands to peripheral hardware, which could improve life quality and health of differently-abled individuals. This system works using electroencephalogram headset to monitor the activity of human brain when certain actions are performed which then are transmitted to a computer system to be analyzed and processed for generation of control signals. Research in neurological studies is a new venue of research for Engineering and medical fields.

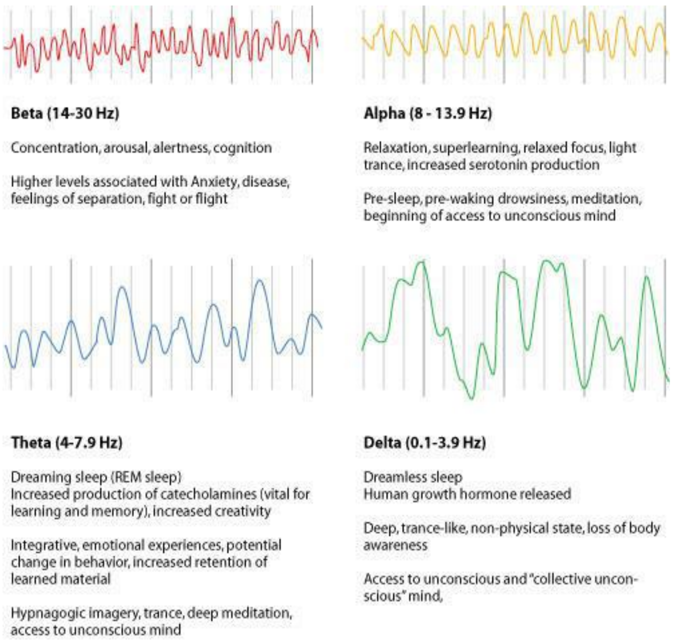

Fig. 1. EEG Data and Brainwave frequency chart

The EEG bands are classified as follows**: -**

- Delta **-** Delta frequency band is of 3.9 Hz or lower. It has the highest amplitude and are the slowest brainwaves.
- Theta **-** This frequency band is between 4 to 7.9 Hz and denote slow brainwave activity.
- Alpha **-** This frequency band is confined between 8 and 13.9 Hz and seen in the brains posterior region.
- Beta **-** Beta brainwave activity is fast and has frequency between 14 to 30 Hz.
- Gamma **-** A gamma brainwave signal is an oscillation pattern with a frequency band between 30 and 100 Hz. The usage of advanced computational tools could help in further study of complex brainwaves.

The chief contributions of present work are (1) Implementation of state-of-the-art brain computer interface (BCI) that responds to users' raw brainwave activity and generate command signal for quadrotor Drone flight. (2) Fabrication of an operational quadrotor drone that responds to the Brain Computer Interfaces system. (3) Envisioning of a Fuzzy Proportional Derivative (FPD) technique capable of adaptive stabilization of the quadrotor Drone resulting in controlled flight.

The present work resulted in safe flight pattern. The mind sensor data was successfully sent to the microcontroller. According to the various parameters flight pattern was set in the program, the flight of the quadcopter was controlled while

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in a focused state and not in an agitated one. The present work was instigated with the vision of a grand future, which achieved singularity in terms of Mind Machine Interfaces.

II. SYSTEM REQUIREMENTS

- EEG-Neuroheadset with FP1 Sensor
- 2-Arduino Microcontroller
- Quadcopter frame
- 4-BLDC motors
- 4-Propellers
- 3-axis gyroscope
- Front camera
- Magnetometer
- Connecting Wires
- Lithium polymer battery (5200 mA)

III. METHODOLOGY

A. Deciphering the Control Signal

The Mindwave Mobile headset correctly measures wearers' raw EEG brain spectrums (mediation and attention power), and the eye blinks. The neuroheadset's reference electrode is positioned on the ear, and FP1 EEG electrode is on positioned on forehead above the eye. This neuroheadset is powered by AAA battery.

The Mindwave mobile headset is based on a proprietary eSense™ technology. It also has a BLE (Bluetooth Low Energy) data transfer module which makes the headset Bluetooth compatible. The inbuilt processor of Mindwave headset has 3 different principals to map human brain activity. It mainly supports BLE 4.0 and Bluetooth 2.0. HC 05 Bluetooth module works using only Bluetooth 2.0, which is used for data transfer of raw brainwave signal data. Mindwave headset acquire wearers' raw data from the inbuilt electrode sensor and sends data to Arduino microcontroller in the quadrotor UAV platform.

The Mindwave Mobile headset accurately measure and outputs the raw EEG spectrums (beta waves and alpha waves), Meditation and Attention eSense™ algorithms and also eye blinks. TGAM1 module could perform wireless pairing with PC or the quadrotor UAV via RF link during real-time testing.

Fig. 2. Neurosky Mindwave Neuroheadset (2-channel)

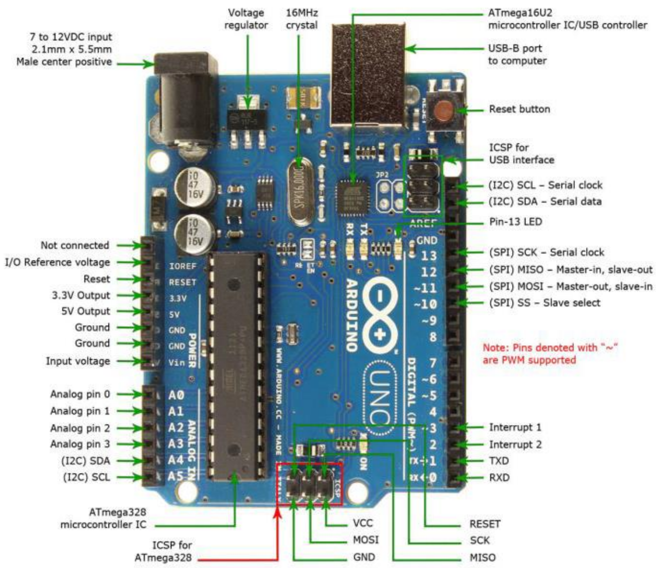

Fig. 3. Arduino Development Board

Arduino Uno microcontroller is totally an open source computing platform which was used to build a digital processing environment to enable interaction with objects in world. It's built on AT mega 328P chip which contain 14 digital pins, 8 pins are used as PWM for output, 6 pins are used as analog inputs, 1 USB connector is used for programming the microcontroller, 16 MHz frequency quartz crystal serves as an internal clock, power jack, and a reset switch. Arduino board is programmed using Arduino IDE or Integrated Development kit which will upload completed programs to execute intended tasks. So after EEG signal acquisition the processing is done in the Matlab software platform which generates the control signal for Arduino microcontroller. The Brain Computer Interface processes the raw brainwave inputs from Mindwave Mobile EEG headset which is interfaced with an Arduino Microcontroller via RF link during real-time testing. The Arduino Microcontroller Receives the control signals and execute various quadrotor UAV movements programmed into it using Arduino Integrated Development Environment. In addition, C# and Matlab software package has been used to write codes. Unity 3D graphic motor provided visual feedback from the virtual computer generated camera.

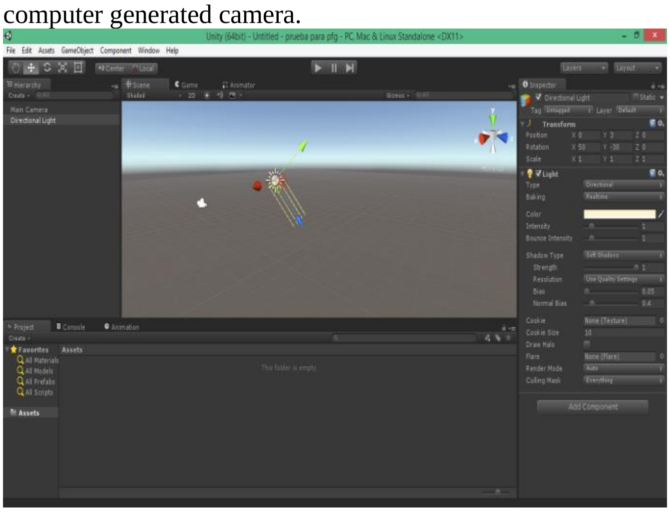

Fig. 4. Unity 3D development environment

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B. Basic Block diagram

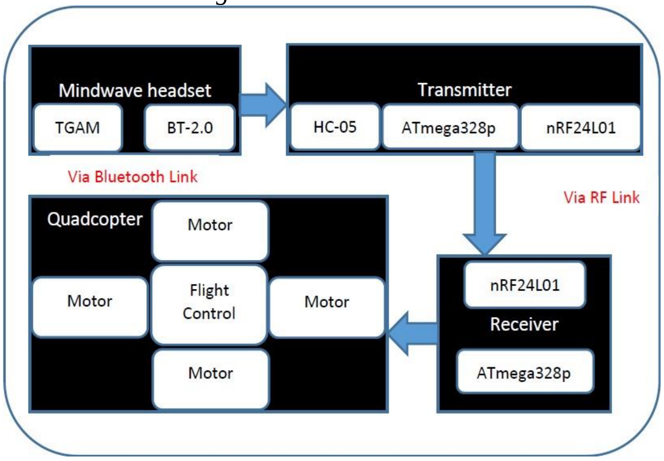

Fig. 5. System Overview

Fig.5, represents the overall framework used for EEG brain signal acquisition, processing and Quadcopter actuation. The proposed system use Mindwave mobile FP1 electrode sensor to map EEG brain activity in real-time to enable the microcontroller for accomplishing controlled flight. Arduino microcontroller take input from FP1 EEG electrode sensor and provide mapped control signal output to the Quadcopter Unmanned Ariel Vehicle for changing direction and speed of flight in the real-world situations. HC-05 Bluetooth module is used to establish communication and data transfer between Arduino microcontroller and Mindwave headset, nRF24L01 module was used to establish long distance RF communication between the receiver and transmitter module of Quadcopter Unmanned Ariel Vehicle. RF link has a long range of 100m and also compatible with Arduino microcontroller.

IV. IMPLEMENTATION

Fig. 6. Photos of the Drone built

In order to prove the concept, a quadrotor UAV (Fig. 6) was fabricated from scratch compatible with Matlab programming platform. The Matlab algorithm hosted on a ground platform was in constant duplex communication with the quadrotor UAV via RF link. The quadrotor UAV is pre-programmed for controlled flight by the use of four servo motors actuated by the input commands received via RF link. Brushless motors were preferred because of high torque per weight, reduced noise levels, more control, reliability, longer life, more power and less electromagnetic interface. The main propulsion system comprises of propellers, motors, Electronic Speed Controller (ESC) and batteries. According to the user brain attention levels the propeller and motor combination produce enough upward thrust to move the quadrotor UAV upwards. The final gross weight of the final prototype was 706 g, and so the thrust prerequisite from the four servo motors is double that of 706 g. An Arduino microcontroller based quadrotor UAV was built using Servo Motors and actuated by using brainwave signals from Mindwave mobile headset. Rotary actuation of the servomotors allowed for precise flight control and navigation. The flight system consists of the four motor position sensor for real time feedback of Quadcopter UAV. A relatively complex controller algorithm which was programmed onto the onboard Arduino microcontroller, enabled real-time neurofeedback.

The figure below (Fig. 7) shows the Quadcopter flight coordinate system. The proportional derivative (PD) controller generate adjustable thrust so that the rotors have four degrees of altitude control namely: yaw, roll, pitch, and hover.

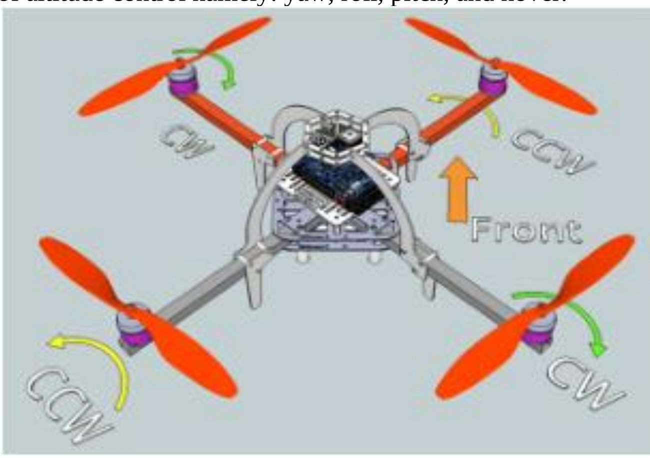

Fig. 7. Quadcopter UAV Coordinate system.

V. RESULT AND DISCUSSION

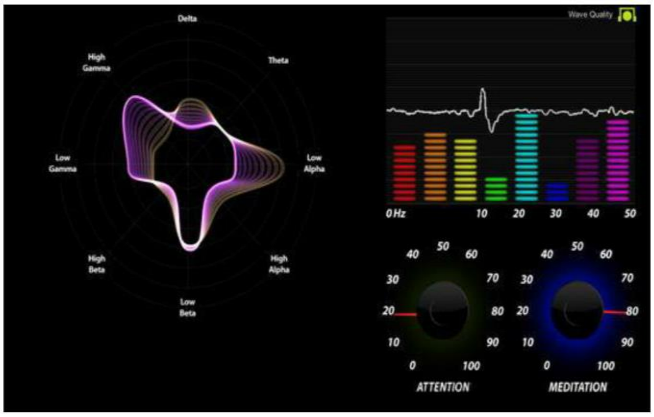

Fig. 8. EEG readings by Brainwave Visualizer

The graphical interface of the application displays the user's raw brainwave data of both concentration and meditation levels and indicate it from 0-100. The quadrotor Unmanned Ariel Vehicle flight pattern was controlled directly by mind.

Fig. 9. Server code & output

Initially, the values from FP1 EEG electrode sensor in Mindwave Mobile headset is displayed on the Arduino Integrated Development Environment serial monitor while interfacing with quadrotor UAV. According to the control parameters fixed in the Arduino IDE program, quadcopter flight pattern was controlled in real-time. The quadcopter was set to ascend and hover when higher frequency brainwaves of the acquired brain map is representing a dominant focused state. Similarly, quadcopter will descend and land when low frequency calm thoughtful brainwaves state becomes the dominating components of brain map received from the Neuroheadset. The Brain computer interface Electroencephalography sensor data works at a rate of 98 Hz via the microcontroller with minimal time delay in real time. The Arduino Microcontroller is programmed with Arduino IDE to accommodate Matlab Programming platform to send additional commands to perform backward, forward and various rotational movements enabling real-time flight control. The whole experimental phase was completely monitored and captured for different brainwave reactions, emotions, and expressions.

The employed system is further reconfigurable by utilizing eye blink parameter for the control of robot in numerous directions. To sum up, the setup and the calibration of quadcopter is attained through real-time transmission of the control signal to different motors, effectively controlling their rotation speeds enabling controlled flight.

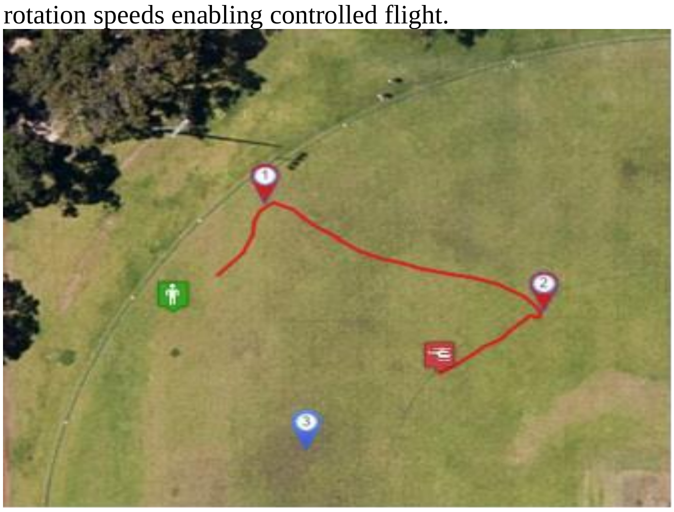

Fig. 10. Real-time testing of navigating waypoints.

Rigorous flight testing was done, and it was found to be greatly accurate and consistent. The testing was done in open fields for various safety reasons.

Table 1: AT Commands

AT command	Arguments[1]	Description
AT*REF	input	Takeoff/Landing/Emergency stop command
AT*PCMD	flag, roll, pitch, gaz, yaw	Move the drone
AT*PCMD_MAG	flag, roll, pitch, gaz, yaw, psi, psi accuracy	Move the drone (with Absolute Control support)
AT*FTRIM	-	Sets the reference for the horizontal plane (must be on ground)
AT*CONFIG	key, value	Configuration of the AR.Drone 2.0
AT*CONFIG_IDS	session, user, application ids	Identifiers for AT*CONFIG commands
AT*COMWDG	-	Reset the communication watchdog
AT*CALIB	device number	Ask the drone to calibrate the magnetometer (must be flying)

VI. CONCLUSION AND FUTURE WORK

In this paper, a brain controlled quadrotor Unmanned Ariel Vehicle was successfully developed and tested which utilize raw electroencephalography signals interfaced with Arduino Uno microcontroller via wireless connection for controlled flight. The developed Mind Controlled Ariel Vehicle is pioneering Brain Computer Interface technology to further provide assistance to people with different motor disabilities. It instigates further research in Mind Machine Interfaces with tremendous real-world application. With the present work complete, using larger motors is all that is required to maintain controlled autonomous flight in higher altitudes, this is now comparatively simple supposing the code would need no alteration.

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