

PROSTHETIC ARM WITH FUNCTIONAL FINGERS AND WIRELESS RECHARGE ON WALK FUNCTION

Submitted in partial fulfillment of the requirements for the award of Master
of Technology degree in Medical Instrumentation

by

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**DEPARTMENT OF BIOMEDICAL ENGINEERING
SCHOOL OF BIO AND CHEMICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade "A" by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Abhijeet Bharathan** (Reg. No. **40440001**) who carried out the project entitled "**Prosthetic arm with functional fingers and wireless recharge on walk function**" under our supervision from **September 2021 to March 2022**.

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DECLARATION

I **Abhijeet Bharathan** (Reg. No. **40440001**) hereby declare that the Project Report entitled “**Prosthetic arm with functional fingers and wireless recharge on walk function**” done by us under the guidance of Dr. **J. PREMKUMAR**, Ph.D., Department of Biomedical Engineering is submitted in partial fulfillment of the requirements for the award of **Master of Technology** degree in **Medical Instrumentation**.

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ABSTRACT

The prosthetic limbs have improved in a variety of areas over the years, including efficiency, tactile characteristics, and weight, but the high charging time that comes with these perks decreases their overall appeal. The goal of this research is to introduce a portable power source into the transradial prosthetic arm to reduce downtime and boost reliability. This power source has been focused to make sure that its able to charge on its own without any excessive intervention by inclusion of any battery source. The incorporation of particular footwear that functions as a regenerative power supply for the prosthetic arm's battery will work by having the individual walk to charge up the battery which can later be used to power up the prosthetic arm, the piezoelectric generator is utilized to generate energy while walking, and a charging pad which follows basic electromagnetic power transmission to make sure that unwanted wired setup can be eliminated is used to transfer the power supply straight to the prosthetic arm while on the move. The prosthetic arm in constructed using cheaper and lighter material keeping in mind the weight constrains and design simplicity. The entire gadget allows the user to utilize the prosthetic arm for longer periods of time while remaining at ease.

Keywords: Prosthetic, transradial, piezoelectric, wireless charging,

TABLE OF CONTENTS

CHAPTER NO	TITLE	PAGE NO
	ABSTRACT	V
	TABLE OF CONTENT	VI
	LIST OF TABLES	IX
	LIST OF FIGURES	VIII
	LIST OF ABBREVIATIONS	X
1	INTRODUCTION	1
2	LITERATURE SURVEY	2
3	AIM AND SCOPE OF THIS INVESTIGATION	10
4	METHODOLOGY	12
4.1	EMG SIGNAL PROCESSING	12
4.1.1	SIGNAL DETECTION	12
4.1.2	NOISE CANCELLATION	12
4.1.3	SIGNAL AMPLIFICATION	13
4.1.4	COMPONENTS USED	13
4.1.4.1	INSTRUMENTATION AMPLIFIER	13
4.1.4.2	HIGH PASS FILTER	14
4.1.4.3	LOW PASS FILTER	14
4.1.4.4	NOTCH FILTER	15
4.2	PROSTHETIC ARM	16
4.2.1	COMPONENT USED	16
4.2.1.1	PLA PLASTIC FILAMENT	16
4.2.1.2	RUBBER CHORD	17
4.2.1.3	FISHING LINE PLASTIC STRING	18
4.2.1.4	SG90 SERVOMOTOR	19
4.2.2	DESIGNING THE ARM	20

4.2.3	CONVERTING THE MESH TO A SOLID FOR PRINTING	22
4.2.4	3D PRINTING	23
4.2.5	CONSTRUCTION	25
4.2.6	MODIFICATION OF SERVO MOTOR	26
4.3	PIEZOELECTRIC GENERATOR	27
4.3.1	LIST OF PIEZOELECTRIC MATERIALS	28
4.3.1.1	QUARTZ	28
4.3.1.2	PZT	29
4.3.1.3	PMNT33	30
4.3.1.4	PZN7PT7%	31
4.3.1.5	PVDF	32
4.3.2	PRINCIPLE	33
4.4	WIRELESS CHARGING	34
4.5	CODING USED FOR THE ARM MOTION	37
5	RESULTS AND DISCUSSION	44
6	SUMMARY AND CONCLUSIONS	50
6.1	SUMMARY	50
6.2	CONCLUSION	51
6.3	RECOMMENDATIONS	52
	REFERENCES	52

LIST OF FIGURES

FIGURE	TITLE	PAGE NO
4.1	SIGNAL PROCESSING FLOWCHART	13
4.2	CIRCUIT CONNECTION	16
4.3	PLA FILAMENT ROLL	17
4.4	RUBBER STRING	18
4.5	FISHING/NYLON STRING	18
4.6	SG90 SERVOMOTOR	19
4.7	THE MESH DESIGN OF PROSTHETIC ARM CREATED IN BLENDER	22
4.8	THE CONVERTED SOLID DESIGN OF PROSTHETIC ARM IN AUTODESK FUSION 360	23
4.9	PRINTING OF THE PALM	24
4.1	PROSTHETIC ARM SCHEMATIC DESIGN	26
4.11	QUARTZ PLATE	29
4.12	LEAD ZIRCONATE TITANATE PLATE PMNT33 ELECTRIC FIELD INDUCED STRUCTURE	31
4.13	PZN7%PT CRYSTAL LATTICE STRUCTURE	31
4.14	PVDF FILM	32
4.15	PIEZOELECTRIC GENERATOR CONNECTED TO TRANSMITTER COIL	34
4.16	WIRELESS CHARGING PRINCIPLE	36
4.17	ARDUINO UNO R3 BOARD	37

LIST OF TABLES

TABLE NO	TITLE	PAGE NO
5.1	COMPARING THE PROPERTIES OF VARIOUS PIEZOELECTRIC MATERIALS	45
5.2	COMPARING THE VOLTAGE OF VARIOUS PIEZOELECTRIC MATERIALS	47
5.3	COMPARING THE WALK SPEED OF VARIOUS INDIVIDUALS	48

LIST OF ABBREVIATIONS

BCI	Brain Computer Interface
CLB	Configurable Logic Blocks
CMRR	Common Mode Rejection Ratio
EEG	Electro Encephelo Graph
EMG	Electro Myo Graph
FPGA	Field Programmable Gate Array
LAB	Logic Array Blocks
PEG	Piezoelectric Generator
PET	Polyethylene Terephthalate
PLA	Polylactic Acid
PR	Pattern Recognition
PVDF	Polyvinylidene fluoride
SECE	Synchronous Electric Charge Extraction
UHMWPE	Ultra High Molecular Weight PolyEthene
VHDL	Very High Speed Integrated Circuit Hardware Description Language
WPT	Wireless Power Transfer

CHAPTER – 1

INTRODUCTION

Amputation can occur as a result of trauma or surgery, but the quality of life afterward is more essential. A prosthetic arm is an artificial device that replaces a person's upper limb, particularly in the case of amputation. The myoelectric (EMG) signal is used by the prosthetic arm to control the mobility of the mechanical hand. This EMG signal is generated by neuromuscular activity within the amputee's remaining limb. The transradial residual limb contracts on its own, producing an electrical signal that the EMG sensor interprets to perform the needed motion. This information is processed in order to control the prosthetic arm. The movement of the hand is caused by muscular contractions, which produce in electrical activity and a signal, which the EMG sensor detects. EMG signals are detected by intermuscular needle electrode and surface electrode. Because EMG recordings are essentially the potential difference between two electrodes, more than one electrode is employed in surface EMG. A monopolar needle electrode is placed into the muscle with a surface electrode as a reference in intermuscular EMG. Despite the fact that electromyogram (EMG) pattern recognition (PR) for multifunctional upper limb prosthetic control has been reported for decades, power efficiency appears to be a problem, requiring the arm to be charged or placed in for a battery replacement several times throughout the day

CHAPTER – 2

LITERATURESURVEY

Three participants (P1, P2, and P3) with unilateral transhumeral amputations were implanted with neuromusculoskeletal limb prostheses and have used them in daily life for over 7 (P1) and 3 (P2 and P3) years without interruption. Two participants (P2 and P3) also received targeted muscle reinnervation for intuitive control of their prosthetic hand. Whereas the long-term home use of non-invasive sensorimotor prosthetic systems has been studied with surface electrodes, this was the first time people with limb loss could use implanted electrodes to control and receive somatosensory feedback from their prostheses in their daily lives unsupervised and outside the constraints of research laboratories. This study is motivated by patient-driven knowledge about the experience of living with neuromusculoskeletal limb prostheses in patients' own homes and social worlds, outside the laboratory and clinical confines. To better understand how and to what extent people incorporate these artificial limbs into their lives and senses of body and self, we conducted in-depth, semi-structured interviews with the three aforementioned participants. We chose interviews as opposed to questionnaires because we wanted to understand the stories and experiences of patients through open-ended questions and explore more deeply the themes offered by patients' *in situ*, unearthing greater detail from their stories than possible in questionnaire form.(Alexandra Middleton, 2020).

Brain–computer interfaces (BCIs) use brain activity to control external devices, thereby enabling severely disabled patients to interact with the environment. A variety of invasive and noninvasive techniques for controlling BCIs have been explored, most notably EEG, and more recently, near-infrared spectroscopy. Assistive BCIs are designed to enable paralyzed patients to communicate or control external robotic devices, such as prosthetics; rehabilitative BCIs are designed to facilitate recovery of neural function. In this Review, we provide an overview of the development of BCIs

and the current technology available before discussing experimental and clinical studies of BCIs. We first consider the use of BCIs for communication in patients who are paralyzed, particularly those with locked-in syndrome or complete locked-in syndrome as a result of amyotrophic lateral sclerosis. We then discuss the use of BCIs for motor rehabilitation after severe stroke and spinal cord injury. We also describe the possible neurophysiological and learning mechanisms that underlie the clinical efficacy of BCIs (Chaudhary U, 2016).

A piezoelectric generator (PEG) can be used to extract energy from ambient vibrations. For that purpose, a proof mass is firmly attached to one end of a bender, while the other end is fixed onto a vibrating case. The voltage supplied to the piezoelectric material produces internal stresses, which create active damping. The power which brakes the movement of the proof mass is not dissipated into heat but is converted into electrical power and fed back to an electrical load.

For a given design of the PEG, the harvested power depends on the operating conditions. First, the resonant behaviour of the bender and its proof mass lead to a strong dependency of harvested power on vibrations. Moreover, the impedance of the PEG and of the load should match, and, then, there exists an optimal electric load to be connected to the PEG connection.

Optimal energy harvesting can be achieved using active solutions. For example, proposes to use a full H-bridge in order to accurately control the voltage supplied to the PEG. For an excitation close to the resonant frequency of the PEG, semiactive solutions can also be used. The SSHI technique, for example, uses a switched inductor to reverse the voltage across the piezoelectric generator and synchronises the voltage on maxima and minima of the displacement. The SECE technique uses a fly back topology to extract the charges for the piezoelectric generator at each maximum of the voltage. In this way, energy scavenging is obtained at any load value and can be used to charge up a battery, in a wireless communication application.

In this work, we are using active energy harvesting, because we control the instantaneous voltage across the piezoelectric material. However, this voltage is not synchronised to a current but directly to the vibration which is measured by an accelerometer. The paper is organised as follows. First, we present a model of the piezoelectric generator, and we calculate the mechanical power losses inside the device while it is being bent. Then we present experimental results of the conversion of mechanical power into electrical power at an excitation frequency which is less than one-half of the generator's resonance frequency (Dixit N. K, 2017)

Myoelectric Prosthetic arm uses the myoelectric (EMG) signal to control the motion of the artificial hand. This EMG signal is the result of neuromuscular activity in the remaining part of amputee's limb. The raw signal is extracted from the limb and after processing it we can get useful information from the signal to control the prosthetic arm. The major benefit of the myoelectric prosthetic arm is that it works according to the will of amputee because the EMG sensor used in this prosthetic device is getting the signal generated by the brain of an amputee.

Hand movement is due to the contraction of muscle which causes electrical activity and a signal is generated, which the EMG sensor reads. Surface EMG and intermuscular EMG are the types of EMG. In surface EMG electrodes are used because the EMG recordings are actually the potential difference between two electrodes. Whereas, in Intermuscular EMG a monopolar needle electrode is inserted into the muscle with a surface electrode as a reference. In EMG signals generated by six separate arm functions were identified and the success rate was more than 90% irrespective of the electrode location and the subject. In the classification rate of 88.4% for EMG signal was achieved using a single channel and optimized ANN, which is outstanding rather than using multi-channel EMG signal (Jafar Hussian, 2018)

- 2.1.** An EMG signal based reliable and efficient hand gesture identification system has been developed for human computer interaction which in turn will

increase the quality of life of the disabled or aged people. The acquired and processed EMG signal requires classification before utilizing it in the development of interfacing which is the most difficult part of the development process. A back-propagation neural network with Levenberg-Marquardt training algorithm has been used for the classification of EMG signals.

This study presents the neural network based classifier modeling using Hardware Description Language (HDL) for hardware realization VHDL (Very High Speed Integrated Circuit Hardware Description Language) has been used to model the algorithm implemented into the target device FPGA architecture consists of an array of logic blocks called configurable logic blocks (CLBs) or logic array blocks (LABs) depending on vendor, I/O pads, and routing channels. Generally, all the routing channels have the same width (number of wires). Multiple I/O pads may fit into the height of one row or the width of one column in the array. An application circuit must be mapped into an FPGA with adequate resources. While the number of CLBs/LABs and I/Os required is easily determined from the design, the number of routing tracks needed may vary considerably even among designs with the same amount of logic.

(M R Ahsan, 2012)

The fundamental idea of this research work is to present an approach to energy harvesting, which basically uses piezoelectric technology and is implemented in a shoe. It takes advantage of the energy that the user waste when walks and thus is able to convert it into electric energy and can be use in an electronic device that requires low power. A piezoelectric generator can be used to extract energy from ambient vibrations. For that purpose, a proof mass is firmly attached to one end of a bender, while the other end is fixed onto a vibrating case. The voltage supplied to the piezoelectric material produces internal stresses, which create active damping. The power which brakes the movement of the proof mass is not dissipated into heat but is converted into

electrical power and fed back to an electrical load. For a given design of the PEG, the harvested power depends on the operating conditions. First, the resonant behaviour of the bender and its proof mass lead to a strong dependency of harvested power on vibrations. Moreover, the impedance of the PEG and of the load should match, and, then, there exists an optimal electric load to be connected to the PEG connection (Quispe, 2017)

The usage of these portable electronic devices is increasing, the demands for longer battery life are also increasing. These batteries need to be recharged or replaced periodically. It is a hassle to charge or change the battery after a while, especially when there is no power outlet around. Now instead of plugging in an electronic device to recharge it, it could receive its power wirelessly. The technology of wireless power transfer is in the forefront of electronic development. WPT systems are designed to transmit power without using wires more efficient than transmitting it while using wires. There could be large number of applications for wireless power systems. In general a wireless power system consists of a "transmitter" device connected to a source of power such as a mains power line, which converts the power to a time-varying electromagnetic field, and one or more "receiver" devices which receive the power and convert it back to DC or AC electric current which is used by an electrical load. Hence, in this work, a wireless battery charger has been proposed for mobile phone charging which is expected to eliminate all the hassles with today's battery technology. The advantage of this device is that it can wirelessly charge up the batteries which can save resources in a long run for the general use of an individual (Shubham Chaturvedi, 2017).

Wireless charging is a technique of transmitting power through an air gap to an electrical device for the purpose of energy replenishment. Recently, wireless charging technology has significantly advanced in terms of efficiency and functionality. This article first presents an overview and fundamentals of wireless charging. We then provide the review of standards, that is, Qi and the

Alliance for Wireless Power, and highlight their communication protocols. Next, they have proposed a novel concept of a wireless charger networking that allows chargers to be connected to facilitate suitable information collection and control. We demonstrate the application of the wireless charger network in user-charging assignment, which clearly shows the benefit in terms of reduced costs for users to identify the best chargers to replenish energy for their mobile devices (Xiao Lu, 2015)

Control of a robotic arm using a brain–computer interface (BCI) for reach and grasp activities is one of the most fascinating applications for some severely disabled people, which is especially challenging for the non-invasive BCIs based on electroencephalography (EEG). In this paper, shared control is applied to realize the control of a dexterous robotic arm with a motor imagery-based (MI-based) BCI and computer vision guidance. With the utilization of the shared control, the subjects just need to move the robotic arm by performing only two different mental tasks to the surrounding area of the target. The accurate pose of the target is estimated by a depth camera equipped in the robot system. Once the endpoint of the robotic arm enters the pre-defined vision-guided region, the robotic arm will grasp the target autonomously. Five healthy and inexperienced subjects participated in the online experiments and the average success rate is above 70% even with no specific user training. The results show that the shared control can make the robotic arm accomplish the complex tasks (reach and grasp) with the simple two-class MI-based BCIs. (Xu Y, 2019).

The control methods for assist robots have emerged but there are still some challenges such as causing fatigue, requiring too much pre-training, or poor online testing results which allows us to question how assist robots can be more practical for assistance purpose. The information transfer rate (ITR) and accuracy is restricted by the limited number of control commands and constant flickering easily causes fatigue, which is not appropriate for people in

rehabilitation. A system with MI for after-stroke rehabilitation exercises has been explained, that controls a robot to drive the arm by letting subjects imagine hands moving. In another work, the left, right, up, and down robot arm movements are driven by imagining the movement of their left hand, right hand, both hands, and the relaxation of both hands. Nevertheless, MI is not practical enough because the imaginary movements with distinct individual differences are not definite, causing participants to need extra pre-training and resulting in lower accuracy.

The main contributions of this research are as follows: (i) a handy and efficient EEG-based method to steadily control assist robots for helping disabled people practically was proposed; (ii) With the method, we developed a safe robot that can assist user to perform up to 36 preset upper-limb movements such as rehabilitation exercises; (iii) both offline and online tests were performed to verify the practicability of the finalized system with detailed comparisons of three classifiers as intention detector; and (iv) good reference for future research was provided by a novel assistive mobile robot with shared control of our method and computer vision (Yonghao Song, 2020)

CHAPTER-3

AIM AND SCOPE OF THE PRESENT INVESTIGATION

- Amputation can occur as a result of trauma or surgery, but the quality of life afterward is more essential.
- A prosthetic arm is an artificial device that replaces a person's upper limb, particularly in the case of amputation. The myoelectric (EMG) signal is used by the prosthetic arm to control the mobility of the mechanical hand.
- This EMG signal is generated by neuromuscular activity within the amputee's remaining limb.
- The transradial residual limb contracts on its own, producing an electrical signal that the EMG sensor interprets to perform the needed motion. This information is processed in order to control the prosthetic arm.
- The movement of the hand is caused by muscular contractions, which produce in electrical activity and a signal, which the EMG sensor detects. EMG signals are detected by intermuscular needle electrode and surface electrode because EMG recordings are essentially the potential difference between two electrodes, more than one electrode is employed in surface EMG.
- A monopolar needle electrode is placed into the muscle with a surface electrode as a reference in intermuscular EMG. For research or kinesiology studies, the latter technique is used.
- Despite the fact that electromyogram (EMG) pattern recognition (PR) for multifunctional upper limb prosthetic control has been reported for decades, power efficiency appears to be a problem, requiring the arm to be charged or placed in for a battery replacement several times throughout the day.
- The device's goals were to:
 1. Compare self-report and performance results of various battery sources and circuits for optimal charging;
 2. Compare self-report and performance outcomes of various battery sources and circuits for optimized charging.

3. Pattern recognition (PR) for a three-degree-of-freedom (wrist rotation, wrist flexion, and hand control) prosthesis,
 4. Suitable wireless charging mechanism,
 5. A device with a lower overall weight and longer battery life.
- Individuals who have had transradial amputations are taken into consideration to make sure that for this application can be made use to its maximum potential.

CHAPTER 4

METHODOLOGY

4.1. EMG SIGNAL PROCESSING

4.1.1 *Signal detection*

The normal EMG signal is 0-10mv and has a frequency range of 20-400Hz, with the greatest signal being between 50 and 200Hz. The surface of the muscle is formed by the EMG signal, which is extracted using electrodes. The following types of noise can taint the signal. Electronic equipment's built-in noise, which can cause interference with the EMG signal in the 0-1000 Hz region. The power line interface (PLI) noise is caused by a 50Hz or 60Hz power source. From 0 to 10Hz, the electrode interface and electrode cable add noise to the EMG signal. The noise emitted by electronic equipment can be reduced through proper design. Because of the change in the number of active motor neurons inside the muscle fibre, the EMG is non-linear and non-stationary in nature. This has an effect on signals with frequencies ranging from 0 to 20 Hz [6]. For EMG recording to have a lower signal to noise ratio, good contact between the skin and the electrode is required (SNR). The signal is generated by muscle contraction and can be recorded as an analog wave. The Ag-AgCl electrodes can be used to minimize noise generated by the electrodes' impedance.

4.1.2 *Noise Cancellation*

The noise caused by the power line interface is eliminated by using a three electrode method differential amplifier to acquire EMG signals. Because the voltage collected from the muscle ranges from V to mV, the EMG amplifier is constructed with variable gain 60dB-80dB. This range will be covered by the proposed EMG sensor. The inherent noise will be eliminated by a low pass filter, yielding an 0-400Hz output signal. In Asian countries, the power source operates at 50 Hz, hence a notch filter can be employed to remove the 50 Hz frequency component from the EMG signal. A high pass filter

with a cut-off frequency of 20 Hz is meant to remove external noise.

4.1.3 Signal Amplification

An instrumentation amplifier with high input impedance is used in fabricate the required differential amplification. By subtracting the voltages V1 and V2, the instrumentation amplifier performs differential amplification. This eliminates noise signals that are common at V1 and V2 (electrode inputs), such as power line interference. The common mode rejection ratio determines how likely a differential amplifier is to reject signals that are common to both inputs (CMRR)[2]. A CMRR of 90 dB is sufficient for the elimination of common signals in instrumentation amplifiers, but newer technology, despite its high cost, allows us to achieve a CMRR of 120 dB. However, there are certain reasons to avoid pushing the CMRR to its limit, such as the possibility that the electrical noise detected by the electrodes is not in phase. A single resistor can be used to control the gain of the instrumentation amplifier (R gain).

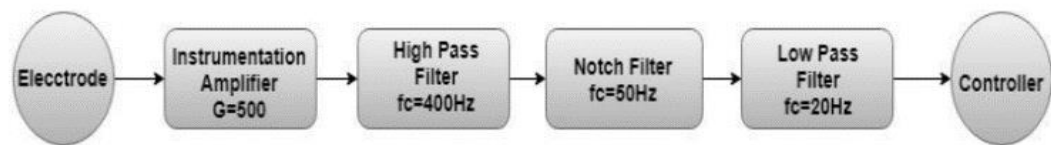


Fig.4.1. Signal Processing Flowchart

4.1.4 Componenets used

4.1.4.1 Instrumentaion Amplifier

An instrumentation amplifier is a type of differential amplifier that has been outfitted with input buffer amplifiers, which eliminate the need for input impedance matching and thus make the amplifier particularly suitable for use in measurement and test equipment. Additional characteristics include very low DC offset, low drift, low noise, very high open-loop gain, very high common-mode rejection ratio, and very high input impedances. Instrumentation amplifiers are used where great accuracy and stability of

the circuit both short-term and long-term are required. Although the instrumentation amplifier used here is IC 741 is usually shown schematically identical to a standard operational amplifier, the electronic instrumentation amplifier is almost always internally composed of 3 op-amps. These are arranged so that there is one op-amp to buffer each input (+, -), and one to produce the desired output with adequate impedance matching for the function.

4.1.4.2 High Pass Filter

A high-pass filter is an electronic filter that can be used to pass signals with frequency higher than that of a certain cut-off frequency and attenuates signals with frequencies lower than the cut-off frequency. The amount of attenuation for each frequency depends on the filter design. A high-pass filter is usually modelled as a linear time-invariant system. It is sometimes called a low-cut filter or bass-cut filter in the context of audio engineering. High-pass filters have many uses, such as blocking DC from circuitry sensitive to non-zero average voltages or radio frequency devices. They can also be used in conjunction with a low-pass filter to produce a band pass filter. The high pass filters is constructed using resistors with either capacitors or inductors. A high pass filter composed of a resistor and a capacitor is called a high pass RC filter. And a high pass filter with a resistor and an inductor is called a high pass RL filter.

4.1.4.3 Low Pass Filter

A low-pass filter is a filter that passes signals with a frequency lower than a selected cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency. The exact frequency response of the filter depends on the filter design. The filter is sometimes called a high-cut filter,

or treble-cut filter in audio applications. A low-pass filter is the complement of a high-pass filter.

In optics, high-pass and low-pass may have different meanings, depending on whether referring to frequency or wavelength of light, since these variables are inversely related. High-pass frequency filters would act as low-pass wavelength filters, and vice versa. For this reason it is a good practice to refer to wavelength filters as short-pass and long-pass to avoid confusion, which would correspond to high-pass and low-pass frequencies. Low pass filters can be constructed using resistors with either capacitors or inductors. A low pass filter composed of a resistor and a capacitor is called a low pass RC filter. And a low pass filter with a resistor and an inductor is called a low pass RL filter.

4.1.4.4 Notch Filter

In signal processing, a band-stop filter or band-rejection filter is a filter that passes most frequencies unaltered, but attenuates those in a specific range to very low levels.^[1] It is the opposite of a band-pass filter. A notch filter is a band-stop filter with a narrow stopband (high Q factor).

Narrow notch filters (the width of the stopband is 1 to 2 decades (that is, the highest frequency attenuated is 10 to 100 times the lowest frequency attenuated)). However, in the audio band, a notch filter has high and low frequencies that may be only semitones apart. Band-stop filter can be represented as a combination of low-pass and high-pass filters if the bandwidth is wide enough that the two filters do not interact too much. A more general approach is to design as a low-pass prototype filter which can then be transformed into a band stop.

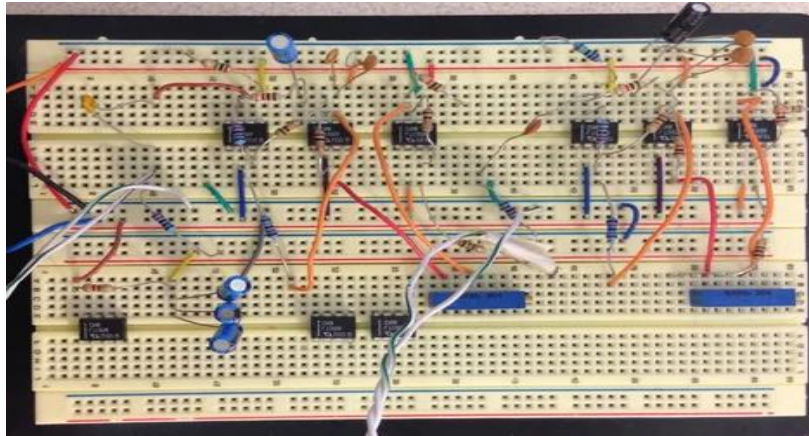


Fig.4.2. Circuit connection

4.2. PROSTHETIC ARM

4.2.1 *Components Used*

4.2.1.1 *PLA Plastic Filament*

Polylactic acid, also known as PLA, is a thermoplastic monomer derived from renewable, organic sources such as corn starch or sugar cane. Using biomass resources makes PLA production different from most plastics, which are produced using fossil fuels through the distillation and polymerization of petroleum. Despite the raw material differences, PLA can be produced using the same equipment as petrochemical plastics, making PLA manufacturing processes relatively cost efficient. PLA is the second most produced bioplastic (after thermoplastic starch) and has similar characteristics to polypropylene (PP), polyethylene (PE), or polystyrene (PS), as well as being biodegradable.

PLA is soluble in solvents including dioxane, hot benzene, and tetrahydrofuran. The physical and mechanical properties differ according to the exact type of polymer, ranging from an amorphous glassy polymer to a semi or highly crystalline polymer with a glass transition of 60–65 °C, a melting temperature 130–

180 °C, and a tensile modulus of 2.7–16 GPa. However, the basic mechanical properties of PLA range between those of polystyrene and PET, with similar properties to PET but a lower maximum continuous use temperature.



Fig 4.3 PLA Filament Roll

The high surface energy of PLA makes it ideal for 3D printing. PLA can also be solvent welded using dichloromethane, while acetone softens the surface of the material, making it sticky without dissolving it so it can be welded to another PLA surface. Ethylacetate can be used as an organic solvent, dissolving PLA and making it a good solution for removing PLA printing supports or cleaning 3D printing extruder heads.

4.2.1.2 *Rubber Chord*

Rubber string are used in the prosthetic arm as it will help in the motion which opposes the motion of the motor rotation hence the process of using a reverse rotation operation can be eliminated from the prosthetic arm. Rubber exhibits unique physical and chemical properties. Rubber's stress–strain behavior exhibits the Mullins effect and the Payne effect and is often modeled as hyper elastic. Rubber strain crystallizes. Due to the presence of weakened allylic C-H bonds in each repeat unit, natural rubber is susceptible to vulcanization as well as being sensitive to ozone cracking.



Fig 4.4 Rubber String

4.2.1.3 *Fishing line plastic string*

The pulley system within the palm of the prosthetic encloses the motor which has the strings connected to it plays an important role in the rotation of the pulley and inadvertently the finger. The string which is made of a thin filament of plastic could be made of material including Nylon, Polyvinylidene fluoride, Dacron and UHMWPE. The most common type is monofilament, made of a single strand. The monofilament is used because of its buoyant characteristics and its ability to stretch under load. The line stretch has advantages, such as damping the force when setting the hook and when fighting strong fish.



Fig4.5 Fishing line/ Nylon String

On very far distances the damping may become a disadvantage. Recently, other alternatives to standard nylon monofilament lines have been introduced made of copolymers or fluorocarbon, or a combination of the two materials. Fluorocarbon fishing line is made of the fluoropolymer PVDF and it is valued for its refractive index, which is similar to that of water, making it less visible to fish. Fluorocarbon is also a denser material, and therefore, is not nearly as buoyant as monofilament.

4.2.1.4 *SG90 Servo motor*

A servomotor is a closed-loop servomechanism that uses position feedback to control its motion and final position. The input to its control is a signal (either analogue or digital) representing the position commanded for the output shaft. The motor is paired with some type of position encoder to provide position and speed feedback. In the simplest case, only the position is measured. The measured position of the output is compared to the command position, the external input to the controller. If the output position differs from that required, an error signal is generated which then causes the motor to rotate in either direction, as needed to bring the output shaft to the appropriate position. As the positions approach, the error signal reduces to zero and the motor stops.



Fig 4.6 SG90 Servomotor

This type of servomotor is not widely used in industrial motion control, but it forms the basis of the simple and cheap servos used for radio-controlled models. More sophisticated servomotors use optical rotary encoders to measure the speed of the output shaft and a variable-speed drive to control the motor speed.

Both of these enhancements, usually in combination with a PID control algorithm, allow the servomotor to be brought to its commanded position more quickly and more precisely, with less overshooting. The maximum torque that can be produced by this motor is around 2.0kg/cm (4.8V). With a speed or rotation being around 0.09s/60°(4.8V), 0.08s/60°(6V). Its operational voltage range is around 4.8 ~ 6V. Each motor weighs around 10.5g summing up to a total of 60g within the palm cavities of the prosthetic.

4.2.2 *Designing the Arm*

The software that was initially used to create the structure for the arm was Blender and it uses an inherent system of measurement which is not based on a measurable unit. However, as the object that is designed will be physically manufactured, it's important to define a unit of scale. To accomplish this the measurement options under "Units" with scroll down "Metric" was selected. By default, one "Blender" unit is equivalent to 1 meter. The "Scale" parameter was lowered such that the equivalence can be decreased to necessary requirement globally. The 3D model on the left does not consist of a volume, but instead only a series of surfaces which are either.

This will cause an issue for many 3D printing programs as they are unable to print models that do not have a defined volume. To ensure your model's printability, it's important to close any holes in your model.

This is possible by clicking 'F' to create an Ngon (or a surface with 'N' faces), then extruding, then click 'Alt+M' to unify the model. It is also possible to use 'Ctrl+F' and "Grid Fill" to close any holes. Often holes of this nature arise when generating a model for an animation or a video game, as a series of surfaces in one of those situations can cheat physics as per what will and will not be seen – physics cannot, however, be cheated during a 3D print. There's no need to overdo your smoothing and subdividing, in fact it is important to minimize polygons to keep the file size down. In the example below, the Surface Subdivision Modifier is used once to attain a high quality surface.

It is also possible to reduce the density of those subdivisions without losing too much of the general information of the surface using the Decimate or ReMesh modifiers as well. It's important to understand the physical limitations of the material in which you plan to 3D print. You must respect the minimum thicknesses for each material, such that every aspect of the model will be both printable and visible. Hence the top view of a hand will be visible by this method. The parts which are below 1mm of thickness can be easily noted as they are indicated in red making it noticeably different than the remaining components. It's important to keep in mind the minimum thickness for each material as you are creating your model, as each material has a different minimum thickness. Thankfully, after uploading, these parts will be automatically highlighted and using the automated thickening tool can prepare the model for 3D printing. Suitable Blender Modifiers can be applied to a model in an interactive and non-destructive manner to enhance the specific parts which are part of the design to make sure they can be constructed without much of an error margin.

The advantage of this technique is that these modifications are non-destructive to the model and do not modify the model's topology when used in Edit mode. Modifiers can be added under the "Modifiers" tab in the properties menu to highlight any specific components. The Mirror

Modifier mirrors the geometry of an object on an axis. This decrements the difficulty as the remaining half of each designed finger can be mirrored to its respective completion. Hence reducing the time for its completion and speeding up the design process.

This modifier is very commonly used and relatively simple to operate. However a few errors ought to be avoided if you're modeling for a 3D print. Always verify that the axis of symmetry is in the central loop of the model. Once that central loop is defined, check the "Clipping" box from within the modifier. This will block any portion of the model from crossing the boundary of the central loop. A best practice would be to put the Mirror mesh first among the list of modifiers – this will ensure that the mesh is manifold.

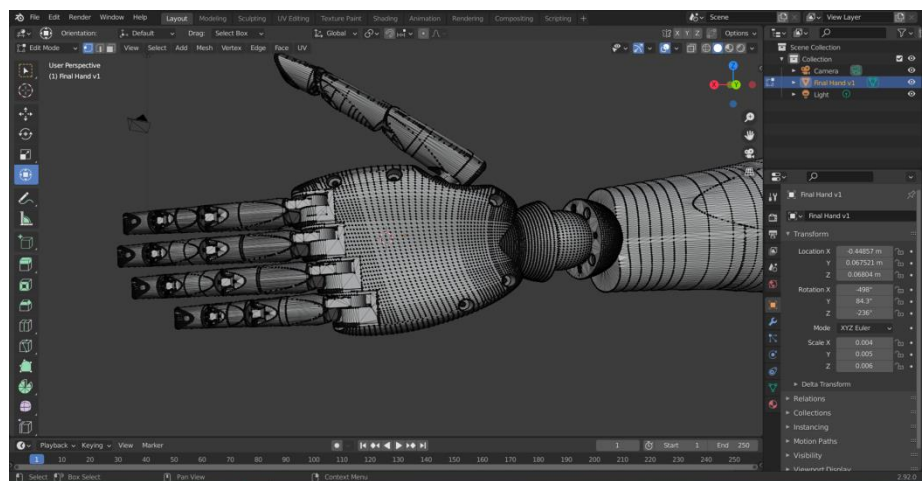


Fig.4.7. The mesh design of prosthetic arm created in Blender

The remaining design could be sped up but on completion the various layers that were used in the designing can be removed or merged with the original image and this makes the entire procedure more easier.

4.2.3 Converting the mesh to a solid for printing

The 3D mesh that was developed earlier won't be suitable for printing hence the use of suitable software to convert the necessary design to solid was required. Now Fusion 360 did a pretty good job of processing this file and turning it into a solid body, but you'll see here in the picture

that there are still. A lot of triangular surface faces that make up the solid body. Sometimes these faces can get in the way of altering the design to your specific needs. To make the design more intact and pleasing, reducing the number of faces by merging them together becomes important. This is also called increasing the resolution of the solid such that it has smoother constitution than predesigned rougher design. By setting the selection priority to faces. This helps to ensure only selected entire component can be altered to reduce the size and dimension. If you go back up to the menu and look at the selection filters you'll see that you can see that activating the "select face priority" feature turned all these other options off and only left the "body faces" turned on making it suitable to determine any possible flaws within the designing to create an even face on its respective individual components.

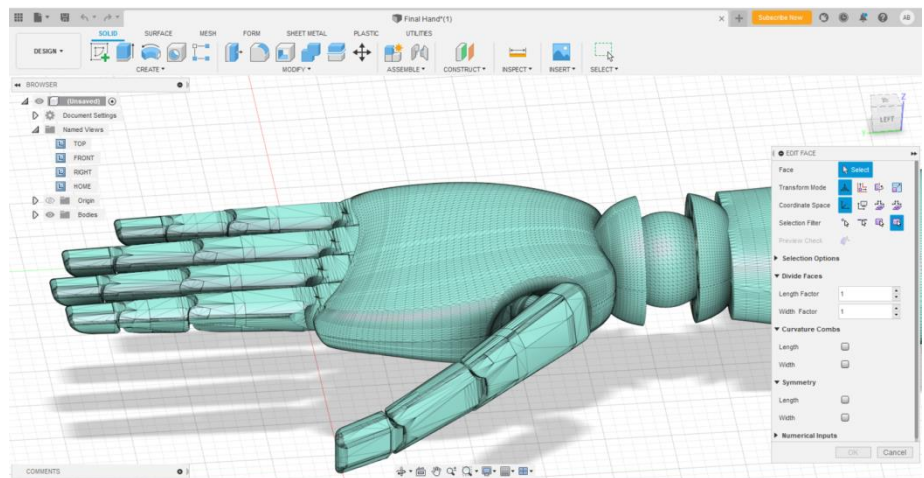


Fig.4.8.The converted solid design of prosthetic arm in Autodesk Fusion360

For the printing prior to the completion of the design we could have an size and ration modulation which encapsules the procedure to be of higher value than the predesigned structure

4.2.4 3D Printing

The finger tips are designed to be printed on a dual extrusion 3D printer, as the internal finger components are too thin to print on their own. By

using single extrusion the trimming of the finger tips can be skipped as they are too thin to print individually and glue on, alternatively redesigning these structures to be thicker can resolve the issue, all the other pieces will print the same on both a dual or single extrusion printer. Here Polylactic Acid (PLA) but ABS plastic would work too Print with support structure I was impatient and to reduce print time I printed the larger pieces like the palm and forearm at 0.3mm layer height while some other pieces, like the fingers, I did at 0.1mm.

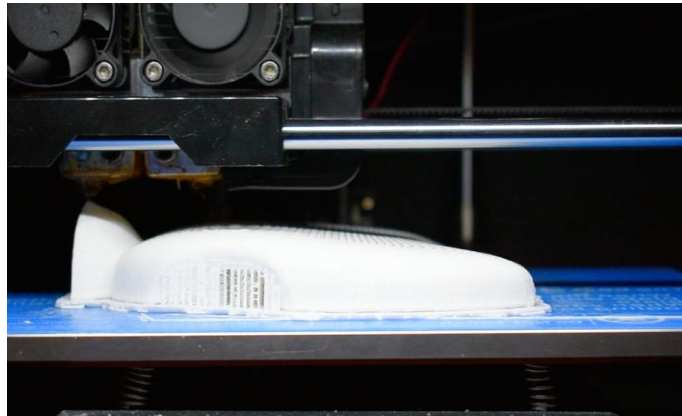


Fig 4.9. Printing of the palm

To maintain the balance between strength and filling ratio, the prosthetic limb model used is made of polylactic acid (PLC) and polypropylene (PP), with the dense region filled with PP and the harder case with polylactic acid. The microcontroller, motors, battery, charging port, and sockets, among other components required for the arm, were held in different sockets and segments. The weight of the arm is also a factor to consider as muscle fatigue occurs if it's too heavy. Magnets surround the charging port, assisting the arm in latching on the charging transmitter and preventing any misalignment. The overall weight, including the electronic components and battery, will be around 3 kg. While the entire weight of the prosthetic arm, including the motors, was an additional 500g, this is a significant weight reduction when compared to commercial prosthetic arms with bulkier battery

4.2.5 Construction

The constructed prosthetic limb contains its own set of movable fingers, each with its own set of wires and motor to conduct finger flexion. The flexion of the rotatable thumb is controlled by a single motor. The clenching movement produced by these fingers is of primary importance in this experiment. The microcontroller, controls the movements based on the EMG feedback from the sensor, which triggers the signal for each individual finger flexion. The prosthesis case (fist and transradial socket) and finger are 3D printed using the residual limb mold. The mold is designed by creating a negative mold of the residual arm to capture its surface accurately.

The signal is detected using appropriate EMG sensors placed along the inner surface of the arm socket. The EMG sensor signal is utilized to determine the appropriate arm motion as configured on the microcontroller [1][11]. The respective servomotor activates and performs the specific motion based on the output signal from the microcontroller. A single servomotor controls the action of the pinky and ring fingers, while the remaining fingers have their own servomotors. The finger joints have cables going through them, allowing a single motor to flex the entire finger. Two stepper motors are located on the wrist, one for wrist flexion and the other for wrist rotation. Tiny grooves are constructed to secure the wrist in position on flexion and extension to prevent breaking on load during wrist flexion [4].

The support structure was cleaned with a drill, to ensure that the holes were big enough. To ensure that string were inserted when hole was drilled for each individual component. Elastic were fed through the holes on the topside, and the fishing line is used for pulling the finger which would contract it and when released the elastic would pull it back. By altering the servomotors, its motion limitation can be eliminated but the

degree becomes difficult to detect hence the potentiometer are removed from the motors and are placed within the gap of the knuckle joints.

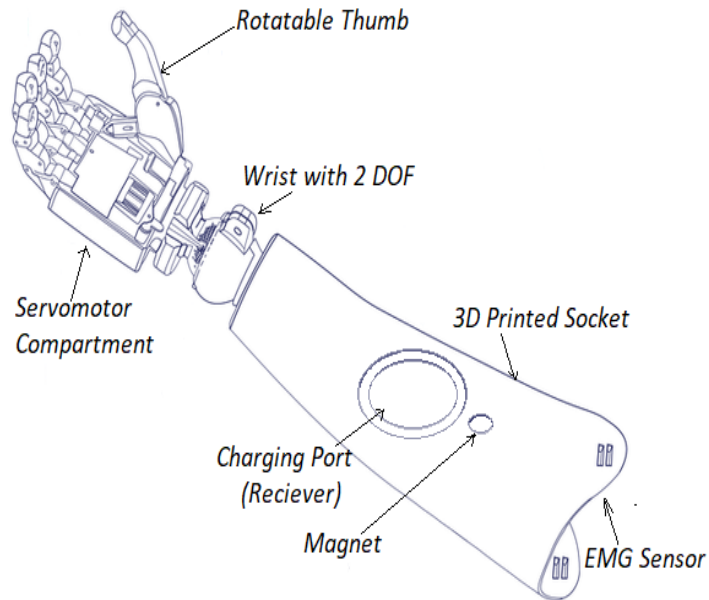


Fig.4.10. Prosthetic Arm Schematic Diagram

4.2.6 Modification of Servo Motor

The rotation of servos is limited by the fact that the potentiometers (a device that has a variable resistance and as it is rotated the change in rotation can be read and from it an angle of rotation calculated) cannot rotate more than 180 degrees. To overcome this restriction, open up the servo and cut off the plastic stopper on the top most gear. Then drill a hole down its axis, this stopper allows the gear to freely spin whereas before it would bite onto the D-pin mount of the potentiometer (see 4th picture above). Now the gear can continuously rotate while the potentiometer does not move at all. Reassemble the servo as it was before and test it with the code below, making sure it continuously rotates in both directions. Make 2 of these servos. When modifying the servo make sure you rotate the potentiometer to the middle position. This is because the code will tell the servo to rotate to either 180

degrees or 0 degrees (depending on the direction of rotation) and since the top gear no longer bites onto the potentiometer, the potentiometer will never move, thus the motor will keep spinning in the same direction trying to reach 0 or 180 degrees forever. If however your potentiometer is rotated to either of the ends it will read an angle of 180 or 0, and the code will not work, hence ensure the potentiometer is rotated to about the middle position.

3 of the servos can be left as is, unaltered: One of the servos will be used as the thumb rotation servo. Two of the servos will be used as the left/right and up/down motion of the wrist. The sg90 servos have insufficient torque to rotate the wrist. In later versions I will make the forearm larger to accommodate a more powerful servo such as two sg90 servos. From the forth servo the only thing we need is the black potentiometer, the rest can be set aside as spare parts. During the alteration procedure it is possible to damage the gear rod hence, those potentiometers from damaged motors can be salvaged to be used within this hollow cavities within the knuckles instead of damaging the potentiometer which is present within the new motors.

4.3. PIEZOELECTRIC GENERATOR

Piezoelectric materials (PMs) can be broadly classified as either crystalline, ceramic, or polymeric. The most commonly produced piezoelectric ceramics are lead zirconate titanate (PZT), barium titanate, and lead titanate. Gallium nitride and zinc oxide can also be regarded as a ceramic due to their relatively wide band gaps. Semiconducting piezoelectric materials offer features such as compatibility with integrated circuits and semiconductor devices. Inorganic ceramic piezoelectric materials offer advantages over single crystals, including ease of fabrication into a variety of shapes and sizes not constrained crystallographic directions.

Organic polymer, such as PVDF, have low Young's modulus compared to inorganic piezoelectric material. Piezoelectric polymers (PVDF, 240 mV-m/N) possess higher piezoelectric stress constants (g_{33}), an important parameter in sensors, than ceramics (PZT, 11 mV-m/N), which show that they can be better sensors than ceramics. Moreover, piezoelectric polymeric sensors and actuators, due to their processing flexibility, can be readily manufactured into large areas, and cut into a variety of shapes. In addition polymers also exhibit high strength, high impact resistance, low dielectric constant, low elastic stiffness, and low density, thereby a high voltage sensitivity which is a desirable characteristic along with low acoustic and mechanical impedance useful for medical and underwater applications. The usage of a piezoelectric material such as PbTiO_3 , PbZrO_3 , or PZT in piezoelectric generators is common.

4.3.1. List of Piezoelectric Materials

Piezoelectric materials are the materials that can produce electric energy upon application of mechanical stress. A commonly known piezoelectric material is quartz. The mechanism involves development of electric charge due to movement of electron upon application of stress. Some of the materials that we have considered for this project were:

4.3.1.1. Quartz

Quartz is a hard, crystalline mineral composed of silica (silicon dioxide). The atoms are linked in a continuous framework of SiO_4 silicon-oxygen tetrahedral, with each oxygen being shared between two tetrahedral, giving an overall chemical formula of SiO_2 . Quartz exists in two forms, the normal α -quartz and the high-temperature β -quartz, both of which are chiral. The transformation from α -quartz to β -quartz takes place abruptly at 573 °C. Quartz crystals have piezoelectric properties; they develop an electric potential upon the application of mechanical

stress. One of the most common piezoelectric uses of quartz today is as a crystal oscillator. The quartz clock is a familiar device using the mineral.



Fig.4.11. Quartz Plate

The resonant frequency of a quartz crystal oscillator is changed by mechanically loading it, and this principle is used for very accurate measurements of very small mass changes in the quartz crystal microbalance and in thin-film thickness monitors.

4.3.1.2. *PZT*

Lead zirconate titanate is an inorganic compound which is a ceramic perovskite material that shows a marked piezoelectric effect, meaning that the compound changes shape when an electric field is applied. It is used in a number of practical applications such as ultrasonic transducers and piezoelectric resonators. It is a white to off-white solid. Being piezoelectric, lead zirconate titanate develops a potential difference across two of its faces when compressed and physically changes shape when an external electric field is applied. The relative permittivity of lead zirconate titanate can range from 300 to 20000, depending upon orientation and doping.



Fig 4.12. Lead Zirconate Titanate plate

Being pyroelectric, this material develops a voltage difference across two of its faces under changing temperature conditions; consequently, lead zirconate titanate can be used as a heat sensor. Lead zirconate titanate is also ferroelectric, which means that it has a spontaneous electric polarization i.e. its dipole behavior that can be reversed in the presence of an electric field.

4.3.1.3. *PMNT33*

PMNT33 ((Pb(Mg $_{1/3}$ Nb $_{2/3}$) oxide)-lead titanate) single crystals are limited owing to their low Curie temperature and phase transition temperatures. Furthermore, the low mechanical quality factor and hysteretic losses, resulting in thermal instability, are significant issues that must be addressed. Tetragonal PMNT single crystals are found to possess high Curie temperature and non-ferroelectric–ferroelectric phase transition is found, which expands the usage range significantly. Tetragonal crystals are also found to have high coercive field and mechanical quality factors, attracting much effort on the characterization of tetragonal PMNT33 crystals which are analyzed to determine its piezoelectric properties

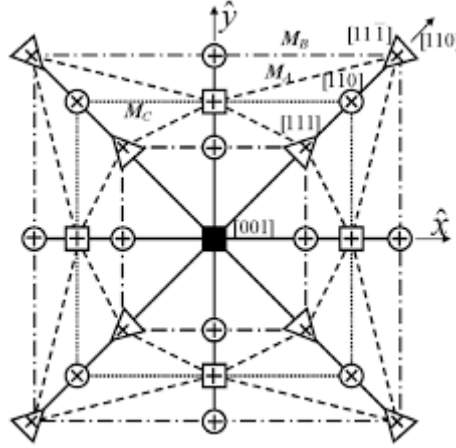


Fig 4.13 PMNT33 electric field induced structure

4.3.1.4. PZN7%PT

Large-size $\text{Pb}(\text{Zn}_{1/3}\text{Nb}_{2/3})\text{O}_3\text{--PbTiO}_3$ (PZN-PT) single crystals of different PT contents were successfully grown using an improved flux growth technique. Measurements made from samples of different orientation cuts revealed that PZN-(6-7)%PT single crystals exhibit exceptional dielectric and electromechanical properties. When poled in [001] direction, these crystals yield K_t 7000, d_{33} around 2800 pC/N and K_{33} along 0.92.

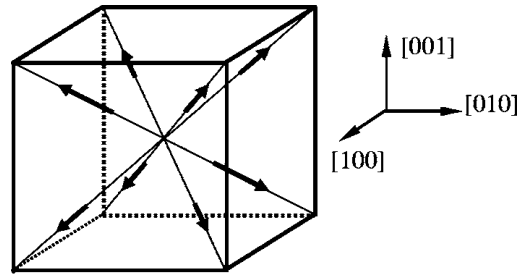


Fig.4.14.PZN7%PT crystal lattice structure

For [011]dimension-cut crystals, optimally poled PZN-7%PT single crystal exhibits very high transverse piezoelectric properties with d_{32} at -3800 pC/N, $k_{32} > 0.90$ and K_t 5000, while PZN-6%PT has d_{32} -3000 pC/N and comparable k_{32} and K_t values but a high over poling field of >2.0 kV/mm. In comparison with melt-grown PMN-PT single crystals, flux-grown PZN-PT single crystals show good compositional homogeneity, superior

and consistent dielectric and electromechanical properties, and higher depolarisation temperatures.

4.3.1.5. PVDF

Polyvinylidene fluoride or polyvinylidene difluoride (PVDF) is a highly non-reactive thermoplastic fluoropolymer produced by the polymerization of vinylidene difluoride. PVDF is a specialty plastic used in applications requiring the highest purity, as well as resistance to solvents, acids and hydrocarbons. Strong piezoelectricity was observed in PVDF, with the piezoelectric coefficient of poled (placed under a strong electric field to induce a net dipole moment) thin films as large as 6–7 pC/N: 10 times larger than that observed in any other polymer.



Fig.4.15 PVDF Film

PVDF has a glass transition temperature (T_g) of about $-35\text{ }^{\circ}\text{C}$ and is typically 50–60% crystalline. To give the material its piezoelectric properties, it is mechanically stretched to orient the molecular chains and then poled under tension. PVDF exists in several forms: alpha (TGTG'), beta (TTTT), and gamma (TTTGTTTG') phases, depending on the chain conformations as trans (T) or gauche (G) linkages. When poled, PVDF is a ferroelectric polymer, exhibiting efficient piezoelectric and pyroelectric properties. These characteristics make it useful in

sensor and battery applications. Thin films of PVDF are used in some newer thermal camera sensors.

4.3.2. Principle

When mechanical force is applied to these crystals, an electric charge is produced. Piezoelectric generators can only generate a charge when they are subjected to a continuously fluctuating force as an input. The rate of charge generation is related to the rate of force change. A piezoelectric generator can create an output of 20V and 20mA utilizing a combination of piezoelectric crystal plates. The piezoelectric generates AC power, which is fed straight into the charging pad (transmitter) in the trouser pocket. The piezoelectric generator's battery charging efficiency is tested experimentally to find the best material and number of piezoelectric plates to employ for this design [5]. As long as the user wears footwear with the imbedded plate during their walk, the piezoelectric generator will be able to provide a reliable source of power to the charging pad. The essential power source is generated during a typical walk as the crystals are impacted by regular contraction [3]. We used six piezoelectric plates in series to increase the load effect on the sensor in this experiment. The use of a rectifier circuit is no longer necessary because rectification occurs within the prosthetic arm when it receives current via induction [7].

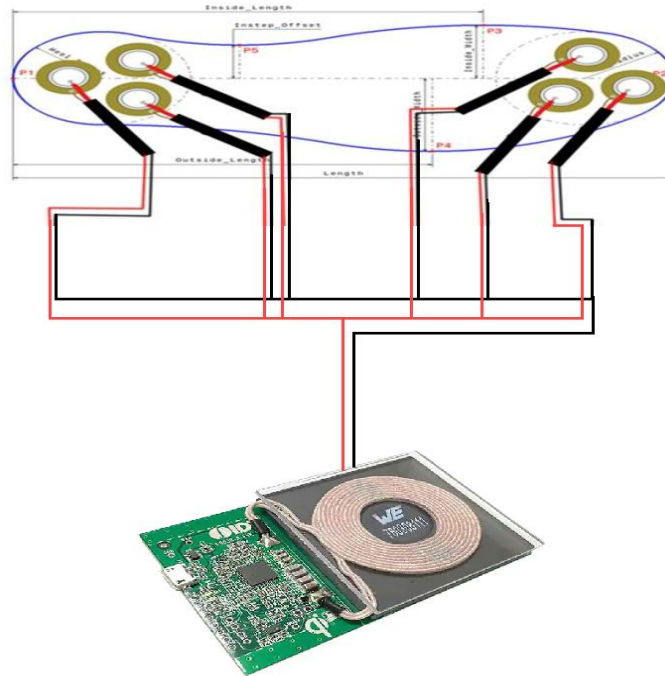


Fig.4.16. Piezoelectric generator connected to transmitter coil

4.4. WIRELESS CHARGING

4.4.1. Principle

Wireless energy transmission is the transmission of electrical energy without wires as a physical link. In a wireless power transmission system, a transmitter device, driven by electric power from a power source, generates a time-varying electromagnetic field, which transmits power across space to a receiver device, which extracts power from the field and supplies it to an electrical load. The technology of wireless power transmission can eliminate the use of the wires and batteries, thus increasing the mobility, convenience, and safety of an electronic device for all users. Wireless power transfer is useful to power electrical devices where interconnecting wires are inconvenient, hazardous, or are not possible.

4.4.2. Execution

Wireless power techniques mainly fall into two categories, near field and far-field. In near field or non-radiative techniques, power is transferred over short distances by magnetic fields using inductive coupling between coils of wire, or by electric fields using capacitive coupling between metal electrodes. Inductive coupling is the most widely used wireless technology; its applications include charging handheld devices like phones and electric toothbrushes, RFID tags, induction cooking, and wirelessly charging or continuous wireless power transfer in implantable medical devices like artificial cardiac pacemakers, or electric vehicles. In far-field, power is transferred by beams of electromagnetic radiation, like microwaves or laser beams. These techniques can transport energy longer distances but must be aimed at the receiver.

Wireless charging allows implants and sensors to be charged over time, potentially eliminating the need for lengthy charging sessions. The inclusion of a charging mechanism allows the user to go about their everyday activities without having to spend any of their allowed downtime charging. The wireless charging port can be used as the prosthetic device's source of power. There are charging pads that use tightly-coupled electromagnetic inductive or non-radiative charging; charging bowls or through-surface type chargers that use loosely-coupled or radiative electromagnetic resonant charging that can transmit a charge over a few centimeters. The coil of a wireless charging pad is usually constructed of copper and is tightly wrapped. This is the medium through which the electricity from the wireless charger is transferred. An alternating magnetic field is created when a current is passed through the coil.

A magnetic loop antenna (copper coil) is used to generate an oscillating magnetic field that can cause current to flow through one or more receiver antennas. The quantity of induced current in the receivers increases when the proper capacitance is added so that the loops resonate at the same frequency.

A copper coil receiver will be packed close to the device's surface on the prosthetic arm. This picks up the alternating magnetic field and creates a current, which is then sent on to the device's battery to charge it via a power rectifier. Because wireless charging relies on the two coils being aligned for power transmission, the device's placement on the charging pad is critical. Hence, magnets which are placed on the device and charging pad transmitter align and secure the device for wireless charging.

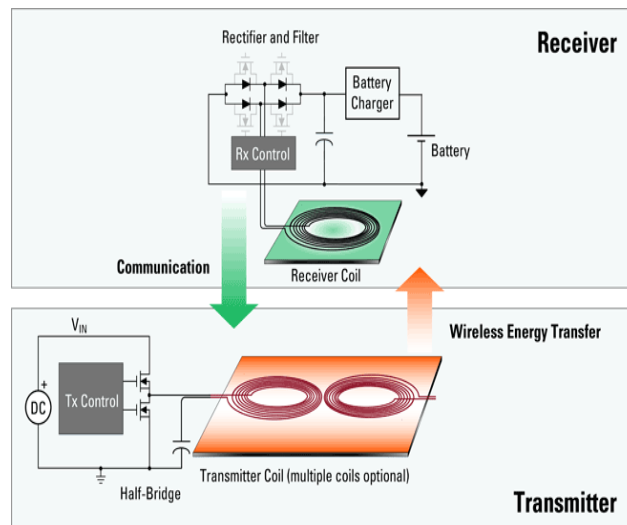


Fig. 4.17. Wireless charging principle

4.5. CODING USED FOR THE ARM MOTION

The microcontroller Arduino Uno which was based on the ATmega328P was used. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; which makes it easier to simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to make it perform the way we need it to. The Arduino Uno has a number of facilities for communicating with a computer, another Arduino board, or other microcontrollers.



4.18 Arduino Uno R3 Board

The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega16U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The 16U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, a .inf file is required. Arduino Software (IDE) includes a serial monitor which allows simple textual data to be sent to and from the board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1). A Software Serial library allows serial communication on any of the Uno's digital pins. Because of how the

potentiometers are orientated in the knuckle the servo has a range of motion of [90, 180] degrees. For example 90 degrees corresponds to the finger being at rest, fully extended, and at 180 degrees the finger is fully contracted. Values outside the range are invalid, and would correspond to bending the finger backwards. The middle finger potentiometer reads values in an analog range of up to 1023, I used the `map()` function in line 134 to convert the range into the same [90, 180] range as the other fingers. The values you map from could be different for different potentiometers, so in `setup()`, there are several lines dedicated to the calibration of the potentiometer. An alternative to recalibrate the pot each time you run the code, would be to simply record the calibration values and set the variables `MidExtd` and `MidCont` equal to them.

The 2-in-1 modified servo motors no longer "look" like servos we can wire them back up the same way to "operate" in the same way as servos. So that the components had to be soldered with the motor and corresponding potentiometer (which is either located in the index and ring finger knuckles), and solder them as in the diagram to the chip. The servo is now "functionally" the same as any other servo within the enclosure. The red servos are regular servos, and the purple ones are servos that have no position reading from their potentiometer. More specifically the 2 purple servos are the servos that were modified into continuous rotation servos in previous steps. With the potentiometer placed in the middle finger knuckle we can get a position reading and use this to control the corresponding purple, continuous rotation servo.

The other purple, continuous rotation servo, used for the thumb contraction has no position reading. This is a serious design flaw and must be fixed in later versions. At the moment it can only be operated by sight (i.e. a person watching the thumb move and telling the Arduino when to stop), if left to its own devices it would just continuously rotate until either the servo or the thumb breaks. I added a momentary switch connected to pin 6, that can be used to tell the Arduino when to stop contracting the finger. The servo

controlling the thumb contraction has no position feedback and must be manually controlled with a momentary switch, see the move Thumb() function for more info.

Finally as mentioned in the step about how to make a continuous rotation servo, it is important that modifying the servo make sure you rotate the potentiometer to the middle position (ie not to either of the extremes of 0 nor 180 degrees). This is relevant for the thumb contraction and the middle finger contraction as we will write() to either of the extremes: 0 or 180, depending on which way we want to rotate the servo. In the function moveThumb() you may need to change the range of rotAngle from [60, 140] to something different depending on what position the servo was rotated to when attaching the thumb, just play around with the range until you find a suitable one for you.

The code that was used has been included below for reference

```
#include
<Servo.h>
Servo ThumbRot, ThumbContract, Index, Mid, PinkyRing, UDwrist, LRwrist; //servos
const int Midpot=A0;          //middle finger potentiometer is connected to A0
const int ThumbButton=6;

int pos, Mpot, angleMid, buttonState;
int MidExtd, MidCont; //the readings of the potentiometer when the middle finger is
contracted and extended

void setup() {
  Serial.begin(9600);
  Index.attach(7);           //attaches the servo to respective pin
  ThumbContract.attach(8);
  Mid.attach(9);
  ThumbRot.attach(10);
  UDwrist.attach(11);
  LRwrist.attach(12);
  PinkyRing.attach(6);

  Serial.println("Need to calibrate range of middle finger potentiometer");
```

```

    Serial.println("Please rotate finger so it is at rest, fully extended");
    delay(2000);
    MidExtd=(analogRead(Midpot));
    Serial.println("Please rotate finger so it is bent over, fully contracted");
    delay(2000);
    MidCont=(analogRead(Midpot));
    Serial.println("The range of the potentiometer is calibrated");
}

void loop() {
    wave();//cycle through each of the hand positions, spending 10 seconds
    delay(10000);
    relax();
    keygrab();
    delay(10000);
    relax();
    fist();
    delay(10000);
    relax();
}

void wave(){
    for (pos = 70; pos <= 110; pos += 1) {
        moveLRwrist(pos);
        delay(15);
    }
    for (pos = 110; pos >= 70; pos -= 1) {
        moveLRwrist(pos);
        delay(15);
    }
}

void keygrab(){           //works for holding objects
    moveIndex(180);
    delay(1000);           //1 second delay to add an object
    moveThumb(130, -1);
    //don't forget to press the momentary button to stop the thumb contracting when it
    has a firm grip
}

```

```

void fist(){
    moveIndex(180);          //contract each of the fingers individually
    moveMiddle(180);
    movePinkyRing(180);
    moveThumb(130, -1);      // to change the value of 130,
    //don't forget to press the momentary button to stop the thumb contracting
}

void relax(){
    moveIndex(90);           //contract each of the fingers individually
    moveMiddle(90);
    movePinkyRing(90);
    moveThumb(130, 1);
    moveLRwrist(90);
    moveUDwrist(90);
    //don't forget to press the momentary button to stop the thumb relaxing
}

void moveThumb(int rotAngle, int contract){
    if (rotAngle<60 or rotAngle>140){          //you might need to change this range
        Serial.println("Error, thumb rotation angle out of range");
    }
    else if (contract<-1 or contract>1 ){
        Serial.println("Error, thumb contraction out of range");
    }
    else{
        ThumbRot.write(pos);
        delay(25);
        if (contract== -1){
            buttonState=digitalRead(ThumbButton);
            while (buttonState== LOW){          //keep rotating pulley until
button is pushed
                ThumbContract.write(0);          //contract the finger
                buttonState=digitalRead(ThumbButton); //make sure you push the button
otherwise the pulley will keep rotating until either the servo or the thumb breaks
                delay(25);
            }
        }
    }
}

```

```

        else if(contract==1){
            buttonState=digitalRead(ThumbButton);
            while (buttonState== LOW){                //keep rotating pulley until
button is pushed
                ThumbContract.write(0);                //extend the finger
                buttonState=digitalRead(ThumbButton);
                delay(25);
            }
        }
        //do nothing if contract=0
    }
}

void moveMiddle(int angle){
    if (angle<90 or angle>180){
        Serial.println("Error, middle finger angle out of range");
    }
    else{
        Mpot=analogRead(Midpot);
        angleMid=map(Mpot, MidExtd, MidCont, 90, 180);    //convert the raw analog value
        if (angleMid<angle){//needs to contract finger to reach the angle
            while (angleMid<angle){
                Mid.write(180);                //goes to the far extreme
                Mpot=analogRead(Midpot);
                angleMid=map(Mpot, MidExtd, MidCont, 90, 180);
                delay(25);
            }
        }
        else if (angleMid>angle){                //needs to relax finger to
reach the angle
            while (angleMid>angle){
                Mid.write(0);
                Mpot=analogRead(Midpot);
                angleMid=map(Mpot, MidExtd, MidCont, 90, 180);
                delay(25);
            }
        }
    }
}

void moveIndex(int angle){
    if (angle<90 or angle>180){
        Serial.println("Error, index finger angle out of range");
    }
}

```

```

    }
    else{
        Index.write(angle);
        delay(25);
    }
}

void movePinkyRing(int angle){
    if (angle<90 or angle>180){
        Serial.println("Error, pinky/ring finger angle out of range");
    }
    else{
        PinkyRing.write(angle);
        delay(25);
    }
}

void moveUDwrist(int angle){
    if (angle<70 or angle>110){
        Serial.println("Error, angle out of range for wrist motion");
    }
    else{
        UDwrist.write(angle);
        delay(25);
    }
}

void moveLRwrist(int angle){
    if (angle<70 or angle>110){
        Serial.println("Error, angle out of range for wrist motion");
    }
    else{
        LRwrist.write(angle);
        delay(25);
    }
}

```

CHAPTER – 5

RESULTS AND DISCUSSION

Determining a suitable piezoelectric material was a vital part of this project hence the ones that are readily available in the market cannot be used as the output voltage that can be collected is insignificant for the project need. Hence different journals were referred to calculate a hypothetically possible value of voltage that it could be produced and could significantly improve the performance of the suggested device. Hence making it a better alternative to the conventional power sources that are being used currently for this same purpose.

The piezoelectric coefficients (d_{33} , d_{31} , d_{15} etc.) measure the strain induced by an applied voltage (expressed as meters per volt). High d_{ij} coefficients indicate larger displacements which are needed for motoring transducer devices. The coefficient d_{33} measures deformation in the same direction (polarization axis) as the induced potential, whereas d_{31} describes the response when the force is applied perpendicular to the polarization axis. The d_{15} coefficient measures the response when the applied mechanical stress is due to shear deformation.

Relative permittivity (ϵ_r) is the ratio between the absolute permittivity of the piezoelectric material, ϵ , and the vacuum permittivity, ϵ_0 . The electromechanical coupling factor k is an indicator of the effectiveness with which a piezoelectric material converts electrical energy into mechanical energy, or converts mechanical energy into electrical energy. The first subscript to k denotes the direction along which the electrodes are applied; the second denotes the direction along which the mechanical energy is applied, or developed. The mechanical quality factor Q_m is an important

high-power property of piezoelectric ceramics. It is the inverse of the mechanical loss $\tan \phi$.

TABLE-I

Table 5.1: Comparing the properties of various piezoelectric materials

Reference	Material name	Piezo electric coefficient	Relative permittivity	Electro mechanical Coupling factor
Zgonik[12]	Quartz plate	$d_{33} = 235$	$\epsilon_{33} = 1984$	$k_{33} = 54.4$
Luo[13]	PZT			
Ye[14]	PMNT33 (Pb(Mg ^{1/3} Nb ^{2/3})oxide)-lead titanate	$d_{33} = 2820$	$\epsilon_{33} = 8200$	$k_{31} = 0.59$
		$d_{33} = 2820$		$k_{33} = 0.94$
Tanaka[15]	PZN7%PT (Lead Zinc Niobate - Lead Titanate)	$d_{33} = 2400$	$\epsilon_r = 6500$	$k_{33} = 0.94$
				$k_t = 0.55$
Sessler[16]	PVDF	$d_{31} = 17.9$	$\epsilon_r = 106$	$k_{31} = 10.3$
		$d_{32} = 0.9$		$k_{33} = 12.6$
		$d_{33} = -27.1$		

From this table we could infer the required values to calculate the voltage based on the pressure applied and other conditions that could factor in to provide a varied output.

$$V = \frac{P * t * d_{33} * k_t}{e * e_0}$$

Where P is the pressure applied

t is the thickness of the material

d_{33} is the piezoelectric coefficient

k_t is the coupling factor of the material

ϵ is the relative permittivity

ϵ_0 is the permittivity in vacuum, When mechanical force is applied to these crystals, an electric charge is produced. Piezoelectric generators can only generate a charge when they are subjected to a continuously fluctuating force as an input. The rate of charge generation is related to the rate of force change. The piezoelectric generates AC power, which is fed straight into the charging pad (transmitter) in the trouser pocket.

The piezoelectric generator's battery charging efficiency is tested experimentally to find the best material and number of piezoelectric plates to employ for this design [5]. As long as the user wears footwear with the imbedded plate during their walk, the piezoelectric generator will be able to provide a reliable source of power to the charging pad.

The essential power source is generated during a typical walk as the crystals are impacted by regular contraction [3]. We used six piezoelectric plates in series to increase the load effect on the sensor in this experiment. The below tabulation shows the possible measure values of the apparatus that was designed which had the piezoelectric materials that was available to be tested to determine a suitable conventional setup which could be used in this setup.

For testing the shoe had the piezoelectric devices installed in 6 separate locations with four of them placed in the toe region and 2 along the heel.

Different materials based on their availability were used in this setup and were placed based upon which the performance was determined. The different materials has their respective coefficient values collected from the various reference paper that helped determine it possible power rating. In the case of volt per stomp the similar setup was used here instead of having the individual perform walking he was made to jump to determine the maximum potential that possible be extracted from this device setup.

TABLE –II

Table5.2: Comparing the voltage of the various materials

S.no	Material	Volt per stomp (mV)	Maximum power (mW)
1.	Quartz plate	2	7
2.	PZT	6	2.4
3.	PMNT33 (Pb(Mg $1/3$ Nb $2/3$) oxide)-lead titanate		18
4.	PZN7%PT (Lead Zinc Niobate - Lead Titanate)		14
5.	PVDF	0.346	1.73

This tabulation help us determine a suitable material that could be possibly used for this experiment. The charging efficiency is measured, and the perfect environment for each individual is established. The essential power source is generated during a typical walk as the crystals are impacted by regular contraction [3]. We used six piezoelectric plates in series to increase the load effect on the sensor in this experiment. The below tabulation shows the possible measure values of the apparatus that was designed which had the piezoelectric materials that was available to be tested to determine a suitable conventional setup which could be used in this setup.

For testing the shoe had the piezoelectric devices installed in 6 separate locations with four of them placed in the toe region and 2 along the heel.

Different materials based on their availability were used in this setup and were

placed based upon which the performance was determined. The different materials has their respective coefficient values collected from the various reference paper that helped determine it possible power rating. In the case of determine the maximum potential that possible be extracted from this device setup.

TABLE III

Table5.3: Comparing the walk speed of various individuals

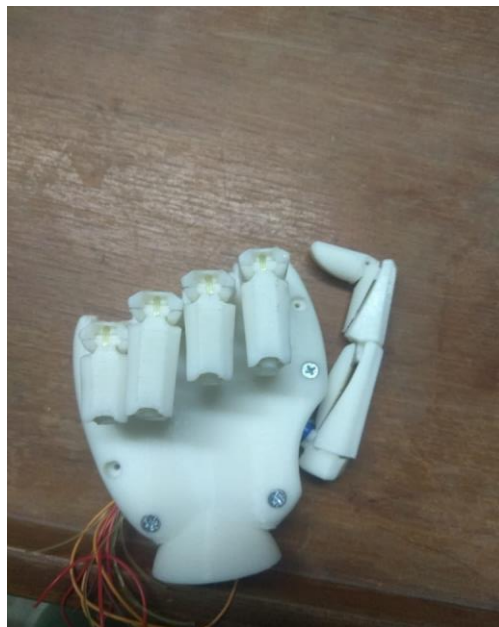
S.No	Variables		
	<i>Weight of the individual(kgs)</i>	<i>Walk Speed(m/s)</i>	<i>Charge efficiency (time taken in hrs)</i>
1.	65	0.5	4
2.	65	1.4	3.6
3.	65	1.8	3.2
4.	75	0.5	3.7
5.	75	1.4	3.3
6.	75	1.8	3

One material which was readily available which was PVDF is used in this part of the experiment to provide with the suitable operation when the person who has the prosthetic arm moves he has to make sure that the charging pads gets align themselves when person moves this makes sure that the circuit is complete to charge the constructed prosthetic. The person is made to move in two different speed to determine the performance issue with charging similarly the weight which was applied on the material was varied by including two different individual for this same purpose and this provides a wider calculative range. Hence during

the operative execution two individuals of varied weights are considered and they are made to perform the above condition to determine a variation that one could come across when this occurs and this would also determine any variation when weight of an individual is factored in the practice



The above image shows the prosthetic arm in the extension position



The above photo shows the prosthetic arm in the pronation position

CHAPTER–6

SUMMARYANDCONCLUSIONS

6.1. SUMMARY

- The transradial residual limb prosthetic was successful constructed which contracts on its own, producing motion based on the electrical signal that the EMG sensor interprets to perform the needed motion. This information is processed in order to control the prosthetic arm.
- The movement of the hand is caused by muscular contractions, which produce in electrical activity and a signal, which the EMG sensor detects.
- EMG signals are detected by intermuscular needle electrode and surface electrode. Because EMG recordings are essentially the potential difference between two electrodes, more than one electrode is employed in surface EMG.
- A monopolar needle electrode is placed into the muscle with a surface electrode as a reference in intermuscular EMG. For research or kinesiology studies, the latter technique is used.
- Despite the fact that electromyogram (EMG) pattern recognition (PR) for multifunctional upper limb prosthetic control has been reported for decades, power efficiency appears to be a problem, requiring the arm to be charged or placed in for a battery replacement several times throughout the day.
- The device's goals were successfully achieved
 - A self-report and performance results of various piezoelectric sources and circuits for optimal charging were deduced and a suitable material for this purpose was determined
 - A Pattern recognition (PR) system was designed to provide input for a three-degree-of-freedom (wrist rotation, wrist flexion, and hand control) prosthesis.
 - Suitable construction for wireless charging was designed which

could provide the suitable charging conditions.

- A device with a lower overall weight comparable to a real arm was designed and its respective battery life was determined.

6.2. CONCLUSIONS

- The output of a less expensive EMG sensor setup was suitable to provide the necessary input to move the prosthetic limb.
- The various walk speed of different individuals were observed to determine the suitable conditions to increase/calculate the efficiency of charging.
- The whole cost of the prosthetic arm, including the piezo generator, would be substantially lower in comparison to its capabilities and ones available in the market.

6.3. RECOMMENDATIONS

- Better piezoelectric materials could have been used if they were available in the market as they are still under development
- Even compact circuit can be designed for future development of the device
- Lighter material or hollow structures could have been designed which does not compromise on the strength of the prosthetic limb.

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