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Development of a Local Prosthetic Limb Using Artificial Intelligence

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ABSTRACT: Electromyography is a special method for evaluating and recording the electrical activity produced by skeletal muscles. It detects electric potential generated through human brain by movement of the muscle cells. Detected signal can be used further into usable information to drive a control system. This paper presents the techniques to design Electromyography based prototype prosthetic arm, in such a way that can imitate the actions like a real human arm. Current prosthetic devices have limited functionality and are cost prohibitive. Designing a cost effective prosthetic human hand is the major focus of this paper. The design features five individually actuated fingers in addition to movable wrist design, which is unseen in commercial products. This study will serve as a platform for future prosthesis development efforts.

KEYWORDS: Electromyography; Prosthetics; Myoelectric; Prosthetic Hand.

I. INTRODUCTION

The development of an advanced human–machine interface is an interesting topic in the field of real world engineering and the biomedical signals, such as myoelectric or EMG (electromyography) signals have a key role to play. Using EMG signals in control systems is a sophisticated technique concerned with the EMG identification, detection, processing, cataloguing, and appliance of myoelectric signals to direct human-assisting robots or rehabilitation or transplantation devices. EMG control systems are used to evaluate electrical activity produced by gaunt or non-plump muscles and myoelectric signals are generated by contraction or flexion of human skeletal muscles, while prosthesis is an artificial organ extension that replaces a missing body part. So this project based study deals with the designing of an artificial humanoid hand for a handicapped (amputee) person based on electromyography systems.

Myoelectric signals (MES) restrain rich information from which a user's intention in the form of a muscular contraction can be observed, using biomedical equipments (in our case the equipment is SEMG electrodes). It has been observed that, amputees or disabled people are able to generate detectable, but progressively varying myoelectric signals during different levels of inert muscle contraction or dynamic limb flexion motion. These signals can be used in a myoelectric control system (MCS), to control rehabilitation devices or assistive robots. The major advantage of a myoelectric controlled devices over other types of control systems, such as body-powered mechanical systems, is its hands-free control; according to a users intention. MES is contained signal type, detected from the surface of skin, and can be made to order for relative strength or speed control in a control design. In myoelectric control, the muscle movement which is required to provide a MES signal, is precisely small and can bear a resemblance to the effort required from an undamaged limb [1].

Myoelectric control is now a proficient substitute to mechanical human-body powered prosthetics commercially available. It provides more proximal purposes and it's easy to design realistic cosmetic appearance. Furthermore, extensive applications using myoelectric control systems have been reported; like functional prosthesis, wheelchairs, grasping and gait generation control, virtual keyboards, gesture-based interfaces, virtual worlds, and diagnoses and clinical applications like functional neuromuscular stimulations. However, despite many advances, capabilities and potentials, myoelectric control has a significant distance from professional and commercial applications. It requires corresponding interfaces to deal with the needs for fine-tuned control and suffers a lack of sensory feedback in comparison to traditional control methods [2].

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II. RELATED WORK

It has been observed that user acceptance of modern prosthetics is aberrant due to their awkward actuation, complex control and requirement of prior training. This is because the modern prosthetic systems are still under their experimental level, and the researches are continuously made to reduce the hinderers up to highest extent. The focus of our research is to design and implement a prototype using modern Myoelectric technology, handling Electromyography (EMG) signals, and to setup a training-free usage functionality which will increase user acceptance ratio.

Several researchers have investigated a set of technological requirements that should be taken into consideration while designing a Myoelectric prosthesis. The design should be embedded with perceptive control in order to enhance the intentional sensing of EMG signals from skeletal muscles; this can be achieved by pacifying the signal flow from the surface electrodes to the controller. The signal flow is classified to effectively monitor user intention through surface EMG electrodes, controlling the actuations of prosthetic device with reference to the signal's amplitude, and sensory feedback to reduce erratic motion. Practical prosthetic organ should comprise each of these key requirements for effective signal flow; figure 1 depicts such a system. Electrodes; controlling the actuations of prosthetic device with reference to the signal's amplitude, and sensory feedback to reduce erratic motion. Practical prosthetic organ should comprise each of these key requirements for effective signal flow; figure 1 depicts such a system.

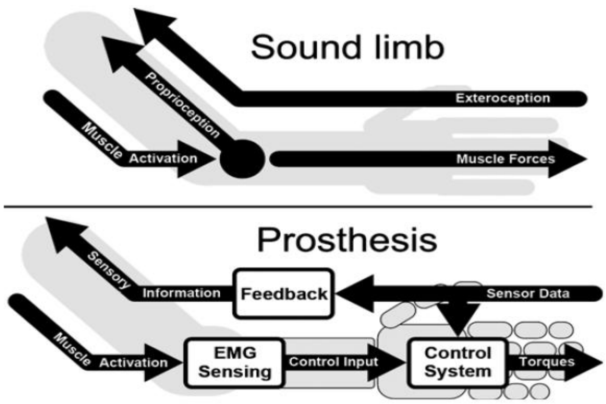

Fig.1. Comparison of signal flow in sound human forearm and desired signal flow

The functional prosthetic system design is categorized into three blocks, EMG sensing, Control System and Feedback System.

EMG Sensing: Myoelectric prosthesis utilizes EMG signals to control the movement of prosthesis. These signals are deposited on the surface of skeletal muscles, actually the signals are result of amputee‘s intention to move his/her organ attached; the neural activity of brain transmits the electric potential of miniature identity on the skin surface of skeletal muscle. The system should effectively accumulate the EMG signal in order to preserve every action at output.

Control System: Once the EMG raw signal is evaluated, it is needed to eliminate the noise caused by neighboring interferences and also to amplify the miniature electric potential to identify the activity. After amplification and filtration, the sensory data is used as an instantaneous input into an algorithm to control the physical prosthesis.

Feedback System: Modern prosthesis provides the systems with close-loop feedback which helps to reduce unwanted movements, improves synchronization and correlates the natural EMG signal with artificial sensory information. The addition of feedback systems has helped a lot to improve user acceptance ratio of myoelectric prosthetic devices. By combining the results of the experiments with the information obtained through the research, we constructed a list of requirements for each of the prosthesis subsystems, shown in table 1.

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TABLE .1 Requirement of prosthetic arm table

System	No.	Requirement
EMG	1	Multiple wrist movements and grasp types should be easily selectable.
	2	Control response time should be minimized enough to pretend realistic feel.
	3	The user should be able to control the grasp power and movement motion according to muscle contraction/flexion.
	4	Wrist movement and grasp type should be Simultaneously distinguishable.
Control	1	Available grasp types: cylindrical grasp, tripod grasp, lateral grasp.
	2	Available wrist movements: Flexion/extension and rotation.
	3	Prosthesis grip should keep the object in holding if once grasped.
	4	Prosthesis grip should prevent slipping or loosening of any held objects in grip.
	5	Grasp execution time and posture should not disturb user by vibration or inertia.
	6	User should be able to control speed of wrist movement and force of grasps by Intention, which involve amplitude recognition if EMG signal
Feedback	1	Continuous and proportional feedback on grasping force should be provided.
	2	Position feedback should be provided to user.
	3	Interpretation of stimulation used for feedback should be easy and intuitive.
	4	Feedback should be unobtrusive to user and others.
	5	Feedback should be adjustable.

III. PROTOTYPING MYOELECTRIC PROSTHETICS

Electromyography is mostly used in modern prosthetics and robotics automation controls. In order for a robotic prosthetic limb to work, it must have several components to integrate it into the body's function: Biosensors (that also can be standard EMG electrodes) detect signals from the user's nervous or muscular systems. It then relays this information to a controller located inside the device, and processes feedback from the limb and actuator (e.g., position, force) and sends it to the controller. The controller then commands an actuator that mimics the actions of a muscle in producing force and movement. Examples include a motor that aids or replaces original muscle tissue. Recently, robotic limbs have improved in their ability to take signals from the human brain and translate those signals into motion in the artificial limb using solely EMG based signals and electronic control processing units [4].

The Myoelectric Prosthetic Hand is designed in a more advanced way to control a robotic prosthetic hand by listening to muscles remaining in the residual limb that the patient can still contract. Because muscles contraction and flexion can generate small electrical signals according to the brain activity, and in order to capture those small signals, surface EMG (SEMG) electrodes are placed on the surface of the skin that can measure muscle movements. Although no buttons are physically pressed by the muscles in this case, their contractions are detected by the electrodes and then used to control the prosthetic hand in a way similar to the switch control method that was used conventionally. This advanced prosthetic hand is equipped with a microprocessor (computer chip) and delicate Ag/AgCl sensors that measure flexion and contraction of muscles and forces while a patient tries to move muscles left after amputation [4]. Over time, the microprocessor learns how the patient flexes and contracts muscles and constantly adapts the stiffness of the movement accordingly. With this prosthetic hand, the prosthesis looks and moves more like a natural hand than any other powered prosthetic hand. Each finger bends at the natural joints so that it can accurately adapt to fit around the shape of the object wanted to be grasped. The technology demonstrates the importance of building sensory feedback into prosthetic devices to make them better able to perform the motions of everyday life and in that sense it points to where the field of neural prosthetics is heading [5]. A microprocessor is used to interpret and analyse signals from muscle electrodes. The microprocessor receives signals from its SEMGs to determine the type of motion being employed by the amputee. The sensory signals are computed by the microprocessor are used to control the servo motor actuators in the finger and wrist joint,

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thus regulated by the extension and compression of a muscle connected with the electrodes. This prosthesis is completely controlled according to signal deposition by the brain activity, and is in closer approximation to an amputee's natural bearing. How the prosthesis applies to the human body is shown in fig. 2. Within the shaded region, this shows where the normal function of a joint which is then removed. To fix this, a different feedback loop is applied from different muscles to control the prosthesis.

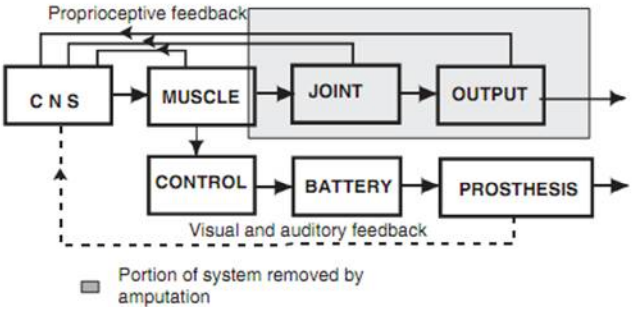

Fig.2. Myoelectric Control Relationship

Myoelectric control is formulated to grant a highly perceptive and handy control mechanism, and allows a high level of performance in terms of effective feedback according to user‘s intentions. Aspects of controllability in myoelectric control systems can be further briefed as following points:

1. Precision or accuracy of prosthetic action
2. Perceptiveness of triggering control
3. Response time should be synced with user‘s sensory

System accuracy is essentially required for intimating the actions according to user intention. It must be as high as possible, though it is difficult to define a threshold of acceptability, because no state-of-the-art scientific attempts or experimentations are done regarding this issue. Accuracy in prosthetics acts as a major concern in developing a prosthetic controller, so we can improve accuracy by filtering and extracting more data from skeletal muscle states, and implementing a potential classifier amplification that accomplishes the extraction process of required information.

Furthermore, involving the number of dynamic muscles that are used in data collection, and developing a feature set with rich information, leads to a boost in system accuracy. Additionally, non-spontaneous type of signalling mostly generates in a breach between a user‘s active and desired intention to allow an action of the prosthetic device. It is achievable by increasing or enhancing user‘s intentional knowledge, or by reducing the need of knowledge to complete an action and this strategy involves high feedback sensory phenomenon. The earlier prosthetics required broad training for amputee, while the later obliges towards development of effective and user-friendly interfaces and according to clinical observations, EMG systems are mostly emerging prosthetics considerations. Therefore, myoelectric control should possess qualities of remembering muscle foundation patterns as blueprint skeletal muscles that can be exercised in an accepted manner to actuate control actions. The ME systems must be sufficiently stout with different or simultaneously varying conditions during operation.

Finally, the response time should be synced accordingly with the feedback response of ME system and it should not cause hindrance perceivable by an amputee during maneuver. Compiling all stated would tend towards operating smooth and continuous control inflicting real-time controls on myoelectric control systems [7].

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IV. FUNCTIONAL DESIGN OF MYOELECTRIC PROSTHESIS

Myoelectric signals (MES) are accumulated by surface EMG electrodes, often called sEMG electrodes; placed on the skin over a skeletal muscle. Electrodes might need minuscule pre-amplifiers which are normally differential, used to differentiate small signals with respect to specific reference. To convert raw signals into useful data format, amplification, filtration, and ADC conversion is required by means of standard EMG instruments, and finally the data is inputted to a controlling system, which includes four main modules:

Data segmentation: involves different techniques that are implemented to manipulate information prior to feature extraction to enhance accuracy & feedback sync response time. **Feature extraction:** This module figure out the features like grasp, gait, pointing etc. for a classifier amplifier. Instead of working with raw signals, featured signal (recognized or learnt) are made input to classifier pre-amplifier to improve classification efficiency. Range or extraction of major effective features is the most crucial stage in myoelectric control design algorithm.

Classification: Classification module is useful to recognize patterns that are featured from signals, this module categorize the features into pre-defined categories. Because of micro-nature and complexity of biological EMG signals, and the manipulation of physical conditions, the amplifiers should be effectively full-bodied and intelligent enough. Amplifiers should be able to catch robustly the adaptive changes during prosthesis operation.

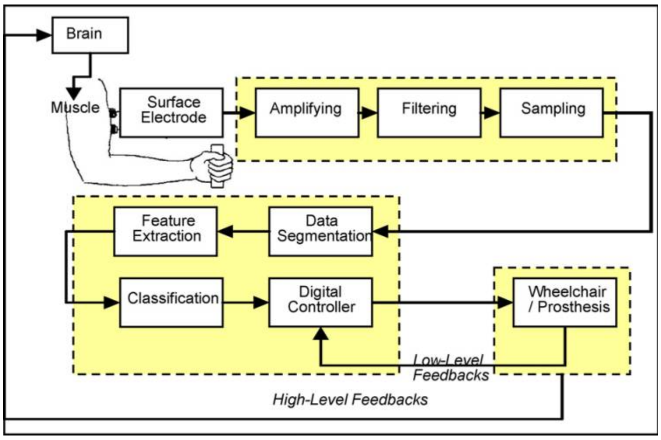

Fig.3. Functional Diagram of Myoelectric Control System [11]

Controller: Generates output commands based on signal patterns and control schemes. Post-processing methods, such as majority voting, which are often applied after classification to eliminate destructive jumps and make a smooth output, are included in this module too. Although some closed loop control schemes, such as obstacle avoidance, can be implemented using sensory feedback, myoelectric control structurally suffers from a lack of feedback. High-level feedback, such as visual or sensation information, can improve the quality of control and dexterity. Due to limits in applying feedback to a neuromuscular system, data fusion applied in MES, and complementary sensory feedback, can improve control performance. Each mentioned module has an important and inevitable function.

V. CIRCUITRY COUNTERPARTS OF THE SYSTEM

The functional design models experimented overview (refer to Fig. 3) of the overall working approach of a simplistic myoelectric system. We can briefly split the work approach into following divisions for better understanding:
a) Acquisition & Amplification, *b)* Algorithm Design, *c)* Prosthetic Structure

Acquisition and Amplification part emphasize the extraction of the signal from the skeletal muscles that is generated from brain due to muscle activity. An analog signal is deposited when person intents to move his/her hand, a simple SEMG surface electrode can be used to extract that EMG signal. Generally three terminal sensory electrodes channel is

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used, with positive channel, negative channel and reference junctions. For instance, the EMG signal generated due to hand closing and opening looks like the plot as shown in fig. 4.

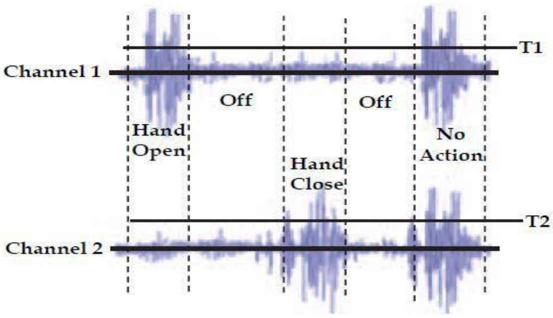

Fig.4. Tow channel EMG amplitudes based prosthesis control [10]

It is clear to recognize and control the prosthetic hand with two-channel terminal and a reference junction. But the signal we extract is relatively low and it needs to be amplified and filtered. **Amplification** section works in that case. A differential amplifier between two signals placed on a signal muscle is used which removes transducer noise and isolates the myoelectric signal, increasing the SNR by negating transducer noise. Since we are using surface mount electrodes, we expect our signals will be very noisy. We expect noise to come from heartbeat, surrounding muscles, temperature and the environment. We cannot have completely isolated movement of just one muscle 60 Hz from the environment. Therefore, a buffer circuit will be implemented between the electrode and the amplifier to protect the usable data. We will also be using lower power to drive out amplification to protect any harm from electrostatic discharge. Combining all factors, we find that the instrumentation amplifier is a type of differential amplifier that includes input buffers. Also, it is beneficial to our needs, because it has a very low DC offset, low noise and very high gain and high impedance. There is one op amp to buffer each input as shown in fig. 5.

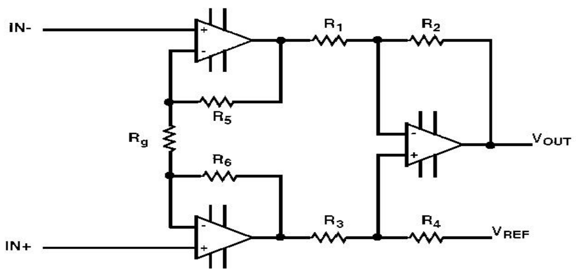

Fig.5. Instrumentation differential amplifier provides a buffer as well as high gain

Rg in the above circuit gives high gain using just one resistor. We have the option to build this circuit or purchase an integrated circuit form. The IC instrumentation amplifier would be more precise and it suppresses the transducer noise well. The 4-pole low pass filter will have to be designed around what signals and noise we get when we test the signal acquired from the electrodes. After successful extraction of data in form of analog or digital signals, a logic based **Algorithm** instruction is to be formulated. It is the most important phase to retain accuracy and precision in the movement of prosthetic hand. Determine what arm motion should occur based on the myoelectric signals from multiple electrodes. This is based on signal amplitude (minus the noise) and also on the signal shape and approximate frequency. The entire project is dependent on successful sampling and digital processing of the myoelectric signal. The FFT implementation could become incredibly complex. If frequency analysis falls through, we can try to collect all the information we need from the amplitudes of the different electrodes. We need to sample 5+ signals simultaneously. It is might needed to use multiple pre-amplifiers and micro-controllers to achieve this (depending on how many A/D conversions we can run on one unit). We would also like to program some easy realistic arm movements using heuristic rules. These are educated decisions on how some motors should operate based on operations of other motors. Generally the most acceptable technique is PID control, but it is not implemented in this domain. Implementing PID can drastically reduce erratic outputs. We can also program some easy realistic arm movements using heuristic rules. These are educated decisions on how some motors should operate based on operations of other motors.

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The overall objective was to build a prototype of a functional Prosthetic Design that replicates the actions and styles of a natural human hand. The characteristics of the prosthetic hand will involve individually actuated active finger, having three bending joints each. The palm skeleton would also hold a passive thumb that could be also positioned by EMG sensing but at relatively lower degree of freedom than fingers. The combined movement of fingers and thumb will provide effective grasp patterns and it will also improve holding power and precision.

Initially, the grip and fingers will remain voluntarily opened; a cable is rolled inside out the finger's joint like a pulley mechanism. One end of the cable is held with the top joint of the finger and the other end will be rolled with a servo pulley. The cable displacement is caused as the servo moves either in clockwise or anti-clockwise direction, causing the finger to bend accordingly. The passive thumb is also moveable with same phenomenon. This displacement is controlled according to the signal amplitude, which helps to provide power variation of grip when grasping fragile objects. Each finger is constructed of synthetic nylon plastic with pinned-hinge joints as shown in Fig.6. These joints offer complete finger bending without lateral deflection. The fingers are adjusted into their aluminium collars which are at stationary position, fixed at palm. This design offers highly reliable movement than current commercial prosthetics.

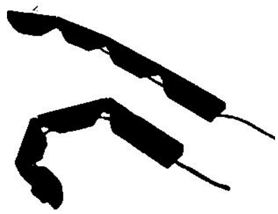

Fig.6. skeletal plastic fingers

Each finger is actuated by a cable running along each joint and their pulleys surface, the free end is then connected with the servo motors resting on palm. The finger design and physical movement fabricates like a realistic human hand fingers. The finger cable is pipelined at a single node in the end within the palm. The node is attached on the servo-head in specific harness style that resembles to the pulley mechanism. When the harness cable is rolled over the servo-head, tension in the finger cable forces the finger to bend. Harness-pulley string, a polyethylene fiber used for fishing, is used to actuate the fingers. This fishing string has adequate tensile strength and, when used in a Teflon liner, offers longer fatigue life than 1/16 in steel cable. Thinner and more flexible than steel, this string can be used within the skeletal nylon fingers that assume tight angles of bending during flexion. The low coefficient of friction, particularly in conjunction with its Teflon liner minimizes frictional losses in the internal mechanisms.

VI. ELECTRICAL POTENTIAL GENERATION

The electrical source is the muscle membrane potential of about –90 mV. Measured EMG potentials range between less than 50 μV and up to 20 to 30 mV, depending on the muscle under observation. Typical repetition rate of muscle motor unit firing is about 7–20 Hz, depending on the size of the muscle, previous axonal damage and other factors. Damage to pre-amplifier modular units can be expected at ranges between 450 and 780 mV. It has been observed through experimentation that the resting potential is about approximately -70 m.

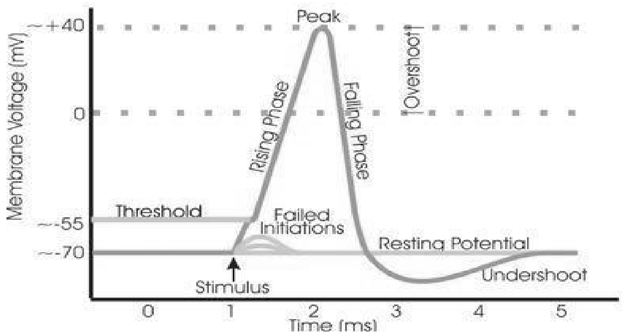

Fig.7. Membrane vs. Time relationship

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It has been observed through experimentation that the resting potential is about approximately -70 mV.

VII. SIGNAL ACQUISITION CONCERNS

Muscle Sensors can be designed to be used directly with a microcontroller. Therefore, our sensors do not output a RAW EMG signal but rather an amplified, rectified, and smoothed signal that will work well with a microcontroller ' s analog - to - digital converter (ADC). This difference can be illustrated by using a simple sine wave as an example in figure 8 below

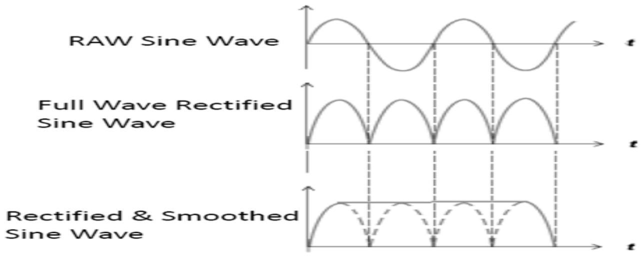

Fig.8. Simple sine wave [8]

There are three electrodes used per signal cable in electromyography, bi-polar nodes and a reference node. There is a differential amplifier between two signals, placed on a signal muscle which removes transducer noise and isolates the myoelectric signal, increasing the SNR by negating transducer noise. Modern electronics and the process of differential amplification have enabled the measurement of EMG signals of low noise and high signal fidelity (i.e. high signal to noise ratio). With differential amplification, it is now possible to measure the full effective bandwidth of the EMG signal. Typical bandpass frequency ranges are from between 10 and 20Hz (high pass filtering) to between 500 and 1000Hz (low-pass filtering). High-pass filtering is necessary because movement artifacts are comprised of low frequency components (typically <10Hz). Low pass filtering is desirable to remove high-frequency components to avoid signal aliasing. In the past, it was common to remove power-line (A/C) noise components (i.e. either 50 or 60Hz) by using a sharp notch filter. See Figure 3.3 below. There are problems with notch filtering because EMG has large signal contributions at these and neighboring frequencies. The result of notch filtering is the loss of important EMG signal information, so notch filtering should be avoided as a general rule [4].

Amplification is also necessary to optimize the resolution of the recording or digitizing equipment. Amplifiers of high quality have adjustable gains of between, at least, 100 and 10 000 to maximize the signal to noise ratio of the EMG signal during each recording. This range of gains provides the sufficient range of amplifications for surface EMG signals which can range typically from 0 to 6mV peak to peak. The quality of the EMG signal, in part, depends on the characteristics of the amplification process. While there may be several stages of amplification, the most important stage is often described as pre-amplification. Pre-amplification implies the first stage of amplification, close to the signal source. There are several important parameters in preamplifier signal conditioning of the EMG signal [6].

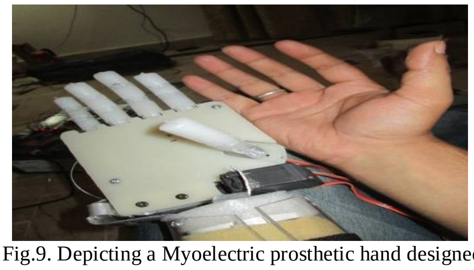
Fig.9. Depicting a Myoelectric prosthetic hand designed

VIII. CONCLUSION AND FUTURE WORK

The development of an advanced human–machine interface has always been an interesting topic in the field of real world engineering, in which biomedical signals, such as myoelectric signals, have a key role to play. Myoelectric control is an advanced technique concerned with the detection, processing, classification, and application of myoelectric signals

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to control human-assisting robots or rehabilitation devices. This research undergoes with recent experimented models and development of myoelectric control, and presents state-of-the-art achievements in terms of their type, structure, and potential application. This research leads as a platform for future developments in the field of myoelectric prosthesis. In order to improve the output, feedback response of the prosthesis can be evaluated using PID algorithms so that we can easily overcome the response time and steady state errors. Additionally, pattern recognition approach is highly useful to enrich realistic or semi-realistic hand actions. Furthermore, signal acquisition can be also improved using IC notch filters and high gain instrumentation amplifiers. The research is not limited to prosthetic upper-limb design, but it can be implemented to design other muscular limbs too (forearm, lower limbs etc.)

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