DEVELOPMENT OF A LIMB PROSTHESIS BY REVERSE MECHANOTRANSDUCTION

A THESIS SUBMITTED FOR PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

MASTER OF TECHNOLOGY

IN

BIOMEDICAL ENGINEERING

By:

AKHAYA KUMAR PADHI

(Roll no. 211BM1216)

Under the guidance of:

Dr. BIBHUKALYAN PRASAD NAYAK

Department of Biotechnology and Medical Engineering,

National Institute of Technology, Rourkela

CERTIFICATE

This is to certify that the project entitled, "**Development of a Limb Prosthesis by Reverse Mechanotransduction**" submitted by **Akhaya Kumar Padhi** is an authentic work carried out by him under my supervision and guidance for the partial fulfillment of the requirements for the award of **Master of Technology (M. Tech) Degree in Biomedical Engineering** at **National Institute of Technology, Rourkela.**

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any Degree or Diploma.

Date:

Place: Rourkela

Dr. Bibhukalyan Prasad Nayak

Dept. of Biotechnology & Medical Engineering

NIT Rourkela

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Akhaya Kumar Padhi

M. Tech (Biomedical Engineering)

National Institute of Technology, Rourkela

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ABSTRACT:

Recent developments in the field of limb prosthesis have focused on the use of body signals of the user to generate the desired motion in the prosthesis. Unlike earlier designs, this approach is more effective and less stressful for the amputee. The signals that have been used up till now are EMG signals, EEG signals and neural signals. Another possible source of body signal is the pH value of the neuromuscular junction, which depends upon the ion movements across the muscle tissue. Hence, it is safe to assume that changes in the pH can accurately mimic the intended changes in the amputated limb muscles, and therefore can be used to turn the user's desired motion into actual motion of the limb prosthesis. In the current model, this is achieved through the means of a pH-to-voltage converter that converts the pH value into voltage that is in turn used to drive the motor. The direction of movement is controlled by a microcontroller-based circuit. Further improvements can be made upon the model presented in this thesis, if the pH values could be more accurately read and employed to determine the direction of the movement of the finger too. Also, attempts can be made to apply the same working principle on more complex models of hand prosthesis, thus producing more applicable results.

Key words: EEG, EMG, Neural signal, limb prosthesis, neuromuscular junction, amputee.

CHAPTER 1

INTRODUCTION

1. INTRODUCTION:

The human body is a complex, but efficient machine. When it is at its best, it runs exactly like a well-lubricated machine. Each organ plays a very specific role, and when it is played to perfection, the machine runs smoothly. Almost all the organs and parts of the body (except the ones that have been rendered insignificant by evolution) are vital to its functioning. In some cases, owing to a birth defect, a disease, or an accident, a person might lose the function of one or more organs. The loss of function ranges from impaired ability to complete absence. In all such cases, one of the ways to make the life of the said person relatively normal is to integrate into his body a construct/implant that is referred to as an 'artificial organ'. It is needed for one or a combination of the following reasons:

1) For providing life-support while the person awaits a natural organ transplant.

2) For improving the overall ability of a person to carry out functions.

3) For helping the person deliver his social obligations and to enable him to interact with society.

4) For cosmetic purposes.

One of the abilities of vertebrate organisms like human beings is locomotion. A man is capable of moving from one point to another, and is also capable of moving an object from one point to another. Most of such motion is achieved by the application of limbs. The loss of a limb severely restricts a person's ability to perform or enable motion. In such situations, to restore the utility of the lost limb, an approximation of a natural limb is implanted or attached to the body. Such an approximate construct is referred to as a prosthetic limb, or in more common terms as an 'artificial limb'.

1.1 HISTORY OF ARTIFICIAL LIMBS:

Artificial limbs are not a modern invention. In less sophisticated forms, they have existed for most part of the history of civilization. They find mention in the *Rig Veda* [1] as being used by the warrior queen Vishpala. Excavations in Egypt have shown them to be present in Ancient Egypt as well. In a particularly telling revelation, a body with a wooden toe was dug out, which was then dated back to the New Kingdom [2] era of Ancient Egypt. The father of History, Herodotus, writes about the Greek diviner Hegesistratus, who replaced his foot with a wooden one after he had to chop it off in order to escape from his Spartan captors. In Roman history there is mention in the writings of Pliny the Elder of a General who used an iron-arm in order to hold his shield up in battle. However, in all these occurrences of their use throughout Ancient and Early Middle Ages, the prostheses were very rudimentary in nature. Their similarity to natural limbs, both in terms of appearance and functionality, was superficial at best. In some cases, they were used solely for aesthetic purposes, offering little or no function at all.

The first marginally sophisticated prosthetic limb seems to have been designed by the German mercenary Götz von [3] Berlichingen in the early 16th century. His model employed a series of catches and springs that made it move. Throughout the course of Renaissance the prosthetic limbs kept getting progressively more refined, and thus more functional. However, the groundwork for modern limb prosthesis was laid by Ambroise Paré [4]. Through his many inventions, he improved amputation surgery and showed possible ways in which natural movement could be approximated through artificial limbs. He incorporated adjustable harness and knee-lock control in his above-knee devices. Once Sir James Syme came up with a new method of amputation that did not involve amputating at the thigh, below-knee devices became possible.

Pieter Verduyn designed the first non-locking below-knee prosthetic. James Potts came up with a design that was made of a wooden shank and socket, a steel knee joint and an articulated foot that was controlled by catgut tendons from the knee to the ankle “Selpho Leg”. It was later improved upon by Benjamin Palmer who added an anterior spring and concealed tendons so as to mimic natural motion. The contribution of Dubois Parmlee, who created a prosthetic with a suction socket, polycentric knee, and multi-articulated foot, is also notable.

The development of limb prosthesis was further revolutionized with materials other than the more traditionally used iron, steel, copper, and wood starting to get used. Marcel and Charles Desoutter [5] designed the first aluminum prosthetic in early 20th century. They used the alloy duralumin to make the leg which weighed only half of what a standard wooden leg would weigh.

The biggest casualties of war are the limbs of the men and women in the armed forces. Naturally, following the Second World War, a significant amount of government spending was diverted towards research and development in prosthesis technology throughout the modern world. The Sabolich Socket was a major achievement that owed its evolution to the stress that was being laid on the need for better prosthesis. It was the torchbearer of a new revolution of the advancement of lower limb technology that started with the invention of Contoured Adducted Trochanteric-Controlled Alignment Method (CATCAM) socket by John Sabolich C.P.O in the early 1980s [6].

The 1990s saw the emergence of microprocessor-controlled prosthetic limb. The first one of the kind was commercially released by Chas. A. Blatchford & Sons, Ltd. in 1993, under the trade name ‘The intelligent prosthesis’. Further refinements in the technology, such as the use of hydraulic controls and pneumatic controls, led to the arrival of more responsive devices that could not only mimic natural [7] motion but also offered greater speed and comfort. One such device was ‘the Adaptive Prosthetic’ that was released by Blatchford in 1998. Stronger and lighter prosthetics started getting developed with the arrival of the new millennium, as the field became a beneficiary of the progresses made in Materials technology. New materials such as carbon fiber allow for less cumbersome limbs that require only a fraction of energy for their operation that the earlier devices needed. The technology of conversion of muscle movements into electrical energy allowed the advent of myoelectric limbs that are more sensitive and are capable of reading weak muscle signals and can convert them into corresponding movement, thus enabling less tiresome motion. CAD [8] based designing of prosthetics has begun to find extensive use in the manufacturing industry in the recent years, and has thus triggered a new phase in the development of prosthetics. Modern prosthetics have allowed amputees to accomplish miraculous feats. A case in point is that of the South-African double below-knee amputee Oscar Pistorius [9] who ran in 400 metres and 4 x 400 metres relay races at the 2012 London Olympics, and became the first amputee to win an able-bodied world track medal at the 2011 World Championships in Athletics.

Figure 1.1: ***Double Amputee Oscar Pictorius Running In The London Olympics 2012. (Reference: [10]).***

1.2 MECHANISM FOR PROSTHETIC MOVEMENT:

Historically speaking, prosthetics, more often than not, have been serving the cosmetic purposes and have offered little by way of functionality. Traditional prosthetics, like Jaipur foot, only allowed an amputee to deliver his most basic functions, like walking or lifting things. With modern advancements, they can now offer a whole range of functions and approximate the natural body parts remarkably. Prosthetics of today can allow multiple degrees of freedom where those of the past offered one at most or none at all.

The modern changes notwithstanding, the basic components of a prosthetic have more or less remained the same through the years. In some form or the other, the following three parts are necessarily present in a prosthetic:

a) Pylon – It is the internal skeleton of the prosthetic aimed at providing structural support. Metal rods have been used traditionally for the purpose, and in the more recent times, Carbon-fiber has been finding increasingly more application as the pylon. Sometimes, the pylon comes with a cover which can be matched with the amputee's skin tone to give it a more natural and aesthetic appearance.
b) Socket – It is the interface between the residual limb and the prosthetic device. It is the juncture through which the forces are transmitted between the limb and the device. It is what holds the prosthetic in place. The fitting of the socket is essential as it can often cause damage to the skin if it is ill-fitted. To achieve a more snug fit, an amputee might typically wear socks before putting on the prosthetic.
c) Suspension system – It is that portion of the prosthetic that keeps the prosthetic attached to the body. Different mechanisms can be applied to achieve suspension. Earlier devices employed harnesses that used straps or belts to hold it together. Modern devices, however, use the suction mechanism, wherein an air tight seal holds it in place.

Broadly speaking, prosthetic movement is of two types:

a) Body powered movement involves the use of the amputee's muscle, arm, knee, shoulder etc. to maneuver the prosthetic, depending on the location of the amputation. For example, a transtibial amputation allows a person the use of his/her knees. Thus a transtibial amputee would typically use his/her own knee to maneuver the artificial limb.

However, a transfemoral amputation denies a person the use of the knee. In such cases, the second type of prosthetic movement is attempted, which is:

b) Externally powered movement. It employs a battery and an electronic system to achieve movement. It is significantly less fatiguing than the body-powered movement and is more intuitive in design. For example, myoelectric devices record the minute muscle, nerve and/or EMB activities through sensors deployed for the purpose; translate them into electric signals, which in turn are employed to run motors that control the movement of the prosthetic. It is evident that the motion thus achieved is more natural and responds to the mental stimulus of the user.

The efficiency of a prosthetic is generally estimated by the fatigue it inflicts upon the user (the less exhausting it is, the better) and also by an empirical evaluation of how well it restores an amputee's ability to perform actions (including complex tasks) like a normal person. The first of these can easily be observed and improvements made accordingly by changes in design, use of light-weight materials, customization of the device to perfectly fit a particular individual, and similar (or a combination of such methods). The second, however, involves more complicated tasks. The complexity of the human body and the way it performs makes it difficult to mimic natural motion.

A good way to illustrate this would be the use of certain examples. A simple task of a person waving his hands is composed of a multitude of smaller tasks. For example, it requires an ability of comprehension of a 3D space, which enables the person to pre-determine the positioning of his hands in the said space. Once that is achieved, the next task involved is the lifting of hands in the necessary direction, and to the necessary extent. Simultaneously, the person also requires keeping the arm at a certain angle (or within a small range of angles) so as to give the motion an appearance of an attempted hand-waving. The next, and the last, step involves the to-and-fro motion of the arm about a mean position, along an axis passing through the elbow. Minor decisions like how many complete to-and-fro oscillations of the arm constitute a wave also come into play; and once that is decided by the person, a stop is put on the movement and the feat of hand-waving is achieved. This exhaustive explanation doesn't even begin to cover how the visual aspects of the entire procedure are processed by the brain and how that information is employed in its translation into desired motion. Additional complexity can also be deduced from the fact that even a seemingly simple-looking task like hand-waving is never perfectly repeatable. Another way of saying that is that no two hand-waves are identical, even if the person performing them is the same. To approximate such an indeterministic action is a herculean task and it can only be achieved with a reasonable amount of success by better understanding how natural motion works. As is perfectly clear from the given example, the execution of motion involves a brain-muscle nexus, so to speak, working in perfect tandem. The academic term that refers to this nexus between the brain and the musculoskeletal system is 'motor coordination', which is explained in the following section.

1.3 MOTOR MOVEMENTS & CO-ORDINATION IN HUMAN:

A human body is capable of carrying out intended actions through a mechanism of coordination between the nervous system and the muscles. This interaction between certain specialized neurons and muscles that precipitates in the achievement of desired motions in the most efficient, smooth and timely manner is called motor coordination. The neurons that facilitate this are called motor neurons. They are a part of the body's Central Nervous System (hereafter referred to as CNS) that project their axons outwards from the CNS and into the muscles, and thus control the movements of the musculoskeletal system, directly or indirectly.

1.3.1 Neuromuscular junction:

The motor neurons form very specialized synapses with the muscle fibers, which are called neuromuscular junction (NMJ). At NMJ, the motor neuron releases a flood of neurotransmitters upon adequate stimulation. These neurotransmitters bind themselves to postsynaptic receptors on the muscle fiber and trigger response in it, thus leading to muscle movement. In human beings, like all vertebrates, these neurotransmitters have an excitatory role. They lead to muscle contraction. The relaxation is achieved through inhibition by the motor neuron. Through, a series of contraction and relaxation, desired motion is carried out as instructed by the CNS. The motor neurons essentially carry signals from the spinal cord to the muscle fibers and can enervate multiple fibers at a time.

1.3.2 Central Command:

A typical motor task, like the one illustrated in the previous section, requires motor combination to work in order to get completed. The brain, at first processes the visual (and other sensory) information, and determines the course of action it has to take. Much of this information is proprioceptive in nature. The brain integrated this with the neural processes in the brain as well as in the CNS to plan an array of motor commands. In the hand-waving example, the brain employs a perception of the self, i.e. proprioceptive information estimating the possible positioning and motor capabilities, to determine what amount of strength is required to perform the task. In addition to this, it determines each and every step of the entire process, integrating the visual information (viz. the height to which the arm has to be raised, the angle that forearm has to make with the hind arm at the elbow joint, the amplitude of the to-and-fro motion of the forearm etcetera) with the said information about the musculoskeletal system. Once it has decided its *modus operandi*, the cerebellum issues a series of motor commands that are relayed through the spinal cord.

1.3.3 Action Potential:

These commands, transmitted in the form of nerve signals, lead to the release of neurotransmitters such as acetylcholine at the axon end. This is achieved by a cause-effect chain. The action potential along the axon causes depolarization of the axon terminal. As a result of this depolarization, there is a decrease in membrane potential, which then causes voltage dependent Ca^{2+} channels on the axon terminal to open up. Once these channels are open, there is an influx of Ca^{2+} ions into axon terminal which causes exocytosis of acetylcholine containing synaptic vesicles. The acetylcholine thus released diffuses across the synaptic cleft and binds to the acetylcholine receptors situated on the motor end plate. Upon the binding of acetylcholine on the receptors, a series of events is set loose. This includes the triggering of an electrical excitation of the sarcolemma by opening of the acetylcholine-dependent Na^{+} channels. The Na^{+} ions thus released find their way into the muscle cells and cause depolarization and generation of end-plate potential. Such depolarization at the neuromuscular junction spreads opening Na^{+} channels at the adjacent sites, thus generating a wave of end-plate potentials which result in the contraction of the muscle. A reverse process involving the inhibition of acetylcholine secretion leads to the relaxation of the muscle. A series of such contractions and relaxations of muscle results in the desired movement. These complex chemical processes, surprisingly, occur within a millisecond thus complicating our job of imitating natural motion through artificial means to a great extent.

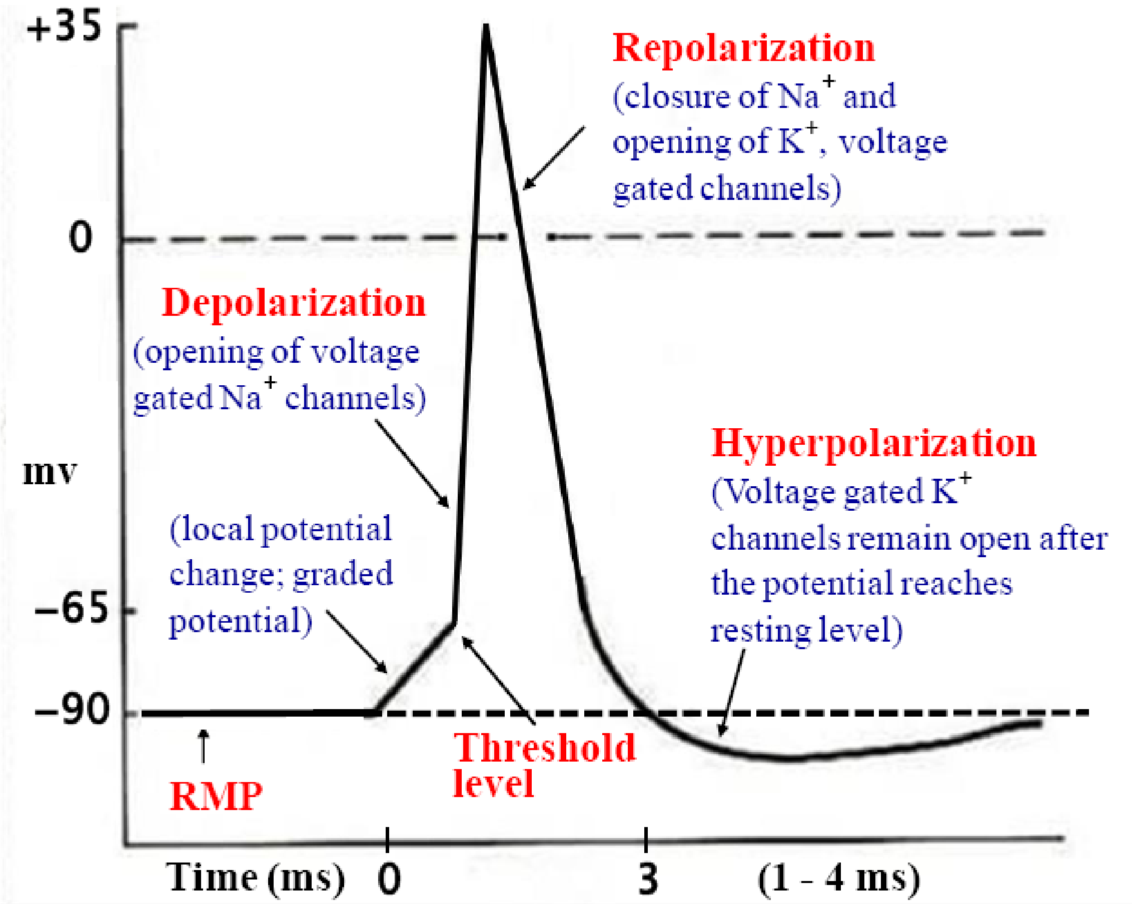

Figure 1.2: ***Stages of Action Potential. (Reference: [11]).***

CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW:

Current trends in prosthetic development focus on the use of signals that the human body produces in order to facilitate motor functions. The signals that are most used for the purpose are EMG signals, EEG signals and Neural signals.

In 1990 Wan et al. [12] suggested the development of an interface between the prosthetic nerves and artificial electrical components that could utilize the control signals coming from the brain to the limb, to control the movement of the replacement limb. They proposed that this could be achieved through the placement of a silicon block containing many small holes (12 µm diameter) at the plane of amputation [13]. They hypothesized that the neurons of the severed limb would grow into and through these holes, thus establishing electrical contact between the external prosthetic and the neurons. This, in turn, would allow the reception of sensory signals that the brain issues to the missing limb, and its translation into actual motion of the replacement limb.

The control signals sent by the brain to the arm/leg muscles are measured at the said neural-electrical interface chip and are then demodulated into pure electrical signals that represent firing rates. The further processing of these signals are done outside the amputee's body and are transduced over to the external mechanism for the same. The greatest challenge of this method is that the number of control signals generated by the brain is in the order of 20000 but only 48 signals can be employed to control the prosthetic limb. This is resolved via the use of a signal cluster that can combine the output of all the neurons that are responsible for the operation of a single muscle group. A neural network controller then generates the required control signals to operate the prosthetic.

A schematic diagram proposed by Wang et al. is given below.

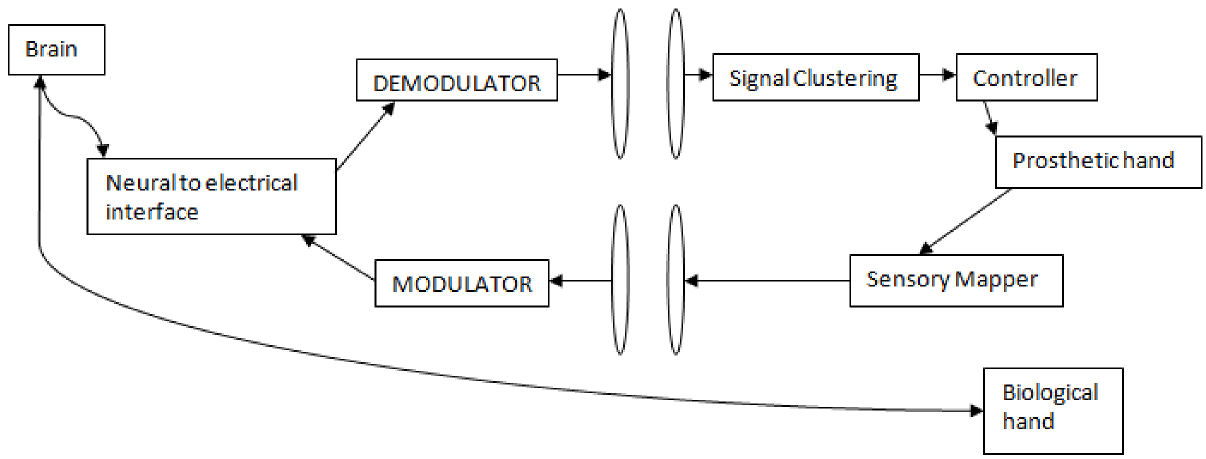

Figure 2.1: ***Architecture for using neural networks to control a prosthetic hand (Wan, et al, 1990).***

In 1991, Ito et al. [14] proposed a method which has the ability to differentiate the intended motion amongst six different kinds of limb movements and choose which one to process. It used multichannel EMG signals pre-processed by a band-pass filter and smoothing filters. The electrode locations can be made flexible by the use of the cross-information amongst the EMG signals. The amplitude and frequency characteristics of the EMG signals are provided by the mentioned filters. This method was designed to be sensitive to gradual changes in EMG patterns using neural networks to do the discrimination. The suggested neural network comprised of two separate sub-systems: the first one was a Hop-Field neural network to extract the features from the EMG, and the second one was an error-back propagation neural network to categorize the feature set.

In 1996, Akazawa et al. [15] published work that proposed a new type of myoelectric prosthetic arm, called Biomimetic EMG-Prosthesis hand that was able to simulate the basic dynamic properties of the neuromuscular system of the human hand.

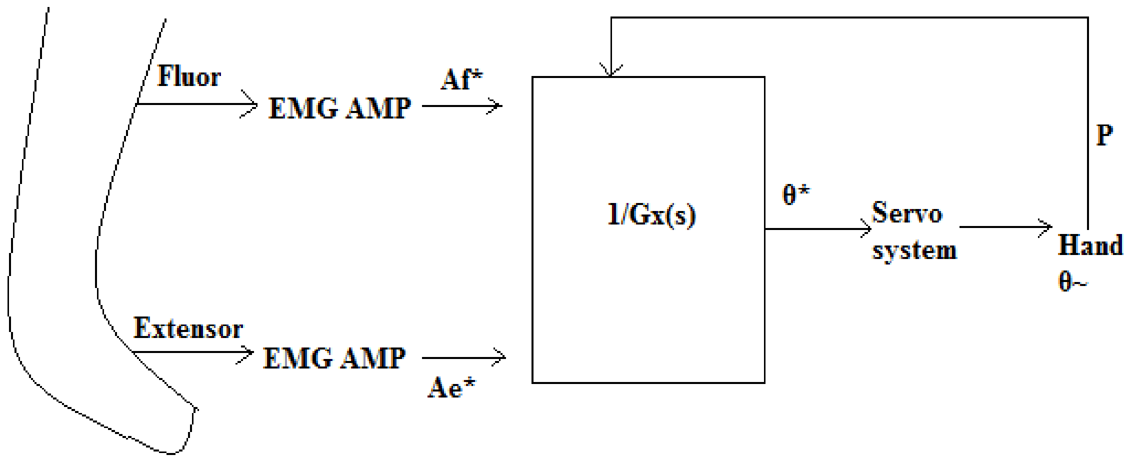

Figure 2.2: ***Architecture Block Diagram of the Prosthetic Hand (Akazawa Et Al, 1996).***

The essential parts of the prosthetic hand were an EMG signal processing unit, a simulation system of neuromuscular system dynamics, and a servo system connected to the terminal device which is the mechanical hand having one degree of freedom. The processing unit calculates the isometric torques of the flexor and extensor muscles. The θ^* is calculated from the measured gripping force P and the torques estimated by the processing unit. The servo system ensures that the angle of the finger of the terminal device in in sync with this angle. This set-up showed encouraging results in the gripping of a soft object.

Kajitani et al. [16] published a paper proposing a hardware chip for prosthetic hand controller in 1999. The Evolvable Hardware chip, hereafter referred to as EHW, showed a shorter learning time than the neural network based models and an increased efficiency in performance. EHW consisted of Genetic Algorithm hardware, reconfigurable hardware logic, a chromosome memory, a training data memory, and a 16-bit CPU core (NEC V 30). For the circuits based on EHW, the average of each action output rate was found to be 85%, which is 5% above that of neural network based circuits. Also, the learning time was significantly short, 800 ms for the EHW against 3 hours for neural networks, which by any measure was a huge improvement and proved that the EHW is a better candidate for myoelectric prosthetic controller chips.

In 2007, Murguialday et al. [17] designed an EEG-based motor imager Brain-Computer Interface (BCI) with the ability to control the movement of a prosthetic hand. The instrumentation of the hand included force and angle sensors to provide haptic feedback and local machine control. This particular design was an improvement over a majority of the previous proposed designs because it used a non-invasive BCI platform. This model used visual as well as vibrotactile haptic feedback and was based on modulation of mu (8-12 Hz) rhythm activity via motor imagery tasks. This provided the user with closed-loop control, and the device was more perceptive towards the user as well as more flexible in force modulation.

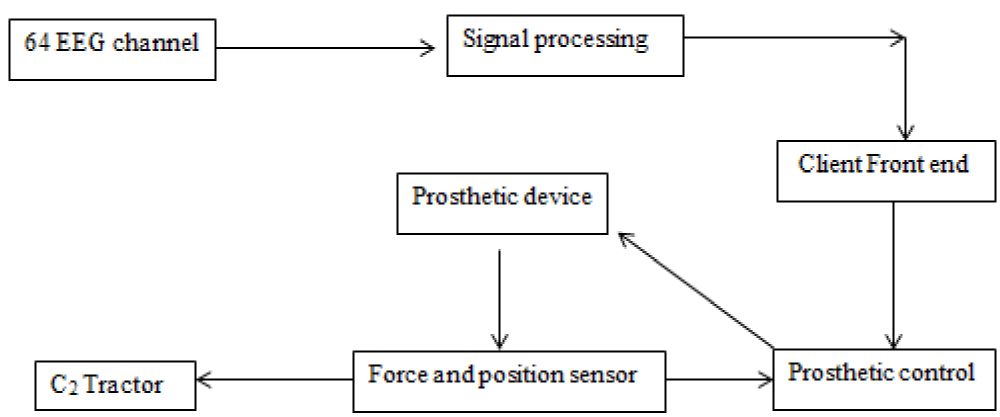

Figure 2.3: ***Experimental Setup Used By (Murguialday Et Al*, 2007)**

Also, in 2007, Mainardi et al. [18] presented a design of an innovative input source for EMG upper limb prosthesis- a laryngophone, also known as the throat microphone. Vocal commands allow the amputee to have better control over the prosthetic device. It used a voice recognition system constituting of a t-mic (for input) and a recognition-core, which was actually an embedded module with several interface signals. Its programming was done in C by using a development board, and was then connected with an embedded hardware. In the two-phase voice recognition process, the system is first taught which words to recognize and then made to compare and match those with the sounds the user makes while speaking those words. In this particular work, a t-mic was preferred as an input device because a conventional microphone uses air-pressure created by the utterance of a sound to create an electrical signal while a t-mic utilizes throat vibrations for the purpose, thus making it more accurate and error-free. This model showed good results with the system recognizing 97% of the words spoken by the user, on an average, and producing the relevant movements in the prosthesis.

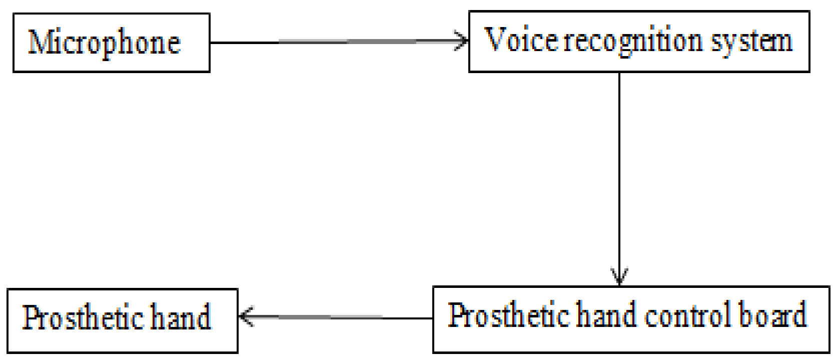

Figure 2.4: ***Architecture for Controlling Hand Prosthesis (Mainardi Et Al, 2007).***

In 2011, Carpuneto et al. [19] presented a paper proposing the use of neural electrodes implanted in the peripheral nervous system to restore sensory-motor function in subjects affected by neurological disorders, injuries or amputation, thus providing a novel approach for the control of hand prosthesis. The particular type of electrode used was the intra-fascicular electrode evolved from TIMEs and LIFEs, is made up of thin films of polyimide, and has two lateral wings for each side in addition to the main shaft. There are two phases in the working, one involving the insertion of the electrode through a pre-made hole and the second involving its partial extraction that allows the wings to unfurl through the tissue. The EMG signals obtained from the electrode are further amplified using commercially available amplifier with certain characteristics. The amplified signals are then de-noised using invariant wavelet transform technique, following which a spike detection and sorting technique based on template matching is used on them. A SVM classifier was trained to classify the feature vector. The decoded information from the motor LIFE signals was then used to control the external hand prosthesis remotely.

In a paper published in 2012, Gonzalez et al. [20] explored the effects of using auditory display to monitor the movements of the prosthetic hand during a complete 'reaching and grasping' task designed for the purpose. Instead of the visual feedback system used earlier, they attempted to use auditory feedback as the sensory feedback system with an aim to improve the motor-sensory performance of the user and decrease the burden at the same time. The results of the study showed a marked improvement in the manipulation of the prosthetic and also lesser mental fatigue.

In 2013, Tello et al. [21] proposed a method of classification of motor tasks using Surface Electromyography (sEMG), with an aim to utilize the classification to ease the control of the prosthesis for the amputees. For the classification, two types of classifiers, K-Nearest Neighbor (K-NN) and Bayesian were compared. Real time simulation was done using the sliding window technique and certain parameters viz. RMS (Root Mean Square), VAR (Variance) and WL (Waveform Length) were used for the purposes of feature extraction. The validation of the classification was done by a proposed model of reclassification using cross-validation. The design was implemented on a computer interface utilizing a simulation of the prosthetic developed using MATLAB™ and Visual C++™. The experiment used four separate group of motor tasks, and the results showed almost 100 % hit rates in the motor tasks including wrist movements in the case of Quadratic Bayesian classifier, and above 98% at the least, in the less complex motor tasks of Set 1-2. However, the linear Bayesian classifier showed significantly lower hit-rates across the task sets, whereas the K-NN classifier showed better accuracy.

CHAPTER 3
OBJECTIVE

3. OBJECTIVE(S):

1. Fabrication of a hinge system that will simulate a mechanical joint.
2. To move the mechanical joint in response to pH change in a biological fluid using a pH electrode and microcontroller assembly.
3. Finally, to incorporate the control unit (pH electrode-microcontroller) and end organ (mechanical joint) in an embedded system that can project neuron-neuromuscular junction-muscle fiber sequence in a biological system.

CHAPTER 4

MATERIALS AND METHODS

4. MATERIALS AND METHODS:

4.1 WORKING PRINCIPLE:

Our model utilizes the changes if pH value of the neuromuscular junction to generate movement in the prosthesis. For this purpose, a pH meter is first used to measure the pH values. Once this value is recorded, it is then converted into the corresponding voltage value using a pH-to-voltage converter. The more a user tries to move the hand, the more changes there will be in the pH value of the neuromuscular junction. The corresponding voltage, therefore, shall also be higher. The voltage that is thus generated is used to run the motor that is, in turn, connected to the artificial finger (representative of the artificial hand). Once the motor runs, its rotation is converted into motion of the finger through a spring and thread mechanism. The direction of the motor's movement is controlled through a microcontroller AT89C52 and the Arduino circuit. Depending on whether the motor runs clockwise or anti-clockwise, the direction of the movement of the finger also changes.

4.2: COMPONENTS USED FOR THE CURRENT PROJECT:

4.2.1: AT89C52 microcontroller:

Microcontroller AT89C52, manufactured by Atmel Corporation, is a cheap, high performance, low-power, CMOS 8-bit microprocessor with 8 Kb ROM (Flash programmable and erasable read only memory). AT89C52 and AT89C51 are compatible and comparable twins of each other, both manufactured by Atmel. It is highly-flexible and cost-effective solution to many embedded control applications.

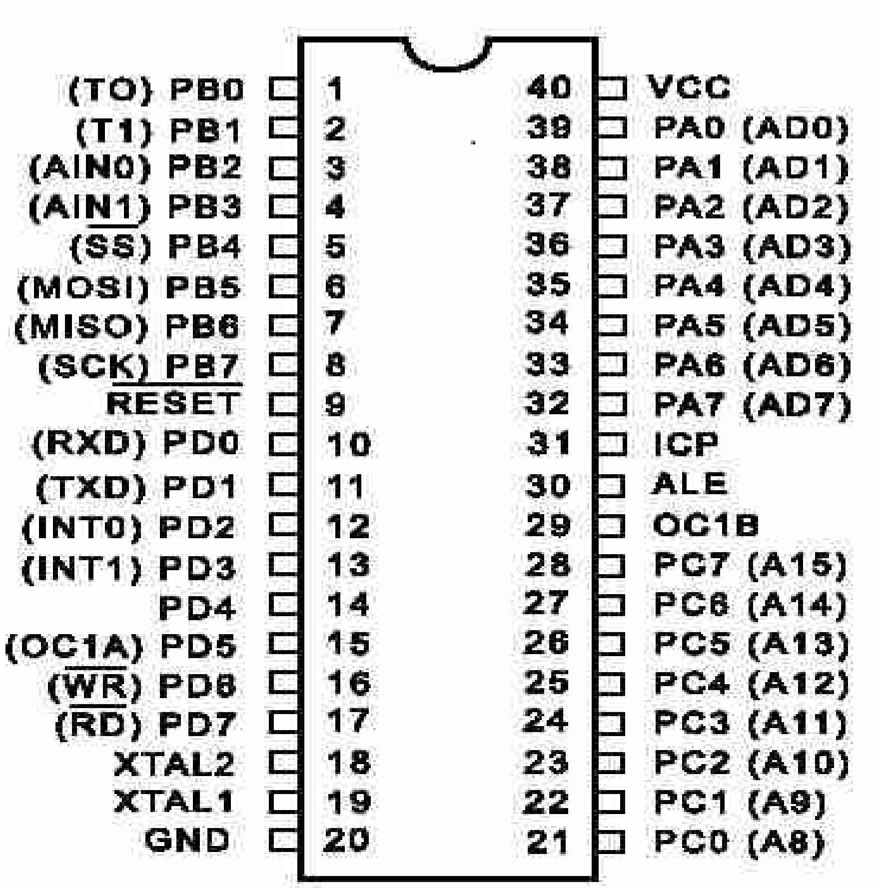

Figure 4.1: ***Pin Diagram of 40 Pin AT89C52 Microcontroller.***

4.2.2: High-voltage, High-current Darlington transistor arrays (ULN2003A):

Darlington Pair IC ULN2003A is a high-voltage high-current Darlington transistor array. It consists of seven npn Darlington pairs that feature high voltage outputs with common-cathode clamp diodes for switching inductive loads. The collector-current rating of a single Darlington pair is 500 mA. The Darlington pairs can be paralleled for higher current capability. Figure**4.2** shows the logic circuit of ULN2003A.

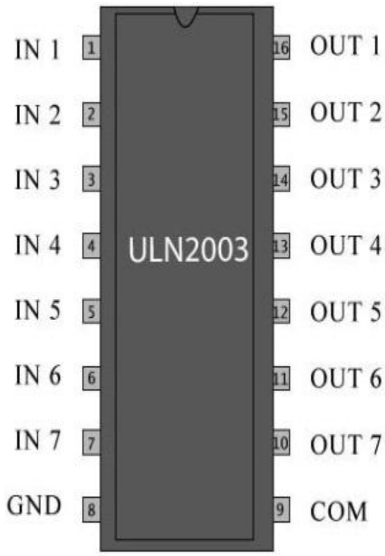

Figure 4.2: ***ULN2003 Pin Diagram.***

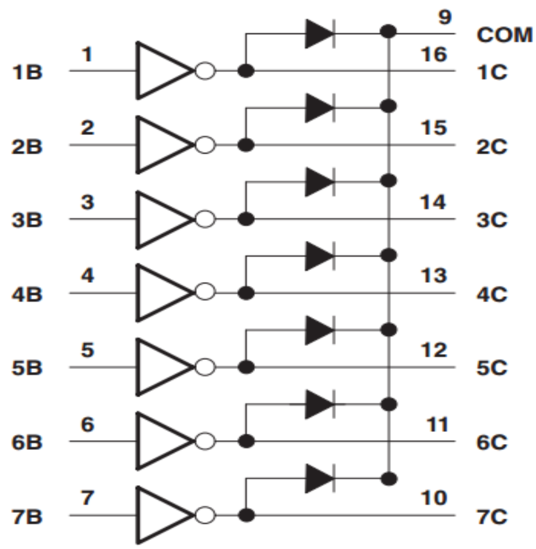

Figure 4.3: ***ULN2003 Logic Diagram.***

4.2.3: CRO (Cathode Ray Oscilloscope):

The cathode ray oscilloscope (CRO) is a device which converts electrical energy into a graphic image, called the trace. It is a vital piece of diagnostic lab equipment for observing and measuring electrical signals at frequencies ranging from dc to GHz. The CR0 is a good device for measuring voltage because it has a very high internal resistance (> 1 MΩ) and does not interfere very much with the operation of the circuit under investigation. The trace can be analyzed in terms of voltage (vertical axis measurements) and time (horizontal measurements).

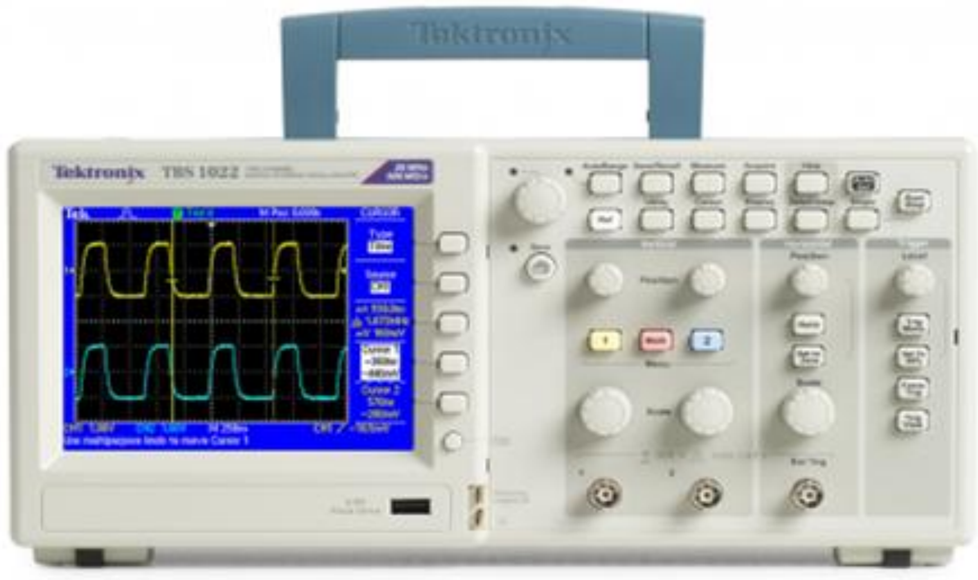

Figure 4.4: ***Cathode Ray Oscilloscope (CRO).***

4.2.4: Function Generator:

A function generator is usually a piece of electronic equipment or software used to generate different types of electrical waveforms over a wide range of frequencies. The function generator produces a time-varying voltage signal at its output terminal. The Tektronix 3021B is capable of producing several standard waveforms (sinusoidal, square, triangle), as well special-purpose user defined waveforms. Although function generators cover both audio and RF frequencies, they are usually not suitable for applications that need low distortion or stable frequency signals. Function generators are used in the development, test and repair of electronic equipment. For example, they may be used as a signal source to test amplifiers or to introduce an error signal into a control loop.

Figure 4.5: ***Function Generator.***

4.2.5: Arduino Uno:

Arduino Uno is a mini-size portable microcontroller board manufactured by Arduino Co. Fig. **FIGURE 4.6** shows the Arduino Uno board. Significant features of this microcontroller include six analog input ports (A0 – A5), a 5V and 3.3V DC power supply ports and 14 Digital output ports. Arduino Uno can be easily programmed in basic C or C++ language. Arduino Co. itself has developed softwares, based on C or C++ as a platform, to program the microcontroller. Interfacing with any computer is very easy using the USB cord.

Figure 4.6: ***Arduino Uno by Arduino Co.***

4.2.6: Ringer lactate solution:

It is a fluid and electrolyte replenisher also called Hartmann's solution. Ringer lactate solution is a standardized sterile physiologic–ie, isotonic– 0.9% solution containing calcium chloride, KCl, NaCl, sodium lactate.

Composition of ringer lactate solution:

Table 1: ***Composition of Ringer Lactate Solution.***

Ingredient(m.w)	mM	Grams per Liter
Nacl (58.44)	130	7.60
Kcl (74.55)	6.0	0.45
$Mgcl_2.6H_2O$ (203.3)	0.7	0.143
$NaH_2PO_4.H_2O$ (137.99)	0.29	0.04
$NaHCO_3$ (84.01)	19.6	1.65
$Na_2HPO_4.7H_2O$ (268.1)	1.3	0.35
$CaCl_2.2H_2O$	3.0	0.44
D-glucose (180.16)	11.0	1.98

4.2.7: pH Meter and Glass Electrode:

A pH meter is an electronic device used for measuring the acidity or alkalinity of a liquid. Every pH meter consists of a special measuring probe called pH electrode or electrode which is connected to an electronics meter that measure and display the pH reading.

The glass electrode is a type of ion selectivity electrode made of a doped glass membrane that is sensitive to a specific ion. The electric potential of the electrode system in solution is sensitive to changes in the content of a certain type of ions, which is reflected in the dependence of electromotive force (EMF) of galvanic element concentrations of these ions.

Figure 4.7: ***pH Meter and Glass Electrode***

4.3: pH READING TO VOLTAGE CONVERTER:

Usually, while using a microcontroller to display a decimal number on a seven-segment display, 4 inputs in the form of BCD codes are used. In our model, the same principle was used.

However, since we have kept the pH value below 7, the BCD values and binary values are equal. So we don't need to use the BCD-to-decimal conversion algorithm, and we use binary to decimal conversion instead. For all practical purposes, in this work, this is perfectly applicable and a lot simpler than BCD-to-decimal conversion.

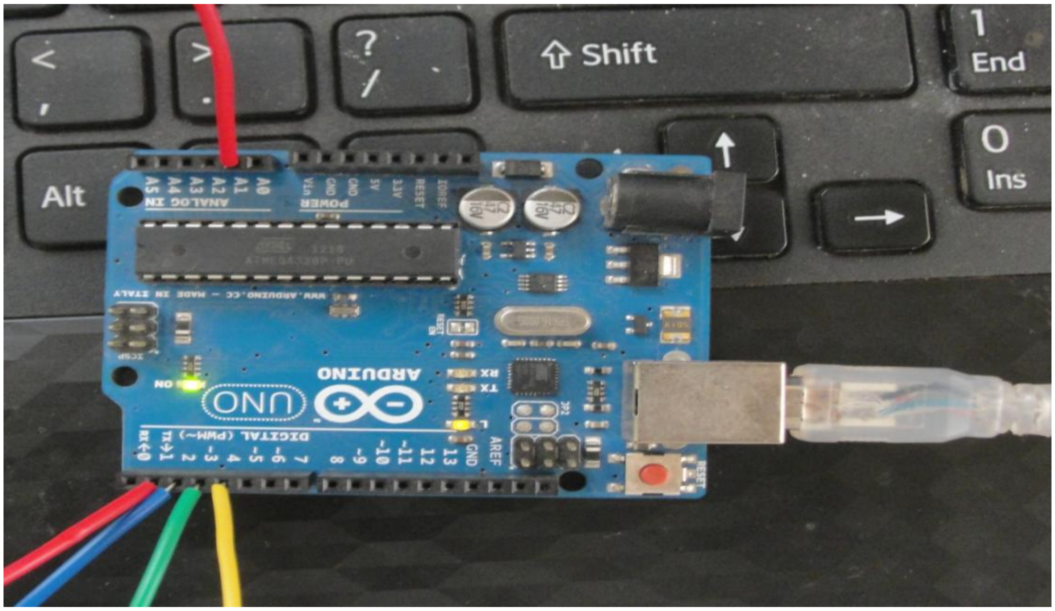

Figure 4.8: ***Whole Circuit Diagram for pH Reading to Voltage Converter***

After the conversion, the generated decimal number was mapped by the program to pre-defined voltage values. For example, if the generated number is 5, then the output voltage shall be 1.5 V. For values less than 5, the corresponding voltage is 1 V and for higher values, it is 2 V.

4.3.1: Arduino Code for pH to voltage conversion:

```
int binary2decimal(byte b)
{

  int dec = 0;
  int power = 1;
  byte mask;
  int weight;
```

```
  for (mask = 0x01; mask; mask <<= 1)
  {
    if (b & mask)
    {
      weight = 1;
    }
    else
    {
      weight = 0;
    }

    dec = dec + (power * weight);
    power = power * 2;

 }

  return dec;
 }

int pwmPin = 9; // output pin supporting PWM


float volt=0;// variable to hold the voltage read

float volt_out;


int value_out;

void setup()

{

 pinMode(pwmPin, OUTPUT); // sets the pin as output

}

void loop(){


  //suppose given voltage is volt//
```

```
 if (volt>3.0)
   volt_out=2.0;
 else if (volt<3.0)
   volt_out=1.0;
 else if (volt==3.0)
   volt_out=1.5;
   value_out = 255*(volt_out/5);
     analogWrite(pwmPin, value_out);
}
```

4.4: COMPARATOR USING OP-AMPS (OP07):

4.4.1 Op-amp (OP07):

The OP07 offers excellent performance in applications requiring low offset voltage; low drift with time and temperature and very low noise. Linear OP-07 is interchangeable with many of the precision op amp device types.

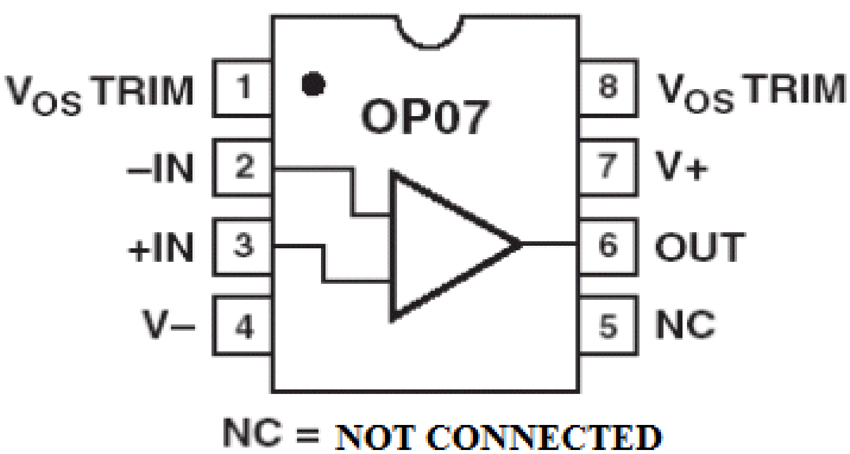

Figure 4.9: ***Pin Configuration of Op07***

The OP-07 also offers a wide input voltage range, high common mode rejection and low input bias current. These features result in optimum performance for small signal level and low frequency applications. Figure 3.7 represent the pin configuration of OP07.

4.4.2: Use of Voltage Divider Circuit:

The voltage divider circuit is a linear circuit that produces an output voltage (V_{out}) that is a fraction of its input voltage (V_{in}). The voltage divider consists of two resistors in series or a potentiometer. It commonly used to create a reference voltage, or to get a low voltage signal proportional to the voltage to be measured, and may also be used as a signal attenuator at low frequency.

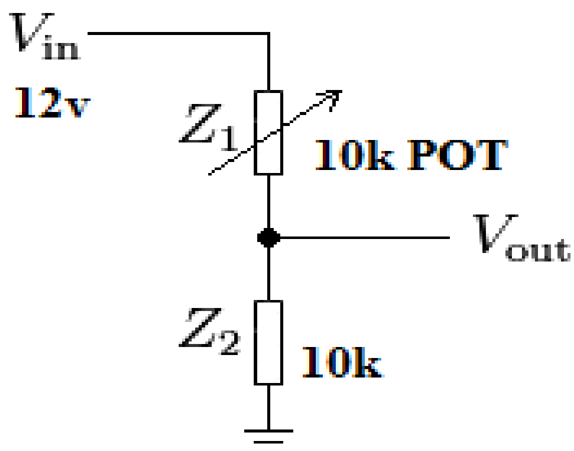

Figure 4.10: ***Diagrams for Voltage Divider Circuit.***

4.4.3: Installation of Comparator Circuit:

The comparator circuit consists of an op-amp (OP07), the inputs of which are taken through pins 2 and 3. The first input is the output of the pH-to-Voltage conversion circuit which is taken through pin 3. For the pin 2, the input is the output of the voltage divider.

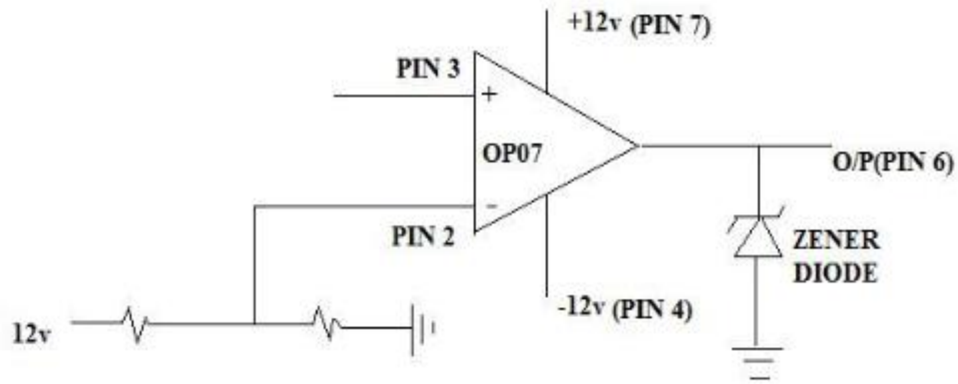

Figure 4.11: ***Comparator Using Op-Amp***

The 12 V DC supply is provided to the op-amp through pin 4 and pin 7. The output is taken from pin 6. This output is then given as input to the microcontroller AT89C52, which is used to control the direction of the motor's rotation.

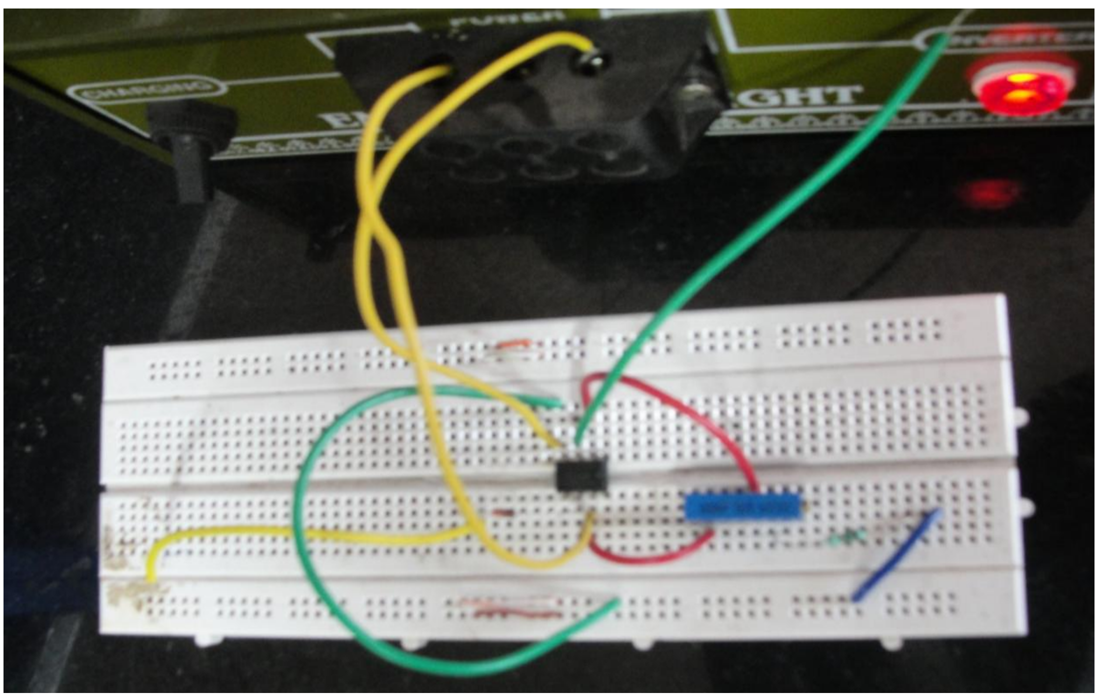

Figure 4.12: ***Whole Circuit Diagram for Comparator Using Op-Amp (Op07)***

4.5: STEPPER MOTOR DRIVER CIRCUIT (using AT89C52 and ULN2003):

The Stepper Motor controller circuit is shown in **Figure 4.13**. The motor was driven by Darlington pair ULN2003 (Pin Diagram: **Figure 4.2**) coupled with Microcontroller AT89C52, commonly known as 8052 Microcontroller (Pin Diagram **Figure 4.1**).

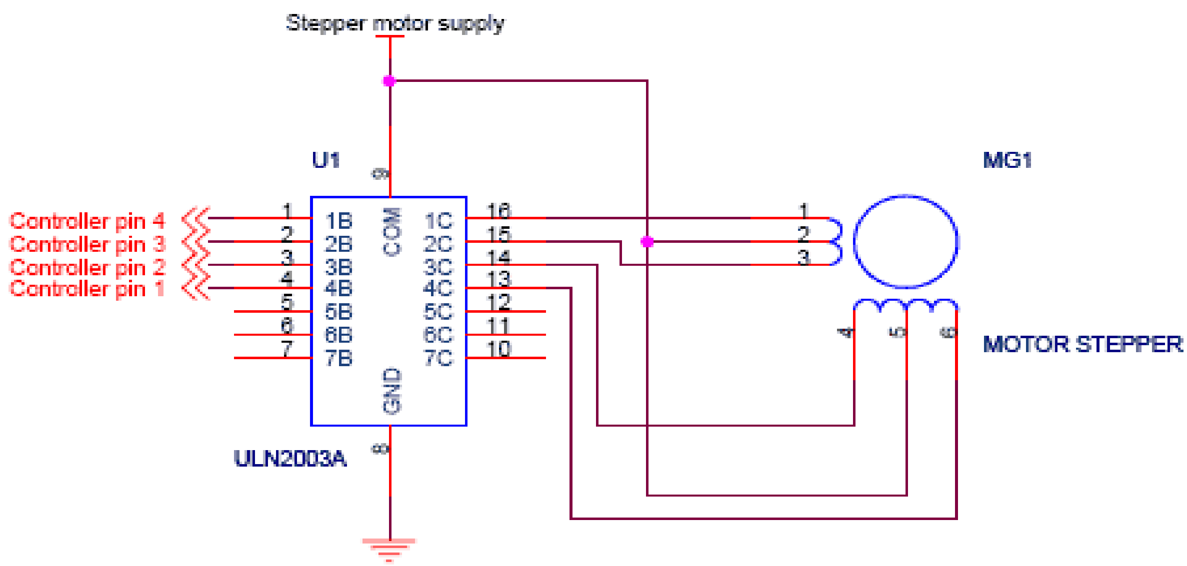

Figure 4.13: ***Circuit Setup for Driving Motor Using ULN2003A And Microcontroller.***

AT89C52 or 8052 microcontroller was programmed using Superprogrammer 580-U and Superpro software. First of all, the C code was written for stepper motor drive, it was then compiled in Keil's µVision IDE for 8052 and hence a .HEX file was generated. After the generation of the .hex file, the file was dumped onto the 8052 microcontroller using the Superpro 580-U. Figure **4.14** shows the Keil's µVision IDE Environment as well as the code used.

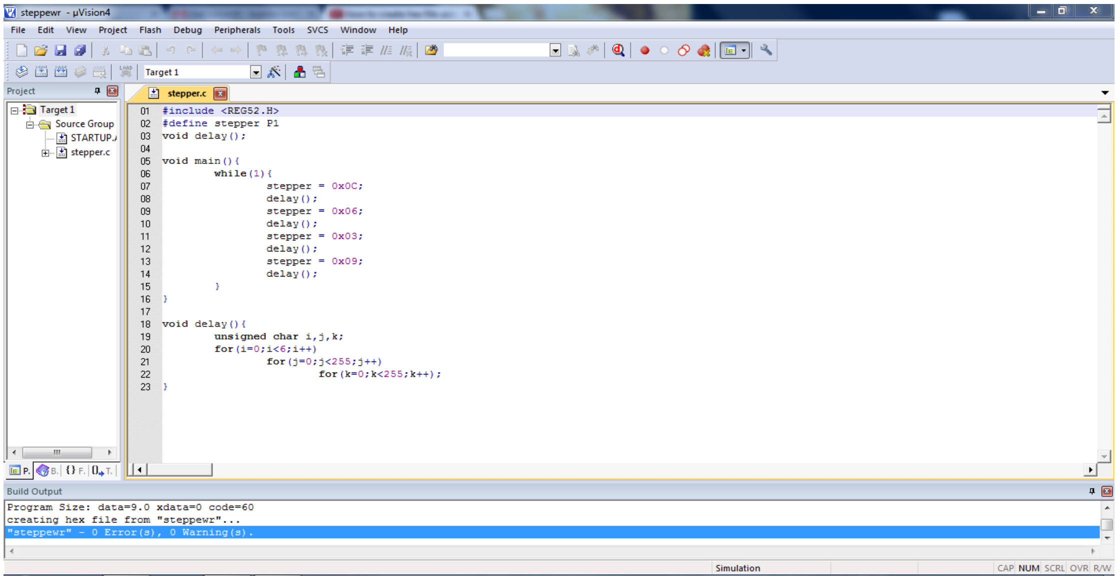

Figure 4.14 ***Keil's µvision IDE Environment and the Code Written For 8052. In The Bottom, It Can Be Seen That An Output Is Printed As "Creating Hex File From "Stepper"… Which Indicated Successful Compilation Of .Hex File to Be Dumped Into the 8052 Microcontroller.***

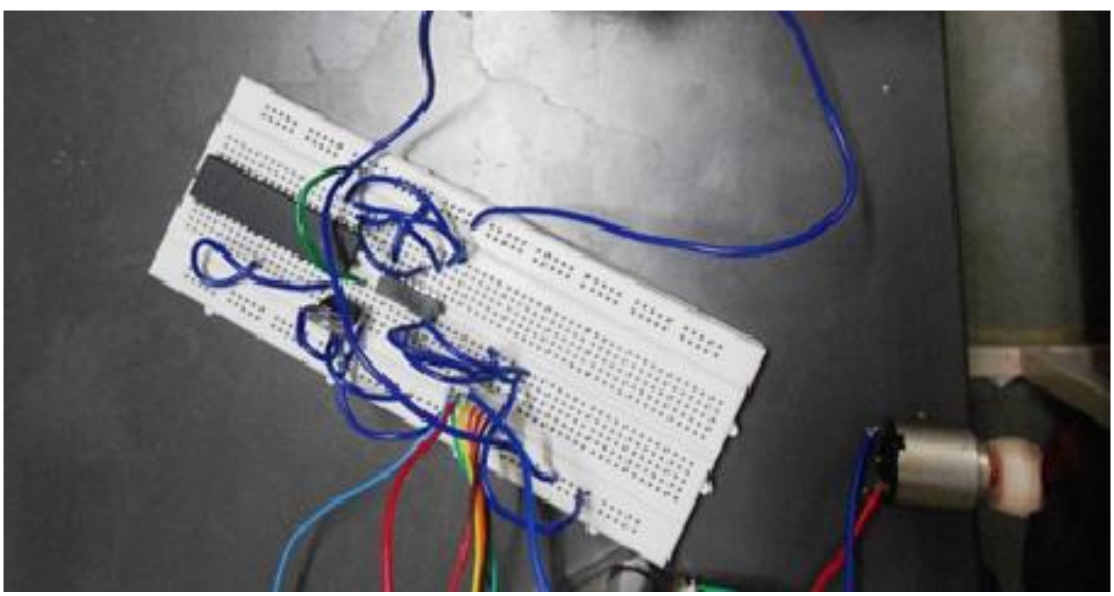

Figure 4.15 ***Whole Circuit Diagrams for Motor Control Using Microcontroller and ULN2003.***

4.6: STEPPER MOTOR DRIVER CIRCUIT (using Arduino Uno and L293D):

The L293D is designed to provide bidirectional drive currents of up to 600-mA at voltages from 4.5 V to 36 V. L293D is designed to drive inductive loads such as relays, solenoids, dc and bipolar stepping motors, as well as other high-current/high-voltage loads in positive-supply applications.

Working Principle of L293D:

Table 2: ***Working Principle of L293D***

Input 1	Input 2	Motor movement
HIGH	Low	Anticlockwise
LOW	High	Clockwise
HIGH	High	Stop
LOW	Low	Stop

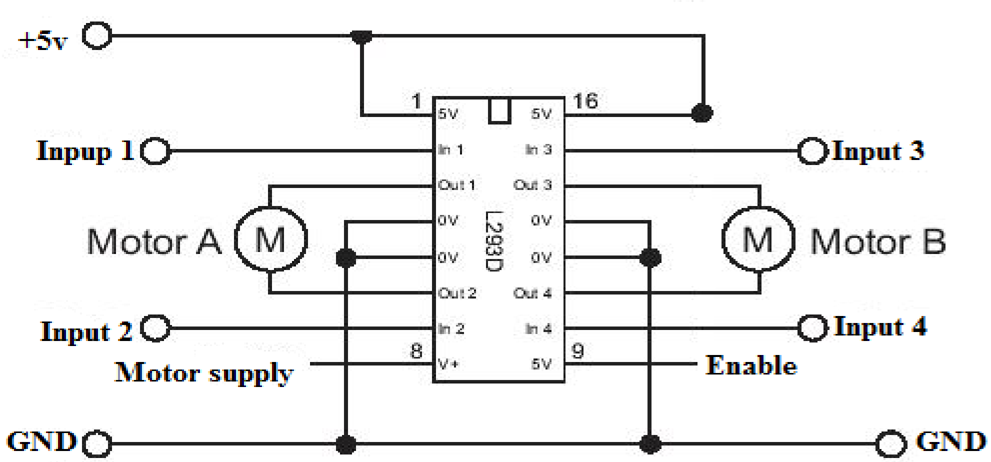

Figure 4.16 ***L293D Motor Driver Ckt.***

Input 1: pin 2 on L293D connected to pin 3 on Arduino.

Input 2: pin 7 on L293D connected to pin 5 on Arduino.

Enable 1: pin 1 on L293D connected to pin 11 on Arduino.

Pin 8 and pin 16 on L293D connected to 3.3v and +5v on Arduino.

Pin 4 and pin 5 on L293D connected to GND on Arduino.

The A0/A1 pin on Arduino of stepper motor driver circuit is connected to pH to voltage converter output terminal.

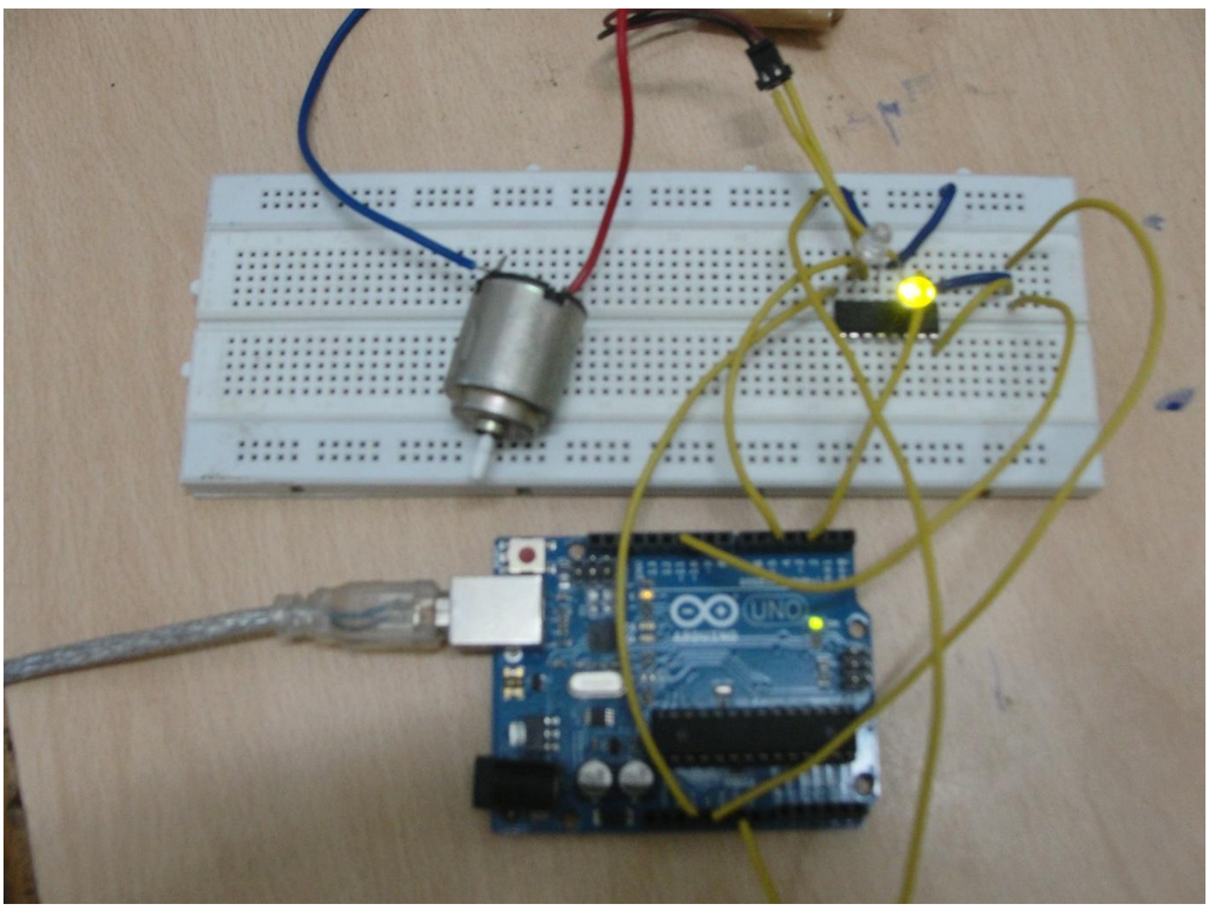

Figure 4.17: ***The Whole Circuit Diagram for Motor Control Using Arduino and L293D.***

4.6.1: Arduino Code for Motor control:

```
int motor1Pin1 = 3;    // pin 2 on L293D

int motor1Pin2 = 5;    // pin 7 on L293D

int enablePin = 11;    // pin 1 on L293D

int potPin = 5;

void setup() {

  // set all the other pins you're using as outputs:

  pinMode(motor1Pin1, OUTPUT);

  pinMode(motor1Pin2, OUTPUT);

  pinMode(enablePin, OUTPUT);

  Serial.begin(9600);



  // set enablePin high so that motor can turn on:

}

void loop() {

  // if the switch is high, motor will turn on one direction:

  int input = analogRead(A0);
```

```
int speed = analogRead(potPin) / 4;

analogWrite(enablePin, speed);

Serial.println(input);

if (input> 300)

{

  digitalWrite(motor1Pin1, LOW);   // set pin 2 on L293D low

  digitalWrite(motor1Pin2, HIGH);  // set pin 7 on L293D high

}

// if the switch is low, motor will turn in the opposite direction:

else if ((input<300) && (input>0))

{

  digitalWrite(motor1Pin1, HIGH);  // set pin 2 on L293D high

  digitalWrite(motor1Pin2, LOW);   // set pin 7 on L293D low

}

else

{

  digitalWrite(motor1Pin1, HIGH);  // set pin 2 on L293D high
```

```
    digitalWrite(motor1Pin2, HIGH);   // set pin 7 on L293D low

  }

  delay(1000);

}
```

4.7: ARTIFICIAL FINGER DESIGN:

The representation of the hand prosthesis is in the form of a single finger with one degree of freedom.

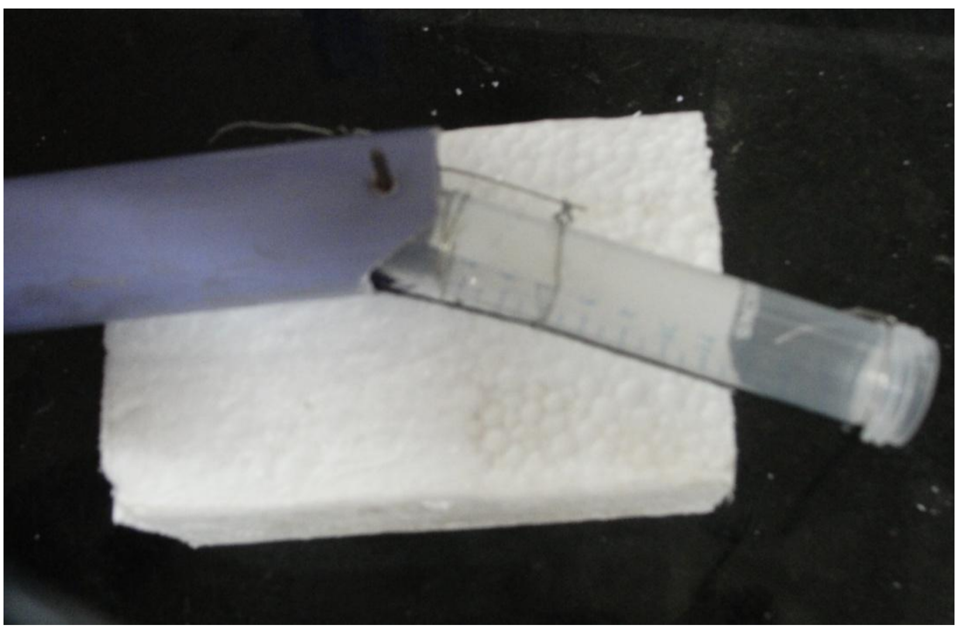

Figure 4.18: ***Design of Artificial Finger***

In our model, it is constructed from a plastic tube conjoined with another plastic tube of a greater diameter through the means of a nail. The thinner tube, representing the finger, is free to revolve 30 degrees about the nail in the horizontal plane. This kind of movement is achieved through a spring that connects the two tubes, and a thread that runs along the length of the finger and provides the mechanical connection with the motor. It is shown in the figure 4.18.

CHAPTER 5

RESULTS & DISCUSSION

5. RESULTS & DISCUSSION:

5.1 RESPONSE OF MICROCONTROLLER TO pH CHANGE:

For the experiments, we take two samples of Ringer's Lactate solution that simulate the neuromuscular pH. To control the pH values of the samples, we use 0.1 M Hydrochloric Acid. The pH value of the Ringer's lactate solution is 7 by default. Upon addition of adequate amounts of HCl, it can fall to lesser values. In the first case, that of Sample 1, we have calibrated the system so as to show no movement at the pH value of 5.0. This is achieved, obviously, through addition of HCl. In the second case, we have calibrated the system so as to remain stationary at the pH value of 5.1, again obtained through the use of HCl. Another difference is in the number of inputs to the pH-to-voltage converter from the pH meter. In the first sample, the number of inputs is fixed at 5, 4 of which are for the digit before the decimal point and 1 for the one after it. In the second sample, however, the inputs are 8, 4 each for the digits before and after the decimal point of the pH value.

Sample 1:

Table 3: ***Movements Corresponding To Different pH Values for Sample 1.***

pH value	Finger movement
4.9	30 degree inward movement
5.0	No movement
5.1	30 degree outward movement

Sample 2:

Table 4: ***Movements Corresponding To Different pH Values for Sample 2.***

pH value	Finger movement
4.5	32 degree inward movement
5.1	No movement
5.3	32 degree outward movement

5.2 MOVEMENTS OF MECHANICAL SYSTEM WITH pH (OR VOLTAGE):

Upon running the program and making the necessary mechanical and electrical connections, in sample 1, a 30 degree movement was observed. When, in this case, the pH value was decreased through the addition of HCl into the sample to a value above 5.0 (say, for a pH value of 4.9), this motion was found to be inward, representing curling-in of the finger. Then, more Ringer's Lactate solution was added into the sample to bring the pH value to above 5.0 (say, 5.1), whereupon the resultant movement was found to be outward, simulating curling-out of the finger. In both these cases, the movement was invariably to a measure of 30 degrees.

In the case of the second sample, i.e. Sample 2, the movement of the finger was 32 degrees. As in the previous case, the outward movement was achieved by an addition over the initial pH value, while the inward movement was obtained through a decrease in the same.

Upon cursory observation, it was evident that the system showed more sensitivity when the number of inputs to the pH-Voltage converter increased. This change in the input accounted for the minutest fluctuations in the value of the post-decimal point digit, and hence was more likely to respond to the change.

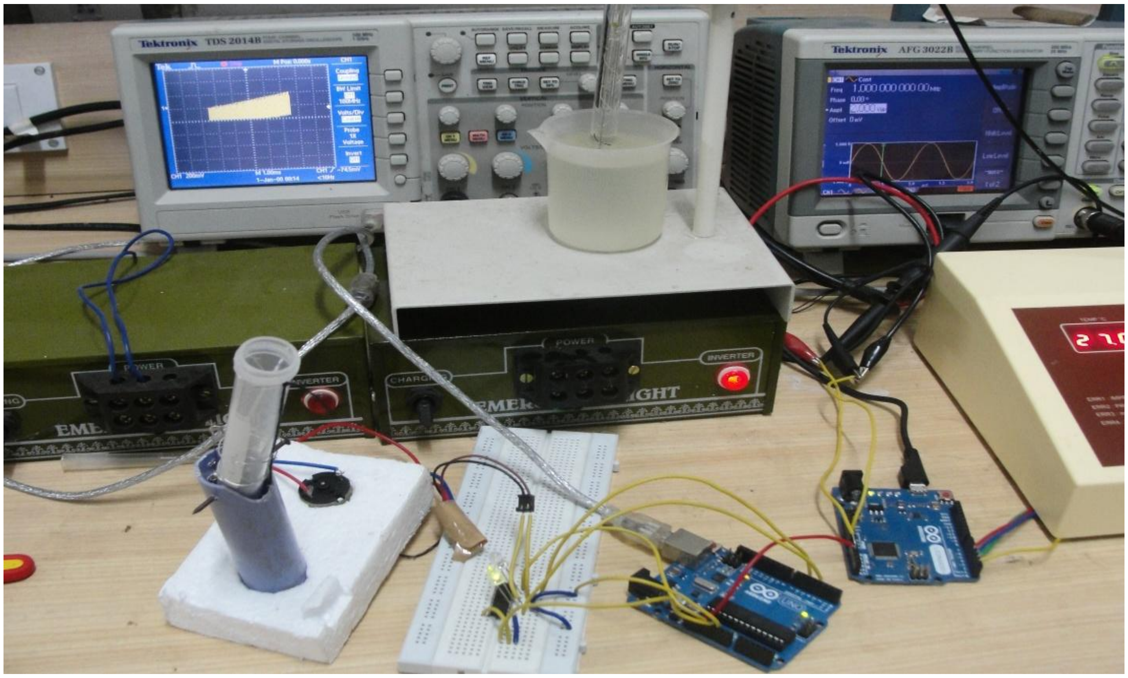

Figure 5.1: ***Picture Showing the Setup Of The Model 1.***

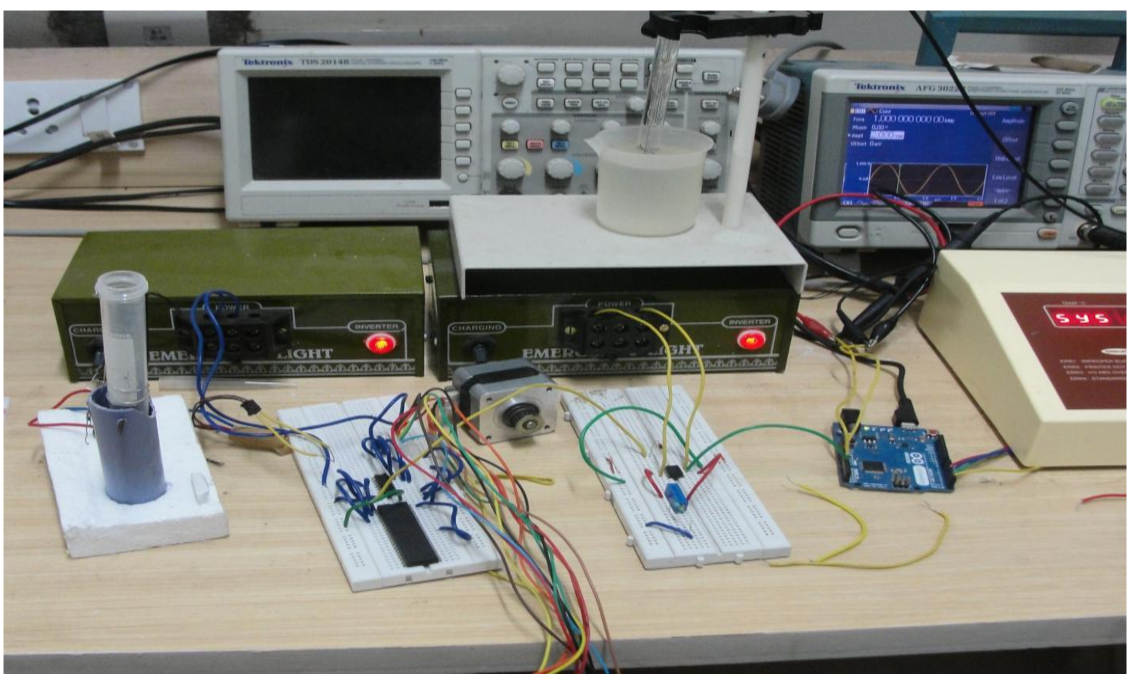

Figure 5.2: ***Picture Showing the Setup of the Model 2***.

CHAPTER 6

CONCLUSION & FUTURE WORK

6. CONCLUSION & FUTURE WORK:

CONCLUSION:

Our system was able to simulate the movement of a prosthetic hand to a reasonable extent. However, the model of ours is more of a representative design than an actual practical one. For the sake of simplicity, the controllable parameters in this work have been kept to a minimum and the simulation of the actual prosthetic device that the model intends to be is minimal. In the future, free of the constraints of time, this work can be progressed further to evolve into a marketable practical design for a pH-based prosthetic device. In that way, a case can be made that this elementary prototype is just a stepping-stone.

FURTHER IMPROVEMENT:

In our system, the maximum movement that was achieved was of 30 degrees. This can be a severely limiting factor in practical prosthetic devices. To be able to simulate the complex and often subtle, but at times powerful and broad movements more efficiently, this value needs to increase. This can be achieved through the use of a better microcontroller, and more effervescent programming algorithm. Also, a programming language more suited to the purpose can be used to increase the sensitivity and selectivity of the device.

Another improvement that can be made is increasing the number of degrees of freedom. A great part of it will involve tweaking the mechanical part of our system to better resemble the mechanical aspects of a real hand. Additionally, the complexity of the finger can be increased, again by improvements over the quite rudimentary design we have incorporated in our system for simplicity. The use of a stepper-motor instead of the basic DC motor used in our system is also recommended to exert better control over the prosthetic movement.

CHAPTER 7

REFERENCE

7. REFERENCE:

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