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Affordable Bionic Hand For Forearm Amputees

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Abstract: *Bionic prosthesis solely work on the logic and framework that is built into themat their production facility. These are primarily based on a set of experiments conducted with their test subjects and on predefined algorithms defined for its frame work. A method to develop a 3D printed affordable Prosthetic Hand, dubbed Evolve, built on the latest Intel Quark based processor and Linux OS is proposed over here. It has a range of sensors with EMG being the primary control input. EMG signals are acquired and passed on to an algorithm to detect the action being performed. It is then fed to the hand to perform a grip pattern. An optical sensor based feedback system is being implemented which rests in the palm of the hand. It feeds back the movement data based on which the closure of the hand is governed. Evolve has a web interface where the user can fine tune the system manually and do a basic diagnosis of its current status. One of the unique features of Evolve is a market place integration. While bionic hands available in the market comes with predefined features, Evolve is trying to change that trend by allowing new features to be developed and installed via the marketplace.*
Keywords*: Bionic Hand;EMG; Servo Control;Robotics Platform*

I. Introduction

Over the years, bionics industry has seen huge advancements in terms of technology and how close it is to recreate the motions of a normal human hand. This comes at a hefty price tag and increased cost of repairs. With the growing number of accidents, warfare, birth defects and deadly diseases throughout the world, cases of amputation has increased more than ever. This called to the need of advanced prosthesis for those in need to support them and help them lead a much normal life. Even though prosthesis are not close to its biological counterpart, they can be used to carry out most of the basic day to day activities. An example to this is a prosthetic leg which help the wearer to walk at a slow pace and also use crutches/walking stick along with it to get better results. Earlier version of limb prosthetics used a wooden peg with a long metal piece. Prosthetic hands started off as a hook with which users can pick object or open doors. With the advancement of technology, the inanimate wooden prosthetics was replaced by much more sophisticated microcontroller and processor based robotic systems that acts according to inputs from the user. This hurled the prosthetics into a much more useable and effective product that is as close to its biological counterpart as possible.

Bionic Hands belongs to a widely researched and developed product category. The high amount of interest in this product accounts to its less complex nature compared to artificial limbs and scope of improvement that are easier to build and implement. Hand amputation is also one of the most common form occurring mainly due to diseases or birth defect.A variety of techniques and methods are used to develop bionic hands that are mechanical or electronics in terms of control and functionality.

Even though bionic hands are in great requirement, a cost effective version of it is very scarce in the market due to the technology involved in its making and cost of materials. A fully functional bionic hand with 14 different grip patterns will cost around 20,000 USD to 35,000USD. This puts the bionic hand into a premium section of products and is not affordable to a large share of the affected population. Other versions that are available for 500USD to 1500USD are either mechanical or electronic microcontroller based units that can perform only a very limited set of functionalities, mostly an open and close grip.

When the process of building an affordable Bionic Hand was commenced, a major part of the research focused on the reasons that increased the cost of existing units. Next in line was the downsides of existing units and review of people who uses it on a day to day basis.Data obtained from both studies concluded on a requirement to restructure the product in terms of hardware used, method of software/firmware upgrade and ease of modifying or repairing the product.

To decrease both the production and repair cost, a new Bionic Hand designhad to be developed. The design should ensure that any sections that needs to be redone or replaced can bemade individually at a very low cost and retrofitted into the existing system. The controlunit and associated software is an integral part of the system that solely determines how close thesystem is to a normal human hand. Most of the systems available in the market currentlyuses EMG based sensors or pressure pads to determine when the user wants to open orclose a system. In addition to this, any additional feature requirements needs to be rolledout by the company or its developers. This reduces the number of features available to auser. Adding to this, existing systems comes with its own hardware modules and sensorsand there is no way in which a custom sensor can be added in. This also affects the ease atwhich a faulty hardware can be replaced. Most of the system uses sophisticated sensors todetect the grip on an object and feed it back to the user to take a decision to operate thehand. All of the above methods increase the cost of the product highly. So aplatform based plug and play system needs to be designed which comes with an effectiveslip sensor to detect the grip. This is required to reduce the cost of additional hardware,software and sensors being built for the system thus making it a much more affordablebionic hand.

II. Issues Identifiedand Remedy

The common issues identified can be summarized as –

- Limited features and feature addition is not possible unless rolled out by the company
- System can't learn from the user's usage pattern
- No provision to add more sensors or hardware
- Bionic hand has no self-feedback to stop closing automatically.
- Highly Expensive
- Inability to talk to other electronics device directly

To tackle these issues and build a much more user friendly and cost effective system, the following implementations were planned and focused on as primary requirements –

- 3D printed Bionic Hand
- Low power EMG based control
- Platform based architecture
- Develop a slip sensor to identify the optimal time to stop hand closure
- GUI with a market place to develop and install additional features
- Option to add additional hardware and allow swappable modules

III. Gesture Recognition System

Existing methods can be broadly classified into(1) Non Biosignal based and (2) Biosignal based Systems. While the former uses techniques that makes use of Image recognition, physical controllers or both, the later deals with signals captured from the user's body.EEG, EOG and EMG based systems are mainly used for gesture recognitionpurposes based on the user's medical condition. For the bionic hand to be user friendly, easy to dismantle and not require any surgical procedures, a non-invasive method of bio signal acquisition is preferred over an invasive one. In order to match the requirements, a Surface EMG system was implemented. This uses electrodes attached to the surface of the skin,on top of the muscle to be monitored, and acquiring the electromyography signals generated while the user flexthemuscle/s.The signal is either taken from the remaining functional muscles ofthe hand or from the shoulder. These systems works based on the amount of muscles thatremains functional and can be tapped with a great degree of accuracy. Individual fingercontrol is done in most of the devices using different commands. Each of the commandsare triggered by a sequence of flexes resulting from a combination of the muscles, ratherthan by individual muscle signals.

Developing an EMG system, started with fixing on the specifications required for the acquisition system. It was set to have an input impedance greater than 1 GigaOhms and CMRR of 100 or higher. This will ensure that the system will work with dry reusable electrodes as well as with wet non reusable electrodes. The block diagram for the system is shown in Fig. 1.

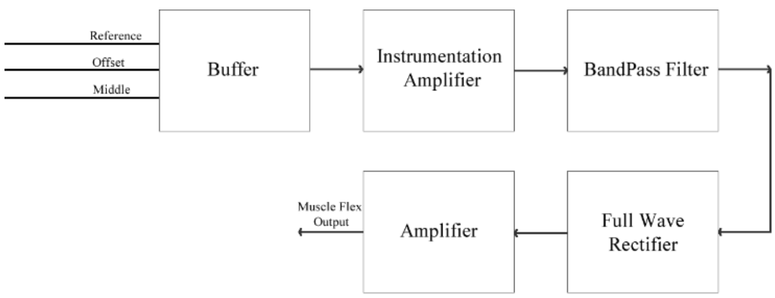
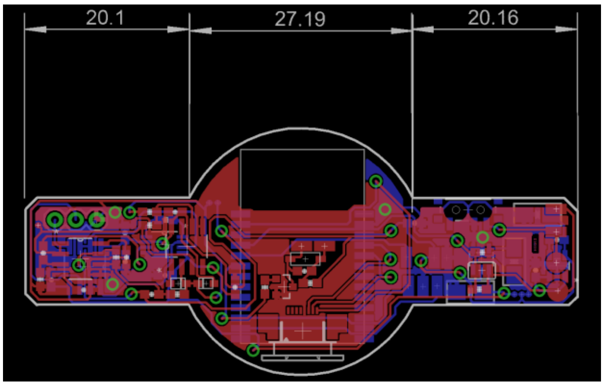


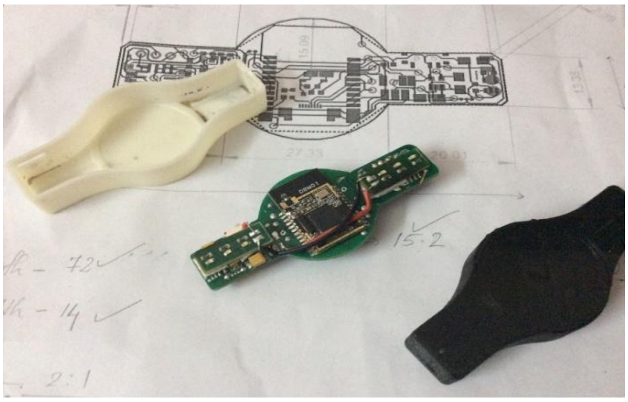
Fig.1 Block diagram for EMG acquisition module

Reference [1] gives an insight on how to a multi-channel noninvasive EMG measurement can be done and methods to remove noise signals.Reference [2] is more useful in understanding active electrode based EMG acquisition, time for which EMG signal needs to be observed and how to segment the signal to obtain meaningful data. This is important as we can increase the hit to miss ratio and obtain high accuracy in most real life scenarios.Reference [3] provides information on using statistical based analysis to obtain accurate EMG information which can later be given to a neural network. Reference [4] shows the optimal positioning of the electrodes to get a good EMG data. Reference [5] gives more information on EMG based signal acquisition and its use case in a bio feedback system.

Stage 1 of EMG module has a Buffer with an Instrumentation amplifier following it. This is the preprocessing and signal acquisition stage. The input impedance of first stage should be in the order of GigaOhms and CMRR should be around 100-110. A buffer opamp with input impedance of 1 GigaOhms and an instrumentation amplifier of CMRR close to 110dB (AD524 by Analog Devices)is chosen so that the system can be used with minimum skin preparation and has low signal distortion at the acquisition phase. A three electrode method is used for signal acquisition. Middle electrode is placed on the belly of the muscle, Offset electrode towards the end of the muscle and Reference to any bony area. The middle and offset signals are given to the first stage differential opamp of instrumentation amplifier. The signal common in both the inputs are subtracted out and the difference signal is obtained at the output. This is mainly used to eliminate the 50/60Hz line noise and find the difference in signal when the muscle contracts. Middle electrode will have the actual EMG signal and the offset electrode will have a smaller version of the EMG signal. Since noise gets affected everywhere equally, both the electrode will have the same amount of noise and this gets subtracted out leaving only the difference EMG signal at the output. With this setup, we were able to cancel out line noise without the use of a notch filter, which would have rejected the 50/60Hz information region of the signal. The reference signal obtained from the bony area of the body is given as the reference signal for the third opamp.Stage 2 consist of a flat-band Band Pass filter and Full Wave Rectifier. Band Pass filter which is designed to pass signal between 30 – 150 Hz. This is the frequency range in which we will get the required muscle flex information. The signal is then given to a full wave rectification unit which outputs an average DC value corresponding to the acquired EMG signal. Stage 3 is an amplifier section. The output signal level at Stage 2 is still in the range of 0-1V. This needs to be amplified to a 0-3.3V range for microprocessor interfacing. This also increases the chance to detect small changes in muscle flex.



(a)



(b)

Fig. 2 (a) PCB design of the EMG circuit(b) Assembled PCB and 3D printed case

Fig. 2(a) shows the EMG module that was designed and developed. Fig. 2(b) shows the final EMG prototype and its 3D printed casing. This is a wireless unit and can also be used as a wired unit. It has an inbuilt ADC and TI SOC unit for analog to digital conversion and perform basic computations on it before it is wirelessly transmitted to a connected system. This unit is capable of transmitting EMG flex data and RAW EMG data. The source is selected using a solder joint in the PCB. EMG flex data is selected by default.

With the implementation of an EMG based system for controlling the bionic hand, muscle flex of a user is mapped on to respective gestures. It does come with its own downsides of not being able to map all the muscles onto the fingers on a bionic hand and to detect a proper grip without any user intervention. While absence of the former doesn't affect the user in effectively controlling the bionic hand for day to day tasks, the latter is a pain point. This is due to the user not having a feel of touch and slip feedback and the control needs to be user driven based on their visual feedback, which is often slow.To tackle this a slip sensor needs to be built that is not available in the industry in its real sense. A reflectance and proximity based optical system detect the slip and interrupt control unit. This unit is placed on the palm of our Bionic hand. In a real life scenario, when the user tries to hold an object and if the grip is not firm enough, the object tends to slip down. This slip is detected and then hand starts closing until there is not slip. The effectiveness of this system is much more evident when the user tries to hold an object which is light weight and is susceptible to breaking if the grip is tighter. Holding an empty paper cup requires a very gentle grip but as soon as the cup is filled with water, it starts to slip. The system immediately recognizes this and tightens the grip just enough to prevent it from slipping down.

IV. Control Unit

The hardware on which system logic runs and external sensors is interfaced with needs to be fixed carefully. It should be cost friendly, has wireless connectivity, enough processing power to adapt to future additions and machine learning algorithms and has a very small form factor so as to accommodate within the palm of the bionic hand. Intel Edison is a module based on Intel Quark SOC that confirms to all of the above requirements and was selected for system implementation. Being a microprocessor based system, it runs a full Linux OS and supports low memory foot print languages like Python and Node.js.

Fig. 3 shows the block diagram for the hardware that was implemented. Actuation of the bionic hand can be performed using a traditional two string method and a DC/Servo Motor attached to its end. A much more costly alternative uses linear actuators. This system is built to support up to 8 DC/Servo/Linear Actuators. It was designed in this way to make sure that the system can be used for different implementations of the bionic hand.

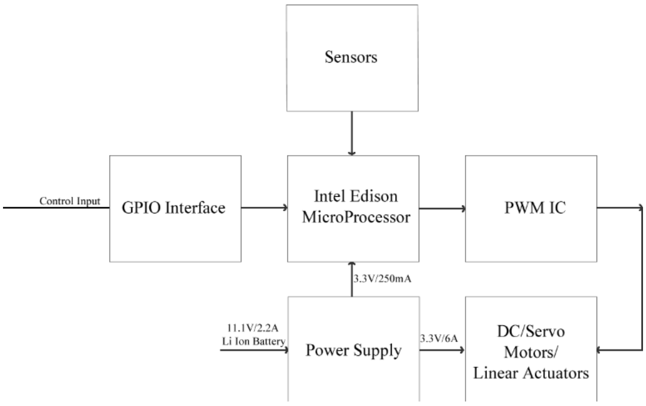


Fig. 3 Block Diagram of Hardware

A low cost version with less load capacity might use micro servos or DC geared motors while a low noise much more compact version will use a linear actuator based approach. Supporting all 3 actuation mechanisms will also ensure that an already built bionic hand can be easily retro fitted with thissystem. To add this functionality, a PWM chip was integrated into the circuit and interfaced with Intel Edison. It is controlled using I2C protocol instruction set and supports up to 8 PWM channels.The power supply is designed to have a high current output of 6A at 3.3V. This provides the power requirement for DC/Servo/Linear actuator connected to the device. Input to the system is an 11.1V 2.2A Li Ion battery. The supply from battery is regulated and provided to both the motor/actuator control and the microprocessor unit. An external charger unit is used to charge the battery.

V. Platform Based Approach

One of the prime focus while developing a bionic hand was the way in which its software is built. To reduce cost with a provision to add new hardware and features and to have a faster computation, a platform based approach built on Python and Node.js was selected. Addition of new sensors or hardware is also easier when a platform based system is built since as it works in a plug and play mode. New hardware along with their driver files are installed into the system. The data is taken in or given as an output based on a specific instruction set native to the system. This makes sure that all the applications developed before and after the new hardware launch is compatible with the system. Evolve is a development platform that is aimed at speeding up the development of bionics and human machine interface (HMI) technology. Functioning as a plug-and-play "brain" for the system, it packages the required internal hardware and software components, allowing developers to focus on building the physical device. Evolve hardware consists of the Intel Edison, which monitors a wide range of input sensors, and controls a set of output devices. The interaction with the input and output devices are handled through a set of pre-written libraries that allow the developers to set up the system with minimal lines of code. The library-based system is also advantageous for the developerwho wants to integrate new and custom hardware to the Evolve system.

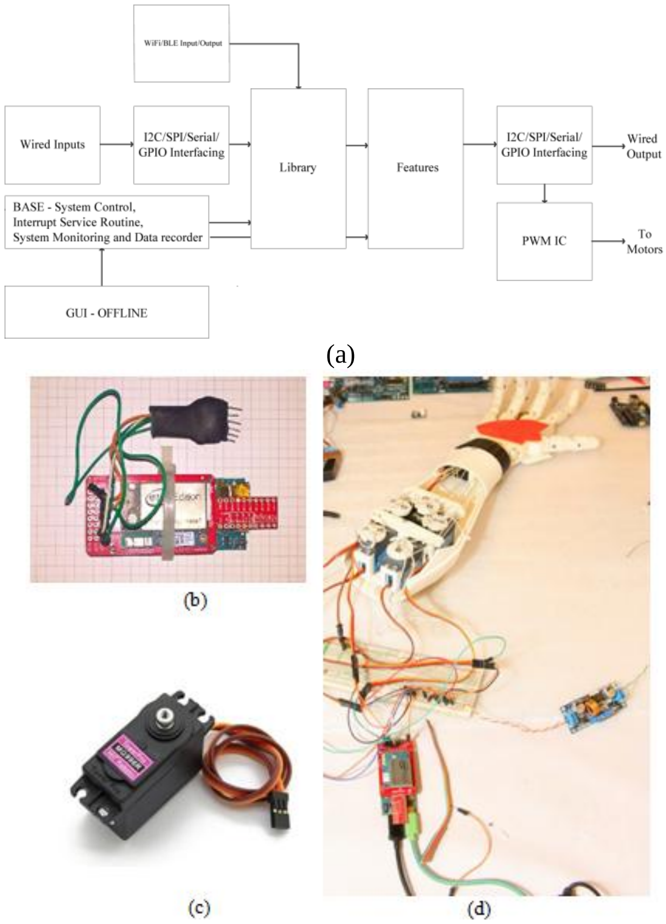
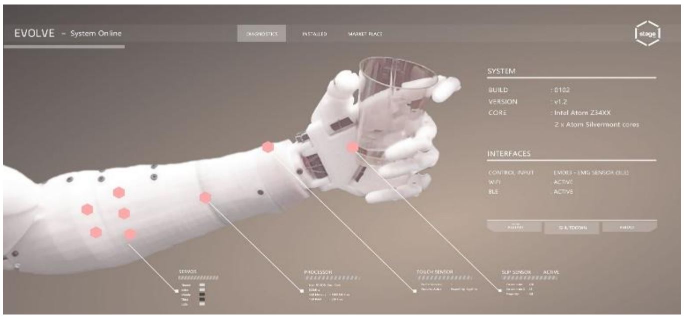
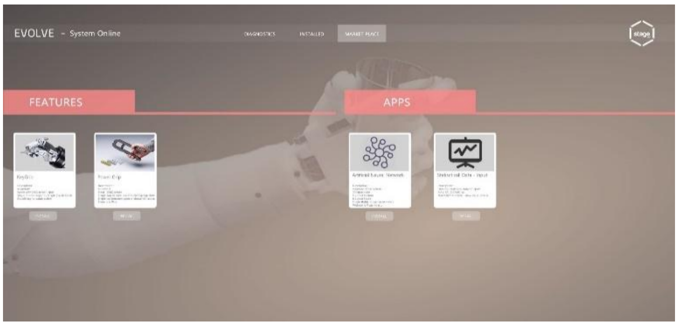


Fig. 4(a) High Level Architecture of Software (b) Intel Edison with PWM Servo Control (c) MG996R Servo used for the 3D printed Hand (d) 3D printed Bionic Hand connected to the system

The software part of Evolve, is built on Python and Node.js which enable developers to interact and develop on an already popular coding language. In addition to that, the Evolve system already has most of the basic system functions coded into easy to use libraries which can be used while developing applications in Python. Interrupt service routines, system monitors and hardware scanning is built in and developers can access them using simple file read/write operations. One of the unique features of the platform is the availability of a GUI with an App Store. Contrary to normal bionics, where the user is stuck with whatever comes pre-loaded on the device, Evolve allows users to download apps and features from an online store, in much the same way as in smartphones. The software API enables developersto design and develop custom apps and features according to their unique requirements. They can also design custom input sensors to work in conjunction with the apps that they design.Fig. 4(a) shows the High level architecture of Evolve system and Fig. 4(b) shows the Intel Edison module with PWM output. Inputs can be wired or wireless. Both of these needs to be interfaced using separate libraries that is provided within the system. I2C, SPI and Serial interfaces has been implemented for accepting multiple sensors running on different communication protocols. Features can be developed using the libraries and other functions provided by the system. 5 features, namely Power, Key, Point, Pinch and Grasp grip, were developed which enables the user to perform day to day tasks. This is available in the market place and comes pre-installed with the system. A customised 3D printed hand, Inmoov Bionic Hand, is used over here. It is connected to 5 Servo motors (MG996R) shown in Fig. 4(c). Fig. 4(d) shows the final build running the Evolve platform. It is powered using a 3.3v 6A power supply unit.



(a)



(b)

Fig 5 (a) Diagnostics page of GUI (b) Market Place

Fig. 5(a) shows the front end diagnostics page of Evolve system. As soon as the hardware is connected to a local Wi-Fi network, the user will be able to view this GUI from a browser on a PC connected to the same network. This page shows the basic details of the system, its status, system controls and inputs connected. Fig. 5(b) shows the market place from where new applications can be downloaded and installed. The applications manager page is where the installed applications can be viewed, uninstalled or have their settings changed.

IV. Conclusion

A low cost platform and associated sensors was developed and implemented for a Bionic hand. When compared with existing systems, it is much advanced due to ways in which users can add hardware module and new features for the system and customize it to their needs. Developers will be able to use this to work on their concepts rather than building a complete system from scratch. 3D printed hand and its 3D model will help the user to print parts that can be used to replace broken parts or built as modified versions suited to their needs. This system reduces the cost drastically by using a community driven software platform, low cost, high processing power hardware and an array of cost effective sensors built for bionic hands. Support for multiple modes of actuation and wired or wireless input also ensures that the user will be able to get a system customized for their needs and can have features that make their daily tasks easier.

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