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A Low-Cost EMG Based Human-Computer Interface Peripheral Device

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Abstract—This paper presents a low cost, energy efficient electromyography-based Human-computer Interfacing peripheral device that picks up data via contact electrodes placed upon the surface of the extremities and critical points of the muscle tissues of the end user's body.EMG data can be treated as isochronous data wherein a constant stream of data is transferred rapidly to the computer as packets with no error reporting as compensation for a fixed bandwidth. A utility -cost analysis is performed to check for the most suitable components in order to attain a system that is highly optimized for the isolated task of EMG data acquisition and its transfer to a computer.

Keywords—Electromyography, body sensors, Human-Computer interfacing, USB interface.

I. INTRODUCTION

The sEMG signal subsystem works by amplifying the neural impulses sent via the brain to the respective muscular tissues. it is found to work best within the frequency band of 50-150 Hz as is articulated in [1]. The overall domain of electromyography, although full of immense potential, has garnered lesser attention than its popular and similar version, electroencephalography. In spite of having scope in various human-computer interfacing applications like vital heath monitoring systems, closed loop feedback sensors in gaming, muscle fatigue sensors, MIDI controllers, seizure detection systems, muscle atrophy detection and numerous other potential applications, the surface EMG systems have had lesser outreach to the general masses. The products in the market sector for recording and imbibing EMG signals into projects, albeit available, are scarce expensive, and require additional modules in order to interface with a computer.
The EMG spectrum as of yet as only observed major applications either in the field of prosthetics wherein it is applied to provide analogue trigger feedback to motor control systems or in high stakes sportsperson health monitoring. Cheap and easy to use EMG signal data readers are not easily available to the general public as of now, except for some add-on board versions which require an Arduino board to convert the data into legible output.

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The USB protocol is fairly common in virtually all computer systems by now. it's possible to discretize and convert analogue EMG impulse signals into hex data to transfer it serially to a computer terminal. Thereafter, a software can read that serial data and filter out the necessary information from the raw input.

This paper attempts to resolve the issue of fragmentation of generic EMG systems for usage in mainstream applications. Potential applications include twitch sensing game controllers, wearable biosensors, generic hardware for usage with software that monitor stats and detect anomalies etc.

II. ARCHITECTURE

The system is constructed by utilising a modular approach that focuses on 3 individual modules serving separate purposes: signal acquisition, signal conditioning, and lastly, the computer interfacing module.Under the signal acquisition module, the standard non-invasive carbon tape surface electrodes are used. The domain of customization of the surface electrodes in order to increase surface conductivity to get better signal quality is open to improvisation. This sector has had quite extensive futuristic innovations like pneumatic electrodes and non-metallic graphene tattoos as is mentioned in [2].

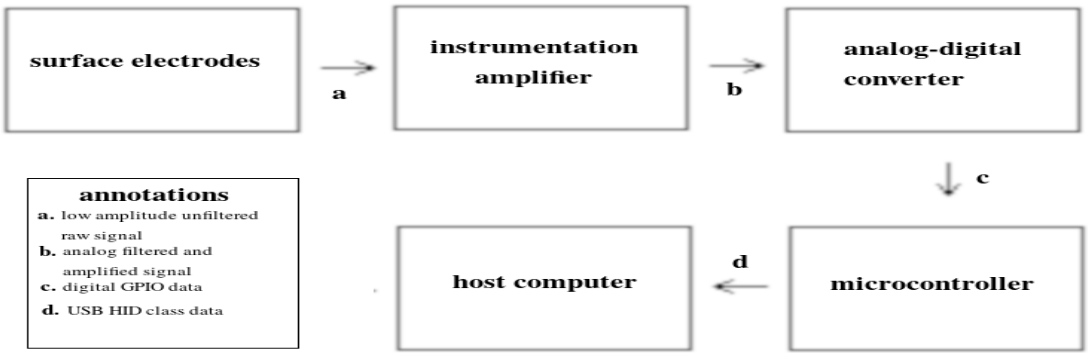

Figure 1 -General system block diagram

The signal conditioning module deals with two tasks: narrowing down the signal to the essential EMG signal frequency band, and amplification of the signal just enough (3.3V – 5 V) so that it can be detected by a microcontroller.

Table 1 -precision amplifier specifications

S.no.	IC name	Resolution	Cost (in rupees)*
1	TSV711	~200uV	23.17
2	TSV731	~200uV	23.17
3	TSZ121	5uV	45.22
4	TSZ181	25uV	56.56

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An Instrumental Op-Amp couple with a low noise active Band pass filter satisfies the criteria for that function. There is a vast array of instrumental amplification ICs which can be deployed to fulfil this purpose. A detailed utility-cost analysis has to be performed in order to select the amplifier best suited for integration into the circuit.

Thereafter, the signal is amplified, but is still in an analogue electrical form. In order for a microcontroller to be able to read it, it has to be converted into digital form.
An ADC with a high sampling frequency and a high SNR would generally be preferred, but the cost factor plays the major criteria in this build. The cheapest route would be an ADC that’s already integrated into the third module.
The computer interfacing module consists of a microcontroller that takes in the signals as analogue input to the ADC integrated into the microcontroller which converts it into hex characters.

Thereafter, the data to be sent to the USB port can be transferred either by using serial USB protocol or directly using software alternatives like V-USB [3] library which enables low frequency controllers to be interfaced via USB with computers.

III. PROPOSED METHODOLOGY

There are two methods with which the sensor data can be transferred using USB: the USB serial protocol and the HID protocol. In order to deploy the system as a serial COM port device, another IC that converts the output of the microcontroller from UART to serial USB data called an FTDI chip is required. The drivers for interfacing the FTDI IC have to be installed separately since they do not come in bundled with some operating systems by default. The integration of the FTDI chip also increases the overall size and cost of the system. An alternative approach to using the FTDI chip would be to select a microcontroller that comes with the USB interface built-in.

There is also an option of selecting a microcontroller which has a built-in USB interface. It takes one to the PIC family of microcontrollers and a select few ATmega microcontrollers with U2 mentioned in their nomenclatures. This has been previously attempted using the PIC18F4550 [4]

The USB serial route adds to the complexity and cost of the whole setup. The HID protocol on the other hand, relies on making a virtual USB port in order to interface with the computer. As an alternative to making the HID circuit, an Arduino Mini board featuring the At mega 328p can be programmed to output data serially to the USB port at a relatively low cost. in most operating systems, the drivers for the onboard FTDI module come pre-installed into the kernel.

IV. MICROCONTROLLER ANALYSIS

The microcontroller to be used in this application needs to be minimalistic in nature since it only serves the purpose of relaying the data from sensor to computer via the USB port. The features of microcontrollers to be selected were analysed from the perspective of both the serial and the HID route.

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Table 2 -microcontroller specifications

S.no.	Name	Built-in USB controller	Pins	ADC bit/channel	Cost (in rupees) *
1.	ATtiny45	No	8	10 / 4	80.37
2.	ATtiny85	No	8	10 / 4	86.72
3.	PIC18F4455	Yes	40	10 / 13	305.97
4.	PIC18F4550	Yes	40	10 / 13	317.96

The V-USB library enables any low-speed AVR microcontroller to use the USB protocol. The library supports microcontrollers with at least a 12MHz oscillator. The V-USB library works by defining arbitrary device descriptors sent via configuration packet and directing the host to recognize the circuit as a HID class device.

Unlike the USB serial data, the data generated by the HID device cannot be read via putty or other port data reader tools. So, in order to read the data in operating systems which do not recognize the system as a keyboard, specialized tools have to be used. The command for reading the HID data off a Debian based machine can be as simple as a single command in the terminal:

cat /*dev*/<type_dir>/<device ID>

The program for other commercial operating systems however, might be more complex. In order to make the data transmission universally supported, it has to be sent serially through the USB port on to the host computer. The HID protocol, in spite of the ease of interfacing, has to compensate by sacrificing the ease of access to the data, unless the program uses a device descriptor that’s universally recognized as a generic keyboard. Some operating systems may not recognize some generic HID devices resulting in the malfunctioning of the system due to unrecognised USB descriptors.

V. DESIGN OF AMPLIFIER AND FILTER

The Instrumental Amplifier used in this system is the TSV711, the base version in the family of TSV71x family of precision Op-Amps.

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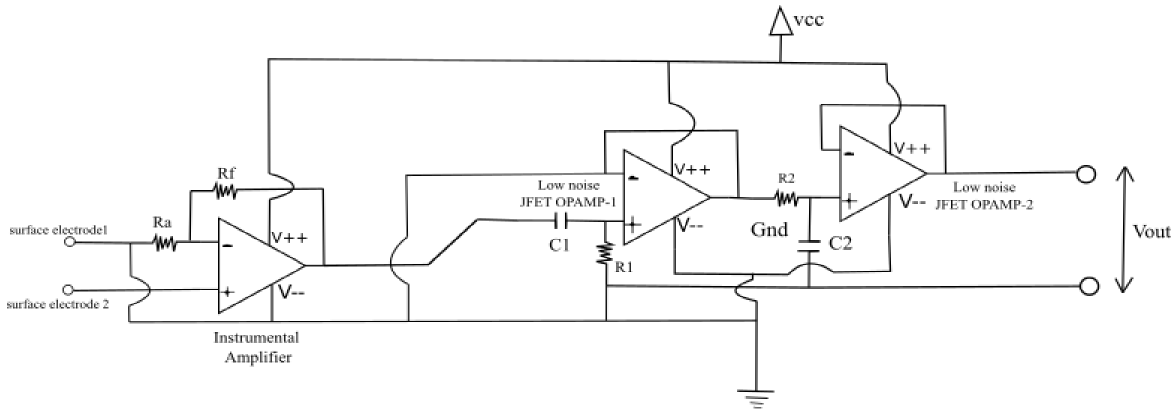

Figure 2 – instrumental amplifier coupled with band-pass filter.

The IC is a 5 pin DILCAN package which boasts a 200μV least value and is ideal for application into the circuit. A common ground terminal indicates that the op-amp may not provide features like input output isolation. Since the input signal is in the order of 10μV-1mV, the isolation can not be ensured using any diode based devices such as opt isolators. The circuit needs to be powered by a USB 5V supply. The Op-Amp setup can be configured in two ways to achieve that: by grounding the negative Op-Amp's V-- and its input (Figure 1.2), or by creating a virtual ground using a simple voltage splitting circuit(Figure1.3). if the V-- terminal is grounded, it causes the Op-Amp to go into unidirectional amplification mode, essentially amplifying only the signal above the baseline. This causes clipping of the part of the signal that's below the baseline. The second method makes the circuit more complex. It involves using a full bridge rectifier (Figure1.3) to bring the negative rail's signal to the positive side. The resulting voltage drop from the full bridge rectifier would ideally be ~1.4 volts.

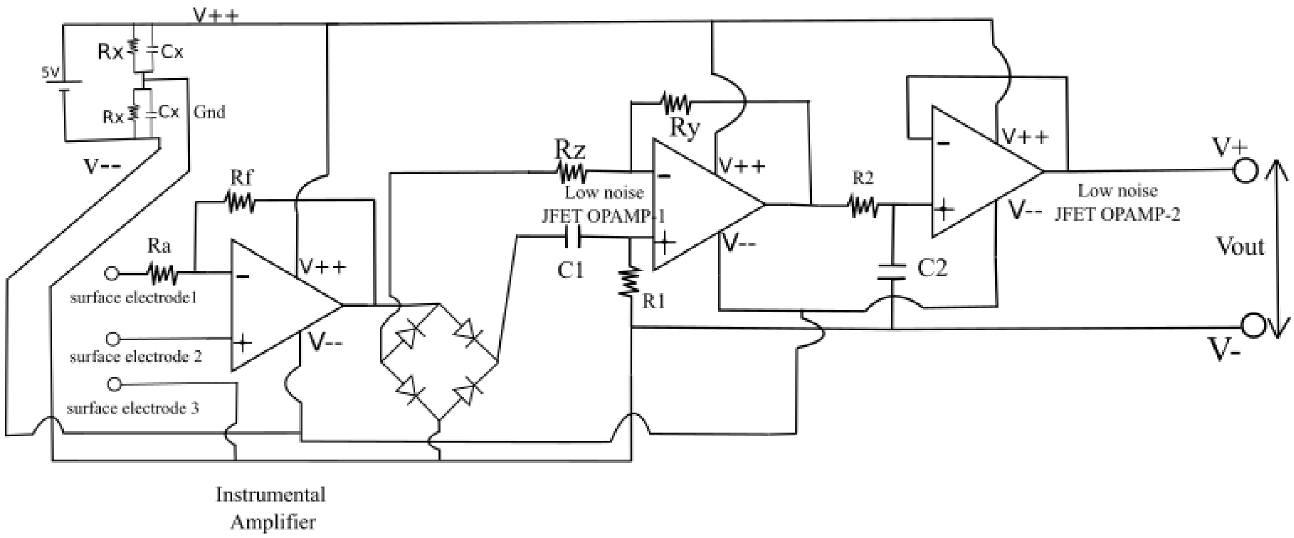

Figure 3 – full signal data acquisition module

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Table 3 – annotations

Annotations	
V--	Negative power in
V++	Positive power in
R_x	Splitting resistors
C_x	Splitting capacitors
R_f	Primary amplifier feedback resistor
R_a	Primary amplifier input resistor
R_z	Secondary amplifier input resistor
R_y	Secondary amplifier feedback resistor
R2	Low pass filter configuration resistor
C2	Low pass filter configuration capacitor
R1	High pass filter configuration resistor
C1	High pass filter configuration capacitor
V+	Output signal to microcontroller
V-	Gnd signal to microcontroller

Making the circuit EMG specific, the input signal is assumed to be the upper limit of the signal i.e. 1mV. Taking into consideration the voltage drop of 1.4 V due to the full wave rectifier, the output voltage must be a maximum of 5V. As the power supplied to both rails is 2.5V in both positive and negative side, a single Op-Amp can only amplify the signal to 2.5V max. Therefore, the amplification provided by the primary instrumentation amplifier will not suffice. In that case, the secondary amplification is provided by the Op-Amp that is also configured as an active High pass filter. Assuming ideal conditions, if the maximum output by the primary Op-Amp is 2.5V, the secondary amplifier must receive 1.1V after full wave rectification. The signal can go to a maximum 2.5 v in the primary amplifier since it has to account for the negative signal. The secondary Op-Amp upon receiving the rectified input has to re-amplify it back to 2.5V. It also acts as a high pass filter with a cut-off frequency of 150Hz. The tertiary Op-Amp is set up in active Low pass filter configuration with unity gain. Its output goes to the ADC of the microcontroller in which 2.5V can be mapped to the highest output value. The primary gain calculated from the amplifier's transfer function is:

$$2.5V = 1mV\left(1 + \frac{R_f}{R_a}\right) \Rightarrow \frac{R_f}{R_a} = 2499$$

the ratio of primary feedback resistance to the primary input resistance would be 2499 in ideal conditions. The value of R_x and C_x must be equivalent for a balanced split between both power supply rails.

The 1.4V voltage drop causes the input to the secondary Op-Amp to be 1.1volts maximum. For the output to reach 2.5 volts again, the gain is calculated to be:

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$$2.5V = 1.1V\left(1 + \frac{R_y}{R_z}\right) \Rightarrow \frac{R_y}{R_z} = 1.\overline{27}$$

Furthermore, the cut-off frequency for first order active high pass filter is to be set to 50Hz. The formula for calculating the cut-off frequency for first order filter is approximately:

$$50Hz = \frac{1}{2\pi R_1 C_1} \Rightarrow R_1 * C_1 = 0.003183$$

now, for the subsequent low pass filter, The value of the product of resistance and capacitance to obtain the cut-off frequency of 150Hz is approximately:

$$150Hz = \frac{1}{2\pi R_2 C_2} \Rightarrow R_2 * C_2 = 0.001061$$

That concludes the relations between various component values required in order to obtain a single supply based signal amplifier and filter.

VI. DESIGN OF INTERFACING MODULE

Moving on to the processing part, once the signal is fed into the microcontroller, its ADC has to be programmed to view the 2.5V input as a maxima. The ATtiny85 was selected as it fulfils the criteria for usage with the V_USB protocol with the minimum additional features. Although, it has a lower 4KB version, the 8KB version was selected only as a primitive excess feature in case the program needed be modified to allow more computations and intermittent preprocessing. The protocol implemented was a software based virtual USB HID protocol which does not require any extra driver packages to be installed on the host system in a majority of cases(tested in Windows 10 and Debian buster). It uses the Digispark keyboard library[6] to register the system as a HID keyboard device. The micronucleus bootloader[5] is flashed onto the ATtiny85 and Digispark API is installed onto the arduino IDE to collectively import preconfigured functions and USB descriptors. The Digispark board comes in a compact USB form factor coupled with a voltage regulator connected between the USB+ and the Vcc of the ATtiny85.

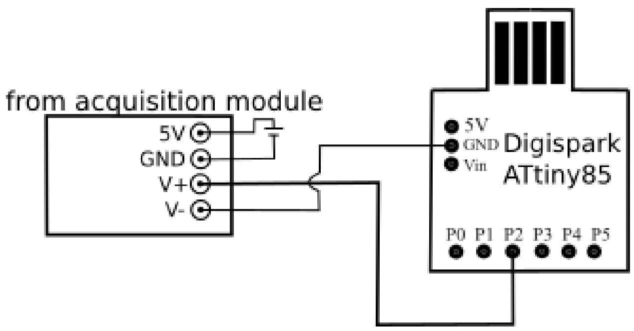

Figure 4 –connection with interfacing module

Once the connections are completed, and the micronucleus bootloader burnt into the ATtiny85, The board can be programmed with considerable ease using the Arduino IDE.

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VII. ALGORITHM

The minimal code for getting the signal in numeric values is as follows:

```
#include "DigiKeyboard.h"
int a = 0;
void setup() {
}
void loop() {
a= analogRead(1);
DigiKeyboard.println(a);
}
```

This results in the system acting as a generic USB keyboard upon being plugged in. The data output of the system can be read by moving the cursor to a text input area, preferably a spreadsheet or a text file/document. Once opened, the data will subsequently appear as typed-in text.

VIII. RESULTS AND DISCUSSION

Upon completing and flashing the program, the system immediately responded with numeric data input from keyboard. The data values registered were found to be in direct proportion to the magnitude of muscular flex recorded by the surface electrodes. This sEMG system can be made to be a cheap input peripheral device for gaming, personal medical healthcare, sports related statistical data acquisition, and a plethora of other unexplored applications. The resulting data derived from the sEMG system can be recorded and used in modelling data centric software and programmes tailor-made for individuals based on their relative stats. In a conceptual instance, a cheap sEMG system can even be used in quantization of manual labour and its proportional monetization.

IX. CONCLUSION

The system, although cheap, comes with a couple of drawbacks. The design is single channel based and hence, can be used on only a single muscle tissue at a time. The frequency of data output to the computer terminal is drastically reduced while using HID keyboard method to accommodate the typing interval delays. Nevertheless, sEMG data constitutes a crucial portion of the vital stats of a human body. Its easier availability can bring about a tremendous boost in data specific applications from companies and individuals subsequently. Reduction in cost of a EMG system hopes to fuel the boost in interest in this underused, yet vast expanse of data.

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