# ANKLE FOOT ORTHOSIS

By

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Bachelors in Electrical (Electronics) Engineering

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# CERTIFICATE

It is certified that the contents and form of thesis entitled **“ Ankle Foot Orthosis ”** submitted by *Abdul Ahad Ashfaq Sheikh (297), Azmat Bilal (326), Usman Abdullah (382), Usman Khan (424),*have been found satisfactory for the requirement of the degree.

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# DEDICATION

To Allah the Almighty

&

To my Parents and Faculty

# ACKNOWLEDGEMENTS

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We are really indebted to all of you, your help and guidance.

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# ABSTRACT

The AFO functions primarily in stance to correct deformity and control motion and in swing phase to compensate for muscle weakness-in the case of the individual with stroke to promote dorsiflexion to provide toe clearance in swing.

A combination of mechanical and electrical components enables to provide a robotic solution for the human foot. The project involved research and implementation of human gaits to provide a close to comfortable walking experience with the help of the device.

The process of achieving a natural walk was started with the help of Matlab simulation and analysis of gaits of a normal human being. And the data acquired through this simulation has been used as a standard. The mechanical aspect was the challenging one but a cost effective and efficient working model has been achieved. A prototype with a novel design is manufactured and is in the process of testing against the standard made during the simulation.

The prototype is operated with help of a micro controller which receives inputs from the Force sensors to identify gait cycle state and then tries to achieve the angle required in that specific stage with help of a motor and feedback from an angle encoder.

## *Chapter 1*

# INTRODUCTION

## 1.1 ORTHOSIS

A force system designed to control, correct, or compensate for a bone deformity, deforming forces, or forces absent from the body. Orthosis often involves the use of special braces [14].

The term orthosis is mostly used for the spinal region and lower limbs. Ankle-foot Orthosis is one particular orthosis which is used for ankle abnormalities. So far this is most widely used orthosis as compared to others i.e. knee orthosis etc.

## 1.2 ANKLE FOOT ORTHOSIS

Ankle Foot Orthosis can be defined as a human wearable robot which helps in compensation for weakness and proper orientation. Since its property of human neural system that it can readjust its connections, ankle foot orthosis can be therefore be used for rehabilitation purpose.

It is an electro-mechanical device which will with the help of pressure sensors, electrical signals and mechanical parts, tries to imitate human ankle and foot movement as closely as possible. A collection of control electronics and integrated circuits are put together for the accomplishment of this task. A study as well as a practical attempt to the solution of deformed feet and ankle’s will be done.

## 1.3 IMPORTANCE

Ankle foot orthosis are used in the treatment of disorders affecting muscle function such as stroke, spinal injury, partial paralysis of foot and partial polio attach on lower limb region. Some walking abnormalities like ‘Foot-slap’ and ‘Drop-foot’ arise due to damaged nerves in the lower limb region. Ankle-foot orthosis are specifically designed for these abnormalities. Ankle-foot orthosis are the most commonly-used orthosis, making up about 26% of all orthosis provided in the United States [13]. Therefore improvement in control mechanism and reducing the cost of AFOs will be a major advancement in medical and bio engineering domain.

## 1.4 PROJECT GOALS

The objective of the project is to provide a working machine for ankle\foot which will provide;

- Cost effective
- Efficient
- More comfortable
- Innovative solution

## 1.5 REPORT ORGANIZATION

This report is organized into following Chapters;

2 Introduction
3 Literature Review
4 Functionality and Design
5 Implementation and Result Discussion
6 Conclusion and Future Recommendations
7 References
8 Appendices

# LITERATURE REVIEW

This chapter reviews the different categories of ankle-foot orthosis (AFO) and the latest trends in the industry. It discusses how the researchers have contributed in this field, transforming it from a simple mechanical support structure into a highly complex digitally controlled device. The limitations and shortcomings in the modern AFOs are also discussed in this chapter.

The Ankle-foot support structures can be divided into two categories, One which are totally rigid and hence are passive in nature. The second category is of AFOs with both mechanical and electronic part which can be termed as powered Ankle foot orthosis. In such designs the proportion of emphasis on mechanical versus electrical sections is different by different scientists thus dividing powered AFOs into further subcategories.

## 2.1 PASSIVE DYNAMIC (PD) AFO

Passive AFOs are such orthotic devices which don’t provide additional power to the ankle movement. They range from simple rigid plastic or metal from to relatively complex designs incorporating latest manufacturing techniques. Majorities of AFO available in the market are Passive Dynamic AFOs due to their simple design and reliable results.

The rigid type of AFOs basically provides fix support to the ankle and there is no moving part in the design. They fix the position of patient’s ankle at one place and cater the problems like drop-foot and foot-slap. A common AFO design in this category is the one designed by

Randy D. F. Mason and William Vuletich [2] in 1981. The material used in them is mostly Polypropylene-based plastic. Latest research has produced light weight models with more comfortable design features. Carbon Fiber based AFOs have been developed by Mario C. Faustini, Richard H. Crawford and Steven J. Stanhope in 2008 using latest Laser fabrication techniques[1], shown in figure 1.

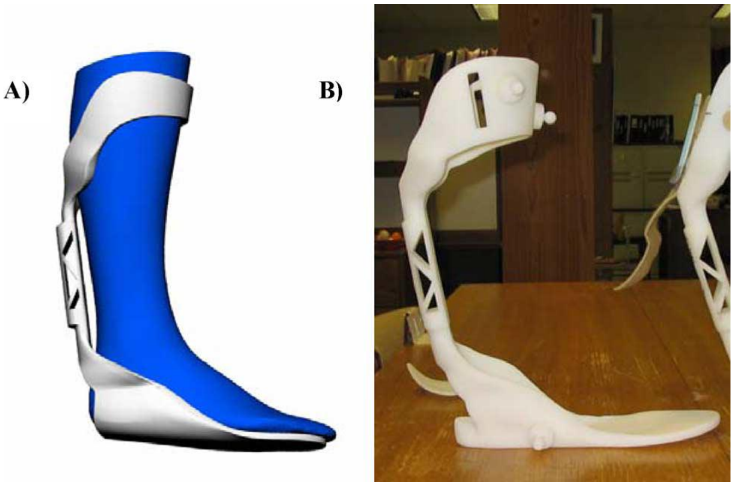


Figure 1: Passive Dynamic Ankle foot orthosis

## 2.2 POWERED ANKLE-FOOT ORTHOSIS

Powered ankle foot orthosis are those orthotic devices which use active power delivering elements for the ankle movement. The additional power can be provided from batteries or by pressure from a compressed gas container. Such AFOs have a processing unit which provides control over the actuators on the basis of sensor feedback. Powered AFOs force the feet to move in a calculated pattern rather than just providing support.

The need for Powered Ankle foot orthosis arose with the discovery that human neural network possesses the ability to reorganize after the damage or injury [4]. It was proved that neural networks improve through repetitive training. The major role of Powered AFOs is in rehabilitation of ankle injuries in which neural network can be remapped.

Powered ankle foot orthosis vary on the basis of actuation mechanism. The following actuation mechanisms have been used by different researchers.

### 2.2.1 Pneumatic Muscles:

Pneumatic muscles are artificial muscles which provide actuation similar to the movement of actual human muscle [5]. They are made up of steel or tough plastic wires mesh with an air tube inside them. They contract when air is blown in them and relax when air is released. The latest implementation of pneumatic muscles in ankle-foot orthosis is done by Masanori Sugisaka, Jiwu Wang, Hiroshi Tsumura, and Masashi Kataoka [6], in which a single Pneumatic Muscle is used to lift the toe up at different stages of walking, shown in figure 2.Sensors are used for feedback of foot position to the controller.

The advantage of use of Pneumatic muscle is that they are more flexible and put less strain on the foot. But one major drawback of this system is that a separate air compressor or container is needed for actuation.

**Figure 2: Ankle foot Orthosis by the use of Pnuematic Muscles**

### 2.2.2 Electromagnetic Actuators:

A powered Ankle foot orthosis was designed by Nobuyuki Yoshizawa in which electromagnetic coil was used for actuation purpose [7]. In such type of AFOs power is given to the coil which pushes the actuator with magnetic force. This particular Powered AFO was designed to provideupright postureand step-forward posture to the ankle,whereas a fixed brace was applied to the ankle, shown in figure 3. Such mechanism cannot be implemented to provide complete ankle movement.

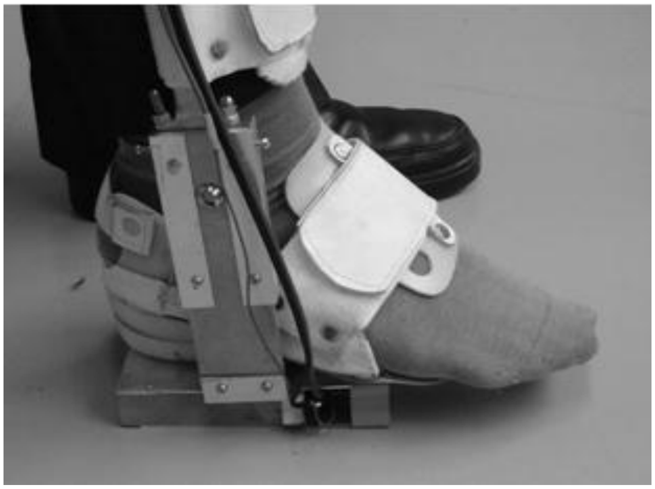


**Figure 3: Ankle foot Orthosis using Electromagnetic coil Actuator**

### 2.2.3 Linear Actuators:

Linear actuators are most wide used actuators in powered ankle foot orthosis. The linear actuator uses a motor for power and converts that rotational motion into linear motion through gears. Linear actuators enable both up and down motion of the foot and as a result more intelligent mechanisms can be designed. The drawback of using motors and gears is that the design becomes too rigid making it uncomfortable for the patient. In order to overcome to this springs are used in series with linear actuators providing much more flexibility in the design.

A particle type of actuator used is ‘Series Elastic Actuator’ (SEA) which is a linear actuator with a spring at its piston [8], shown in figure 4. Joaquin A. Blaya and Hugh Herr used this series elastic actuator in Ankle foot orthosis in 2004 to assist drop-foot patients [9],shown in figure 5. The latest version of AFO using Series Elastic Actuator are designed by Joseph Hitt, A.Mehmet Oymagil, Thomas Sugar, Kevin Hollander, Alex Boehler and Jennifer Fleeger in 2007 [10] and by Alexander W. Boehler, Kevin W. Hollander, Thomas G. Sugar and Dosun Shin in 2008[11].

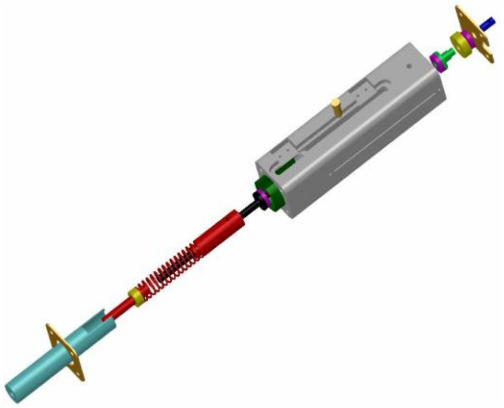


Figure 4: Series Elastic Actuator(SEA)

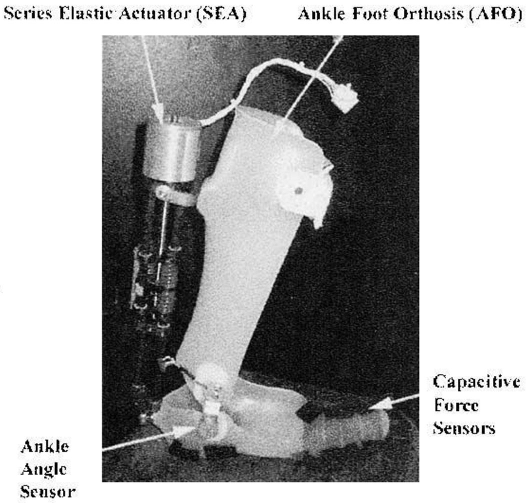


Figure 5: AFO using Series Elastic Actuator

## 2.3 FORCE AND TORQUE MEASUREMENT

In order to design a support structure for ankle, a complete knowledge of forces and torques acting on a foot must be gained.A detail research on forces and toques acting on a foot was done by Philippe Sardain and Guy Bessonnet [12]. In their research a comparison was made between actual foot and a mechanical foot and the forces acting on it at different points. The results showed that mechanical foot motion pattern is almost similar to the real foot patternexcept at few points where its pattern becomes irregular. It was also studied that artificial support structures can provide comfortable movement if they are designed to follow actual foot force and torque pattern.

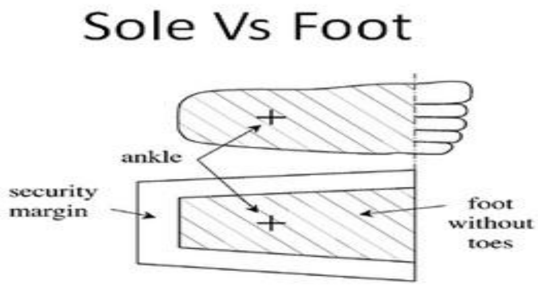
### 2.3.1 Forces and torques acting on Human Foot

The different forces experienced during a normal dynamic walk had to measured or known. For the development of an anthropomorphic biped robot, Bip, involving two French

Laboratories [12] performed a series of experiments to measure forces and torques exerted during different walking phases.

A few concepts have been defined at the beginning to carry out the experiments which included the concept of Centre of pressure (CoP) and Zero Moment Point (ZMP).

The field of pressure forces (normal to the sole) is equivalent to a single resultant force, exerted at the point where the resultant moment is zero this point is termed CoP. It is mostly related to the contact forces. Whereas The ZMP is the point on the ground, where the tipping moment acting on the biped due to gravity and inertia forces, equals zero.the tipping moment being defined as the component of the moment that is tangential to the supporting surface. Thus explaining that ZMP is not actually the point where the moment sum is zero but it’s the point just before the tipping point. The scientist carried out experiment with both natural and mechanical feet. In mechanical feet a mechanical sole was attached with the feet and walking with different dynamics was performed. The mechanical sole designed was inspired from the Honda P2’s foot which has an extended heel and no toes.



Dimensioning principle of the robot sole.

**Figure 6: Comparison between Natural and Mechanical Foot**

## 2.4 HUMAN WALKING PATTERN

The scientists [12] divided the walk in four main phases for a single foot;

- Heel Strike (HS)
- Foot-Flat (FF)
- Heel-Off (HO)
- Toe-Off (TO)

Thus total eight phases for both the feet in this experiment the right foot is presented with "1" as a subscript and left with "2" subscript . The different stages of the walks were summarized with the help of the figure below;

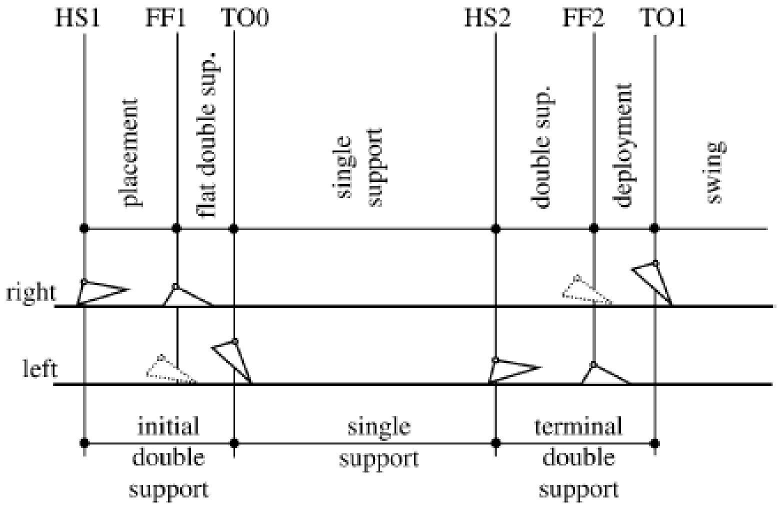


Figure 7: Human Walking Pattern

### 2.4.1 Similarities between Natural and Artificial Foot:

According to the scientist the natural walk and mechanical walks are almost similar in the following ways

- The pattern of the forces and moments is almost identical
- Gaits almost similar
- The CoP is at the same place in front of the ankle after the placement of the foot
- CoP same when the heel leaves the ground

### 2.4.2 Differences between Natural and Artificial Foot:

Whereas they differ in the following aspects;

- In Bip feet, the CoP jumps from the heel to the front of the ankle where as its smoother in natural walk
- the pressure force increases sharply at foot-flat phase of walk in Bip feet as compared to natural
- total force as regards the two feet in support is abnormally greater with metallic shoes (Bip)

The following graphs show comparisons of the mechanical and naturals walks in terms of Forces, torques and CoPs respectively;

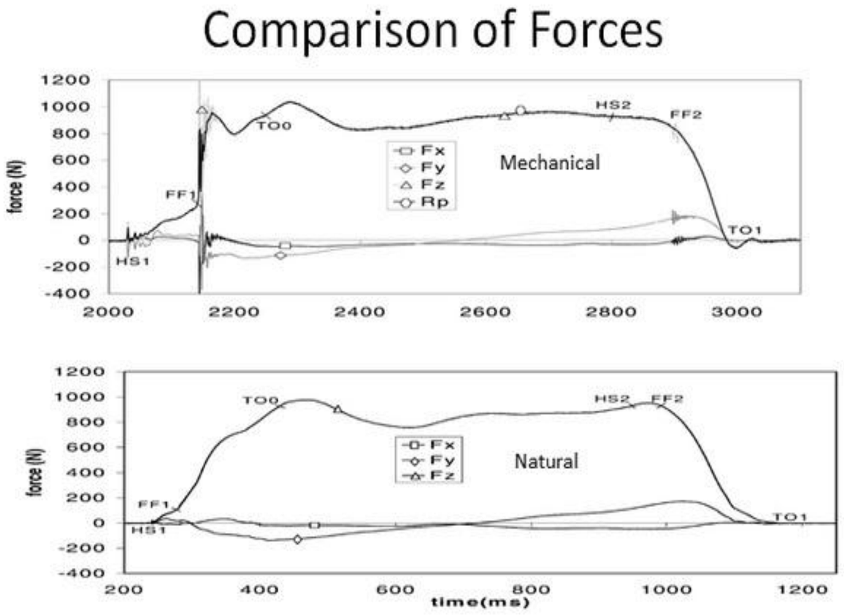


Figure 8: Comparison of Forces

The graph explains that throughout the walk the envelope of the forces exerted remains the same and thus gaits are identical to the only difference that the foot experiences is in the change from the Foot-flat phase of the right foot and toe-off phase of the left foot that is taking place . The change is sudden in the mechanical part where the transition of forces is smoother in the natural.

Similarly in moments the envelope remains the same but the transition is somehow a bit abrupt at foot flat and the toe-off phase. And the peak moment of the mechanical part is 200Nm greater than the natural walk which not much of a difference.

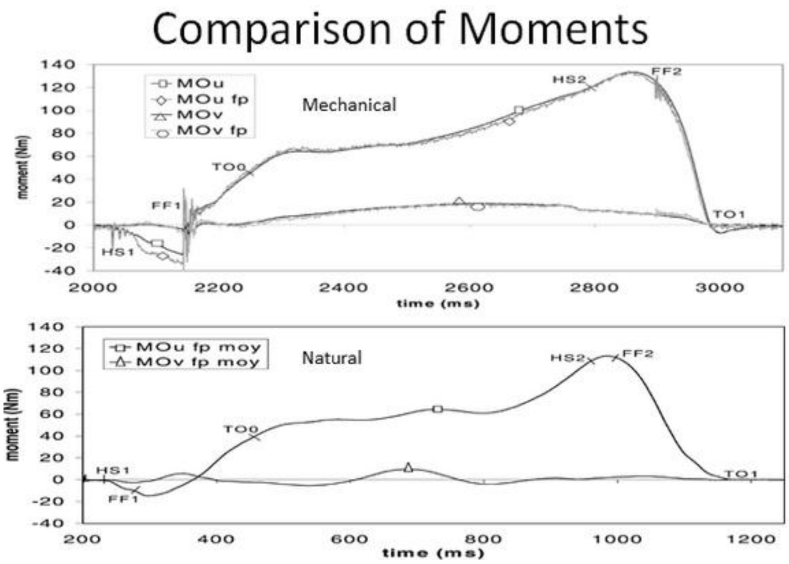


Figure 9: Comparison of Moments on Foot

The Cop transition in the mechanical foot is sudden from the heel to ankle where as in natural walk it changes very smoothly due to the presence of the toes.

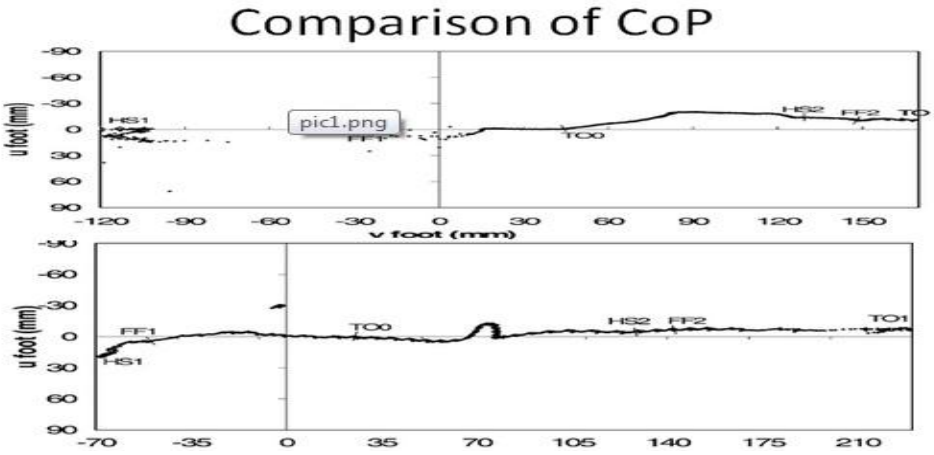


Figure 10: Comparison of Centre of Pressure

## 2.5 MICROCONTROLLERS

A microcontroller (sometimes abbreviated µC, uC or MCU) is a small computer on a single integrated circuit containing a processor core, memory, and programmable input-output peripherals. For the efficient mechanical control of our *AFO* (Ankle foot orthosis design), by the electronics design, we'll need microcontrollers. These microcontrollers will take input from the pressure sensors attached on our AFO, and depending upon the programming will generate certain output. This will then control the speed, rotation and brakes of motors eventually. Any further discrepancies in the mechanical system will be solved by efficient programming. Some of the microcontrollers which can serve the purpose are explained below;

### 2.5.1 8051 Microcontroller

8051 microcontroller [15] is optimized for 8 bit control application. To facilitate byte operations, it provides fast addressing modes for accessing the internal RAM. Also allows direct bit manipulation in control and logic systems that require Boolean processing. It supports a number of addressing modes. All of the port lines are bit addressable and each one can be treated as a separate single port. Separate ports for input and output are reserved, which can't be changed via programming. All four ports are bi-directional, each consisting of a latch, an output driver and an input buffer. The code for the microcontroller can be written either in C language or in assembly language.

External as well as internal interrupts can also be used, which can help triggering the output. Timers are also there 16 bit timers and 8 bit auto reload timers, which generate signals depending upon programming. A crystal/ceramic oscillator is there responsible for generation of clock pulses.

### 2.5.2 AVR Microcontroller

AVR [16] is also a CMOS 8 bit microcontroller based on the enhanced RISC architecture.it has Up to 16 MIPS (million instructions per second) throughput at 16MHz, 32 × 8 General Purpose Working Registers, Real Time Counter with Separate Oscillator, Four PWM Channels and internal ADC (analog to digital converter). And hence this is more efficient than 8051 microcontroller's series, and has more advanced usage options. All the four ports can be used as input and output depending upon programming.

**Figure 11: Atmega16 Microcontroller**

By executing powerful instructions in a single clock cycle, the AVR microcontroller achieves throughputs approaching 1 MIPS (million instructions per second) per MHz allowing the system designed to optimize power consumption versus processing speed.

All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC(complex instruction set computing) microcontrollers. In order to maximize performance and parallelism, the AVR uses Harvard architecture – with separate memories and buses for program and data. Instructions in the program memory are executed with a single level pipelining. While one instruction is being executed, the next instruction is pre-fetched from the program memory. This concept enables instructions to be executed in every clock cycle.

### 2.5.3 Pic Microcontroller

PIC microcontrollers [17] can also make are task easy. The name PIC initially referred to "Peripheral Interface Controller". The main edge which these microcontrollers have over others is that it is used in industry and for commercial purposes. More of its system functionalities are similar to AVR microcontroller but Its main core features include, High performance RISC (reduced instruction set computing)CPU. Interrupt capability (up to 14 sources). It also has Power-up Timer (PWRT) and Oscillator Start-up Timer (OST), Power saving SLEEP mode and Selectable oscillator options. It’s another advantage is that it has a small instruction set to learn.

Moreover PICs are popular with both industrial developers and hobbyists alike due to their low cost, wide availability, large user base, extensive collection of application notes, availability of low cost or free development tools, and serial programming (and re-programming with flash memory) capability.

**Figure 12: Mikrochip Microcontroller**

*Chapter 3*

# FUNCTIONALITY

The complete design of the ankle foot orthosis can be divided into two portions;

- Mechanical section.
- Electronic section.

## 3.1 MECHANICAL DESIGN SPECIFICATIONS:

The Mechanical design of the prototype is made on PRO-E. It's an ingenious design made of aluminum and compromises around 13 different parts joined together .The parts include bearings, rotator parts and supporting parts

### COMPLETE DESIGN

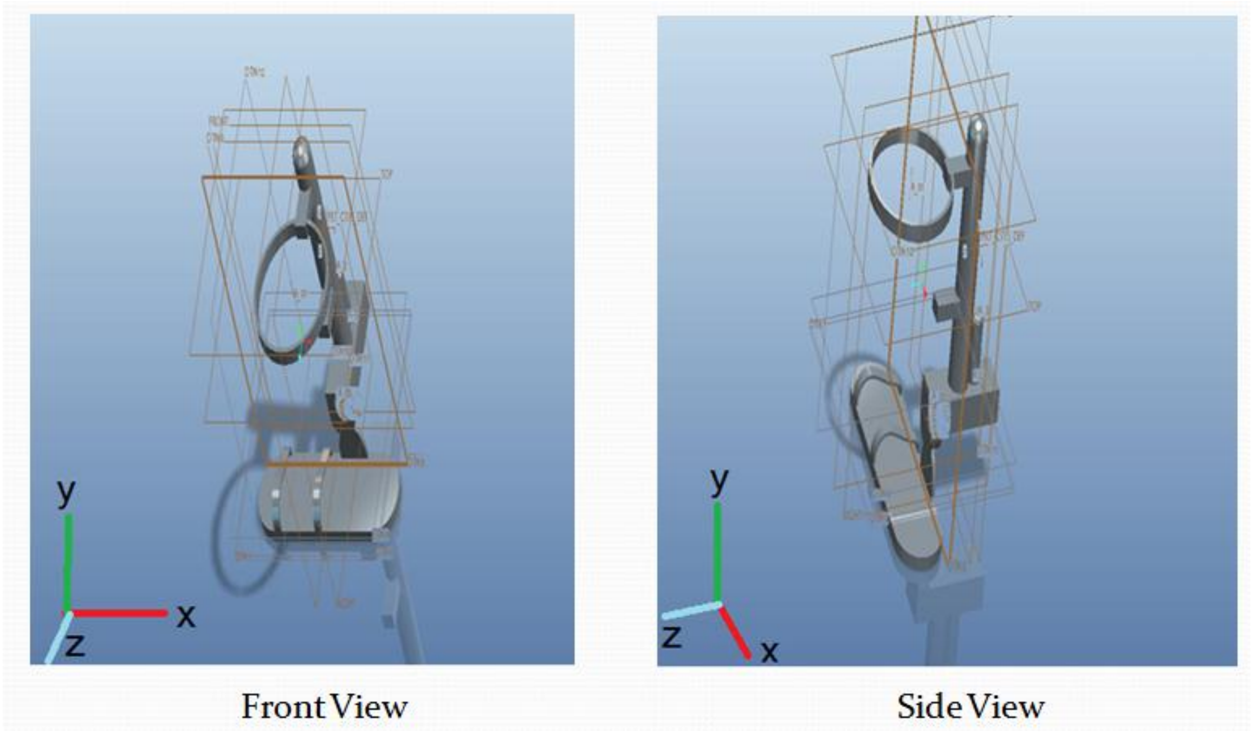


Figure 13: (a)

Figure 13 : (b)

## ROTATORY RING 1:

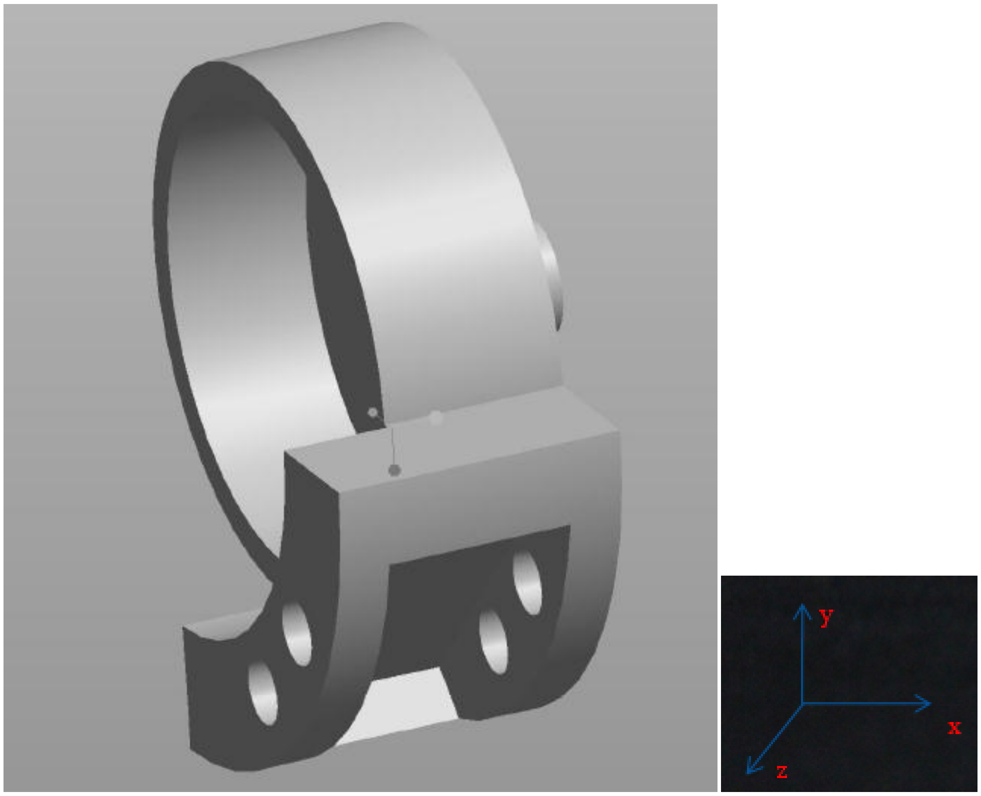


Figure 14:

## ROTATORY RING 2

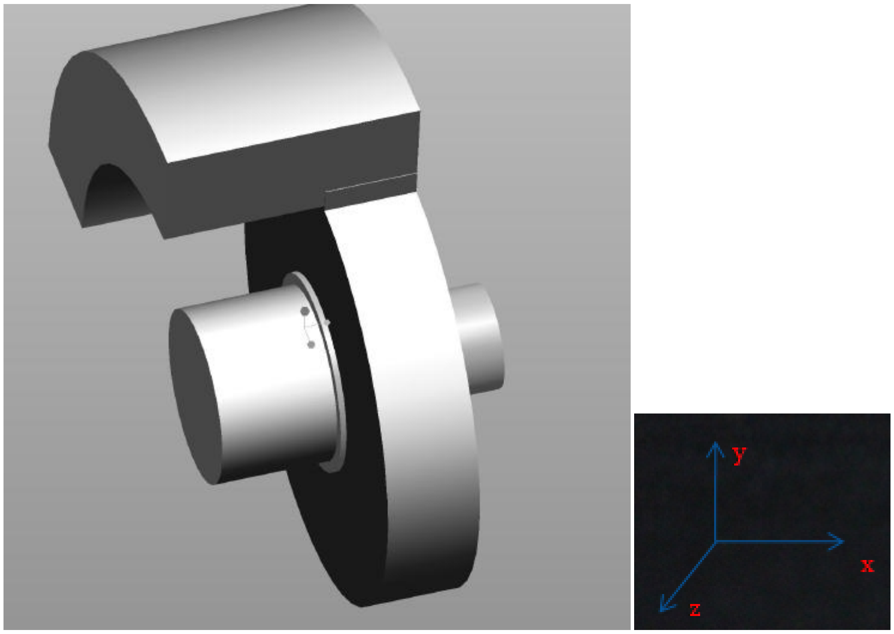


Figure 15:

## FOOT-JOINT

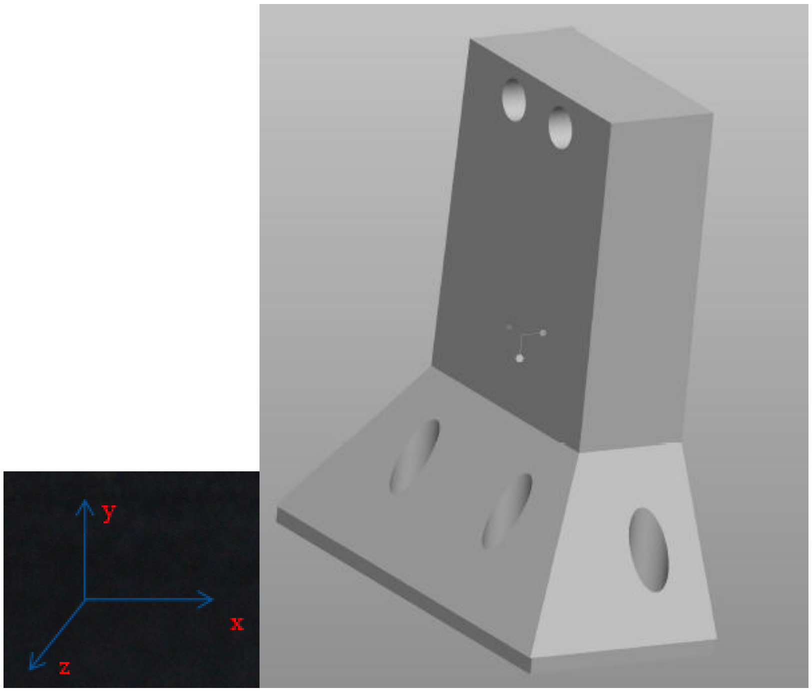


Figure 16:

## GEAR

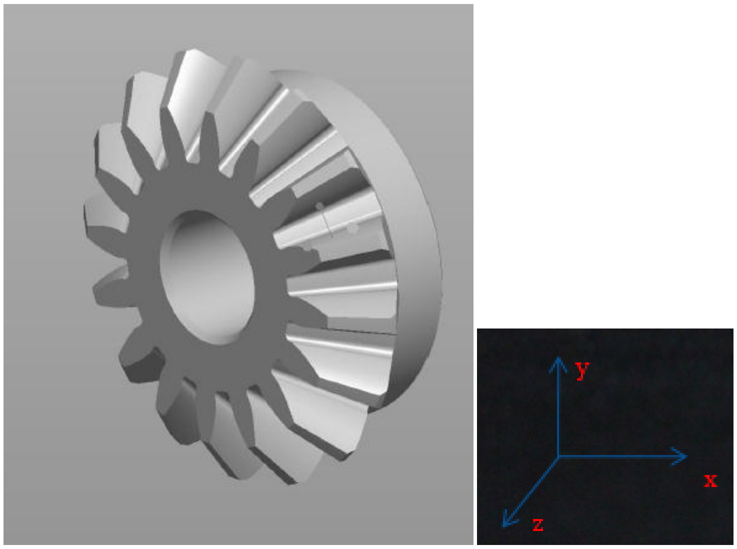


Figure 17:

### CASING FOR THE ROTATION MECHANISM

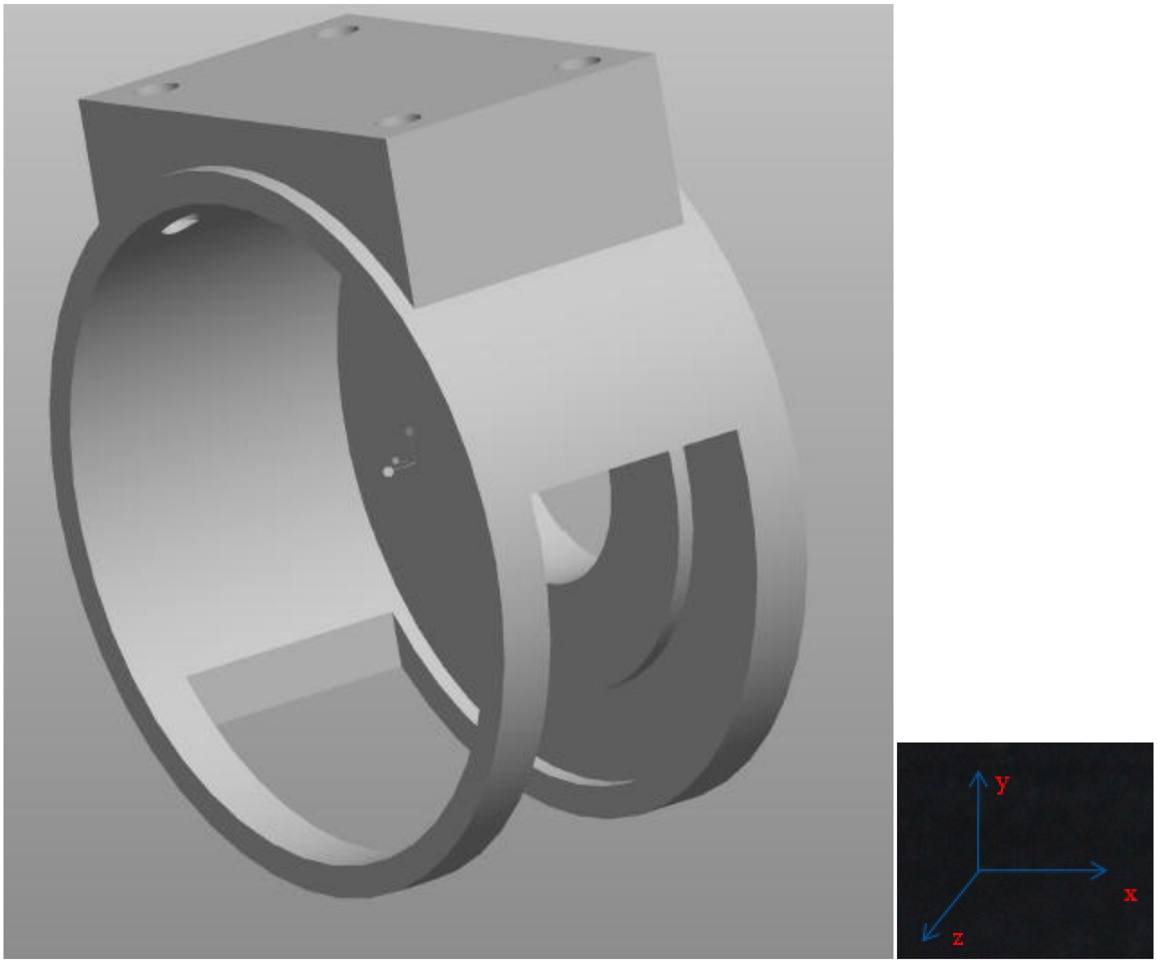


Figure 18:

## 3.2 ELECTRONICS DESIGN SPECIFICATIONS:

In order to turn the mechanical structure from passive to an active power delivering mechanism a standalone electronic processing unit is designed. The complete electronic circuit will be portable and attached on the outer edge of the mechanical structure. Power to the system will be provided from a battery pack attached to the waist of the patient.

Like any robotic system, the AFO has a processing unit, sensors for input and actuators to produce desired response. The sensors will take input and convey the information to the processing unit which will in turn produce the response to the input through actuators. Each of these elements are explained in detail below:

### 3.2.1 FORCE SENSITIVE RESISTORS:

FSRs are robust polymer thick film (PTF) devices that exhibit a decrease in resistance with increase in force applied to the surface of the sensor. The standard 402 sensor is a round sensor 18.28 mm in diameter.  With the help of these we will now calculate the forces acting upon the base surface of the device to develop the device to move and function accordingly. These FSRs will give different voltages values depending upon the force exerted on them. . Applying a force to the surface of the sensing film causes particles to touch the conducting electrodes, changing the resistance of the film. As with all resistive based sensors, force-sensing resistors require a relatively simple interface and can operate satisfactorily in moderately hostile environments. Compared to other force sensors, the advantages of FSRs are their size (thickness typically less than 0.5 mm), low cost and good shock resistance. However, FSRs will be damaged if pressure is applied for a longer time period (hours). A disadvantage is their low precision: measurement results may differ 10% and more.

## Mechanical Data

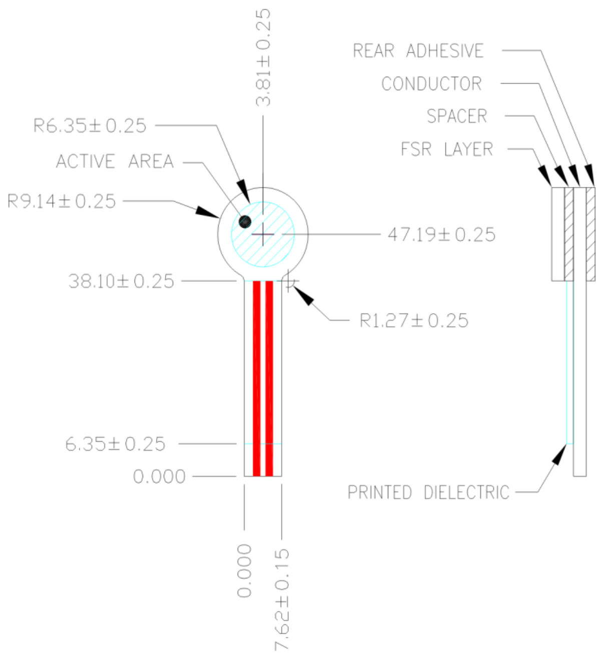


Figure 19:

## INTERLINK TECHNOLOGY

**Figure 20:**

**Patented Force Sensing Resistor** technology from Interlink Electronics provides sensor-based interface capabilities for a wide variety of products - from home gaming controllers to satellite-guided agricultural machinery. For more than 15 years, Interlink has used FSR technology to create innovative custom solutions for industry-leading companies like Microsoft, IBM, Sony and many others. We offer both custom FSR products that perfectly match the unique interface requirements of specific applications - and a range of standard FSR products for more basic "touch sensitive" applications.

### 3.2.2 FSR accuracy

- Dynamic measurement, only qualitative results are generally obtainable.
- Force accuracy ranges from approximately ± 5% to ± 25% depending on the consistency of the measurement and actuation system
- Repeatability tolerance held in manufacturing, and the use of part calibration. Manufacturing ranges from ± 15% to ± 25% of an established nominal resistance.
- The force resolution of FSR devices is better than ± 0.5% of full use force.

### 3.2.3 FSRs how they work

- Particle size at the scale of microns
- Formulated to reduce temp. dependence, and improve mechanical properties
- Force on the surface causes particles to touch conducting electrodes changing the resistance

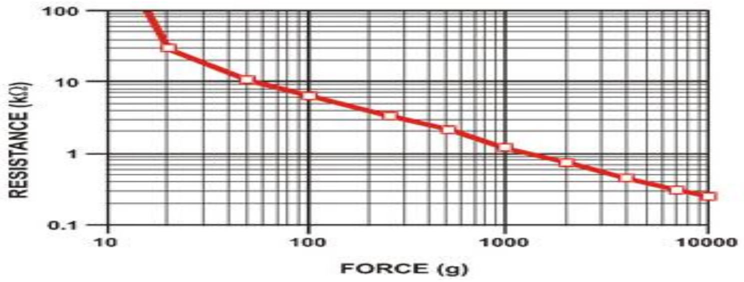


Figure 21: Resistance vs. Force

- FSRs consist of a piezoresistivity conductive polymer, which changes resistance in a predictable manner following application of force to its surface
- Usually come in a sandwich sheet on sensing Film
- Film: 1) electrically conducting and 2) non-conducting particles suspended in matrix.

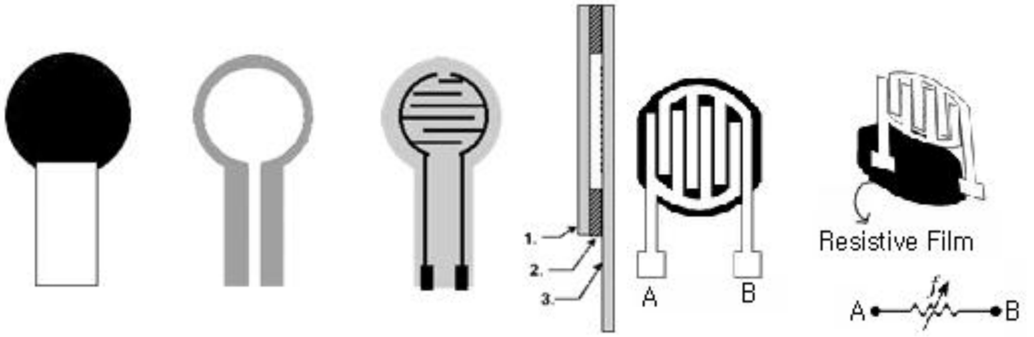
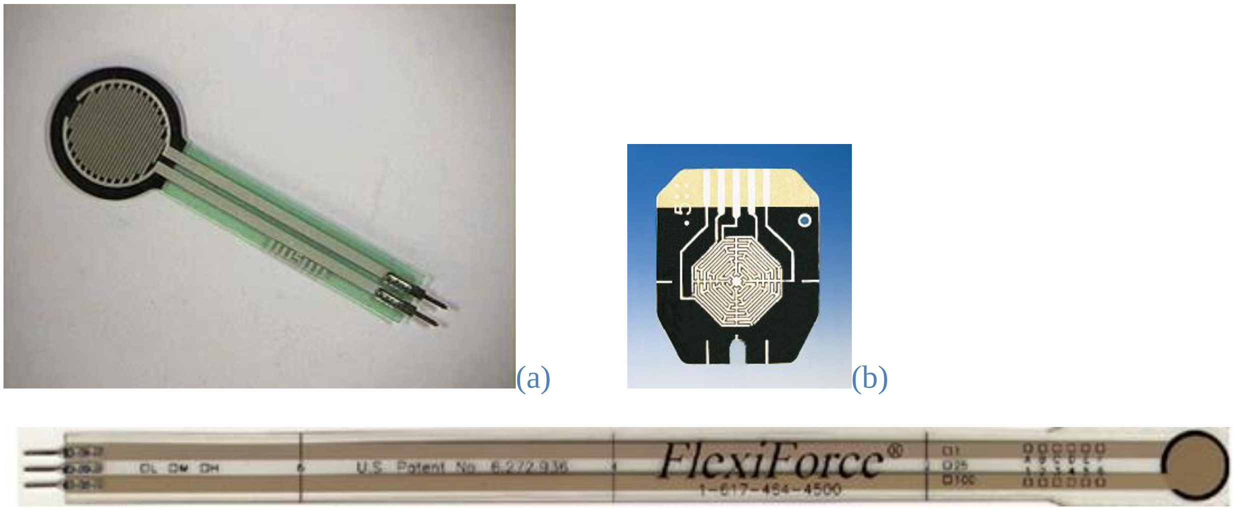


Figure 22: Types of FSRs.

### 3.2.4 Fsrs types

- Basic sensors – single point (usually circular)
- Simple array - Two or more PS$^3$s on a single substrate with one common conductor track plus an individual track for each sensor cell.
- Matrix – rows and columns
- Continuous Strip – up to 15 meters
- Co-ordinates & Pressure
  Sensing Sensors



(a) (b)

(c) **Figure 23: (a) (b) (c)**

### 3.2.5 PROCESSING UNIT:

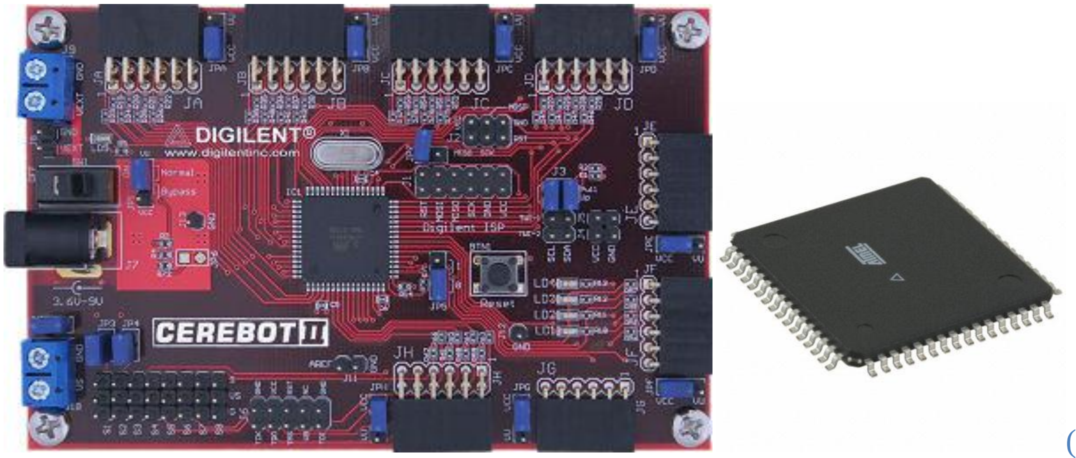
The main processing unit of the devise is an Atmel AVR 8-bit microcontroller with 64k byte of internal Flash memory. The main features of Atmega64 microcontroller are;

- a serial peripheral interface (SPI)
- two USART serial interfaces
- Atmel TWI serial interface
- eight 10-bit analog inputs
- two 8-bit timer counters
- two 16-bit timer counters
- 64KB program flash
- 2KB user EEPROM
- 4KB internal RAM
- An analog comparator.

The microcontroller IC is mounted on an AVR developmental board named as Cerebot 2 which is developed by DIGILENT Corporation. The main features of this AVR board are;

- an ATmega64L microcontroller
- eight hobby RC servo connectors
- eight Pmod connectors for Digilent
- peripheral module boards
- an on-board voltage regulator
- multiple flexible power supply jumper
- options
- support for the Digilent JTAG-3 Parallel
- and JTAG-USB programming cables
- support for the Atmel AVRISP in system
- programmer
- support for the Atmel AVR JTAGICE
- mkII debugging tool
- ESD protection and short circuit
- Protection for all I/O pins.

The Cerebot II is designed for embedded control and robotic applications as well as microprocessor experimentation. It has two programming interface options: The Digilent in-system-programming option and the Atmel AVRISP in-system programmer. Due to the ease in Programming and suitable processing capability, this developmental board has been selected.



(b)μ-controller

(a) Cerebot Microcontroller Board

Figure 24:

## 3.3 ELECTRONIC DEVICES.

### 3.3.1 THE POWER BOARD:

This circuit is a specific voltage regulator. With the help of an LM1084 IC and parallel capacitors, the circuit limits input 12v into 5v regulated voltage to drive the circuitry. To obtain 12v regulated voltage, a large capacitor is used to remove vibrant oscillations if incurred. Also with the help of a potentiometer we can change the output to the desired within the limit of 12.

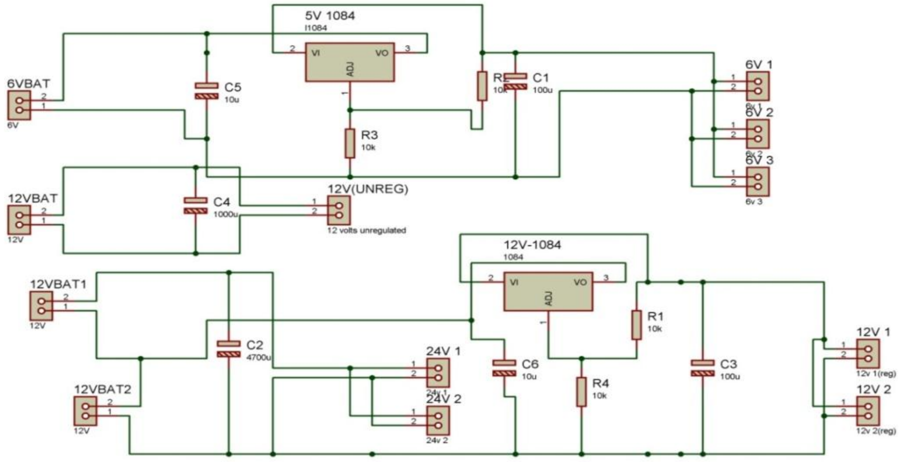


Figure 25: Power Board Circuit

## Power Board (PcB)

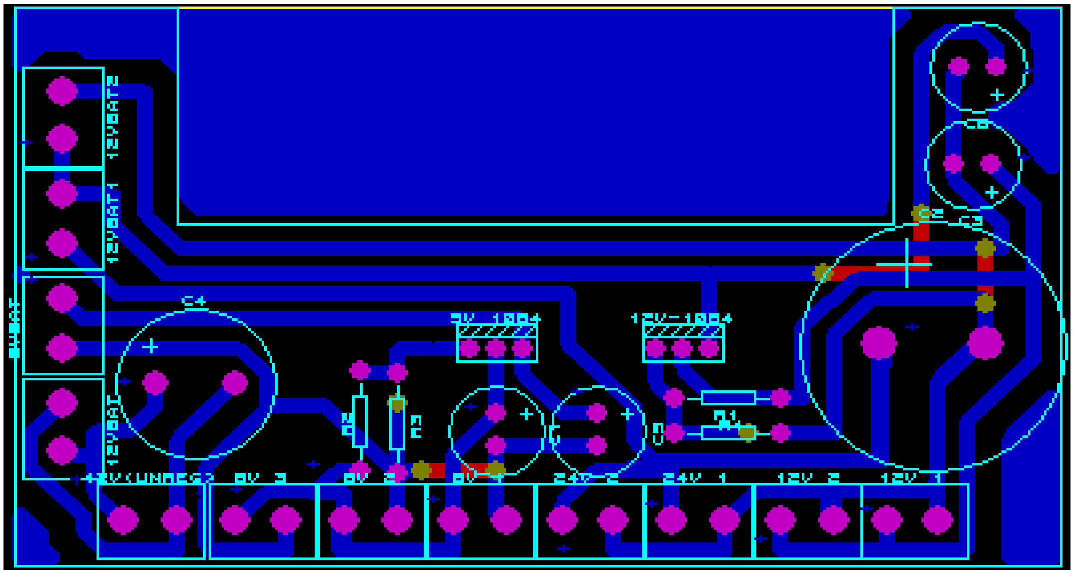


Figure 26: Power Board (PcB)

### 3.3.2H-BRIDGE

The h-bridge design presented here is capable of drawing a 10A current for the operation of the device, the circuit has the ability of short circuit protection, and the circuit also is current limiting not to over pass the safety limit for the device and circuit.

With the help of a variable potentiometer we can adjust the demand of the current required which is a very good addition as the demands might be various for operation. This is a MOSFET h-bridge as they provide with fast switching requirements. There is also a octocouplar circuit which provides the circuit isolation control with high power circuit so that the circuit is not burnt or damaged.

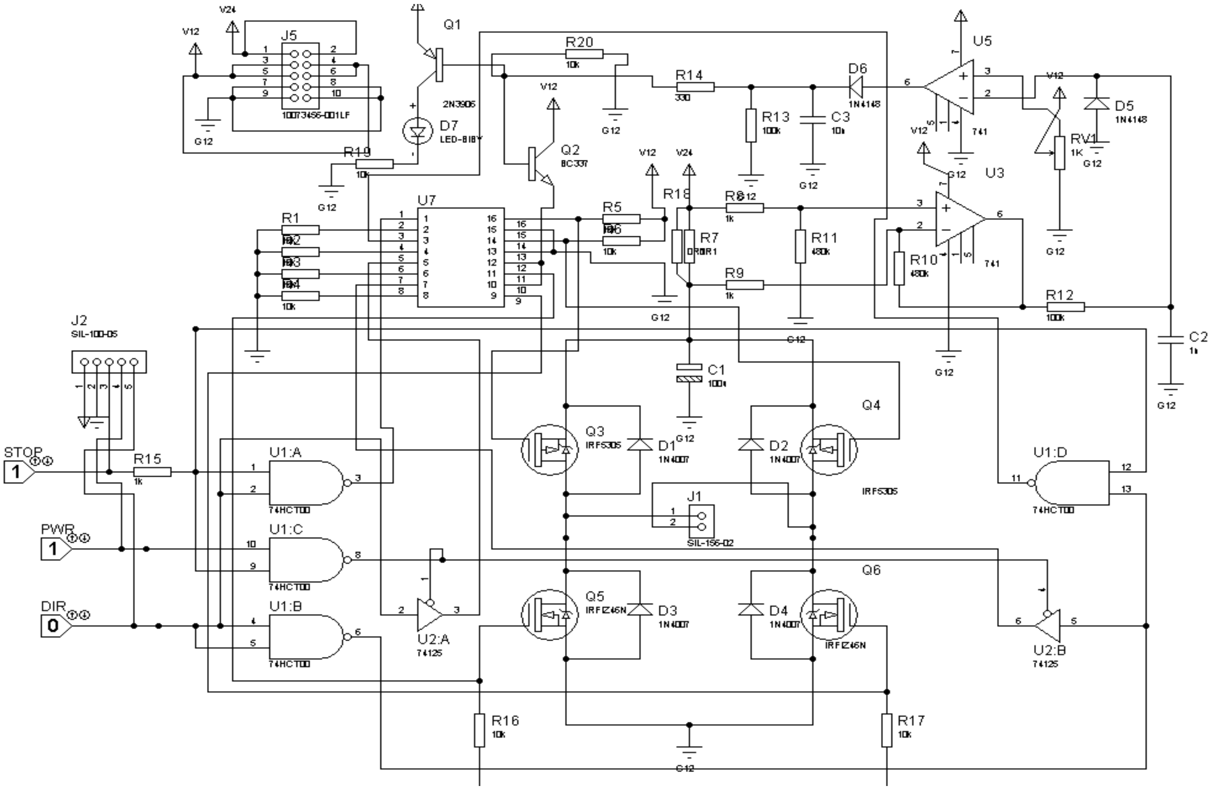


Figure 27: H-Bridge Circuit

## H-BRIDGE (PCB)

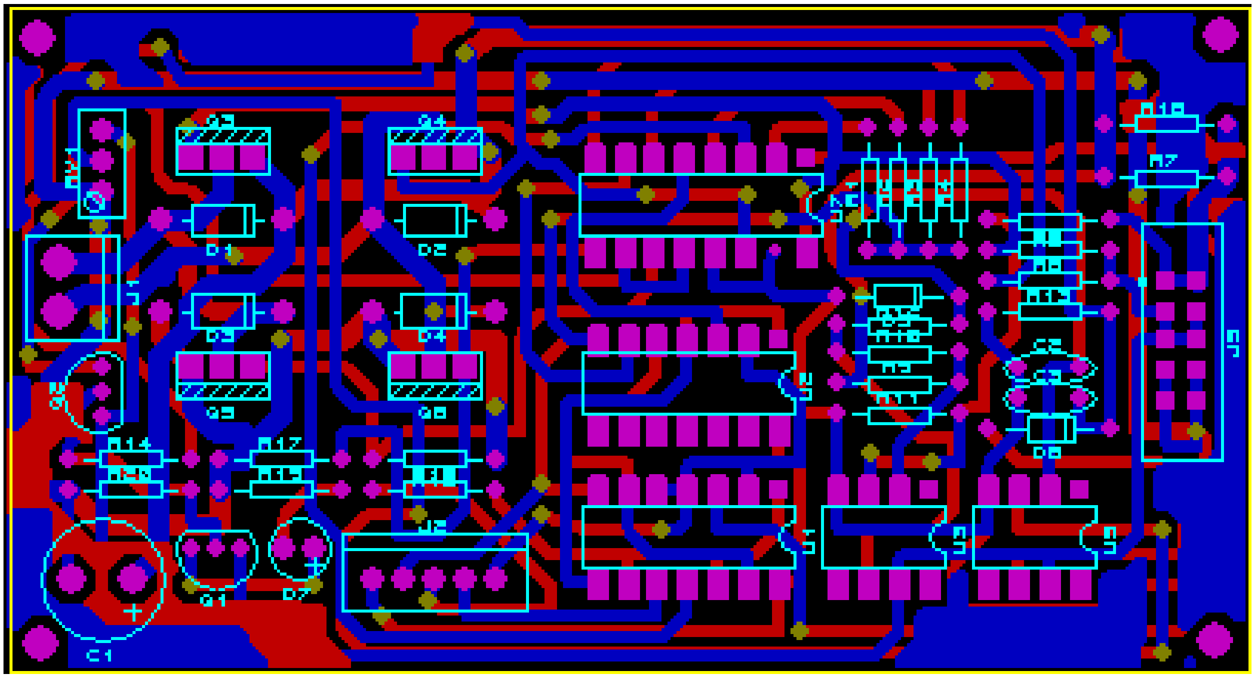


Figure 28:

### 3.3.3 ACTUATOR:

A single DC motor will be used to provide the mechanical motion to the system. The speed and direction of the motor will be controlled by the microcontroller according to the feedback from the sensors. The motor will then produce a rotary motion to at the ankle joint moving the foot base to the required position. The motor selected for this purpose is a 24V brushed DC motor by Dunker Motor. The motor is operated at 24V DC. It has a gearbox of conversion ratio of 256:1. As a result the end torque is ~4 Nm continuous (14 Nm peak) and a maximum RPM of 30 rev/min.

Figure 29: Dunker Motor

## 3.4 MODELING AND SIMULATION:

The human gait analysis was done through two setups first was the process of mathematical modeling second was the simulation of the experimental data

### 3.4.1Mathematical Modeling

The mathematical modeling of the  gait was done though the free-body diagram of the human foot and different force finding techniques were applied to them. The principle of law of conservation of momentum was applied to in order find the torques required during the foot motion.

The human walk is divided into four main parts

i. stance Phase

ii. Heel-strike Phase

iii. Heel-off phase

iv. Swing phase

### 3.4.2 Stance Phase:

In stance phase the human feet is placed flatly on the ground and the human body is shifting in the forward or backward direction. Figure 30F

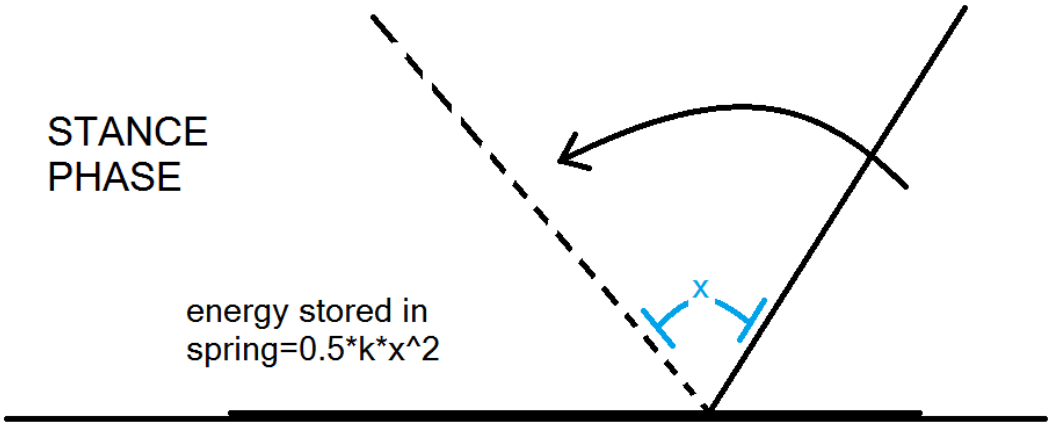


Figure 30:

### 3.4.3 Heel-off Phase:

The Phase of the walk in which the heel takes off from the ground and is followed by the lifting of the toe

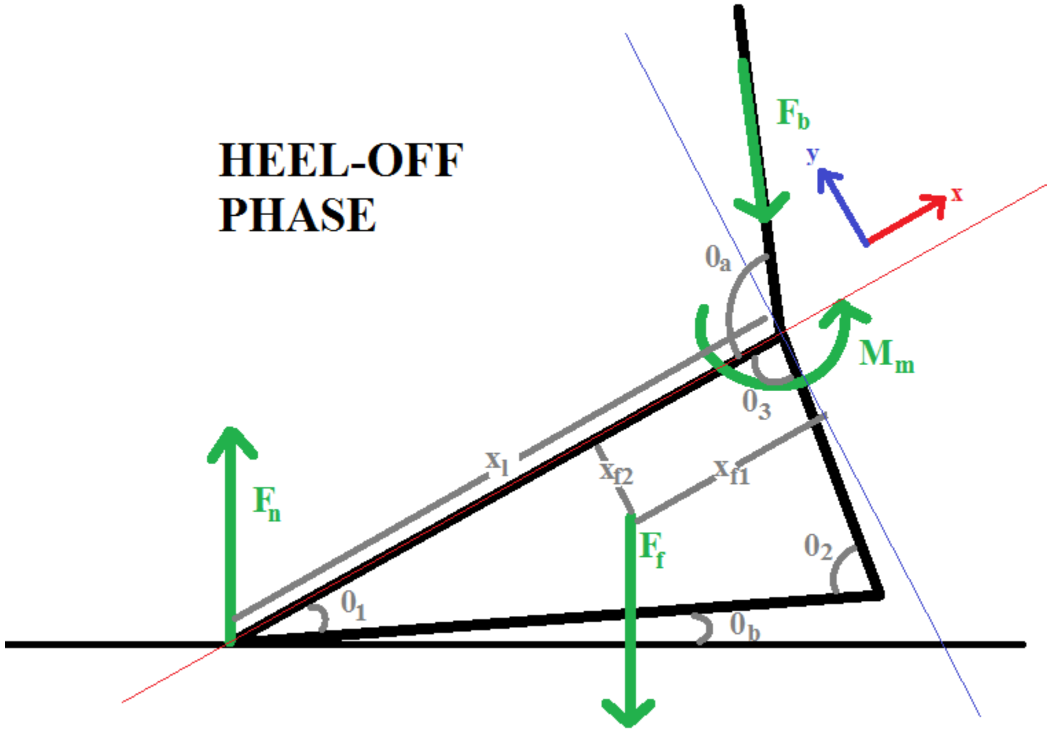


Figure 31:

$$M_m= [F_n.\ \sin (90-\Theta_1- \Theta_b).x_l] + [I.d^2\ \Theta_a/dt^2] + [F_f.\ \sin (\Theta_1+ \Theta_b).x_{f2}] - [F_f.\ \cos (\Theta_1+ \Theta_b).x_{f1}]$$

### 3.4.4 Swing Phase:

The phase in which the human foot is not in contact with the ground but is in a swinging action.

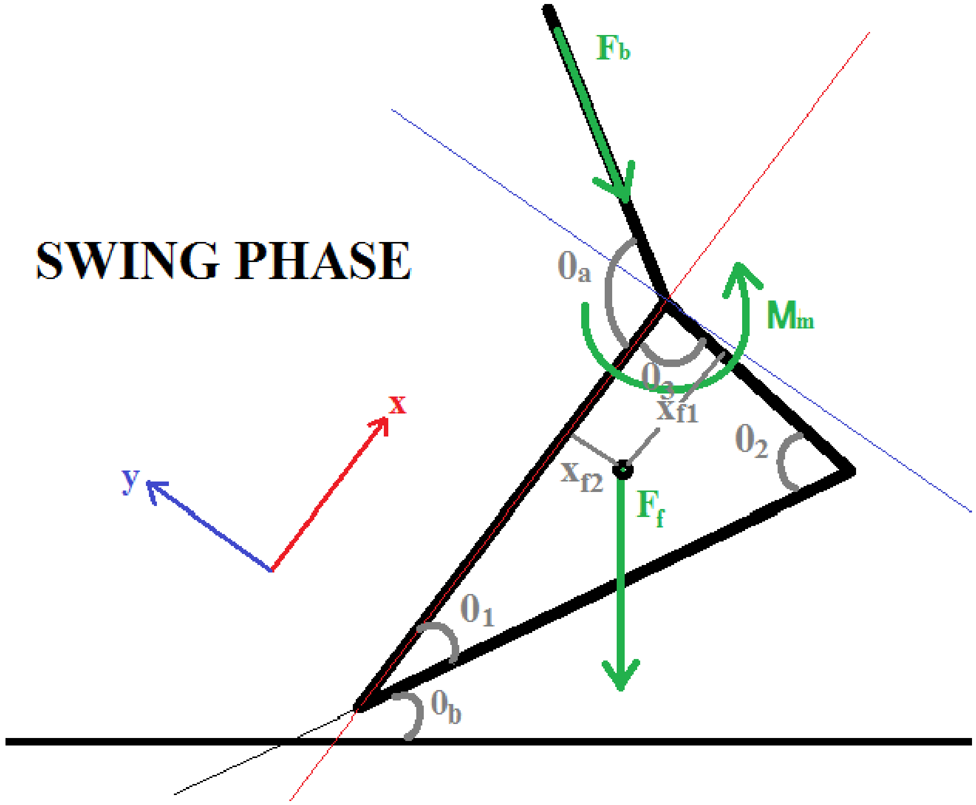


Figure 32:

$$Mm = -[F_f . \cos(\Theta_1 + \Theta_b).x_{f1}] + [F_f . \sin(\Theta_1 + \Theta_b).x_{f2}] + [I.d^2\, \Theta_a/dt^2]$$

### 3.4.5 Heel Strike Phase:

The Phase of the walk in which the foot heel strikes the ground and is followed by the rest of the feet till toes.

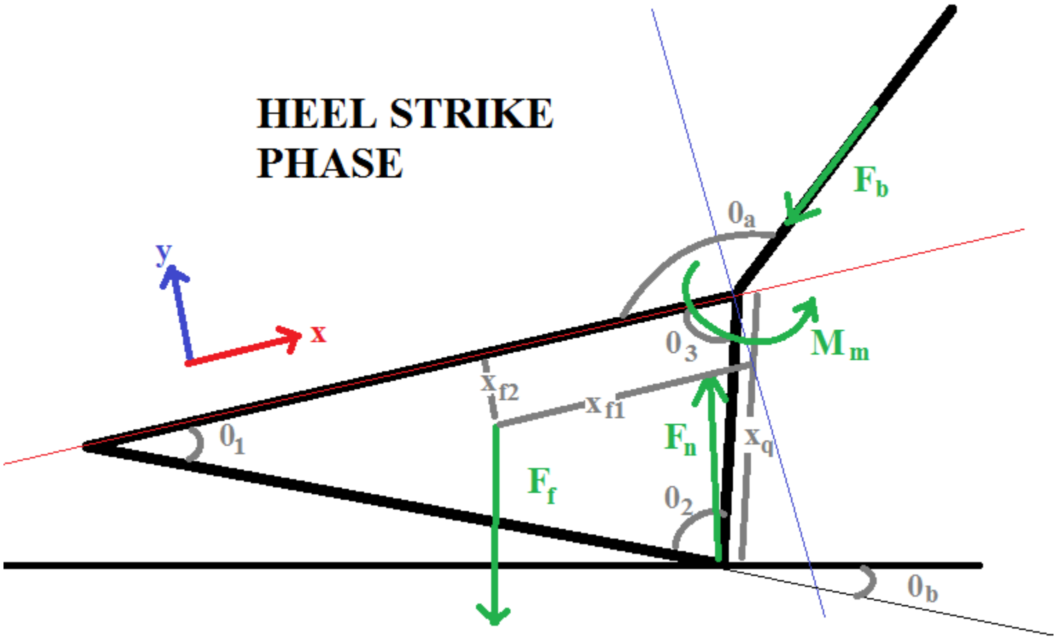


Figure 33:

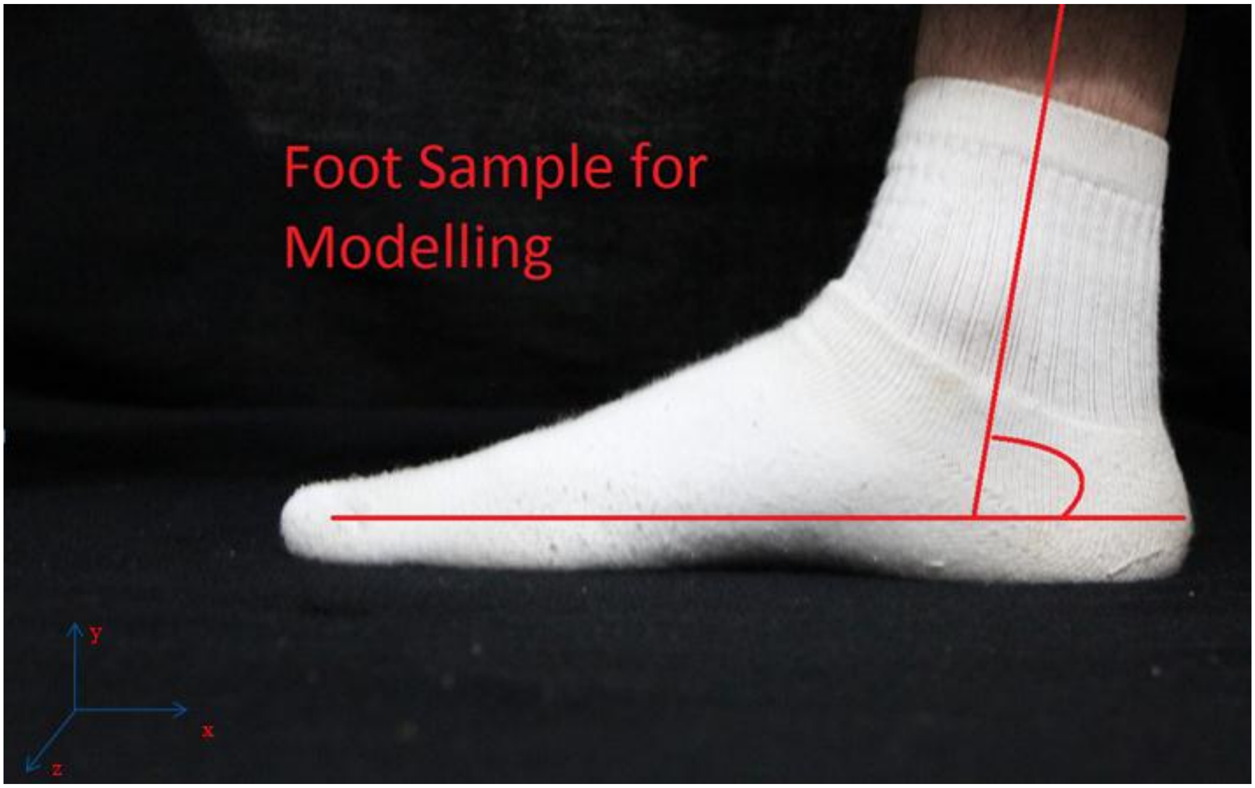
$$Mm= - [F_f. \cos(\Theta_1+ \Theta_b).x_{f1}] + [F_f. \sin(\Theta_1+ \Theta_b).x_{f2}]- [I.d^2 \Theta_a/dt^2]-[F_n.\cos(\Theta_b+ \Theta_2+ \Theta_3-90).x_q.\cos(90- \Theta_3)]+[F_n.\sin(\Theta_b+ \Theta_2+ \Theta_3-90).x_q.\sin(90- \Theta_3)]$$

## 3.5 SIMULATION:

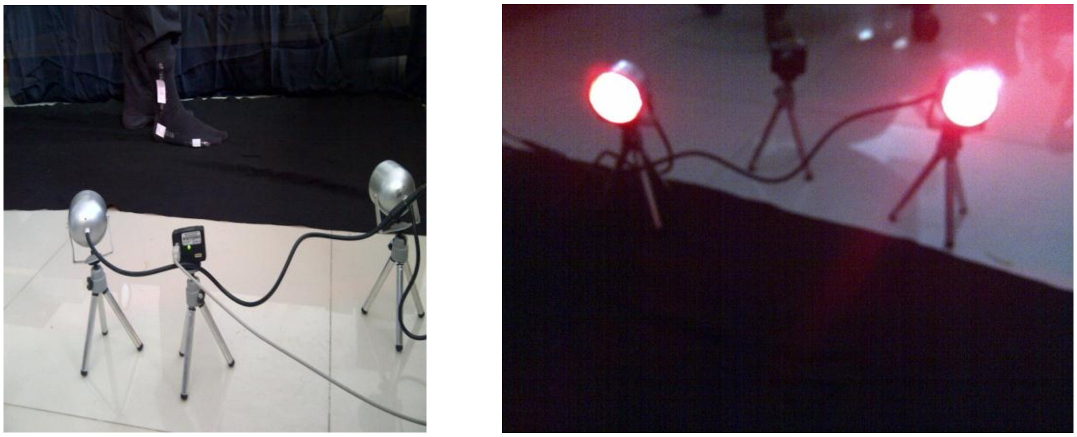
In order to solve the mathematical model some information unknown information had to be extracted with the help of experimentation. To find the angle between the ankle and the feet a motion capture System was setup for it. National Instruments image acquisition setup was use which consisted of

- Digital Camera
- LEDs for light adjustment
- Software for Image Acquisition

The test subject was made to walk in front of the cameras in a non-interactive background with markers placed on different crucial point of the feet the motion of that walk was captured and converted into frames to be processed in Matlab.



. Figure 34: (a) Foot Sample



(b) National Instruments Setup (c) National Instruments Setup

Each frame of the acquired motion was processed through Matlab and different image processing techniques of object detection, Size detection and Centre Location were used to derive the location of each of the marker Each frame is processed such that each of the marker is detected on the foot, after which the area of the marker is located and a certain center mark is placed on the detected object. “+’ is placed on the smallest marker, “x” is placed on the medium sized marker and “o” is placed on the largest marker.

Location of each marker is noted in arrays sorted according to sizes. This gives us complete information about the change in position for that marker during the cycle.

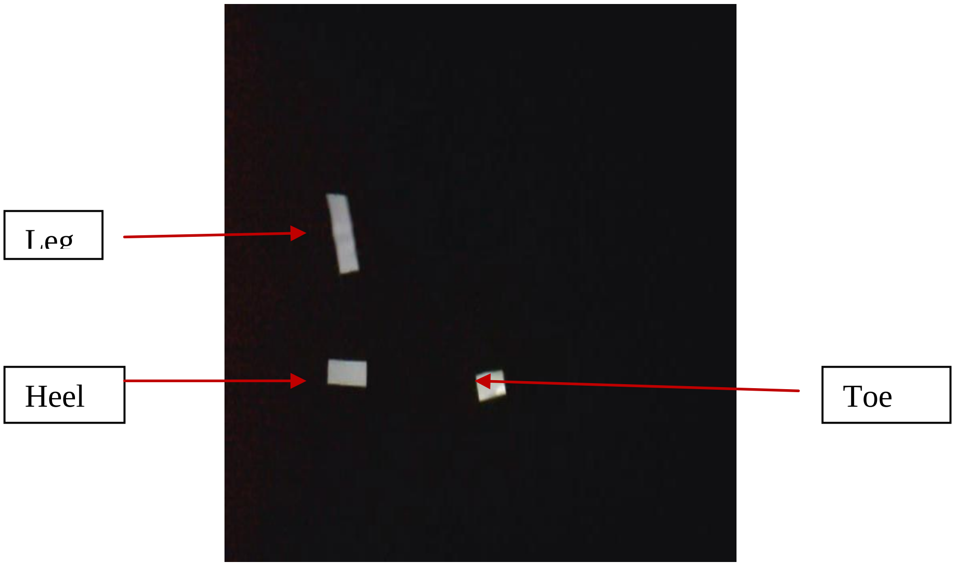


Figure 35: Motion Clip (Image Processing)

### 3.5.1 RESULTS:

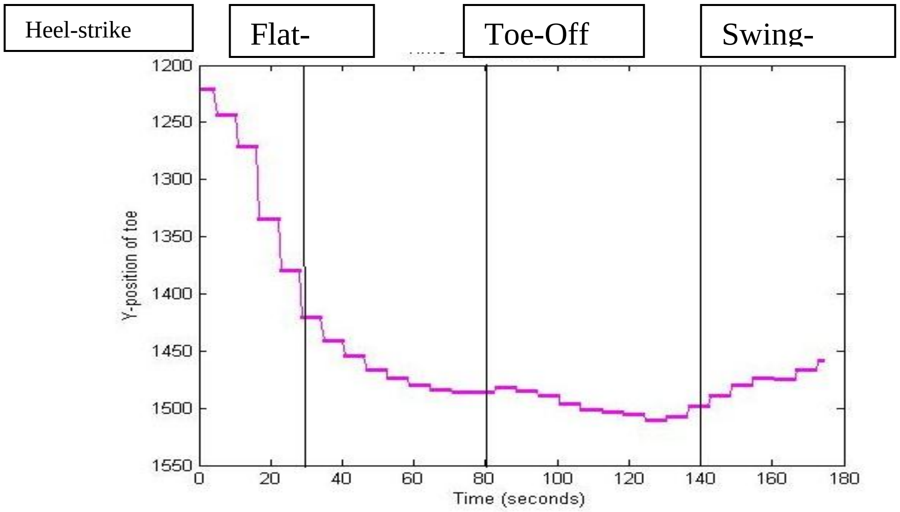
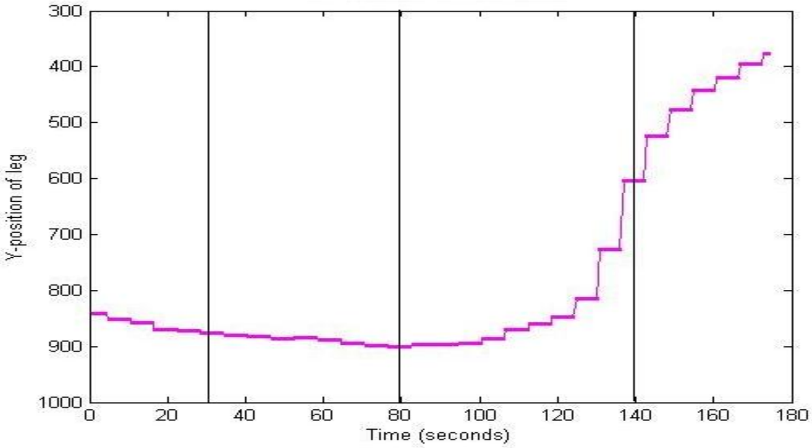
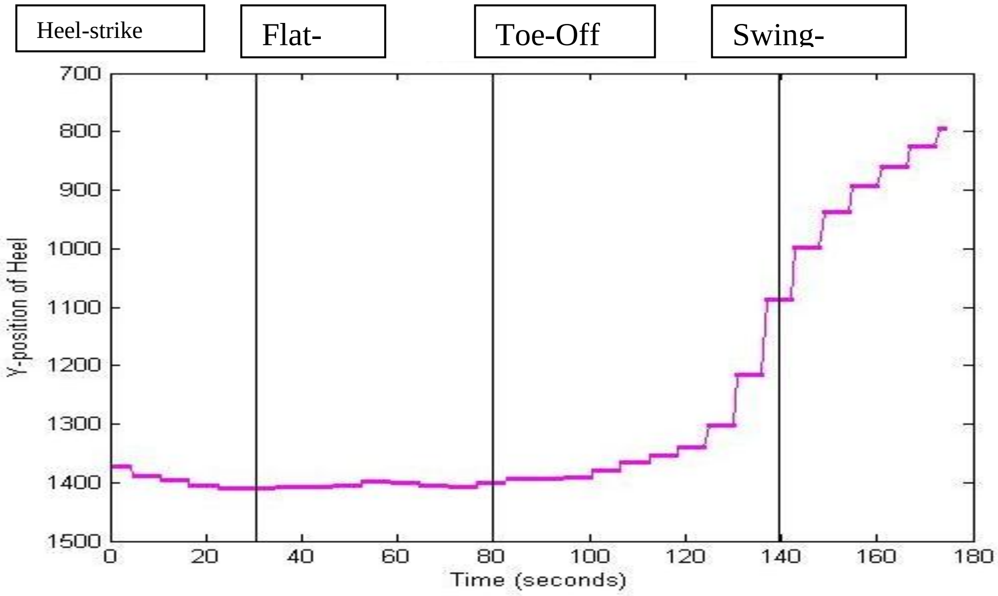

Heel-strike
Flat-
Toe-Off
Swing-
Y-position of toe
1200
1250
1300
1350
1400
1450
1500
1550
0
20
40
60
80
100
120
140
160
180
Time (seconds)

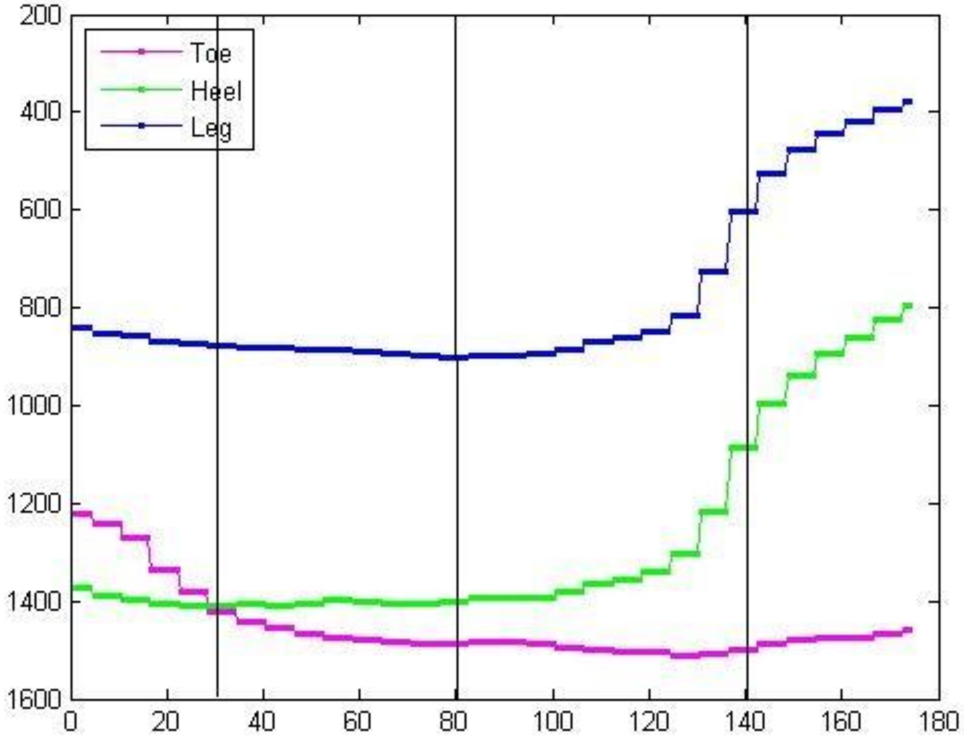
Figure36: (a)


Y-position of leg
300
400
500
600
700
800
900
1000
0
20
40
60
80
100
120
140
160
180
Time (seconds)

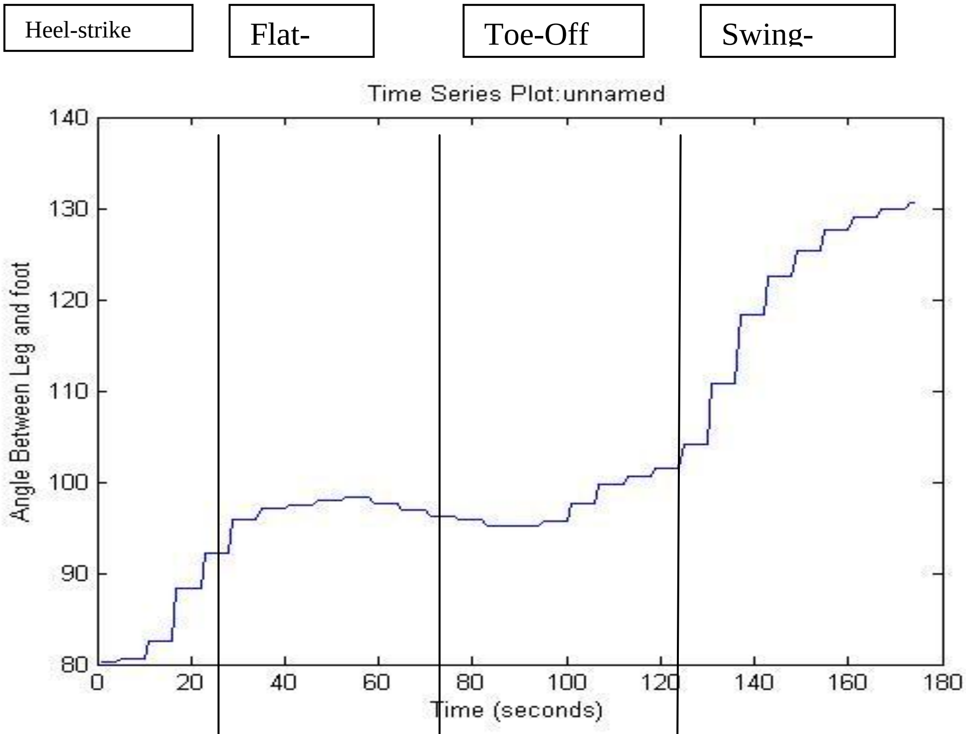
(b)



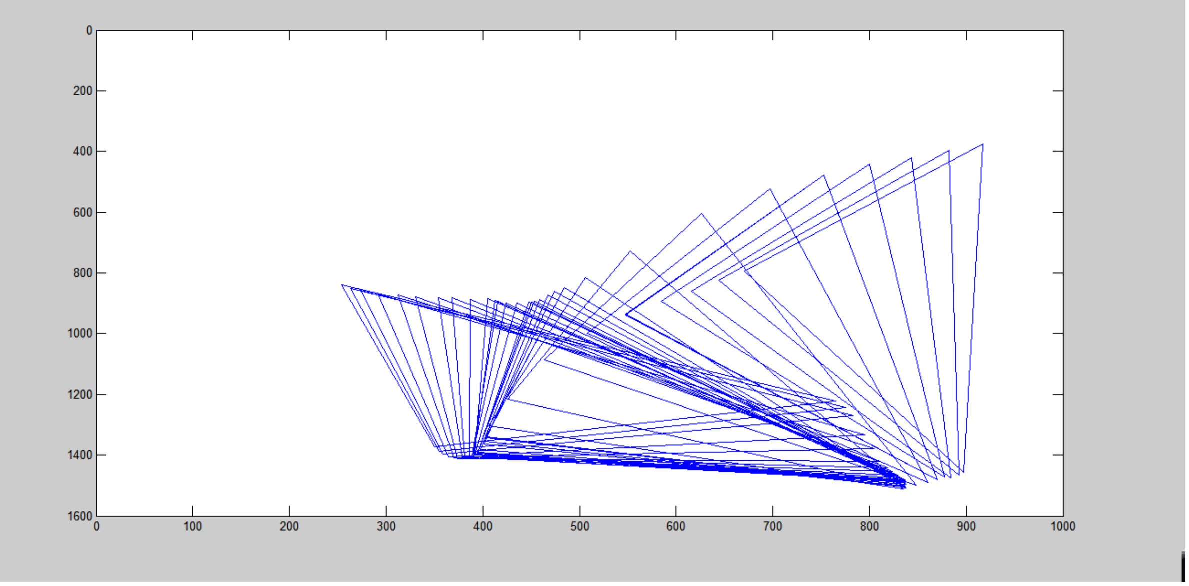
(c)



(d) Y –position of leg, Toe and heel



(e) Angle vs. Time



(f) Triangle showing the path followed by the foot at different stages

The results obtained enabled us to extract the angle between the leg and the foot which as shown in the figure varies from 80 degree to 130 having a maximum change of around 50 degrees which is in accordance with the latest research papers on the movement of the human ankle.

*Chapter 4*

# IMPLEMENTATION

After the Design of the mechanism, fabrication of the prototype was a real challenge. Before the fabrication the selection of material was an important factor as the strength and weight of the prototype played a key role in the success of the project without any backlash. There after a careful analysis aluminum was selected as the material for the prototype due it good strength and light weight.

Fabrication process was divided into different Phases

## 4.1 FEASIBILITY OF THE DESIGN:

Initial fabrication of the prototype was planned on the Rapid Prototyping Facility available i*n School of Mechanical and Manufacturing Engineering. A*s Rapid Prototyping is quick process, the correctness of the design was to be tested least time as possible but due to the some malfunctioning of the Machine the Rapid Prototype couldn’t be obtained. Thus in order to ensure the working and feasibility of the design before fabrication different mechanical Experts such as Mr. Hassan, Dr. Yasar Ayaz were thoroughly consulted and after their feedback and Satisfaction the fabrication was proceeded.

## 4.2 Lathe Machine:

The Circular part of the prototype were to be made by Lathe Machine , as lathe machine can only cut objects in a circular manner thus only one part of design was to be manufactured. The 2D-drawing of the circular part was provided to MR. Zahid the Lathe Operator at MRC lab SMME and due to his fine skill a refined part was obtained.

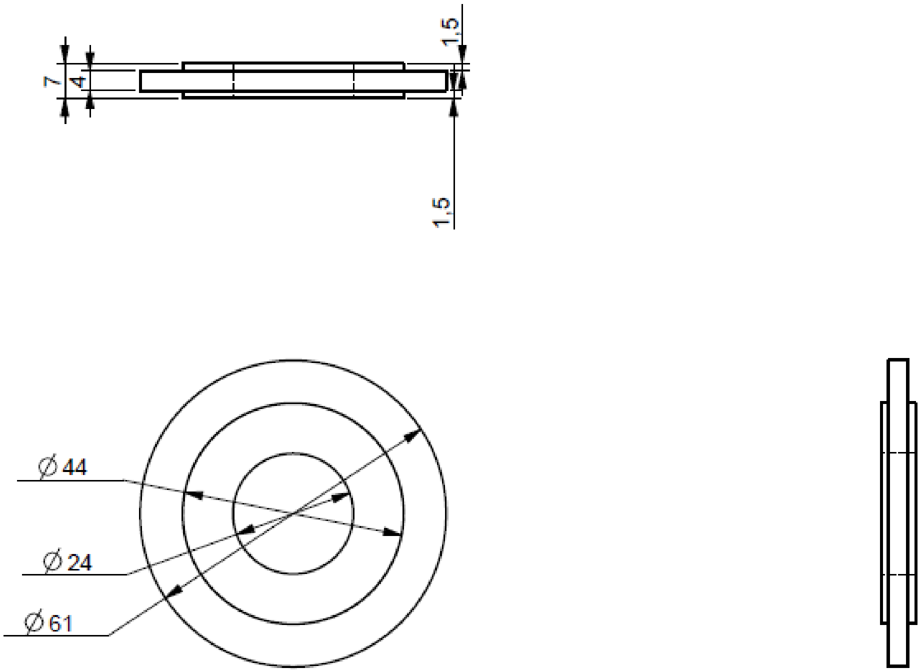


Figure 37: (a) 2D- drawing of the Circular Lid

Circular part made on lathe machine

(b)

## 4.3 CASTING

As most of the parts of the design were semicircular they couldn't be made on the lathe machine and due to the unavailability of the CNC (Computer Numerical Controlled) machine at SMME the decision of casting the parts was made and then later to be refined on the CNC machine. By this process less time of the CNC machine will be required for the parts and thus making it possible to get the final product in a timely manner. The casting process requires manufacturing of wooden model which is placed in sand to obtain moulds of the models. Wooden moulds were made of the parts shown in figures.

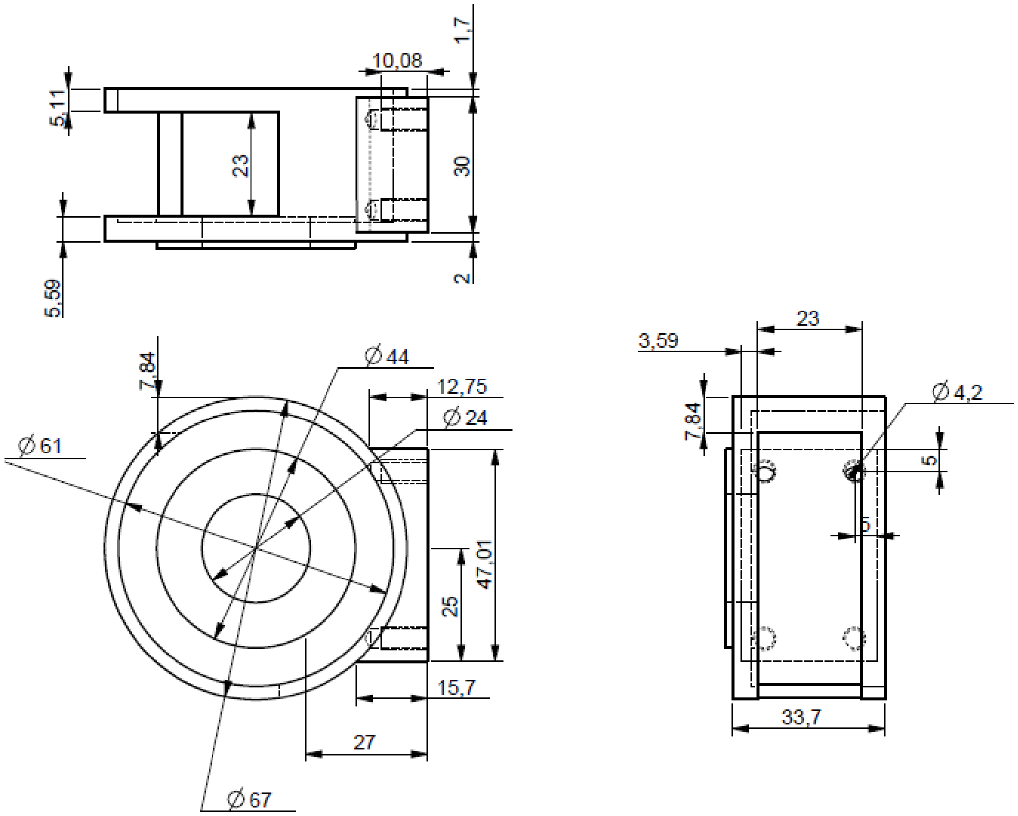
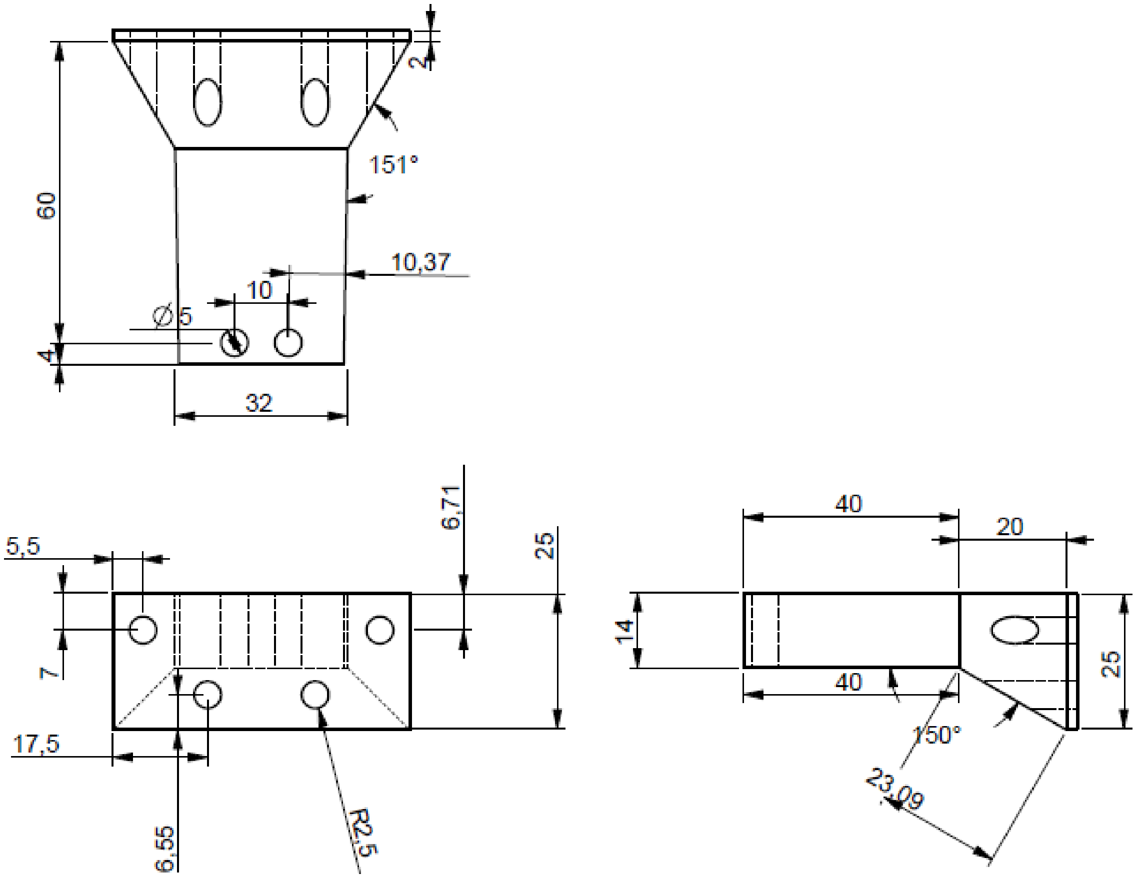


Figure 38: (a) 2D drawing of the casing



(b) 2D Joint rod

Figure 39: Physical Casting Process

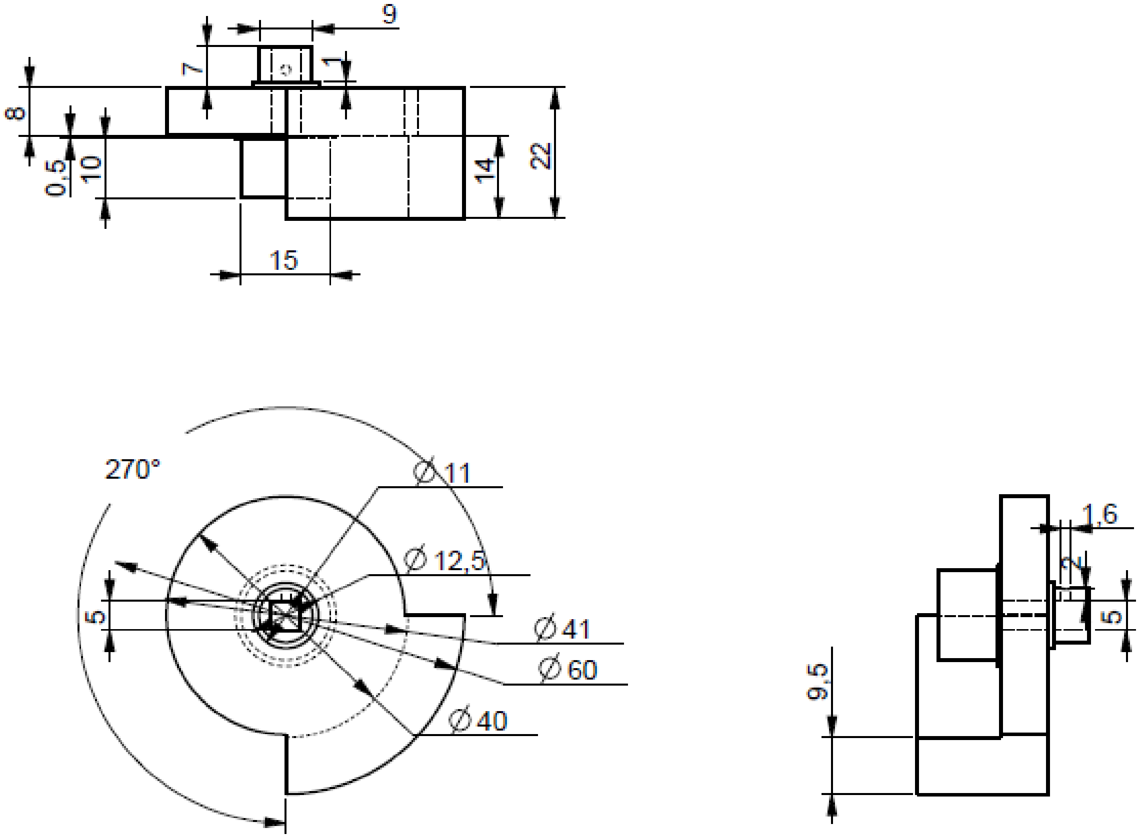


Figure 40: 2D drawing circular ring2

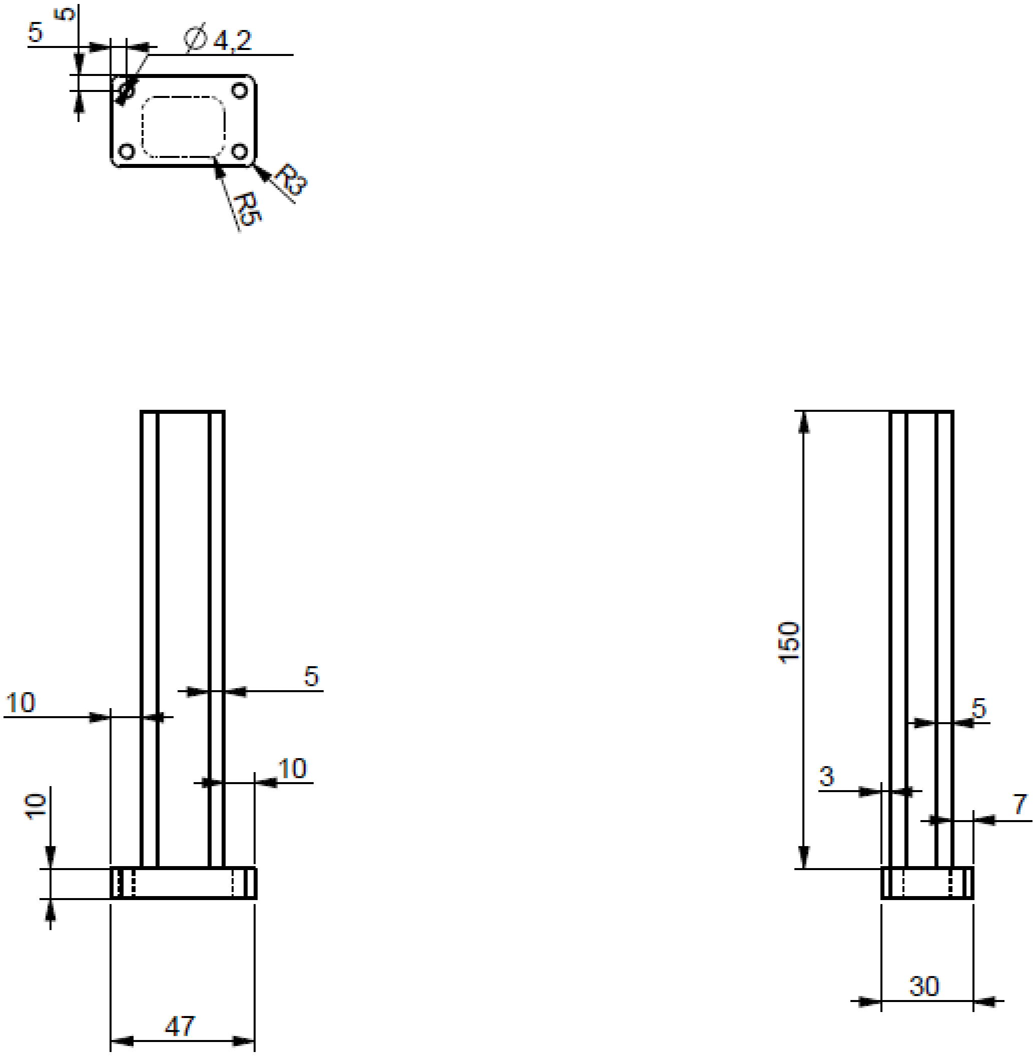


Figure 41: 2D Drawing Supporting Rod

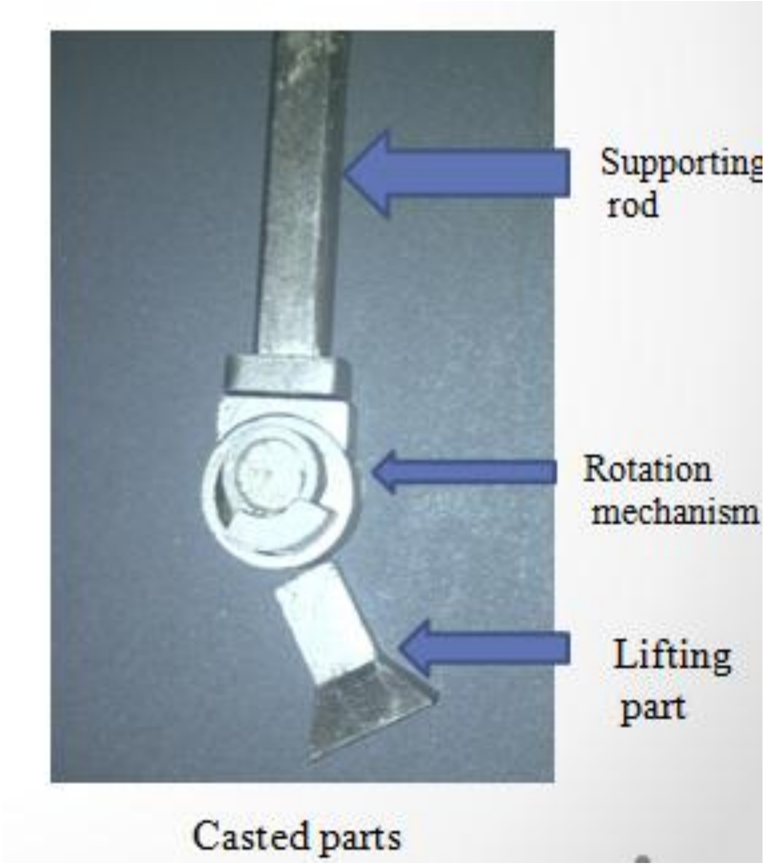
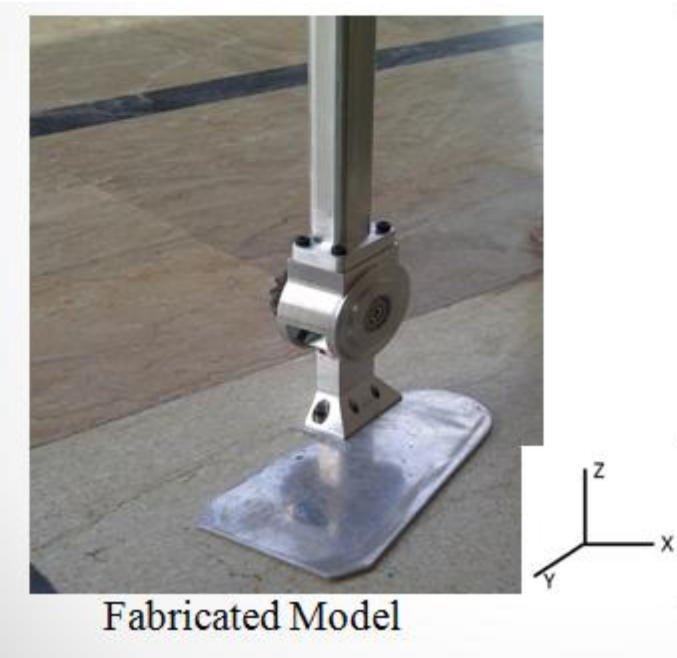


Figure 42: Unassembled Parts.

### 4.3.1 Fine Cutting of the casted parts:

After the casted parts were obtained they were to be cut finely by CNC machine but due to some unavoidable circumstances the machine was not free even for the short intervals.

A different approach was applied to get the prototype fabricated. Khan Research Labs (KRL), Kahuta were contacted for the fabrication process and due to their generosity and openness to research the Project fabrication was approved and all the semicircular parts shown above were made from scratch on the CNC machine with precision of millimeters. As shown in the fig below the prototype fabricated is exactly the same as desired in the 3D design the worked absolutely fine without any modifications needed.



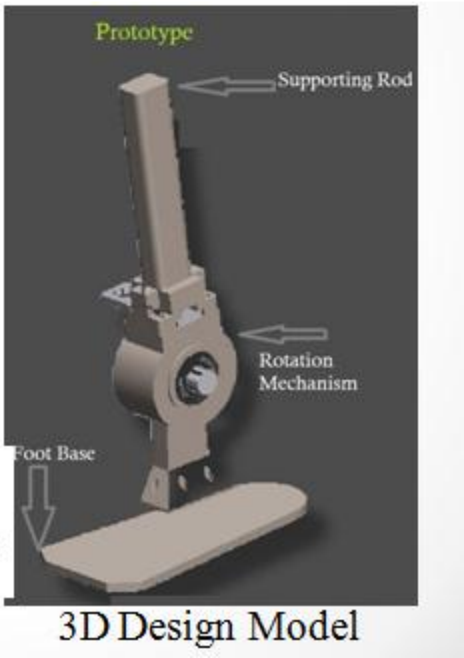


Figure 43:

Figure 44:

## 4.4 System Model:

Alongside the mechanical manufacturing the electronic system of the prototype was under development the following system model was established and implemented.

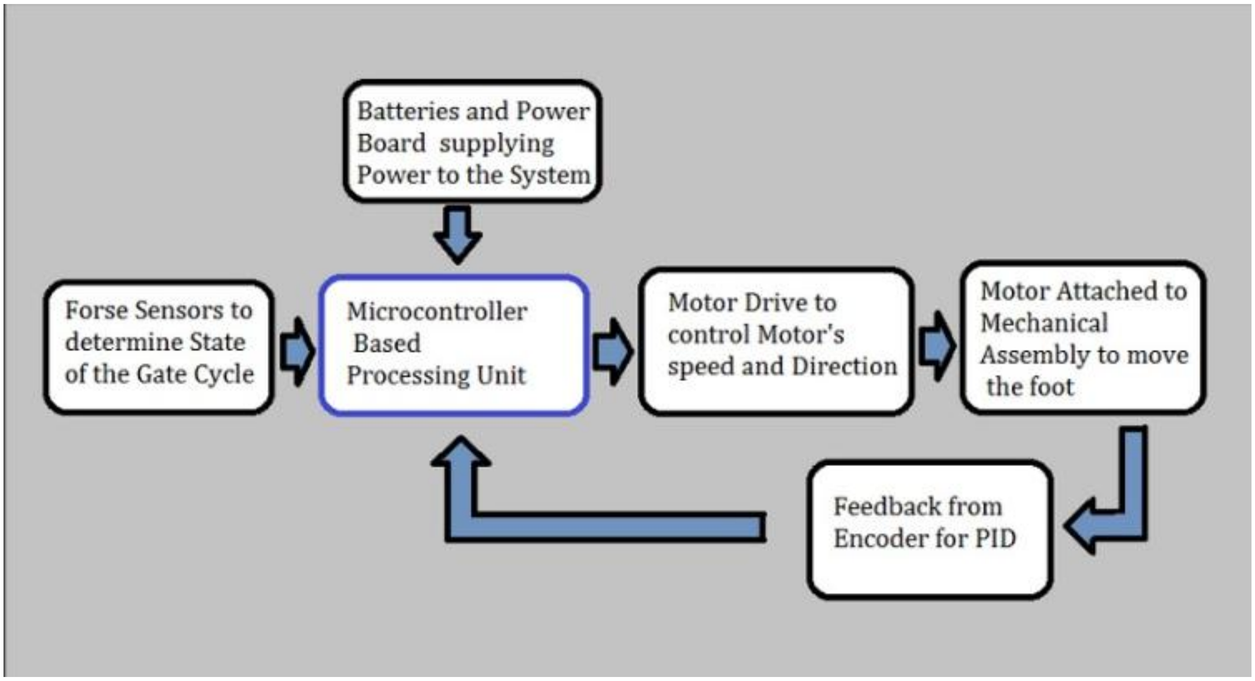


Figure 45: System Model

Five interlink sensors are used to detect the state of the cycle. Force sensor were arranged in the Form of a grid and the placement of the force sensor graphs were based on the force intensity graph and were placed only at the points where the intensity of was maximum.

The values obtained from the base of the foot are passed to ADC channel of the microcontroller. To go from one state to another the motor turns the base such that foot base ready to be moved into the other phase. To ensure that the required state is achieved an optical encoder is used which provides feedback on the movement of the motor.

The controller compares the change in the forces to define the states it is in there are four states defined such that.

1. If the both sensors have the same value but relatively smaller values then the foot is in the swing phase and it has to move to the Heel Strike phase
2. Having greater force at the heel than the toes mean its in the heel strike state and it has to move to the heel-off phase
3. Having more force at the toe than the heel mean its in the heel off phase and it has to move to the Swing state

### 4.4.1 Microcontroller processing:

The micro controller takes input from the force sensors and provides the required PWM to the motor. And at same time it takes feedback from an Incremental encoder which gives digital pulse for every 0.5 degree it moves theses pulses are counted and added into the absolute value to confirm if the desired value of the angle is achieved.

### 4.4.2 Combination of the Electronic and Mechanical Component:

The mechanical and electrical components were combined in such way that ease of carrying and portability was kept under consideration the force sensor grid, Optical Encoder and the motor are the only electrical components attached directly to the mechanical prototype and the rest of the of the electrical equipment including the controller and batteries are attached to human waist with the help of a belt thus reducing the weight on the foot significantly.

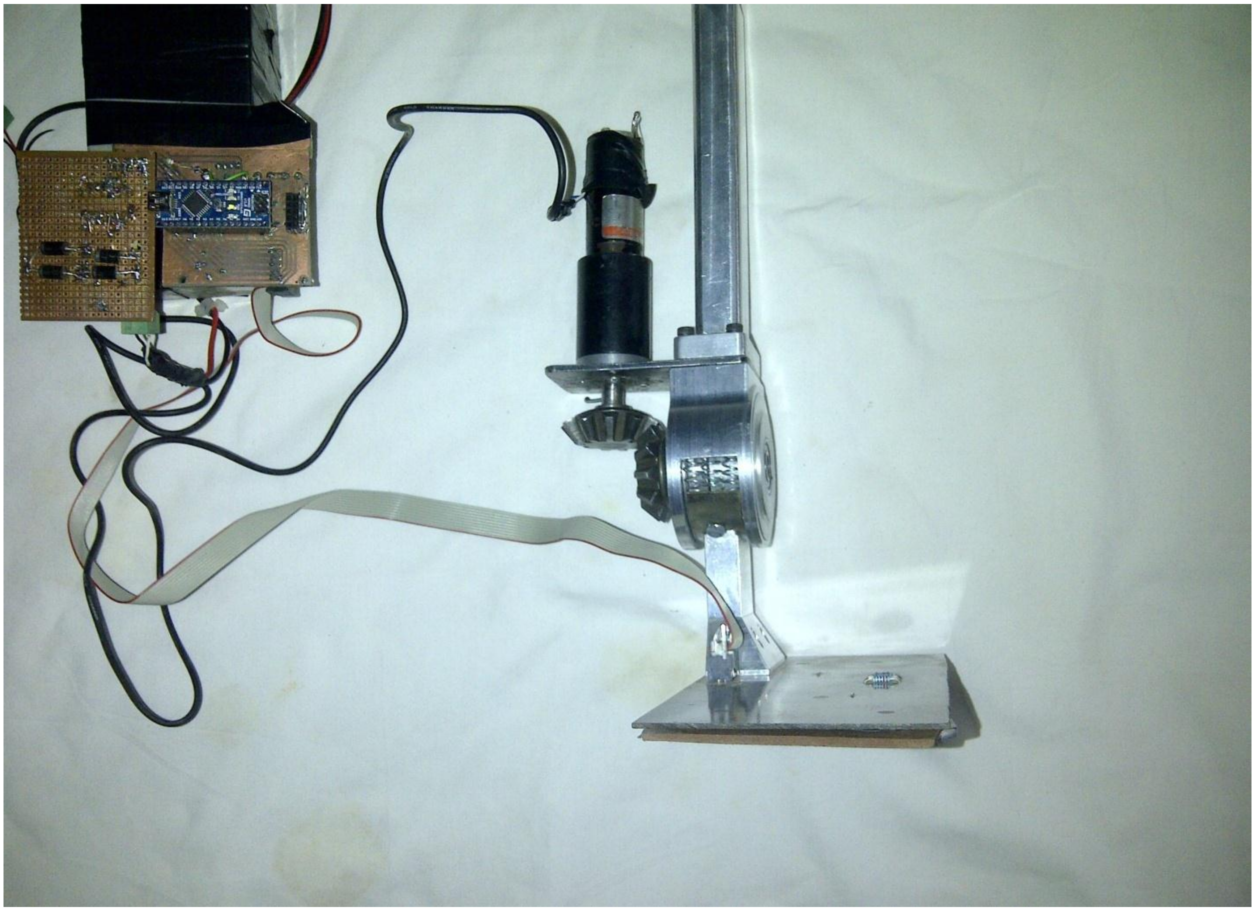


Figure 46: Complete Structure

## 4.5 RESULTS AND FUTURE WORK

### Results :

After the implementation of the designed project it was tested on a normal foot to test the validity of the basic concept of the AFO. It has been able to achieve the following targets

- After the intensive calculation and modeling the motor selection has been proved correct as it lifts the foot with the current value of less than 1A.
- It is able to place the foot on the ground in a controlled manner thus catering for the “Foot Slap” abnormality.
- The lifting of the Toe had been a difficult part of the project as it requires the most force but torque produced by the motor proved sufficient to provide assistance in lifting the toe thus catering for the “Drop Foot” abnormality.
- The placement of the springs along the circumference of the rotary mechanism was a new concept introduced and it has catered well for the purpose of storing energy during the Stance and releasing it in the heel off phase thus avoiding the usage of motor in the transfer from Stance phase to Heel-off phase.
- The major and one of the most Encouraging result obtained was the low weight of the AFO Prototype. It weighs 1.6 kg which is less than already existing AFOs. Thus making the design not only a very compact one but the one of the lightest one too.

Figure 47: Weight of the Prototype (1.552 Kg)

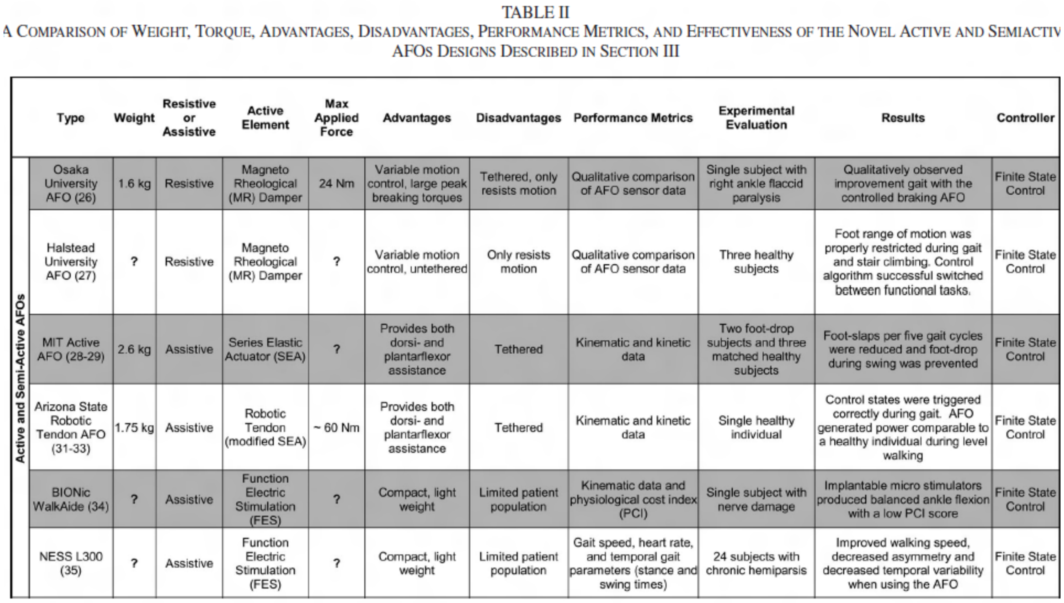


TABLE II

A COMPARISON OF WEIGHT, TORQUE, ADVANTAGES, DISADVANTAGES, PERFORMANCE METRICS, AND EFFECTIVENESS OF THE NOVEL ACTIVE AND SEMIACTIV AFOs DESIGNS DESCRIBED IN SECTION III

| | Type | Weight | Resistive or Assistive | Active Element | Max Applied Force | Advantages | Disadvantages | Performance Metrics | Experimental Evaluation | Results | Controller |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Active and Semi-Active AFOs | Osaka University AFO (26) | 1.6 kg | Resistive | Magneto Rheological (MR) Damper | 24 Nm | Variable motion control, large peak breaking torques | Tethered, only resists motion | Qualitative comparison of AFO sensor data | Single subject with right ankle flaccid paralysis | Qualitatively observed improvement gait with the controlled braking AFO | Finite State Control |
| | Halstead University AFO (27) | ? | Resistive | Magneto Rheological (MR) Damper | ? | Variable motion control, untethered | Only resists motion | Qualitative comparison of AFO sensor data | Three healthy subjects | Foot range of motion was properly restricted during gait and stair climbing. Control algorithm successful switched between functional tasks. | Finite State Control |
| | MIT Active AFO (28-29) | 2.6 kg | Assistive | Series Elastic Actuator (SEA) | ? | Provides both dorsi- and plantarflexor assistance | Tethered | Kinematic and kinetic data | Two foot-drop subjects and three matched healthy subjects | Foot-slaps per five gait cycles were reduced and foot-drop during swing was prevented | Finite State Control |
| | Arizona State Robotic Tendon AFO (31-33) | 1.75 kg | Assistive | Robotic Tendon (modified SEA) | ~ 60 Nm | Provides both dorsi- and plantarflexor assistance | Tethered | Kinematic and kinetic data | Single healthy individual | Control states were triggered correctly during gait. AFO generated power comparable to a healthy individual during level walking | Finite State Control |
| | BIONic WalkAide (34) | ? | Assistive | Function Electric Stimulation (FES) | ? | Compact, light weight | Limited patient population | Kinematic data and physiological cost index (PCI) | Single subject with nerve damage | Implantable micro stimulators produced balanced ankle flexion with a low PCI score | Finite State Control |
| | NESS L300 (35) | ? | Assistive | Function Electric Stimulation (FES) | ? | Compact, light weight | Limited patient population | Gait speed, heart rate, and temporal gait parameters (stance and swing times) | 24 subjects with chronic hemiparsis | Improved walking speed, decreased asymmetry and decreased temporal variability when using the AFO | Finite State Control |

Figure 48: Comparison of already existing AFOs

## *Chapter 5*

# Conclusions & Future Work

## 5.1 Conclusions:

- That an alternative mechanical electronic structure can be provided for the disability of an ankle due to the problems of Drop Foot or Slap Foot.
- Electronics can be implemented with mechanical structures and made to imitate a human foot and provide for its assistance.
- With the use of image processing a model of the foot's movement can be implemented and later made to physical implementation.
- The angle between the foot and the leg changes from 80˚ to 130˚. And our results are in accordance with the latest research.

## 5.2 Future Work:

The results obtained from the AFO are satisfactory and a lot of future work can be done it to improve them further.

- The weight of the device can improved significantly by replacing the heavy metal supporting rod with a lighter substitute such as wood or plastic as the only purpose of the rod is to provide support thus making it more comfortable for the patient.
- The Device at the moment is capable of providing only one walking speed which can further enhanced to walk at different speeds as desired either by providing them with the option of different speed modes or making the device intelligent by placing Accelerometers on them to detect the change in speed of the swing phase and adapt to new gate change rate intelligently.

- A medical certification can be achieved by collaborating with medical institution providing assistance to patient with similar abnormalities thus providing the opportunity to test the device on real life subject and optimize it a proper way.

- The product can be made generic so that every person can use it for their own benefit and ease.

- Using an information relaying system such as Bluetooth or GSM module the gait data can be transmitted for supervision or monitoring.

- The outlook of the device can be worked on and made more commercial.

- Device synchronization can also be made easy as in attaching the device to your PC and making it do additional functions as they come along.

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