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Design of Low Power and Miniature Wearable Electromyogram for Human-Machine Interface.

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ABSTRACT

Today, human-machine interface (HMI) has become a very common part of life, and more intuitive simpler gesture-based system, whether it's upper or lower limb had been constructed. The various Biopotential signal can be used as a gesture signal such as Electroencephalogram (EEG) and Electromyogram (EMG). In this paper, we're going to discuss on EMG as Human Machine Interface (HMI). Basically, EMG signals are processed to attain parameters that are related to the muscles' temporal activities. Using these parameters, a unique signature is constructed for each gesture. Based on data extracted from numerous research paper on low power and wearable EMG, we can see some underlying similarities stated by each author. Most of the paper emphasizes the performance of Analog Front End (AFE), Micro-Controller Unit (MCU), Transceiver, and Data Classifier. To achieve a low power consumption, the focus must be put on the selection of the active components which are the MCU, Operational Amplifier (Op-Amp) and the wireless transmission module. On top of that, the mode of operation needs to be defined such that the appropriate power will only be used when needed. The design of the miniature and low power wearable EMG will be the focus on powering the module with 100mAH Lithium Polymer battery (Li-Po), which would have operational time approximately 4-5 days. At the end of this study, the dimension for this module should be (50 x 25 x 15) mm^3 in size, 4 to 5 hours' battery life to accomplish small form factor and low power mode operation.

INTRODUCTION

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METHODOLOGY

System Design

The developed EMG system consists of disposable Silver-Silver Chloride (Ag-AgCl) biopotential electrode as sensor, a low power instrumentation preamplifier module which measure and amplifies the EMG signal, ATMEGA328 processor for analog to digital converter (ADC), digital filtering, and data acquisition, HC05 module for wireless transmission and a computer with Processing IDE for display.

System Block Diagram

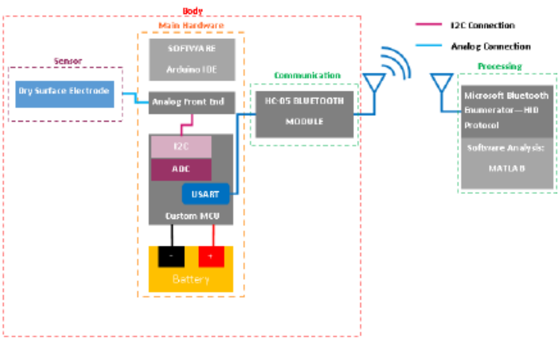

Fig 1: The whole block diagram of the system.

Biopotential Electrodes

EMG is muscle action potential signal which is bio signal of the order of few microvolts. To extract this signal, we have used Ag/AgCl biopotential disposable electrodes. The AgCl layer allows current from the muscle to pass more freely across the junction between the electrolyte and the electrode. This introduces less electrical noise into the measurement. Proper skin preparation and placement of electrodes are necessary. For single channel acquisition, three electrodes are needed, two serve as active electrodes and one ground electrode. The inter electrode distance is kept 20mm per Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) project recommendation for surface EMG measurement [3]

Preamplifier Unit

EMG signal varies from a 6 microvolt to 200 microvolt range and frequency band is extended from 10Hz to 500Hz. High input impedance amplifier must be used due to the high impedance between

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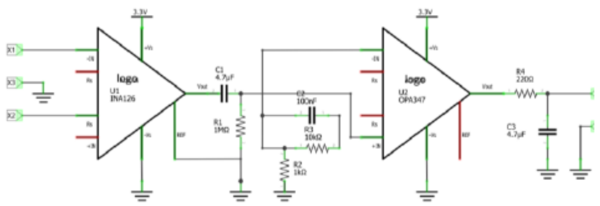
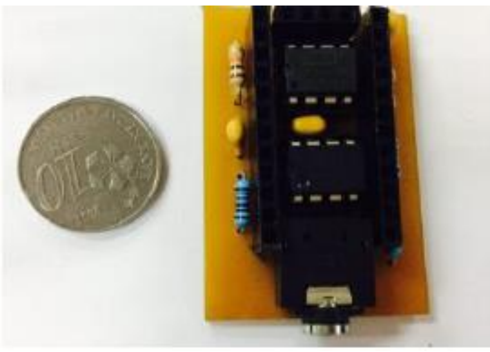
the skin and the electrodes. As the level input signal is in microvolt and has very high input impedance, the choice of a low noise amplifier is a very important consideration. As the system needs to be wearable, so low power, small size and light weight is a critical parameter that needs to be considered. Therefore, the use of a low power amplifier such as INA126p which processes stable gain range up to 1000, 10G ohm input impedance and low noise. The INA126 are precision instrumentation amplifiers for accurate, low noise differential-signal acquisition. Their op-amp design provides excellent performance with low quiescent current (175 µA/channel). Combined with a wide operating voltage range of ±1.35 V to ±18 V, makes the INA126 ideal for portable instrumentation and data acquisition systems. Gain can be set from 5 V/V to 10000 V/V with a single external resistor. Laser-trimmed input circuitry provides low offset voltage (250-µV maximum), low offset voltage drift (3-µV/°C maximum), and excellent common-mode rejection. It performed well, plus the requirement of single polarity supply imposed great advantage of running the system with small batteries. The second amplifier is the micropower rail-to-rail operational amplifier, OPA347 where its main advantage of using is its single supply and low voltage operation. It works well with only +3V power supply. The small size and low power consumption (34µA per channel maximum) of the OPA347 make it ideal for portable and battery-powered applications. The input range of the OPA347 extends 200mV beyond the rails, and the output range is within 5mV of the rails. The OPA347 also features an excellent speed/power ratio with a bandwidth of 350kHz. Preamplifier design is divided into 2 stages. Use of 11 and 101 in the respective stages makes a total gain of 1111. AC coupling of two IN-amps especially in single supply operation is a bit challenging due to a very high input impedance of in-amps and after the DC blocking capacitor, the voltage swing is well below ground. The first problem is solved by providing a ground return from the input of the second stage by a 10K resistor. The second problem is solved by using the very low gain of only 11 and thus limiting the max voltage swing after the capacitor to 150mV, which is inside the permissible input voltage range of INA126. Differential signal from two active electrodes is amplified according to the equation:

$$V0 = (8+100K\Omega/Rs)*VC.$$

There are 2 such preamplifier sections for EMG extraction, arranged in cascade mode, which is INA126 and OPA347.



(a)



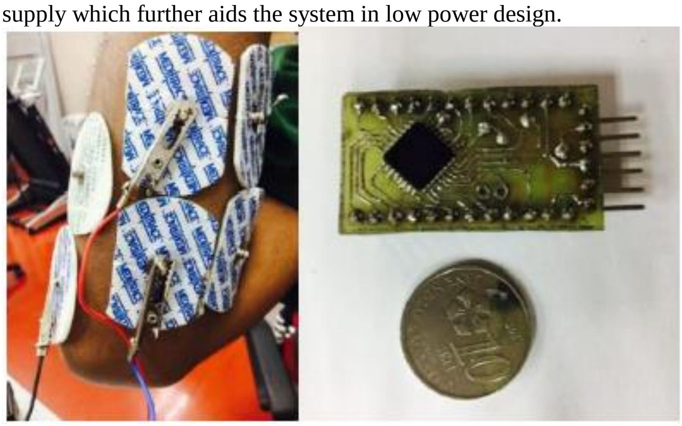
(b)

Fig 2: Schematic of (a) INA26 and OPA347 based preamplifier and (b) picture shows the practical circuit.

Processor Unit

Amplified EMG signal needs to be digitized for further processing [2]. ATMEGA328p microcontroller is used for data acquisition. 10 bit, 6 channel A/D converter used with a sampling speed of 16 kHz. The sampled data is sent to the USART with a baud rate of 57600 bps. Here is the flow chart of the embedded C program written for the implementation of the system. We have used the built in calibrated internal RC oscillator to minimize the noise. Also, the use of the noise reduction mode of ATmega328 minimized digital switching noise in the circuit [2].

Wireless HC05 bluetooth module: HC05 2.4GHz bluetooth module is used for wireless transmission. HC05 module operating range is within a medically prescribed standard, which is in ISM band. It provides reliable and high-speed data transmission. It has been used in the system for indoor application up to 5 metre range. HC05 module draws the low current of about 20mAmp and runs in 3.3volt supply which further aids the system in low power design.



(a) (b)

Fig 3: (a) Biopotential electrode placed on forearm flexor muscle, and (b) ATmega328 with HC05

Software Section

Raw EMG signal is treated in software section to extract useful features. EMG Signal is divided into 50ms window length. Moving window averaging is done. From raw EMG signal, we extract root mean square value whose amplitude can be related. 20 consecutive RMS values are averaged and displayed in a 1 sec display window, averaging causes low pass filtering. Digital band pass filter is designed for 0.01 to 100Hz frequency pass band. A bar chart representation has been designed which increases or decreases its value per force or torque applied thus giving a visual feedback to the user. Single channel unwhitened amplitude processor was formed as simple RMS processor, EMG amplitude estimate:

$$s(t) = \sqrt{\Sigma_{i=t-N+1}^{t} m^2(i)}$$

where, N= smoothing window length, m= waveform at sample time t.

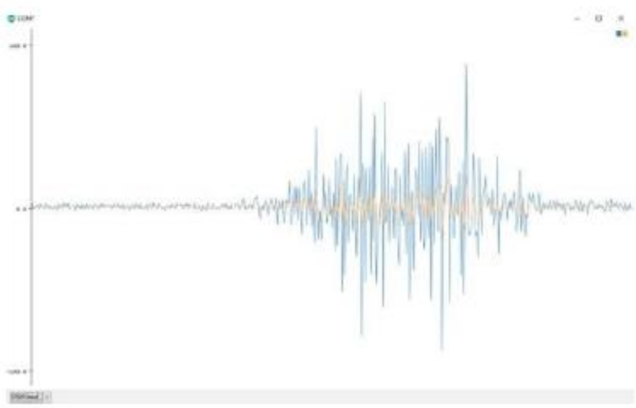


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Fig 4: clean EMG signal

Experimental Analysis

EMG extraction system is used to extract the EMG signal during hand flexion against yielding isometric contraction. EMG signal is acquired using bio potential electrode and EMG preamplifier unit versus Cleavemed 100 Bioradio™. The signal is filtered and processed to extract root mean square value. The clean signal then is recorded by Processing™ IDE for recording. Both signals are recorded simultaneously with a bit rate of 16bit per second. The recorded data have been processed using Mathwork® MATLAB™ 2013a. Using Mean Absolute Error and Mean Squared Error, both signals were compared and analysed in raw data and after the spectral envelope is done. The flexion involves one shot contraction, followed by delayed contraction for 5 seconds and lastly pulsed contraction with duration of 2 seconds. EMG signals are acquired simultaneously and reading in software shows variation in EMG data with the change in contraction.

Parameter:

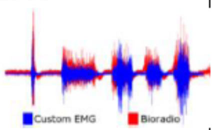
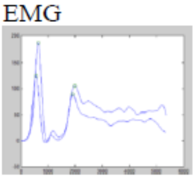
AGE=23 yrs, HEIGHT=159cm, WEIGHT= 49KG, SEX M
MUSCLE WIDTH =30 cm, MUSCLE LENGTH =18.5 cm,

RESULTS

Performance Testing

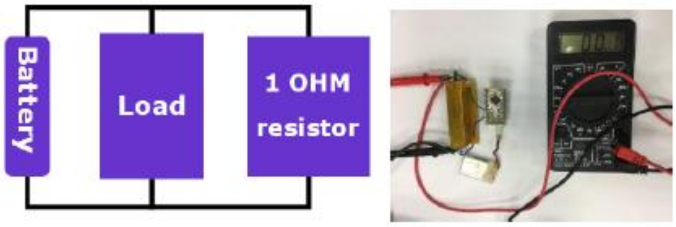
In this testing, the error between Custom EMG signal and Bioradio EMG signal was calculated using Mean Absolute Error (MAE) and Mean Squared Error (MSE).

Table 1: show the error (MAE and MSE) of EMG unit (blue) compared to Bioradio (red)

	Mean Absolute Error $MAE = \frac{1}{n}\sum_{i=1}^{n}\lvert x_i - \hat{x}_i\rvert$	Mean Squared Error $MSE = \frac{1}{n}\sum_{i=1}^{n}(x_i - a)^2$
Raw Signal of EMG 	$\frac{34\times10^7}{2.5434\times10^6} = 13.37$	$\left(\frac{34\times10^7}{2.5434\times10^6}\right)^2 = 178.76$
Spectral Envelope of EMG 	$\frac{36\times10^6}{2.5434\times10^6} = 14.05$	$\left(\frac{36\times10^6}{2.5434\times10^6}\right)^2 = 197.40$

Low Power Testing

Low power testing conducted to measure the device operational time and prove the low power operation. To calculate the operation time of the device, the setup shown in figure X below was carried out. We choose 1ohm resistor, because per Kirchhoff Law, V=IR, and when R = 1 Ohm, then V=I. From this, we can get the current which the device draws from the battery from voltage reading. We use the multimeter to get the reading, and the results are as follows:



(a) (b)

Fig 5: (a) Current draw measurement setup (b) measurement of voltage which reflect current draw.

Table 2: Current draw and Time for current consumption for each part.

Component	Current Draws (mA)	Time for current consumption (hour)
(INA126 + OPA347)	0.01	24000.00
Custom MCU	19.33	12.41
EMG Unit	23.87	10.05
Bioradio		8.00

Discussion

The overall planning of wearable EMG with 100 bitrates per second therefore, it must be wireless, wearable, and light weight while allowing a full range of motion [5]. The system block diagram, based on figure 2.1, displays the overall connections that will be made for the complete design. The sensors (electrode) are displays in the leftmost column with individual busses that will lead to the custom MCU. Light blue symbolizes the analog connections required for the sensors, while darker purple represents the I2C connections. USART references the serial connections (Rx and Tx) that will be used for the HC-05 Bluetooth module. From the Bluetooth, the desired telemetry packets will be transmitted to the MATLAB application installed on a computer. Furthermore, the EMG extractor unit designed gave reliable output readings during EMG torque experiment. Gain over the time was constant without much drift. The proposed design fits its purpose of being a low cost, low power single supply extractor unit. The overall system runs on 3.3v which extends battery life for long term use, the system can be run using only 240mAh. Compact size and extremely low weight about 100gm makes it an ideal wearable device. Incorporation of the wireless HC05 module which operates in 2.4GHz ISM band ensures all medical protocols and provides the reliable and high-speed method of data transmission. It further makes the system compact offering complete freedom of mobility during experiments.

CONCLUSION

This work presented design of miniature Electromyogram that consists of two interesting properties: (1) reduction in power consumption, which significantly lowers the average power consumption (2) a construction process of robust and low-cost analog front because the noise is not sparse on the sparsity basis. The proposed circuit design has increased device lifespan to approximately 2 more hours, compared to Bioradio, which is just 8 hour and desirable mean average error of 13.37, which provide the good background for establishing wearable wireless.

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