Bi-Wheel Rescue Robot with sEMG Powered Robotic Gripper Over IOT Framework in Emergency and Rescue Operations

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Abstract: In this paper, we will deliberate two different techniques of maneuvering a bi-wheel rescue robot with robotic gripper (BRRRG) to precisely mandate the positioning of the robot using sEMG and android mobile application over the IoT framework. The Electromyogram of a subject is captured non-invasively, amplified, rectified, filtered and quantified to precisely control the robotic gripper based on set prehensile patterns. The signals of interest are acquired from two different muscles of the upper forearm namely Flexor Carpi Radialis and Flexor Carpi Ulnaris. Android based mobile application is designed to appropriately position the chassis of the robot from anywhere in the world. It is observed that with set prehensile patterns every subject's muscle contraction varies and hence the study presents the variation in threshold voltage for each test subject based on the gender, age and muscle buildup. With the grip offset of 0.39% and accuracy of 93-95%, its application in the field of emergency rescue can be further explored. The proposed system is designed such that the threshold voltage can be easily programmed and the uniformity with which a subject can control the robotic grip is studied.

sEMG- Surface Electromyography, IOT – Internet of things, WiFi - Wireless Fidelity, Robotic Gripper, Forearm muscles

I. INTRODUCTION

Electromyography (EMG) is a technique for evaluating and recording the action potentials generated at the muscles when these cells are electrically or neurologically activated. Exploitation of EMG for clinical interventions and medical instrumentation is of interest to many researchers. But detection and processing of the raw data to utilize it to full potential is a work under progress.

Panagiotis K. Artemiadis et.al trained a mathematical model to decode upper limb motion from EMG recordings, using a dimensionality-reduction technique [1]. The frequency and intensity of Motor Unit Action Potentials in EMG data provide insightful information about the characteristics of the signal to explore biomedical applications or hardware implementations incorporating the processed data. Few such applications in medical instrumentation are EMG based human-machine interface, upper limb prosthesis, gait analysis and applications in sports medicine. The biologically-inspired parallel actuation system proposed by Dr. Anthony L. Crawford et.al is based on the behavior/strength space of the Flexor Digitorum Profundus (FDP) and the Flexor Digitorum Superficialis (FDS) muscle [2]. The equation below represents a simple model of the obtained EMG signal:

$$Y(n)=g(r)p(n-r)+w(n)$$

where $y(n)$, modeled EMG signal, $p(n)$, point processed, represents the firing impulse, $g(r)$, represents the MUAP, $w(n)$, zero mean addictive white Gaussian noise and N is the number of motor unit firings [3].

The Prosthetic Hand Control Interface using ESP8266 [4] illustrates an IoT/Wi-fi based hand prosthesis that permits the amputees to choose a hand gesture one wishes to perform using an Android mobile application. The system allows the inclusion of various grips without any restrictions giving the user higher degree of freedom.

This paper describes a study taking the system [4] one step further by transmitting the sEMG data over the internet to remotely control the grip of a robotic gripper to perform lifesaving actions like emergency rescue and robotic surgery.

A webpage based remote controlled bot with video streaming for the safety and security of the elderly demonstrates a system that can be accessed over the internet [5]. However, evidently it also puts forth a challenge in the form of the volatility of webpages and their access speed. Hence the proposed work designates the usage of a mobile application to control the robot especially in the case of an emergency and offline access.

This work deliberates two operational techniques utilized to maneuver a Bi-Wheel Rescue Robot with Robotic Gripper (BRRRG); one to precisely position the robotic gripper using live Surface electromyography (sEMG) through IoT while another to drive the entire framework via the Wi-fi based android application. sEMG is a non-invasive technique that captures the action potentials transmitted through the action site to the surface of the skin during muscle activation.

As robots come closer to humans, an efficient human-robot-control interface is an utmost necessity. A mathematical model is trained to decode upper limb motion from EMG recordings and converted to machine known language. This paper presents the non-invasive method of measuring electromyogram from the Flexor Carpi Radialis (FCR) and Flexor Carpi Ulnaris (FCU) muscles [6] and digitization of the signal to control a subsystem.

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The robotic gripper subsystem of BRRRG incorporates dc-motors for actuation, and sEMG sensors to control the grip position. The biosignal acquisition circuit is designed to be compact, inexpensive, and easy to attach to multiple users.

II. SYSTEM DESCRIPTION

Block diagram

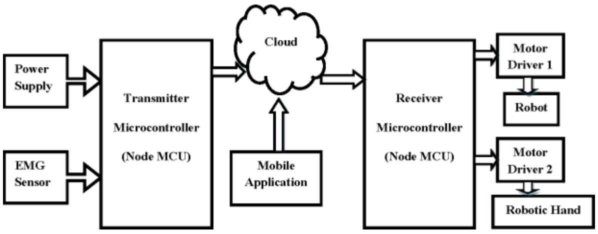

Fig 1: Block Diagram of the Bi-Wheel Rescue Robot with sEMG Controlled Robotic Gripper over IoT Framework

The proposed system can be classified into two main subsystems (a.) BRRRG, a Bio-Electro-Mechanical structure in the form of a robot capable of emergency rescue (b.) IoT framework to integrate and transceive the data for proper positioning of BRRRG

A. Hardware Development

The chassis of the robot is stabilized on a two wheel axis with a metallic spherical caster wheel in the front for smoother kinematics. Primarily the input to position the terminal device, in this case a robotic gripper mounted on the frontal side of the chassis, is captured from the surface electrodes in the form of a subject's EMG. The EMG readings are recorded, filtered, rectified and amplified using the signal acquisition and conditioning circuitry. The entire setup can be hooked onto a workstation for the real-time analysis of data with an exclusively static power source of +Vs and –Vs for the bio-signal acquisition system. A single channel EMG with 3 surface electrodes is used to capture the action potentials generated between a unique point of interest each on FCR and FCU. The data points (a1, a2, a3…) of interest are then fed to a microcontroller enabled with an inbuilt Wi-Fi module which in turn regulate the movement of the robotic gripper remotely. The current location and the situation around BRRRG is monitored through live video streaming via an inbuilt Wi-Fi enabled camera.

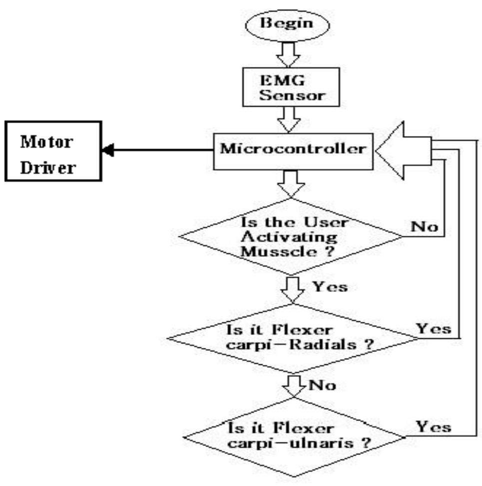

Fig 2: Flow chart of the Robotic Gripper Module

Once powered the EMG sensor continuously captures and sends the crude analog information which is refined by the intermediary circuitry before reaching the microcontroller. Microcontroller then converts the incoming analog data from FCR and FCU to the digital form and scales the muscle action potential to volts. Subsequently it compares the received data with the data points (a1, a2, a3…) and sends the appropriate signals to the motor driver via cloud to precisely control the grip of the robotic gripper. The entire system is powered by a standalone12V rechargeable battery locked securely for remote operations.

B. IoT Framework and Mobile Application

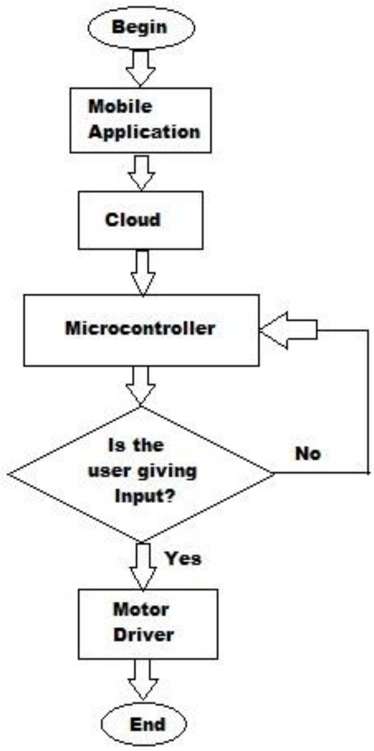

Fig3: Flow chart of the cloud based remote control of the Robot

To enable the remote access of the system a closed loop network is developed that comprises IoT transceiver with cloud as a communication medium and an easy to operate mobile user interface is developed on Android platform that provides a 360 degree view of the area to precisely position the robot at the chosen location. The microcontroller acting as the transmitter converts various grip positions of the subject to data points (a1, a2, a3…) for comparison with the threshold and transmits the information to the cloud. The receiver (microcontroller) mounted on BRRRG collects the information from the cloud and drives the robotic gripper to perform multiple tasks. The robot itself is engaged by the Android mobile application with a simple GUI controlled by the user to move in different directions. It also enables the user to conveniently select the speed of motion of the robot mapped Low, Medium and High on the home screen as shown below.

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S.No.	Speed Mapping	RPM	Duty Cycle
1.	Low	10-30	10%-30%
2.	Medium	31-60	31%-60%
3.	High	61-100	>60%

Table1: Speed selection of the Robot

Each of the icons for directions specified in the application corresponds to a set value in the cloud that is received by the Wi-Fi enabled receiver (microcontroller) which consequently drives the motors to maneuver the robot. These numbers indicate different movements as shown below. In addition the application is enabled with screen space to provide the real time first-hand view of the robot's vicinity to the user.

S.No.	Icon Representation	Cloud Value	Robot Direction
1.	⇧	1	Moves Forward
2.	⇨	3	Moves Rightward
3.	⇦	4	Moves Leftward
4.	⇩	2	Moves Backward

Table 2: Representation of cloud values for multi-directional motion

III. METHODOLOGY

EMG measurement approach

A single channel surface EMG (Bipolar) is utilized to design the system. The subjects' right arm is considered for this study and skin is prepared by cleaning the area of interest (AoI) with alcohol. Point A (A) is designated 2.5 inches below the elbow joint and 1.5 inches inwards from the arm's curvature on FCR. Point B (B) is located on the same horizontal axis adjacent to Point A on FCU. Region surrounding Point A and Point B is considered the AoI. Surface electrodes are placed on A and B with the third electrode acting as a reference placed at Point C (located in the posterior shown with a dotted line for visual representation), bony area located on the elbow.

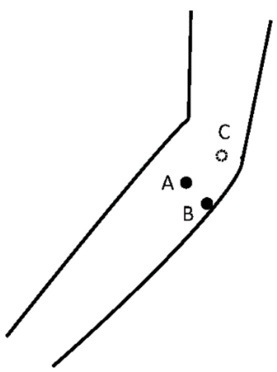

Fig4: Illustration of sEMG placement on a given subject

Hand motions are voluntary in nature and produced by the stimulus generated in the motor cortex region of the brain translated to the neuromuscular junctions via the spinal cord [7]. The prehensile patterns considered for this study are generated from the coordinated actions of intrinsic muscles, which control the hand posture and hand position, and extrinsic muscles, which control hand flexion and extension. The amplitude and frequency of the EMG activity (Motor Evoked Potential, MEP) captured at the surface of the hand muscles is proportional to the intensity of stimulus (S) generated in the motor cortex region.

$$\mathbf{MEP} \propto \mathbf{S}$$

IV. EXPERIMENTAL SETUP

The study captured single channel EMG data of 4 different subjects between the age group 18-21, including both male and female and having different muscle mass. The AoI lied between points A and B of the respective subjects. They are hereby referred to as subject 1, subject 2, subject 3 and subject 4.

Each subject is trained on generating 4 different voluntary limb movements (LM) to extract the MEP data of interest.

Step 1: LM 1: The anterior forearm is extended along with the palm and fingers and rotated 90 degrees inward and rested on the workbench

Step 2: LM 2: The posterior forearm is extended with hand facing the ground; hand is then flexed with the fingers pointing downwards

Step 3: LM 3: The posterior forearm is extended with hand facing the ground; hand is then extended with the fingers pointing skywards

Step 4: LM 4: The posterior forearm is extended with hand facing the ground and fingers forming a closed fist with tight grip

In each experiment the subject was asked to generate the LM's stepwise in a set of motions as presented below. The experiment was repeated in three cycles for each subject to check for the range and repeatability of the action potential and robustness of the setup. Muscle fatigue was taken into consideration during the experiment and hence the muscles are rested after each step in the cycle. The EMG of the subject is captured continuously during the experiment. Each LM lasted for 10 seconds with a gap of 1 second in lieu of muscle fatigue.

S.No.	Number of cycles	Step Number	Time of start(seconds)	Time of end(seconds)
1.	1	1	1	10
2.	1	2	11	21
3.	1	1	Rest	Rest
4.	1	3	23	33
5.	1	1	Rest	Rest
6.	1	4	35	45
7.	2	1	47	57
8.	2	2	59	69
9.	2	1	Rest	Rest

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10.	2	3	71	81
11.	2	1	Rest	Rest
12.	2	4	83	93
13.	3	1	95	105
14.	3	2	107	117
15.	3	1	Rest	Rest
16.	3	3	119	129
17.	3	1	Rest	Rest
18.	3	4	131	141

Table3: Experimental iterations to evaluate the repeatability and robustness of the system

The processed and amplified data is available to the microcontroller in the analog form; it is converted in terms of voltage to feed the robotic gripper to obtain multiple grips suitable to handle variety of objects. The obtained analog values of MEP are converted into voltage by using the formula mentioned below.

$$V = M * P$$

V = Sensory data in volts
M = Mapped sensor value
P = 0.00488, Step Value

Two different trails were laid to decipher the accuracy and precision of the robot's remote placement through the Android app. BRRRG was maneuvered through each of these trails over 5 iterations each to test for any data transmission lag that may offset the positioning of the robot.

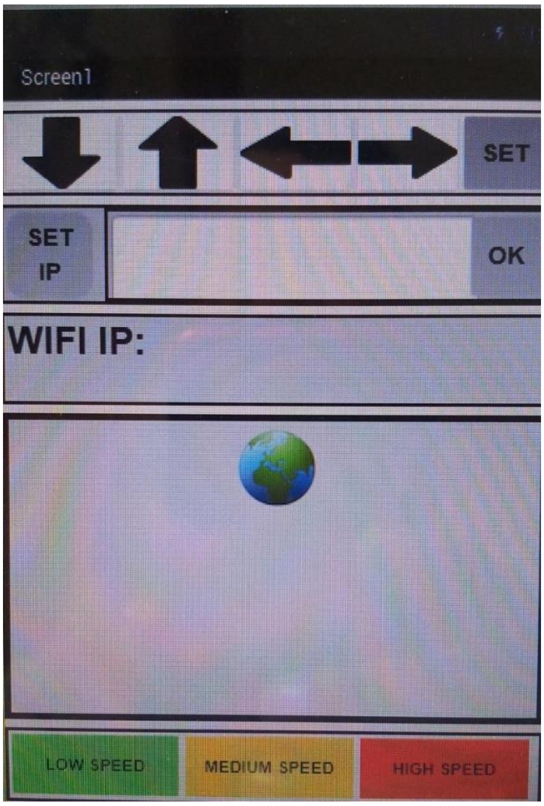

Fig5: Screenshot representation of the Android Mobile Application used for the study

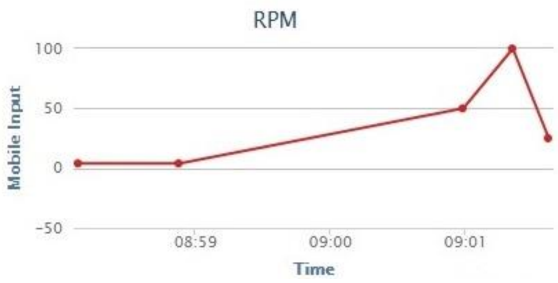

Fig6: Speed Input via IoT (Cloud)

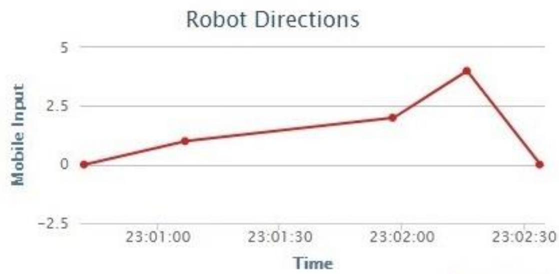

Fig7: Robot Directions via IoT (Cloud)

In Trail 1 the robot is moved from point A to point D with the distance between two consecutive points being 150cm. The mobile phone was connected to a data network whereas BRRRG was positioned in another room with the receiver connected to a local network. The real time positioning of the robot and the target points was monitored through live video streaming over the internet.

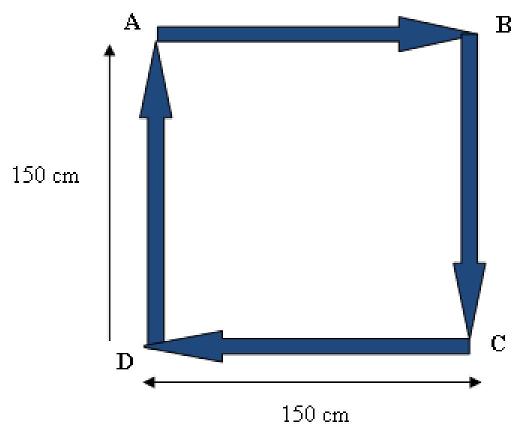

Fig8:Trail1-Pathway for Robot Movement

Step1: BRRRG starts at point A upon clicking the forward button, moves for 150cm till point B.

Step2: From point B upon clicking the right turn the robot moves 150cm to point C.

Step3: From point C upon clicking the right turn icon the robot moves 150cm to point D.

Step4: From point C upon clicking the right turn icon the robot moves 150cm to point A where it started.

In Trail 2 BRRRG is moved across 5 different points starting at the point of origin, O. The distance between any given point to the origin is 50cm. The robot trail is mapped in real time using the live video streaming on the mobile application.

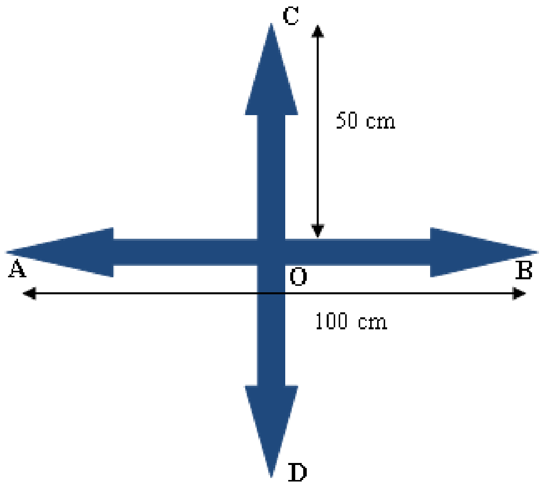

Fig9: Trail2-Pathway for Robot Movement

Step1: BRRG starts at point O, upon clicking forward button the robot moves 50cm forward till point A.

Step2: From point A upon clicking the reverse button the robot moves backward till the click is released at point B after 100cm

Step3: Then it is moved halfway forward to point O, thereby clicking the right button to move 50cm right to point C

Step4: The robot is then maneuvered in reverse to point D

Step5: From point D the robot is moved back to point A via the origin by clicking the left button

V. RESULT ANALYSIS

The MEP data of interest of four different subjects captured by sEMG sensors from forming various patterns is analyzed. The table below correlates various limb movements with the mapped sensor value obtained from the microcontroller on the transmitter section. The value M is then converted to voltages V1, V2, V3 & V4 and sent to the cloud in the form of numbers from 5-8 respectively. The microcontroller on the receiver side captures the cloud value and performs the assigned gripper tasks like Stop, Grip1, Grip2 and Release. It is observed that the M value varied from subject to subject depending on the gender, muscle composition and sometimes the combination of two. Three cycles of stepwise iterations performed by a single user also had +/-4 offset of M. Hence the range of M is derived from the study of values obtained from 4 different subjects.

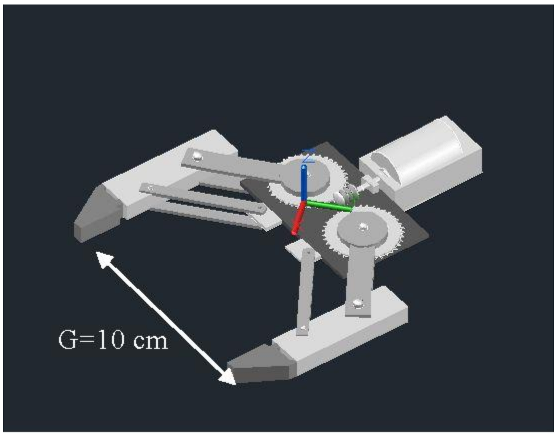

Fig10: Representation of Gripper width, G

Image was adopted only for visual representation Courtesy: Instructables

S.NO.	LIMB MOVEMENT	PICTORIAL REPRESENTATION	MAPPED SENSOR VALUE(M)	VOLTAGE OUTPUT	CLOUD VALUE	GRIPPER TASK	WIDTH OF THE GRIP
1.	LM1		0-50	V1	5	Stop	Anywhere between 1-10cm
2.	LM2		60-150	V2	6	Grip 1 – G/2	5 cm
3.	LM3		180-350	V3	7	Grip 2 – G/4	2.5 cm
4.	LM4		350-500	V4	8	Release	10 cm

Table 4: Correlation between Limb Movement-Amplified Sensory Value-Cloud Value-Robotic Grip

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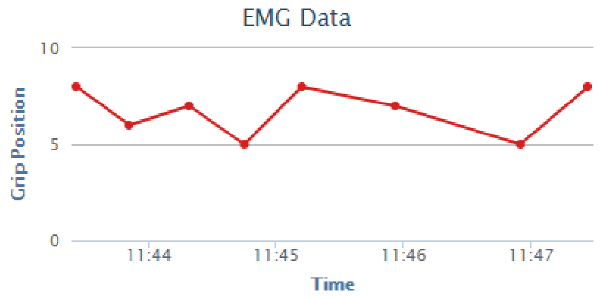

Fig11: Subject's Hand Grip Position via IoT (Cloud)

The mapped values generated from various limb movements of a single subject are plotted below against time. The gap between two readings can be seen as the limb was rested for a given period to avoid muscle fatigue.

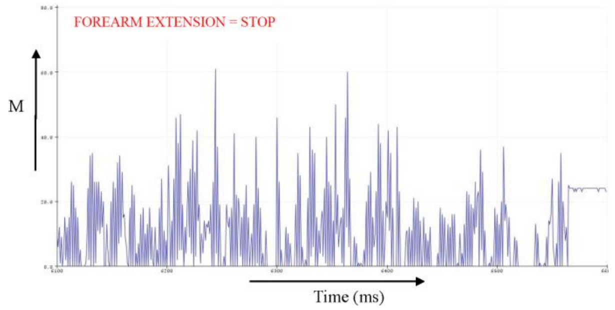

Fig12: Sensor Value Vs Time for LM1

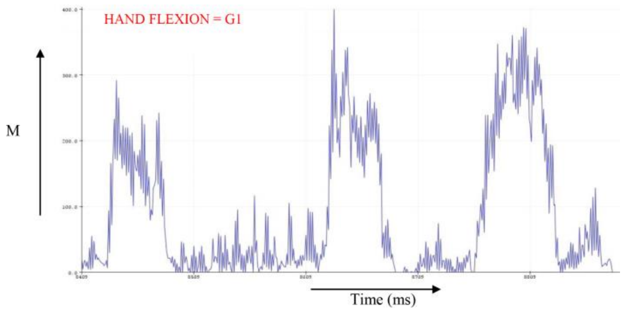

Fig13: Sensor Value Vs Time for LM2

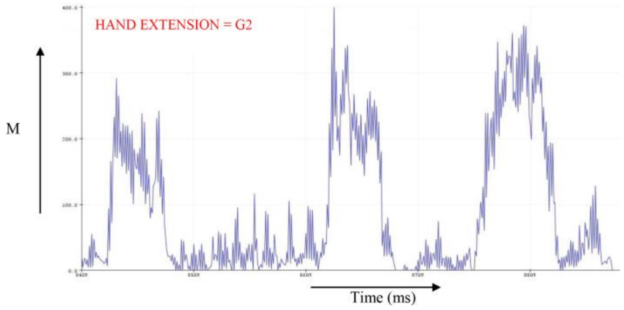

Fig14: Sensor Value Vs Time for LM3

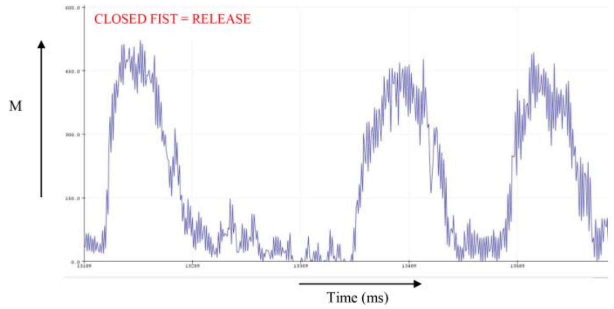

Fig15: Sensor Value Vs Time for LM4

The M value is converted to the voltage output of the microcontroller for four dissimilar LM's of four different subjects as mentioned in the table below.

S.No.	Subject	LM1, Forearm Extension (V1)	LM2, Hand Flexion (V2)	LM3, Hand Extension (V3)	LM4, Closed Fist (V4)
1	Subject 1	0.212 to 0.231	0.348 to 0.591	0.928 to 1.397	1. 943 to 2.291
2	Subject 2	0.198 to 0.225	0.301 to 0.548	0.881 to 1.031	1.712 to 2.010
3	Subject 3	0.219 to 0.234	0.591 to 0.697	1.465 to 1.629	2.238 to 2.306
4	Subject 4	0.221 to 0.239	0.646 to 0.709	1.572 to 1.677	2.331 to 2.388

Table 5: M values converted to V for various LM of different subjects

BRRRG is maneuvered across Trail1 and Trail 2 repeatedly for 5 times each. It has been observed that the user was able to navigate the robot across these pathways over the IoT framework with an offset of +/-5 cm with an accuracy of 93-95%. This can be due to the data transmission lag caused because of using a third party cloud.

CONCLUSION

With the offset of 0.39% of grip and accuracy of 93-95% of robot's position this technique of navigation and remote control over IoT can be explored for rescue operations and also can be used for various purposes like handling, welding and painting .They can also be used for household purposes to pick and drop objects. Its live video streaming facility is an added advantage that may also assist the user in real time assessment of emergencies and rescue operations. The concept can be extended to biomedical applications like robotic surgery and prosthetics [8].

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