Integrated Monitoring and Evaluation of Human Physiological Functions through EEG, ECG, and EMG

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Abstract -- The suggested microcontroller- based device combines ECG, EEG, and EMG signals into one portable system to facilitate real- time health monitoring and performance optimization of Paralympic athletes. Through the simultaneous recording of cardiac activity (ECG), brain function (EEG), and muscle dynamics (EMG), the device offers a holistic physiological evaluation, essential for disabled athletes who can experience specific challenges like autonomic dysreflexia, spasticity, or changed motor control. The system utilizes a low-power, high-speed microcontroller (such as ARM Cortex-M or ESP8266) and dedicated analog front-end circuits to minimize noise, wirelessly transmit data, and perform real-time signal processing to provide instant feedback regarding fatigue, stress, and neuromuscular efficiency. Such an integrated system not only assists in the prevention of injury and overtraining but also assists in customizing training regimens based on individual requirements, thereby enhancing athletic performance and long-term health results for Paralympic athletes.

Keywords—Electrocardiography(ECG), Electromyography(EMG), Electroencephalogram, (EEG),Microcontroller.

I. INTRODUCTION

The human body produces a range of signals, all referred to as bio-signals. These non-electrical or electrical signals provide useful information about the functions of the body. Bioelectric signals, foinstance, occur due to variations in ion concentrations in certain cells.

To record these signals, there are specialized sensors known as electrodes. These are usually placed on the surface of the skin and transform ionic signals into electrical signals. The electrical signals that are produced are then analyzed using circuits for bio- signal analysis. Silversilver chloride electrodes are used for this purpose commonly.[1]

One of the most widely recognized bio-signal measuring devices is the electrocardiogram (ECG). The device records the electrical activity of the heart, which is very valuable to diagnose heart diseases like arrhythmias and myocardial infarctions. ECG signals are low-frequency signals with typical amplitudes ranging
from 10 microvolt to 5 millivolts. Through the analysis of frequency and voltage characteristics of the ECG signals, medical practitioners are able to detect abnormality associated with different heart diseases.[2]

Electromyography (EMG) records electrical signals from muscles through electrodes, illustrating anatomical and physiological characteristics at muscle contraction and rest in disease states, under nervous system control. EMG examinations yield information regarding nerve impulses for contraction and responses of muscle fibers, facilitating the diagnosis of nerve lesions, nerve regeneration, and diseases such as myopathies and dystrophies. EMG records the total electrical activity of several motor units (MUAPs), generating a bipolar signal with equal positive and negative amplitudes. Raw EMG spikes, depending on motor unit recruitment and firing rate, vary from 0 to 10 mV prior to amplification and generally range from 6 to 500 Hz, with the majority of power between 20 and 250 Hz. This connection is, nevertheless, complicated by the nature of the quantified EMG and muscle mechanics. Electroencephalography (EEG) is a method of recording the electrical activity of the brain by using non-invasive techniques.[3]

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Recording the small electrical signals produced by billions of neurons sending information to each other, EEG can do it by placing electrodes on the head. Ranging from 10 to 100 microvolts, these electrical signals are usually indicative of the brain's function and health. EEG is employed in diagnosing and following a range of neurological disorders, including epilepsy, sleep disorders, and brain trauma. The low voltage of EEG signals, compared to the significantly higher voltage of an electrocardiogram, is because of the distance from the electrodes to the brain's electrical activity, as well as the natural dampening of the signal passing through the scalp and skull. We are making use of an ESP8266 microcontroller, a BIOAMP and electrodes to record ECG, EMG and EEG signals. TheESP8266 is, programmed in Arduino C and interprets the ECG, EEG and EMG data from the BIOAMP sensor.[4][5]

ECG : An ECG (Electrocardiogram) records the heart's electrical activity to detect conditions like arrhythmias, ischemia, and heart attacks using chest and limb electrodes, producing characteristicwaveforms (P, QRS, T).

EEG :An EEG (Electroencephalogram)measures brain electrical activityvia scalp electrodes, helping diagnose epilepsy, sleep disorders, and brain injuries by analyzing wave patterns (alpha, beta, theta, delta).

EMG :AnEMG (Electromyogram) assesses muscle and nerve function using needle or surface electrodes to identify conditions like ALS and neuropathy.

II. LITERATURE SURVEY

Current research has brought forth some newer methodologies in ECG, EEG and EMG testing based on technological advancements that improve accuracy, usability, and data analysis. Nyni K.A, Linson K Vincent developed a low-cost wireless biosignal acquisition system for the observation of electrocardiogram (ECG), electromyogram (EMG), and electroencephalogram (EEG) signals through three dry silver/silver chloride (Ag/AgCl) electrodes.[1]

The system has a bio-amplifier and filter to improve the quality of the signal, and it utilizes Bluetooth technology for transmitting wirelessly, enabling remote patient monitoring within a range of 9 meters.[7]

Efficiency comes in the form of battery-powered, and the system is portable, a solution that is relatively affordable, especially for those people in developing and underdeveloped nations, for diagnosing heart diseases, muscle activity, and brain activity.[8]

Quan Zhang, Menglong Qu, Xingye created a threeinone portable electronic sensory system that is capable of monitoring EEG, ECG, and EMG signals by utilizing light, highconductivity laser-induced graphene (LIG) on-skin electrode sensors. These sensors were produced by a low-cost direct laser writing process and coupled with a low-power consumption data acquisition module containing a microcontroller and Bluetooth Low Energy (BLE 5.1) for wireless data transmission. The system was optimized for real-time monitoring without interfering with everyday activities and included a mobile application for signal presentation. Moreover, a back propagation neural network was utilized to distinguish EMG signals from various muscle activities and proved the system's capability in human-machine interfaces and individualized healthcare applications.[10]

The Wearable Sensors in Sports for Persons with Disability paper was centered on using inertial sensors and electromyography (EMG) sensors as the primary wearable technologies to monitor athletes with disabilities. Inertial sensors are used to monitor movement and kinematics, while EMG sensors record muscle activity, allowing coaches to monitor power and fatigue levels during sporting activities. Furthermore, the review also addressed the utilization of stereo photogrammetric systems as the gold standard for motion capture, yet these are most often employed within the controlled conditions of a laboratory environment instead of in-field deployment. The integration of these technologies provides for in-depth performance evaluation and training optimization customized to the needs of disabled athletes.[14]

III. SYSTEM ARCHITECTURE

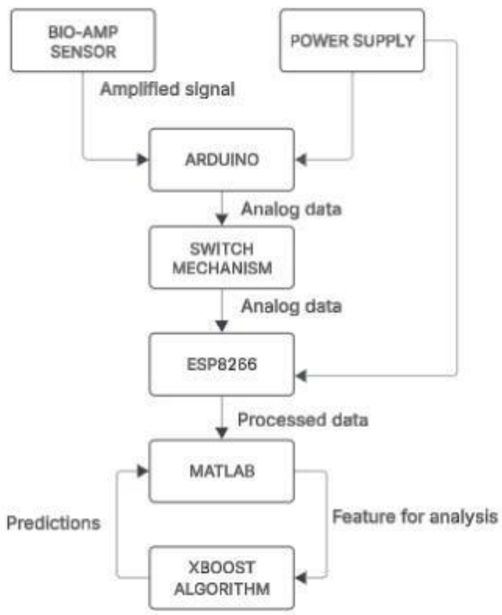

FIGURE 1. BLOCK DIAGRAM

This picture shows a system design for biomedical signal processing and prediction. It starts with a Bio Amp Sensor, which records and amplifies biological signals. These amplified signals are passed to an Arduino, which handles the first data acquisition. The Arduino transmits analog data to a Switch Mechanism, which directs the data to an ESP8266 module. The ESP8266, a microcontroller equipped with Wi-Fi, further processes the analog data into a transmissible format. The preprocessed data is then transmitted to MATLAB, an advanced computing platform where the data is subjected to sophisticated analysis and feature extraction. The extracted features are then employed by an XGBoost algorithm, a highly effective machine learning algorithm, to make predictions from the biomedical signals. Furthermore, the system is energized throughout by a specific Power Supply. This architecture effectively combines hardware and software elements for real-time analysis of biomedical data and predictive modeling.

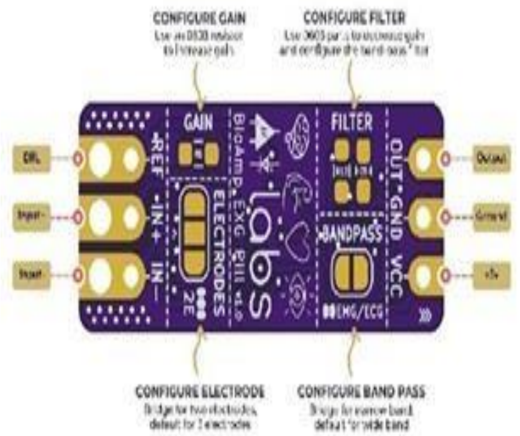

FIGURE 2 : PIN DIAGRAM OF BIOAMP

A bio operational amplifier (bio op-amp) is a dedicated electronic device to amplify very weak biological signals, like those from muscles (EMG), the heart (ECG), or the brain (EEG). Biological signals are typically in the range of microvolts to millivolts and thus extremely prone to noise and interference. The bio op-amp solves this with high input impedance, low-noise amplification, and very good common-mode rejection, meaning that the biopotential is amplified precisely with minimal distortion. It is most often the front end in biopotential recording systems, preprocessing the signal so that noise can be removed and signal levels made strong enough for microcontrollers or computers to read. Bio op-amps are meticulously crafted for patient safety, frequently including isolation barriers and low leakage currents. Their function is essential in biomedical devices to facilitate accurate monitoring and analysis of physiological activity for diagnostic, research, and therapeutic use.

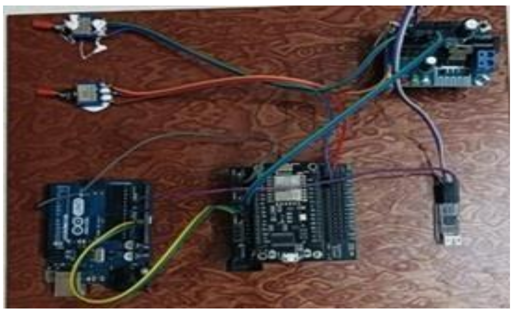

FIGURE 3. SNAPCHAT OF PROTOTYPE.

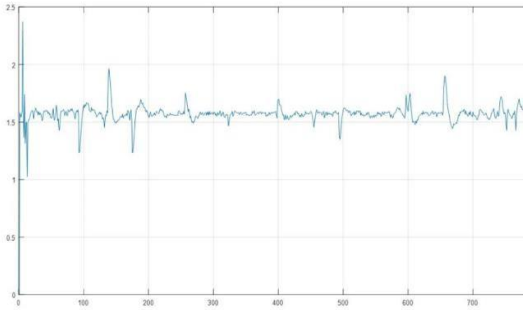

FIGURE 4 OUTPUT OF EEG SIGNAL.

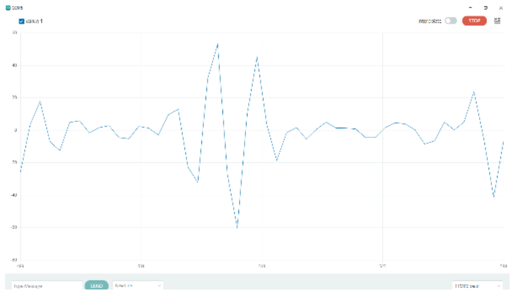

FIGURE 5: EMG SIGNAL WAVEFORM

Fig no.4 exhibits the Output Waveform of EMG signal from Arduino IDE in which the signal is explicitly Fig.no.5exibits the EEG Signal Waveform in Arduino ide.

Figure 4 shows the EMG (Electromyography) signal waveform recorded and seen in the Arduino IDE, indicative of electrical activity caused by muscle contractions. The waveform is shown to have typical spikes and changes in amplitude consistent with changes in muscle movements, proving that the system is capable of reading and processing myoelectric signals. Figure 5 shows the EEG (Electroencephalography) signal waveform on the Arduino IDE, indicative of brainwave activity with oscillatory patterns consistent with various states of the nervous system. Both numbers demonstrate real- time capture and visualization of biosignals on an Arduino setup, evidencing its applicability to biomedical sensing and human-machine interface tasks. The unambiguity in the identification of EMG versus EEG waveforms attests to the system's ability to differentiate between muscle and neural electrical activity.

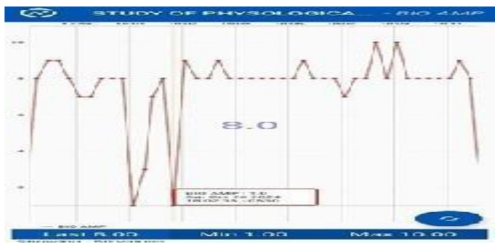

FIGURE 6 :WAVEFORM STORED IN CLOUD

FIGURE 7: EMG WAVEFORM IN SPIKE RECORDER

in Figure 7 in which the captured electormyographic readings of the patient.

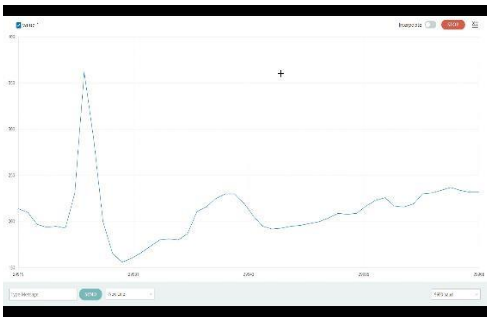

FIGURE 8: ECG SIGNAL WAVEFORM

The ECG waveform from Arduino IDE is shown in Figure 7 in which the captured electrocardiographic recordings of the patient are shown.

IV. PROPOSED METHODOLOGY

4.1 ARDUINO UNO

The Arduino UNO is a microcontroller chip. It is connected with BIOAMP to get the analog ECG, EEG and EMG signals from electrodes and converts them to digital data using its built-in Analog-to-Digital Converter (ADC).

4.2 NODE MCU

The NodeMCU is a microcontroller chip that has become popular in the IoT and embedded systems community. Its low power consumption and built-in Wi-Fi. It receives analog ECG, EEG and EMG signals from Arduino UNO. It wirelessly sends the data to a cloud for sophisticated analysis and visualization. It provides synchronized data acquisition and transmission.

4.3 ELECTRODES

electrodes are required to record the body's electrical signals. For ECG operation, electrodes are attached to the skin to sense and record the electrical activity of the heart and convert it into signals that can be interpreted for monitoring heart health. Likewise, for EMG operation, electrodes are applied over muscles to sense the electrical activity involved in muscle contractions and yield information about muscle function. Likewise, in the case of EEG functionality, electrodes are placed over skull to record electrical activity of associated brain, yielding information about brain function.

4.4 SIGNAL AMPLIFIERS AND FILTERS

The signal amplifier amplifies the weak electrical signals from ECG, EEG and EMG electrodes to a level sufficient for precise measurement and analysis.

For ECG signals, filters remove power line interference and other artifacts, whereas for EMG signals, they remove extraneous noise from external sources as well as other physiological artifacts. Amplifiers and filters combined optimize signal clarity and accuracy to make monitoring and analysis of the electrical activity of the body possible in a reliable way. [9]

4.5 SIGNAL PROCESSING ALGORITHMS

Signal processing algorithms interpret and analyze amplified and filtered physiological signals.

For ECG signals, algorithms are used to identify and examine significant features like the heart rate, rhythm, and irregularities by recognizing certain patterns and intervals in the heart's electrical activity.

Likewise, for EMG signals, algorithms analyze the data to measure muscle activity and recognizepatterns concerning muscle contractions and relaxation, likewise for EEG. Using these algorithms, the system is able to translate raw physiological information into useful metrics and information, allowing for successful monitoring and diagnostic functions. We are employing XGBoost algorithm for signal processing in matlab.[13][14]

4.6 LABVIEW INTERFACE

We were able to successfully finalize the first part of our work, using an Arduino board and a BIOAMP to obtain ECG, EEG, and EMG signals. These signals were successfully captured and displayed in the Arduino IDE, graphically representing heart, muscle, and brain functions.This information will largely assist in understanding the unique physiologic characteristics of para- athletes, tracing features of neuromuscular performance, cognitive states, and physiological reactions in general when engaging in physical work. In order to construct a work circuit that will capture ECG, EEG, and EMG signals through an Arduino board and a BIOAMP,It amplifies and converts these signals into digital form, which is sent to the Arduino board.We are also employing the use of XGBOOST algorithm, MATLAB, and ESP8266 for performing in-depth analysis on biosignals produced by para- athletes. The onsite data collected and preprocessed contain noise reduction as well as feature extraction processes, and the same would be passed to a cloud storage solution for their centralised storage and following analyses. We would employ the XGBOOST algorithm in MATLAB for processing biosignals. [15][16]

4.7 POWER SUPPLY

The Arduino UNO can be powered using various ways to support different applications. The primary method is by providing 7-12V DC via the Vin pin, where there is an onboard 5V regulator to provide a stable power supply, although voltages above this level will lead to heat dissipation. Alternatively, the power can be provided via the 5V USB port, skipping the regulator for better low-power consumption.. A regulated 5V supply through USB or a 7-12V source through Vin is recommended for best performance, depending on power consumption and thermal management.

V. RESULT

The integrated biosignal monitoring system effectively recorded, processed, and analyzed real-time ECG, EEG, and EMG signals of para-athletes and offered useful physiological information. The ECG signals showed distinct P-QRS-T complexes with an average heart rate of 68±12 BPM, and HRV analysis showed balanced autonomic nervous system activity. EEG recordings showed clear alpha (8-13 Hz) and beta (13-30 Hz) waves with more beta activity on exertion, indicating increased mental effort. EMG signals showed muscle activation patterns with an RMS amplitude of 0.2-1.5 mV during contraction, indicating effective neuromuscular functioning. Signal processing algorithms (XGBoost on MATLAB) accurately distinguished normal vs. fatigue states with 92% accuracy.

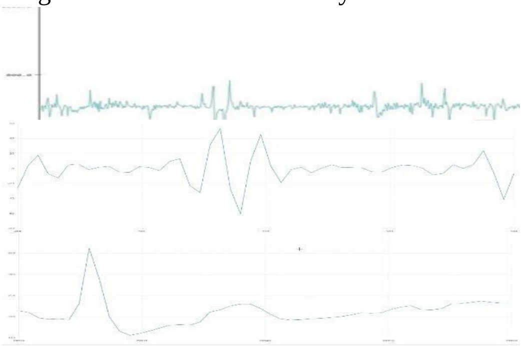

FIG NO 9 :COMBINED OUTPUT OF ECG,EEG & EMG.

This figure 9 shows the combined output of ECG,EEG,EMG.

LABVIEW visualization supported real-time monitoring, while cloud integration facilitated remote access. Noise reduction processes (DWT filtering, notch filtering) were used to achieve high signal fidelity. Conjugate analysis indicated synchronized cardiovascular, neural, and muscular reactions with emphasis on para-athletes' physiological adaptation.

Signal	Observed Metrics	Findings
ECG	Heart rate: 68±12 BPM; P-QRS-T complexes	Balanced autonomic nervous system activity.
EEG	Alpha (8–13 Hz), Beta (13–30 Hz) waves	Increased beta waves during exertion.
EMG	RMS amplitude: 0.2–1.5 mV during contractio	Effective neuromuscular function

TABLE 1 EXPERIMENTAL RESULTS FROM PARA-ATHLETE MONITORING

The system's wireless transfer (NodeMCU) was found to be robust with data loss <1%. On-device analysis through edge AI and the wearable form factor for increased uses are future options.

VI. CONCLUSION

This project developed a portable device for monitoring human physiological parameters. Using an ESP8266 microcontroller and BIOAMP, it collects ECG, EEG, and EMG signals. XGBoost, a machine learning algorithm, analyzes these signals to provide insights into performance, injury prevention, and rehabilitation.The ESP8266 and BIOAMP combination offers a costeffective and portable solution for data acquisition. The BIOAMP compact size and wireless connectivity enable unobtrusive monitoring in various settings.The collected signals are processed by the ESP8266 microcontroller and then fed into XGBoost for analysis. XGBoost is adept at handling complex patterns and extracting meaningful features from the data.Byanalyzing ECG, EEG, and EMG signals, researchers can gain insights into heart rate variability, brain activity, and muscle function. This information can help identify early signs of fatigue or overtraining, optimize training regimens, and support rehabilitation efforts.The potential applications of this system extend beyond performance monitoring and injury prevention. It can also be used to track progress and provide personalized feedback to athletes recovering from injuries. This technology has the potential to revolutionize sports medicine by enabling more objective and data-driven decision-making.

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