Real-time Control of a Mobile Robot using Electrooculogram based Eye Tracking System

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***Abstract*—This paper describes a system architecture starting from the sensor design to the algorithm implementation to control a mobile robot using electrooculogram based eye tracking system. Various methods exist to control external devices with muscle movements, Electrocardiogram (ECG) or Electroencephalogram (EEG). The proposed system works with Electrooculogram (EOG) by sensing eye movement and is found beneficial for paraplegic/quadriplegic patients who can get assistance from a 2-DOF robotic arm to perform their daily tasks. This low cost design can be easily implemented on an embedded robotic platform for implementation in various domains.**

Keywords—embedded robot; EOG; EEG; tracking control

I. INTRODUCTION

Robotics is now used commonly in healthcare and rehabilitation engineering. In the past, various other applications involve Ariel, ground as well as marine robots with applications both in industry, domestic and military [1-3]. Wireless control for real time application requires special considerations on the network part [4-7]. Real-time control of robot using brain or muscle signals is meant to deploy hands free intelligent control of a robot for gaming, healthcare and technological use [8]. Efficient alternative controlling abilities are important for motor-disabled persons, elderly people and patients suffering from several types of Sclerosis or other diseases that affect hand and facial muscles [9-12]. Manipulation and Interfacing of brain electrical signal with computer and to obtain useful data to be able to command, control or communicate with external world [13]. It is basically a communication system between brain and electronic device [14]. Commands are ordered from the brain signals same like we give commands to our hand. Brain signals are called Electroencephalography (EEG).

Electroencephalogram (EEG) and/or Electrooculography (EOG) has numerous applications e.g. as an input/feedback gaming device to strictly sophisticated medical applications. EEG controlled game provides joy and entertainment as well as new source of controlling an application. In human-machine interaction, EOG signals generated by the human eye movements have been recently used by several researchers. Keeping in view the acquisition challenges and real time control based on EEG alone, various multimodal techniques have been used to facilitate the handicapped patients for rehabilitation. This paper is organized as follows: Section 2 describes the system architecture, Section 3 details about the biomedical sensing followed by Section 4 which describes the algorithm and implementation results while Section 5 concludes the paper.

II. SYSTEM ARCHITECTURE

The real time control of a robotic ground vehicle by using bio-signals e.g. EEG signals or EOG tracking is a challenging area. Data is collected from the sensor electrode. The electrode is placed on the scalp according to 10-20 system. It is also possible to use Emotiv headset for the same purpose. As a next step, Interfacing and signal manipulation in digital domain is performed using software tools in the computer. Pre-processing (DFT, PSD, filtration of a signal), feature extraction, classification etc. The extracted filtered digital signal can be used as a command to control an electronic device.

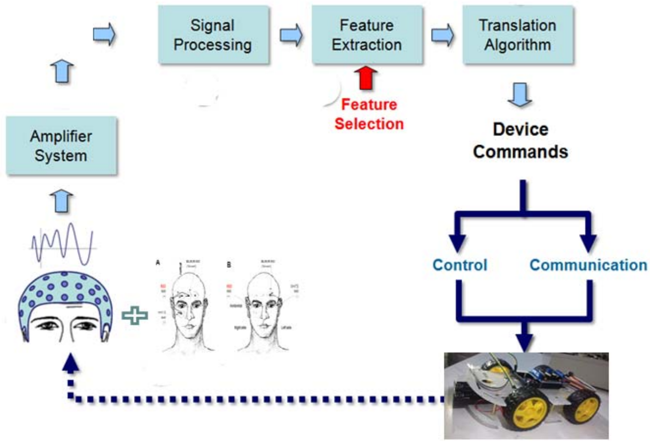

Fig. 1. Block diagram of EEG/EOG based control architecture

Hybrid techniques involve the brain EEG signals and electric potential measurement to detect eye movement. There are two signal acquisition methods namely invasive and non-invasive. In invasive techniques, the electrodes are

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planted inside the brain tissue. Whereas, in a non-invasive scheme, the electrodes are placed on the scalp of the subject and signals are measured from the surface of brain [15]. Invasive techniques give better results and more accurate information, but rarely used because they require expensive surgery and have huge risk as we have to deal with brain tissue.

III. BIO POTENTIAL SENSING

Several signals from the human body can be utilized in robotics and biomedical sensing, medical diagnosis and external actuation applications as shown in Table 1. These signals are low-powered, low frequency and low-amplitude in nature which makes them a challenge for real time acquisition.

A. EEG Sensors

Emotiv EPOC sensor is used as a platform for research applications and high-resolution, multi-channel and portable system [12]. EEG, quality electrodes, FFT, real-time wireless data display and great battery timing are its features. Similarly, BIOPAC includes data acquisition hardware with amplifiers to record electrical signals from the heart, muscle, nerve, brain, eye, respiratory system, and tissue preparations. A data acquisition system receives the signals from electrodes and transducers. Electric signals are in microvolts (1/1,000,000 volts) with extremely small range of amplitudes; so that the hardware can cripple these electrical signals, filters or blocks unwanted electrical noise signals and read them on the computer. Electro-Cortico-Gram (ECoG) measures the neuro signal activity on the cortical surface of the brain.

TABLE I. BIO-POTENTIAL SIGNAL MEASUREMENTS

Sr. no	**Types of Signals**			
	Classification	***Position***	***Amplitude***	***Frequency***
1	Electrocorticogram (ECoG)	Cortex	5 mV	200 Hz
2	Electroencephalogram (EEG)	Scalp	300µV	100 Hz
3	Electromyograms (EMG)	Muscle	10 µVpp-1mVpp	10Hz-1kHz
4	Electrooculograms (EOG)	Skull near eyes	100µVpp -1mVpp	10Hz-1kHz
5	Electrocardiograms (ECG)	Chest	10µVpp-10mVpp	0.1Hz-100Hz

In this experiment, EEG signal collected from the brain which has information of brain activities. It is our job to find the desired information for specific type of activities. Motor cortex is responsible for the signal of our motor movements. In the present research we used both sensors for data acquisition. The Emotiv data acquisition is shown in Fig. 2.

Fig. 2. Data Acquisition through Emotiv Sensor

B. EOG Sensor

Electrooculography is a technique to measure electrooculogram, it is basically measuring and recording of the corneo-ratinal standing potential, the difference which exist across the cornea (positively charged) and retina (negatively charged) of human eye [16]. We observed this potential difference when we move our eyes in different directions. It is logical to consider that wherever muscular activity is involved, there'll be a corresponding potential produced by the biological phenomenon. Actually, the muscular movement activates and deactivates the ions inside the skin, and then the propagation of these ions results out in the form of current. For measuring the EOG, we placed electrodes around the eyes. For recording of vertical movements, we placed electrodes on the top and below of our eye and for horizontal movement recording, we placed electrodes on top and bottom of human eye. The reference electrode is however placed on the forehead [17].

C. EMG Sensors

Electromyogram (EMG) is another bio-potential signal of interest. In the modern world of technological era, controlling a robot using EMG signals is getting popular in many applications. From the last few years, due to the rapid growth of robotic systems, it seems that the world is transforming towards automation and increased use of robotics; therefore, a safe and secure control of a robot is pivotal [18]. A number of many more controlling methodologies are in the implementation stages for robots and all these capabilities are vital for handicapped/disabled persons, patients suffering from sclerosis and other muscular diseases, elderly people and also for the entertainment and amusement purposes.

Human eye tracking system has been used with effective success rate in human computer interfaces to take command of a robotic operation. An eye-tracking system is an approach which enables us to measure the activity of our eyes and an eye tracker device is using eye movement and position measurement to achieve this. Eye-tracking demonstrates the gaze of the subject. In a broader sense, eye-movement can be recorded by three different techniques, these are:

a. Eye attached tracking with magnetic coils or special contact lenses

b. Optical tracking using video processing

c. Electric potential measurement i.e. EOG (Electrooculography)

Each of the above mentioned techniques have their own specifications, advantages and shortcomings. For example, in the eye attached tracking, special contact lenses or magnetic field sensors are attached firmly to the eye for recordings which enables us to take data from the horizontal, vertical and torsion directions. This method is not preferred globally because it can induce inaccurate measurements.

Optical tracking using video processing and electric potential measurement i.e. EOG measurements are most widely used techniques for more accurate recordings of eye movement measurements. In an optical tracking system, one should use a good quality camera and the rest of the accuracy depends on the video processing. Though, EOG is quite a good approach for collecting data and interpreting in real time as compared to image processing which is rather time consuming and its results are not of the required quality [19]. So, for highly accurate readings and speed, EOG based electric potential measurements are appropriate.

Fig. 3. Data Acquisition through BIOPAC

IV. ELECTROOCULOGRAM BASED TRACKING SYSTEM

Electrooculography is a technique to measure electrooculogram, it is basically measuring and recording of the corneo-ratinal standing potential, the difference which exist across the cornea (positively charged) and retina (negatively charged) of human eye [16]. We observed that this potential difference is significant when we move our eyes in different directions. It is a proven fact that wherever muscular activity is involved, a respective bio-potential is produced as in actual, the muscular movement activates/deactivates ions inside the skin, and then the propagation of these ions results out in the form of current. For measurement of EOG, we placed the electrodes around the eyes. For recording of vertical movement, the electrodes are placed on top and bottom of the subject's eye. The reference electrode which plays a key role is placed on the forehead as shown in Fig. 3 [17].

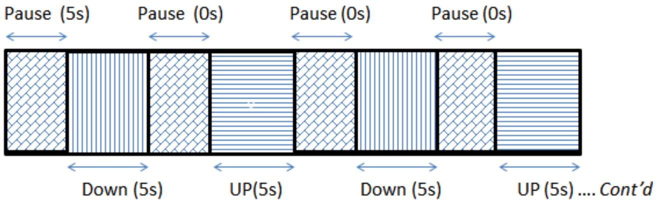

Fig. 4. DAQ protocol

A. Data Acquisition from EOG sensor

This protocol has been observed during EOG signals acquisition through purpose built sensor. More elaborating protocol diagram is shown in Fig. 4. Following this protocol, actual signal is obtained when eye movement takes place because we get a difference in potential when there is some muscle activity due to eye movement. This change in magnitude is proportional to the direction of eye movement i.e. UP/DOWN movement of the eye.

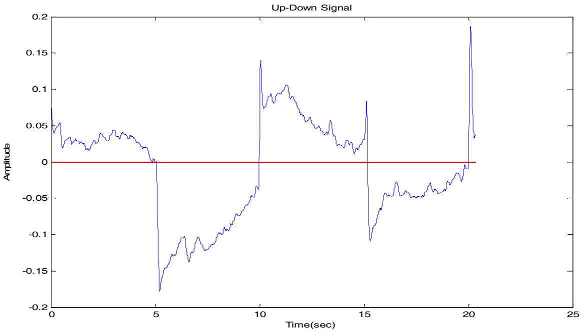

Fig. 5. EOG data acquisition (sample)

In Fig. 5, the data samples are plotted with the mean value of the signal as close to zero. It shows a sample of 20 sec data following the protocol with 5 sec initial pause and then 5 sec down and 5 sec UP as mentioned previously.

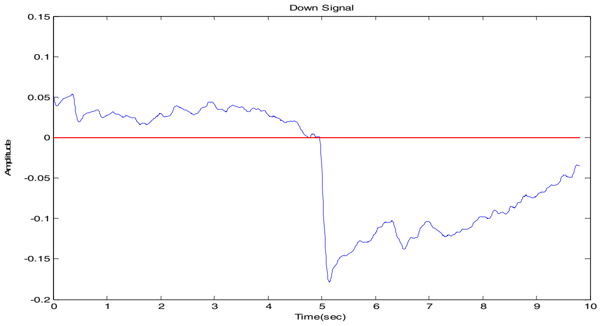

Fig. 6. Segmented data for DOWN movement (5-10s)

We segmented the data in UP and DOWN movements as shown in Fig. 6 and 7. This transition is found helpful while designing the control logic for mobile robot.

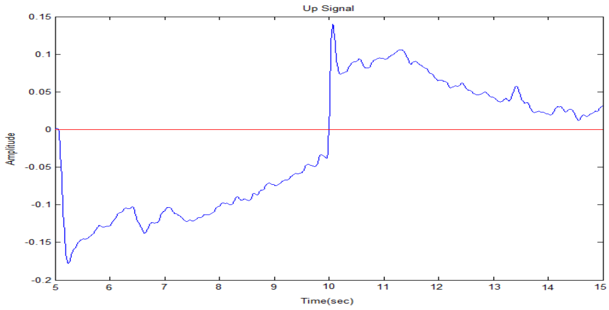

Fig. 7. Segmented data for UP movement (10-15s)

As shown in Fig. 7, the segmented part of 20 sec data having the UP movement data from 5-15 sec with transition at approximately 10 sec.

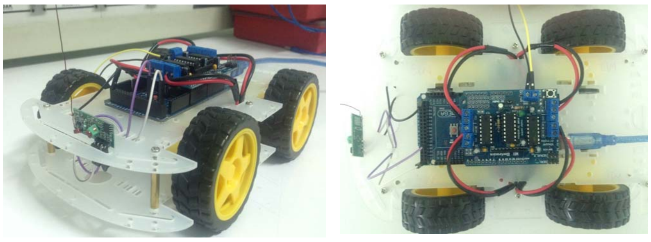

Fig. 8. Interfacing of Motors Shield with Microcontroller and Motors

B. *Offline Signal Processing*

Starting with the offline signal processing using Matlab, the EOG signal is analyzed and passed through a 70Hz low pass filter to remove high frequency noises. The signal's power spectrum density (PSD) is also plotted as it depicts the power of a signal at each frequency as shown in Fig. 9.

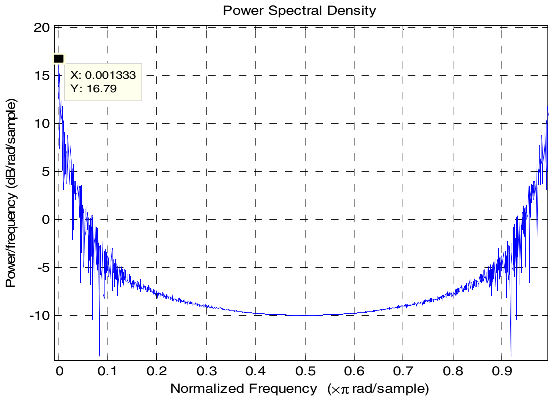

Fig. 9. Power spectral density plot of the EOG signal

C. *Classification of Signals*

A set of signals representing the state of an electrical, mechanical or biological phenomenon can be classified on the basis of the parameters like nature of the dependent and independent variables, number of independent variables, based on energy and power and on causality etc. The signals are classified as energy signals, power signals, casual and non-casual, random, periodic and aperiodic, analogue and digital, and most common as continuous and discrete time signals.

EOG signals classification process permits us to differentiate between the intended UP/DOWN movement. So, when the data acquisition is done, filtering is performed followed by the feature extraction, then the classification process decides about which part of our signal should use UP and DOWN movement respectively. Various supervised learning algorithms are preferred for such classification. Examples include Neuro-Fuzzy, Echo-state Networks, SVM etc. which are trained with offline training data and a binary threshold is set i.e., zeroes for down signal and ones for UP signal, then we test the SVM which initially gives a 68% true positive and further work can also result in better efficiency. Moreover, different classifiers can also be utilized for this purpose. In order to simplify the classifier, we have only used thresholding to decide about the UP/DOWN movement for real time implementation.

V. HARDWARE IMPLEMENTATION

The overall hardware is divided into two parts. First part includes collection of electric potential of the user's body through EOG sensor as shown in Fig. 10. The sensor provides data to microcontroller which further classifies this signal through vector based detection and transmits the result to the receiver side. Second part includes the robotic car containing four dc gear motors connected with L293D H-bridge module which is further connected to microcontroller. The receiver takes data from the transmitter and provides information to the microcontroller to calculate the motor's angular speed commands.

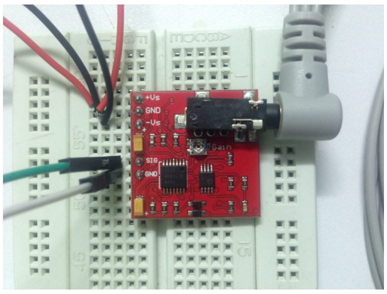

Fig. 10. EOG sensor V3

A. *Robotic Car*

For implementation of our work, the forward/backward motion of the four- wheel drive robotic car is targeted. This particular setup comprises of four D.C gear motors in contact with four wheels, Microcontroller (Arduino mega), a motor shielding module (L293D), a 9-volt battery and a set of RF transmitter and receiver as shown in Fig. 8.

B. *Interfacing of Motors Shield with Microcontroller and Motors*

L293D is a motor driver IC that drives DC motor in both directions. L293D module IC has 16 pins that can control a pair of D.C motors in the same direction. It works on the basic concept of the H-Bridge circuit that allows the voltage to flow in both directions. It is imperative to know that the voltage level must always change direction to turn the motors clockwise or counterclockwise for forward/backward direction respectively, hence, the H-bridge IC is capable of driving the D.C motors.

In a single L293D chip, there are two h-Bridge circuits in IC-package, which can independently rotate the two D.C motor. Due to its size, it is widely used in robotic application for controlling D.C motors. Four D.C gear motors are connected with motor shielding module (L293D) through the wires from motors into the ports of motor shielding module, the ports specifies as M1 for motor 1, M2 motor 2, M3 for motor 3 and M4 for motor 4 on the motor shielding module. Then, this whole assembly of motor shielding module is exactly compatible to Arduino mega. The pins of the motor shielding module are connected over Arduino mega. The four D.C gear motors are connected with motor shielding module (L293D) through the wires from motors into the ports of motor shielding module, the ports specified as M1, M2, M3 and M4 for the four motors on the motor shielding module. Then, this whole assembly of motor shielding module is exactly compatible to Arduino MEGA. So, the pins of motor shielding module are connected to Arduino MEGA [20].

C. *Data Collection, Processing and Communication*

It is imperative to collect data from the EOG sensor and apply commands to the mobile robot to control in forward and backward direction.

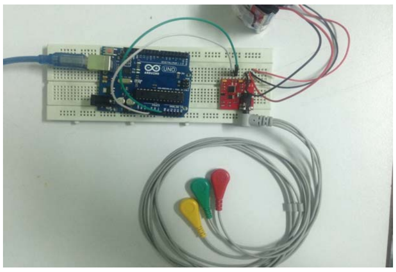

Fig. 11. Interfacing EOG Sensor with Arduino

D. *Sensor Configuration and Interfacing*

The sensors we are using in our project for the acquisition of EOG signal are “Three-lead differential Muscle/Electromyography sensor”. The interfacing of our sensors is explained below.

a) Connection with batteries

The +Vs pin on our sensor is connected to the positive terminal of 1st 9V battery, then, the sensor’s –Vs is connected with the 2nd 9V battery. The current junction point of our batteries is joined to the GND pin of our sensor.

b) Connection of Electrodes

The sensor box contains the signal interfacing and conditioning circuitry with 3 electrodes namely; red, blue and black cap. We connected the red cap electrode at the upper side of our eye, the blue cap electrode on lower end of our eye and the blue cap electrode which is used as a reference electrode on non-muscular and a bony part of our body nearby other two electrodes.

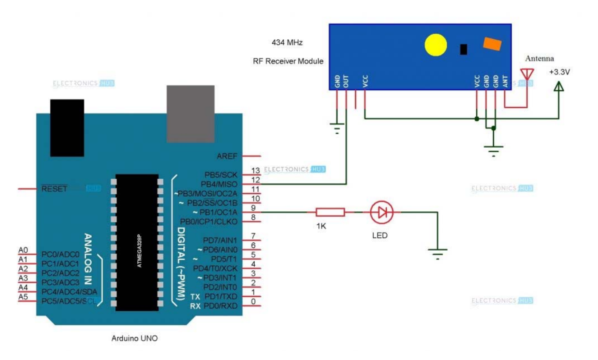

Fig. 12. Interfacing of Receiver with Microcontroller

c) Connection of Arduino (UNO) Controller

We connect the SIG pin to our sensor with an analog pin on the Arduino (for example, A0) and then connect the sensor's GND pin with a GND pin on the Arduino.

d) Interfacing of Transmitter & receiver with Microcontroller

The mobile electronic robot is controlled using eye tracking by means of electric potential measurement system in which we transmit signals in the form of (0, 1), the circuit diagram consists of a transmitter and a receiver component and the circuit for the transmitter part of the project is shown in Fig. 12.

VI. CONCLUSION

In this paper, we presented a simple and low cost scheme to control the forward/backward motion of a ground robotic vehicle. Several interesting features and applications can emerge from this test-bench. In biomedical and assistive robotics domain, such systems are found useful in the case of steering the wheel chair of disabled persons for whom; it can not only improve their quality of life but also enable them to participate in various daily life activities without depending on a helper for assistance. Moreover, further research is undergoing in developing a hybrid EEG/EOG based low-cost robotic control for precise tracking of a robot which is further beneficial in steering a food tray or a glass full of water to serve a paraplegic/quadriplegic patient.

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