WALKING AID FOR SEMI PARALYZED AND AGED PEOPLE

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BONAFIDE CERTIFICATE

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ABSTRACT

Injuries to lower limb joints, especially the knee and ankle are most of all musculoskeletal disorders. Because of the importance of the lower limb in everyday activities such as walking, running, the injury to these joints is urgently considered in practice. An exoskeleton suit is a powered mobile machine supplied at least part of the activation-energy for joint movement. The suit may be designed to assist and protect human to aid the survival in other dangerous environments. One of the main purposes uses an exoskeleton suit to enable a soldier to carry heavy weight during running or climbing including armor or weapon. Most of exoskeleton suit is designed by using hydraulic system. Another application could be therapy rehabilitation ,nursing in particular. An exoskeleton suit could reduce therapy process for patient to be trained by one therapist. Our project is a wearable bionic suit which enables individuals with any amount of lower extremity weakness to stand up and walk over ground with a natural, full weight bearing, reciprocal gait. A simple four bar mechanism is used to provide movement of legs. Battery powered motors drive the legs, replacing deficient neuromuscular function.

The person wearing the suit will be able to sit, stand and walk with assistance from a trained companion.

- Provides a means for people with as much as semi paralysis, and minimal forearm strength,to stand and walk
- Helps patients to re-learn proper step patterns and weight shifts using a functional based platform
- Designed for utility and ease-of use in physiotherapy.

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TABLE OF CONTENTS

LIST OF FIGURES

Figure No. **Title page** **Page No.**

LIST OF TABLES

ABBREVATIONS

DGO	**Driven Gait Orthosis**
CoP	**Centre of Pressure**
ZmP	**Zero Moment Point**
GUI	**Graphical User Interface**

NOTATIONS

T	**Torque**
P	**Power**
N	**Speed**
ω	**Angular velocity**
w	**Weight**
d	**Distance**

1. INTRODUCTION

1.1 GENERAL

Walking also known as ambulation is one of the main gaits of locomotion among legged animals. Walking is defined as an inverted pendulum gait in which the body vaults over the stifflimb or limbs with each step. Muscles and bones play the major role for walking. Due to aging muscles losses their strengths. Muscles cannot contract as quickly because more fast contracting muscle fibers are lost. Due to this the ability to walk decreases. The other factor causing loss of muscle function is paralysis. The lack of mobility often leads to limited participation in social life.

As a method of providing walking assistance for paraplegicpatients and aged people, exoskeleton-type assistive devices have recently received a great deal of attention, since these devices can provide full mobility similar to human walking. Notable studies on exoskeletons for paraplegic patients have recently been reported in the U.S. and Israel. The University of California, Berkeley, and Berkeley Bionics have recently developed e legs , which is a lower-extremity exoskeleton. The purpose of our project is to conceive a system empowering lower body disabled people with walking abilities that let them perform their usual daily activities in the most autonomous and natural manner. Rehabilitation is a required but difficult process for patients trying to recover the full control of their hips, knees, or other parts of their body. Some of the most important types of rehabilitation include neuromuscular rehabilitation for neutrally impaired patients due to spinal cord injury and muscle or ligament rehabilitation for patients with one ormore of hip, knee, or ankle replacement surgeries.

Recent studies have confirmed that locomotors movements can be induced and trained in paraplegic patients using partial unloading of the body while standing on a moving treadmill. Other results also proved that paraplegic patients who have taken such locomotors training acquired greater mobility compared to the other control group without training. This exoskeleton leg must be the same joints in the right position and the same degree of freedoms in the right distribution to make itself analogous to the human lower limbs. Human leg has three joints, hip, knee and ankle. There are related muscles driving separate joints. Physiological model of the leg consists of muscles, bones and other many complex ingredients. Therefore, it is impossible to build a perfect mechanism to simulate such a complicated model. However, it is feasible to build a simplified model in mechanism to realize most functions that human lower limb has. The system of leg-exoskeleton suit is properly designed to hold with human leg by belts integrated with DC motors, sensors, microcontroller and drive system. The weight of the leg exoskeleton suit is very important. The structure is not only light but also ensured for its durability. Thus, mild steel is selected to be the structure of the leg exoskeleton suit.

1.2 OBJECTIVES

Our objective of this project is to design and fabricate an exoskeleton structure for semi paralysed and aged people. The main functions of this structure is in walk assistance for those people who cannot walk or stand by themselves. Although, many existing exoskeleton devices are in the commercial market, they mainly uses two/three actuator system or driven by pneumatic or hydraulic systems. It makes the whole system much more complex and of high cost. Our aim is to build a cost effective, low weight and simple structure that can provide human gait for semi paralysed and aged people.

2. LITERATURE REVIEW

2.1 EXOSKELETAL DEVICE FOR REHABILITATION (USING TWO ACTUATORS)

The present invention relates generally to equipment used to facilitate rehabilitation in human beings suffering from infirmity and, more particularly, to an exoskeleton device useful for that purpose.

2.1.1 Background of the invention

Rehabilitation is a required but difficult process for patients trying to recover the full control of their hips, knees or other parts of their body. Some of the most important types of rehabilitation include neuromuscular rehabilitation for neutrally impaired patients due to spinal cord injury and muscle or ligament rehabilitation for patients with one or more of hip, knee, or ankle replacement surgeries. The spinal cord is capable of relearning the ability to walk through proper training even when cut off from the brain. A large proportion of people with spinal cord injury who sustain motor in complete lesions can regain some recovery in their walking ability. Symmetrical movements of lower extremities consistent with normal physiological gait patterns provide some of the critical sensory clues necessary for maintaining and enhancing walking ability.

Exoskeletal devices have the potential to be used during the sitting, standing, and walking stages of rehabilitation. But such a versatile device is not currently available. In view of the shortcomings of the known approaches, there is an apparent need for an improved exoskeletal device for patients requiring rehabilitation. It is therefore an object of the present invention to provide a modular exoskeletal device that permits components to be added as rehabilitation progresses through the sitting, standing, and walking stages. Thus, for example, only two actuators are provided during the standing stage while four actuators are provided during the walking stage. An additional object is to provide stationary control and computing software and hardware so that the patient need not carry this extra load. A related object is to provide an exoskeletal device offering reduced weight and power consumption.

2.1.2 Working of exoskeleton with two actuators

To achieve these and other objects, and in view of its purposes, the present invention provides a modular exoskeletal device adapted to the lower extremities of a patient during rehabilitation. The device has only two actuators during the standing stage of rehabilitation. Two additional actuators can be added, as modules, during the walking stage of rehabilitation. The actuators are a fixed to the patient and provide controlled motion to at least one of the joints of the patient. A stationary control unit is separated from the patient. The control unit communicates with and directs the actuators, and has a hybrid control algorithm; such that the actuator forces are adjusted as the patient regains control of some joint motions, which is based upon the sliding-mode control theory. A back brace is a fixed to the patient and helps to keep the torso of the patient in a stable, substantially vertical position. It is to be understood that both the foregoing general description and the following detailed description are exemplary, but are not restrictive, of the invention.

2.2 PNEUMATIC EXOSKELETON LEG FOR LOCOMOTOR TRAINING OF PARAPLEGIC PATIENTS

This work introduces a new driven gait orthosis (DGO) based on the pneumatical exoskeleton leg for locomotor training. This device can drive the lower-limb of a patient in a physiological way on the moving treadmill following the given gait which fits to the individual needs. Therefore, it can help a patient who suffers lower-limbs paralysis to recover his walking ability. Mechanisms were designed based on the optimization from the view of human gait and the Ergonomics. Displacement sensors were mounted to allow a closed loop control consequently to make each limb's motion as similar as possible to that of the human specimen. Each actuator is controlled by an algorithm, which consists of fuzzy and bang-bang. This solution allowed the existing strong nonlinearities to be easily managed with high response. The satisfying experiments results demonstrated the effect of the hybrid algorithm.

Recent studies have confirmed that locomotor movements can be induced and trained in paraplegic patients using partial unloading of the body while standing on a moving treadmill. Other results also proved that paraplegic patients who have taken such a locomotor training acquired greater mobility compared to the other control group without training. In order to improve the treadmill training for patients and reduce the workload of the therapists, a driven gait orthosis (DGO) has been employed in this study. This device makes it possible to apply automated locomotor training to non-ambulatory patients even without the assist from other people.

Many researchers have proposed ideas to develop DGO in different ways. In 1972, Hughes developed a plan for a pneumatically driven exoskeleton. Pneumatics is ever-adaptable and ever-innovative and has earned itself a major role in many fields. In addition, pneumatic cylinders are inexpensive and relatively lightweight for the amount of force they can deliver compared with servo motors. Kinematics control of a pneumatic system is an alternative solution for positioning applications, which can eliminate the complexity, expense and maintenance of motors, large power supplies and servo amplifiers associated with conventional motion control systems.

2 .2.1 Mechanical Design of Driven Gait Orthosis (DGO)

In order to design a DGO based on exoskeleton leg that can fit the patient perfectly, the exoskeleton mechanical structure must accord with the Ergonomic's principles very well. In other words, the exoskeleton mechanical design will ensure that patients will not feel any counterwork when they wear this device.

2. 2.1.1 Physiological Model and Mechanical Model

This exoskeleton leg must be the same joints in the right position and the same degree of freedoms in the right distribution to make itself analogous to the human lower limbs. Human leg has three joints, hip, knee and ankle. There are related muscles driving separate joints. Physiological model of the leg consists of muscles, bones and other many complex ingredients. Therefore, it is impossible to build a perfect mechanism to simulate such a complicated model. However, it is feasible to build a simplified model in mechanism to realize most functions that human lower limb has. Human's hip joint equals to a spherical joint in mechanism. It has 3 rotation DOFs, the same as the ankle joint. Whereas, the knee joint equals to a revolute joint in mechanism. It has 1 rotation DOF and only rotates in the sagittal plane.

2.2.1.2 Structure Design of DGO

Since the number and DOF of joints on the exoskeleton leg is defined, what should do next is to assign material, dimension to each part and determine the distribution of the cylinders.

The exoskeleton DGO should stand by other principles as below:

1) It should be lightweight for the sake of the patient’s comfort. Meanwhile, it should has enough strength. The high rigidity aluminium can meet this requirement.
2) It should be designed length adaptable for every different individual. That is to say, the thigh part must be adjusted in a range of length to accommodate mostly people with different physical size to wear. Adding a translational joint to the thigh part allows the DGO length adaptable.
3) The positioning of actuators should make cylinders provide the maximum torque to drive the exoskeleton legs and cover the physiological space that human legs can reach to.

2.3 SIMULATION OF LEG-EXOSKELETON SUIT FOR REHABILITATION

The system of leg-exoskeleton suit is properly designed to hold with human leg by belts integrated with DC motors with encoder and force sensors, microcontroller and drive system [Refer Appendix figure 2]. At shaft of DC motor at each joint of the leg-exoskeleton suit, encoders are integrated to measure the rotational angle of hip, knee and ankle joints. In design, the leg-exoskeleton suit has six degree of freedom. Each leg has three DOFs for hip, knee and ankle as shown in figure following . The weight of the leg exoskeleton suit is very important. The structure is not only light but also ensured for its durability.

The array of force sensors are attached under belts at foot area, near under knee joint and under hip joint to measure force exerted by the human that use as input in active mode. The hardware of leg exoskeleton suit is driven by six motors mounted with encoders. The motor drive system, encoders and sensors are exchange information with microcontroller. Then microcontroller will send the information to PC station to display the information of leg-exoskeleton suit and sensors. The PC station can receive the command from user with Graphical user interface application.

2.3.1 Simulation

The kinematic motion of leg-exoskeleton suit is analysed and simulated by MATLAB software. Firstly, they have designed the structure of leg-exoskeleton suit by using robotic toolbox [Refer figure 2]. The hardware consists of main three joints in left and right sides and the parameters relationship between the links and joints is described based on Denavit and Hartenberg method. In simulation, the revolute, speed and acceleration of joints are studied how is the possible motion of the leg-exoskeleton suit. The results of simulation are considered to design and construct the real hardware. Many types of motion are simulated to test the conflict of links and joints. The angles of left hip, knee and ankle joints are specified in simulator with started position (0, 0, 0) and the final angle of joints are position (-90º, 45º, 90º) in 10 second. The revolute angle, velocity and acceleration of hip, knee and ankle joints are shown in Appendix figure 2, figure 3, and figure 4.

The study of possible motion of leg-exoskeleton suit is focused to construct the real hardware. The design of leg-exoskeleton suit is achieved by Solid work software. By this software, the possible motion and conflict between links and joints can be simulated. In this work, three types of physical rehabilitation, which are active, active-assistive and passive motion, are analyzed and simulated. In order to leg-exoskeleton suit can operate following all types of rehabilitations, the control algorithm is designed to cover all types. In simulation, the active motion is only accomplished. The sensed force is used as input in control algorithm and the output as revolute angle, velocity and acceleration of hip, knee and ankle joints is given. The revolute, velocity and acceleration of each joint in left leg are simulated by MATLAB robotic toolbox. The leg-exoskeleton suit is specified at position of hip, knee and ankle joint angle(0, 0, 0) and the end of trajectory is position (-90º, 45º,90º).

2.4 STABILITY IN EXOSKELETONS

2.4.1 Centre of Pressure in an Exoskeleton Robot

Since the wearer does not have the ability to move his or her legs actively, the exoskeleton has to actively move links that guide the human legs. In this regard, the exoskeleton for paraplegic patients is close to a humanoid robot in terms of active motion. As the concept of the ZMP is generally used for many biped humanoid robots, it can be used to check stability while an exoskeleton worn by a patient is operated. In addition, it could also be used to estimate the human intention of walking, since one of the fundamental walking principles is the translation of body mass - more exactly, the centre of mass - which is deeply related to the ZMP. Instead of using the ZMP, the CoP is used in the assistive exoskeleton for the purposes of detecting the human intention to walk and checking stability in this study. This approach can be deemed valid for the following two reasons: the coincidence between ZMP and CoP and the popularity of CoP in the medical field. Both ZMP and CoP are the coincident point on the supporting plane -normally flat ground - as long as there exists contact between a foot and the ground.

The CoP is defined in biomechanics as the point where the resultant force of all ground reaction forces acts. This terminology is frequently used in the field of biomechanics. On the other hand, ZMP is a criterion for dynamic stability that is generally used in the field of biped walking robots. It was theoretically proven that the

CoP is the coincidence point with ZMP when the two feet are in contact with a plane or when one foot is in surface contact, except for the case of contact with the foot′s edge. The CoP has an important meaning in the walking process, as described at the beginning of this paper. Since there are limited contact points on the exoskeleton, the CoP can be calculated by the following definition:

$$\mathbf{P}_{CoP} = \frac{\sum\left(\mathbf{n} \times \left(\mathbf{P}_i \times \left(\mathbf{F}_i \cdot \mathbf{n}\right)\right)\right)}{\sum\left(\mathbf{F}_i \cdot \mathbf{n}\right)} \qquad (2)$$

Where $\mathbf{P}_{CoP}$ represents the location of the CoP in the global coordinate, **n** is the normal vector of the ground, and $\mathbf{F}_i$ is the force of the contact point i . With an assumption that x is the coordinate in the forward direction and y is that in the side direction on the ground, the equation can be expressed in the form of:

$$\left(x_{CoP}, y_{CoP}\right) = \left(\frac{\sum F_{n,i} x_i}{\sum F_{n,i}}, \frac{\sum F_{n,i} y_i}{\sum F_{n,i}}\right) \qquad [3]$$

where (x_{CoP}, y_{CoP}) represents the coordinate of the CoP,(x_i, y_i) is the coordinate of contact point i , and $F_{n,i}$ is the force component normal to the ground at the contact point i . In this initial stage of development, we only considered the contact points of four force sensors in both feet and two force sensors in both shanks. In the case of walking with crutches, the locations of the end tips of the crutches and the measurement of the force at these points should be taken into consideration in equation

CoP is a method for determining the intention of a patient to walk, the positions of all the contact points where the forces are transferred from the exoskeleton and the wearer to the ground must be known. For this purpose, we use the following sensors:

a) Angle sensors at all joints (14 DOF in the legs)

b) A force sensor measuring the reaction between the exoskeleton and the ground

c) A force sensor measuring the reaction between the wearer and the exoskeleton's foot

d) A ground contact sensor system in the exoskeleton foot

2.5 FACTS IN STRUCTURAL DESIGNING OF EXOSKELETON

A circular pipe shape has been selected for the links dueits advantage of lightness, since the shape has a high area inertia of moment compared with the other cross-sectional shapes in all directions, meaning better strength in shear and bending moment for the unit mass. Duralumin is commonly selected as the material of the link, on the basis of low cost. The proper dimensions have been selected through a strength simulation. Since the weight of a human leg is about 10% of a person's total weight, 80N force is reasonable if the person is assumed to weigh 800N for tolerance. The worst load condition is assumed such that the link bears shear due to 80N force vertically.

2.6 SAFETY IN EXOSKELETONS

The exoskeleton is worn by a human and, thus, safety is a critical factor. To prevent injuries caused by the actuators through any malfunction of the system, safety elements such as mechanical stoppers should be implemented on the joints. These elements will secure the safety of the activated joints upon any unexpected malfunction of the system. The user is not stable when only wearing the exoskeleton since the two active joints in the knee and hip lack of support. Incorporating additional active joints can enhance the stability but will also increase the weight as well as the power requirement of each joint. To supplement the stability problem, forearm crutches that can be controlled by the upper limbs of the user are used.Forearm crutches will increase the walking stability of the wearer of the exoskeleton by providing additional controllable tools to support the body on the ground.

3. METHODOLOGY

Topic is selected as per the suggestions made by our group members based on the current technological and experimental developments in the field of Mechanical Engineering.

- For the detailed study of our topic we referred some books and search on internet for papers presented by experts related to our topic.
- As the result of our search we found some journal papers related to our topic. From those journal papers a basic journal paper is selected.
- The basic journal paper is thoroughly studied and further supporting journals are searched.
- Constructed basic structure of our project on AutoCAD, linkage, NX8, Autodesk inventor Fusion assembly 2012 software.
- The dimensions and force analysis of the structure is to be done.
- Structural implementation, components to be selected as planned in the project reviews
- Suitable assistance from experts will be taken for fabrication and microcontroller unit implementation.
- The problems that may arise in the assembling will be fixed after detailed evaluations, and suitable changes will be accepted.

3.1 PPRIMARY DESIGN OF LINKAGE

This exoskeleton leg must have same joints and the same degree of freedoms to make it analogous to the human lower limbs. Human leg has three joints, hip, knee and ankle. [Refer Appendix figure 7]There are related muscles driving separate joints. Suitable material selection, positioning of actuators, different forces acting on it are required for the design.

3.1.1 Tools for Designing

Linkage software

Linkage is computer aided design software used for quick prototyping of linkage mechanisms. The number of operations needed to add a link and get it connected to other links in the mechanism has been minimized to the lowest number possible, making this program ideal for “throwing together” a working machine. The mechanism is edited and animated in the same window allowing for quick analysis and modification while working on a design. It is simplistic for a CAD program but that is the intent.

Mechanisms can be designed with pivot connectors or sliding connectors. Inputs to drive the mechanism can be rotary or linear. The number of connections on a link and the number of links is virtually unlimited.

Features :

- Lets the user create any configuration of links, connections, gears, and chains. There is no limit to using specific types of linkages and mechanisms.
- Runs at 30 frames per second when simulating the mechanism visually.
- Can move, rotate, scale, stretch, cut, copy, and paste, any set of selected connectors and links.
- Can align selected connectors in many ways including at right angles, any angle, in a parallelogram or rectangle, etc.
- Allows you to assign drawing capability to any connector to visualize its path during simulation.
- Automatically displays dimensions of parts in mm or inches in a way that is suited to manufacturing individual parts.
- Will draw dimension/measurement lines manually.

- Will draw points and lines separate from the simulated mechanism.
- Uses pivoting connectors as well as less common sliding connectors.
- Allows for any number of rotating and/or linear inputs.

Autodesk Inventor

Autodesk Inventor, developed by U.S.-based software company Autodesk, is 3D mechanical CAD software for creating 3D digital prototypes used in the design, visualization and simulation of products. Autodesk Inventor uses ShapeManager, their proprietary geometric modelling kernel.

Inventor includes an integrated motion simulation and assembly stress analysis environment. Users can input driving loads, friction characteristics, and dynamic components, then run dynamic simulation tests to see how a product will work under real-world conditions.

SIEMENS NX (8)

NX, formerly known as NX Unigraphics or usually just U-G, is an advanced high-end CAD/CAM/CAE software package originally developed by Unigraphics, but since 2007 by Siemens PLM Software.

It is used, among other tasks, for:

- Design (parametric and direct solid/surface modelling)
- Engineering analysis (static, dynamic, electro-magnetic, thermal, using the Finite Element Method, and fluid using the finite volume method).
- Manufacturing finished design by using included machining modules.

Key Functions

- **Computer-aided design** (CAD)
  - Parametric Solid modelling (feature based and direct modelling)
  - Engineering drawing (Drafting)
  - Sheet metal design
  - Assembly modelling and Digital mock-up
  - Routing for Electrical wiring and Mechanical Piping

- **<u>Computer-aided engineering</u>** (CAE) (Simulation)
  - Stress analysis / Finite element method (FEM)
  - Kinematics
  - Computational fluid dynamics (CFD) and Thermal analysis
- **<u>Computer-aided manufacturing</u>** (CAM) (Manufacturing)
  - Numerical control (NC) programming

Design of the structure is done with the help of softwares such as linkage, NX8, AutoCAD, inventor fusion etc. Linkage helps to get the rough idea of the dimensions required and the animated view of the feasibility of our design. First 3-D modelling was done using NX8 and then complete figure was modeled in inventor fusion. The dimensions of one of our group member is selected as default and design will be based on that.

DIMENSIONS:

- Upper limb : 0.5 metre
- Lower limb: 0.45 metre
- Foot: 8 inches

In order to design an exoskeleton leg that can fit the patient perfectly, the exoskeleton mechanical structure must accord with the Eagonomic's principles very well. In other words, the exoskeleton mechanical design will ensure that patients will not feel any counterwork when they wear this device.

This exoskeleton leg must be the same joints in the right position and the same degree of freedoms in the right distribution to make itself analogous to the human lower limbs. Human leg has three joints, hip, knee and ankle. There are related muscles driving separate joints. Physiological model of the leg consists of muscles, bones and other many complex ingredients. Therefore, it is impossible to build a perfect mechanism to simulate such a complicated model. However, it is feasible to build a simplified model in realize most functions that human lower limb has. Human's hip joint equals to a spherical joint in mechanism. It has 3 rotation DOFs, the same as the ankle joint. Whereas, the knee joint equals to a revolute joint in mechanism. It has 1 rotation DOF and only rotates in the sagittal plane. [Refer Appendix figure 1]

The lightweight modular exoskeletal device (a biped robot) of the present invention its the lower extremities of patients requiring rehabilitation due to neuromuscular injuries; hip, knee, ankle replacement surgery; or other infirmity. Although the device could be used in different stages of rehabilitation such as sitting, standing, and walking, one feature of the device is in assisting the patient to exercise in the standing position.

3.1.2 DESIGN USING LINKAGE

Figure 3.1 Linkage Generated Design

3.1.3 DESIGN USING INVENTOR FUSION

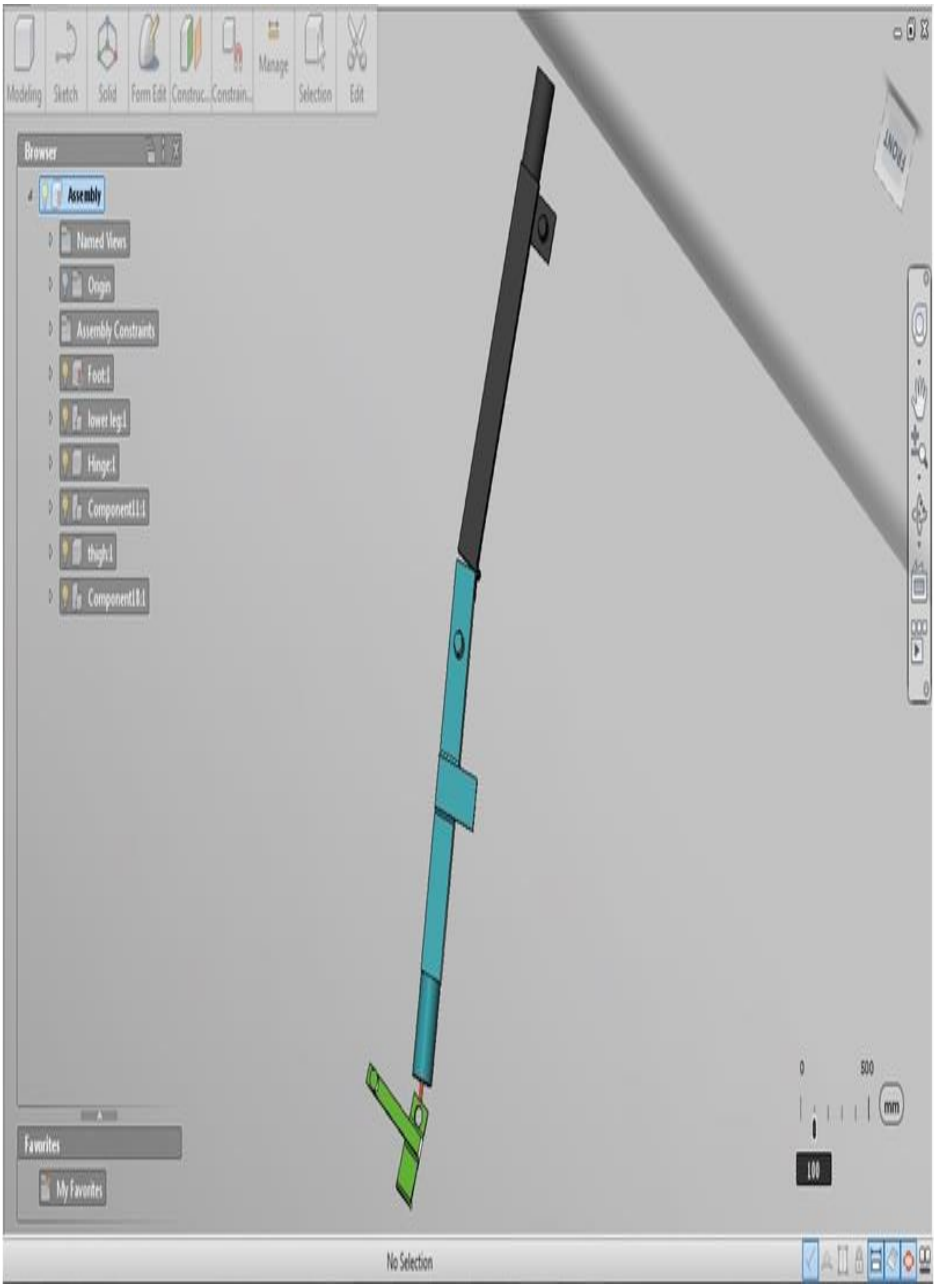

Figure 3.2 Modelling using Autodesk Inventor

3.1.4 COMPLETED DESIGN USING NX 8

Figure 3.3 Completed Design using NX8

3.1.5 Force study

This exoskeleton leg must be the same joints in the right position and the same degree of freedoms in the right distribution to make itself analogous to the human lower limbs. Human leg has three joints, hip, knee and ankle. There are related muscles driving separate joints. Physiological model of the leg consists of muscles, bones and other many complex ingredients. Therefore, it is impossible to build a perfect mechanism to simulate complicated model. However, it is feasible to build a simplified model in mechanism to realize most functions that human lower limb has. Human’s hip joint equals to a spherical joint in mechanism. It has 3 rotation DOFs, the same as the ankle joint. Whereas, the knee joint equals to a revolute joint in mechanism. It has 1 rotation DOF and only rotates in the sagittal plane.

3.1.5.1 Lower limb anatomy

In following figure, there are two muscles around hip joint, which are gluteus maximus and rectusfemoris muscle in the leg respectively. During the human walking period, the two muscles interact to generate appropriate torque to drive the hip joint to form the right gait. Similarly, there are another two muscles around knee joint, which are shares biceps and vastusmedialis muscle. They drive the knee to accomplish the right gait.[Refer Appendix figure 8]

3.1.5.2 Weight of the body

As the previous section says, the assistance should be given the thigh parts. According to the book Human Body Dynamics: Classical Mechanics and Human Movement by Aydin Tozeren, the average percentage of weight for each body part is as follows:

Table 3.1 Weight of Body Parts

SL.NO	BODY PARTS	%
1	Trunk(Chest ,back and abdomen)	50.80%
2	Thigh	9.88%
3	Head	7.30%
4	Lower leg	4.65%
5	Upper arm	2.7%
6	Forearm	1.60%
7	Foot	–1.45%

The exoskeleton is designed on the right leg of the patient. His weight of the leg can be calculated as follows:

- The weight of the patient selected =60 kg.
- Percentage distribution of thigh = (9.8%60) = 6.86 kg.
- Percentation distribution of lower leg = (4.65 %60) = 3.25 kg.
- Total weight of one leg =6.86 + 3.25 = 10.11 kg.
- For the safety aspects 12 kg is taken as the weight of one leg.

3.2 SKELETON MODEL FOR TWO LEG

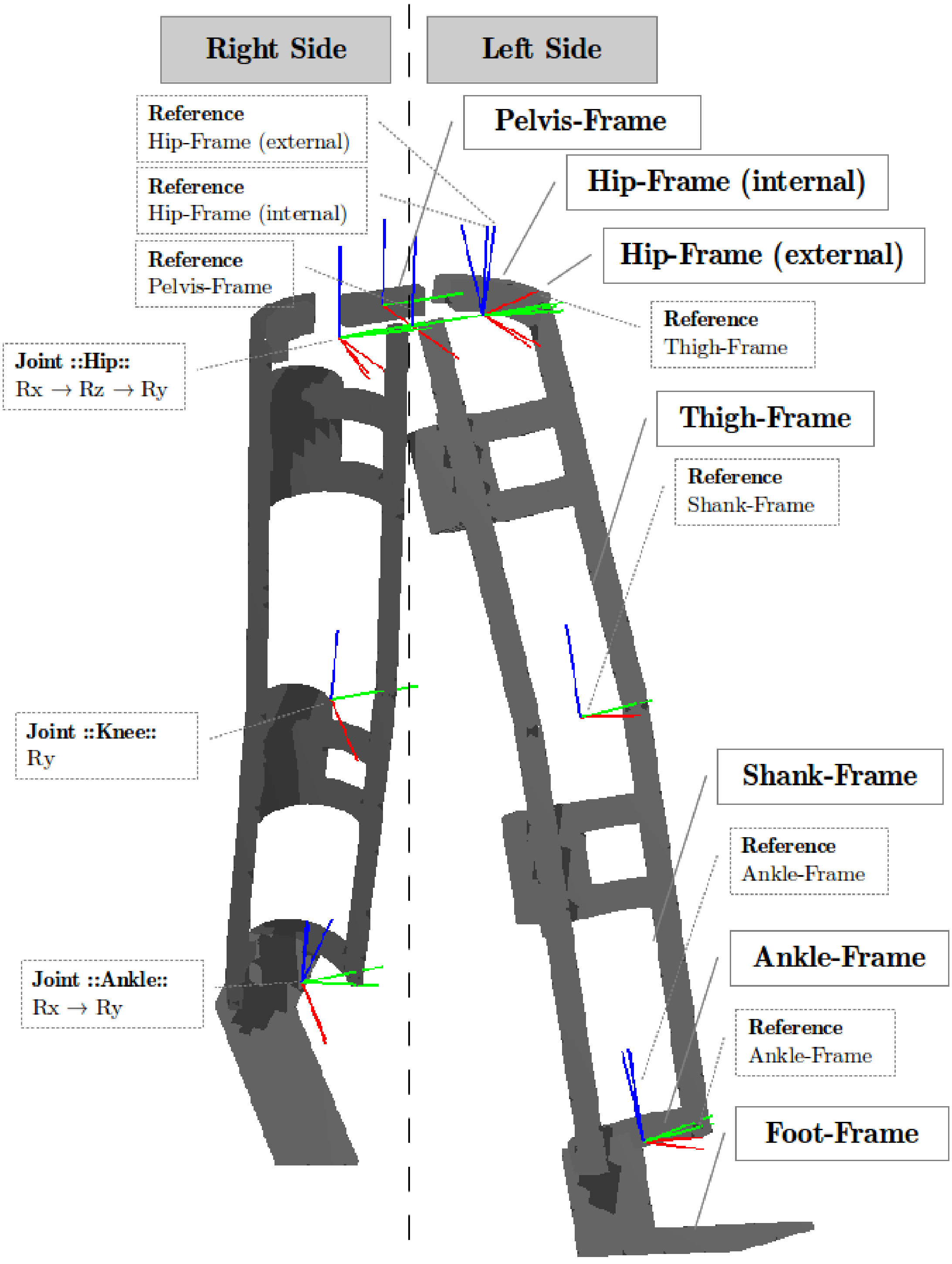

Figure 3.4 Skelton Model

3.3 MATERIAL SELECTION

It should be lightweight for the sake of the patient's comfort. Itshould has enough strength. It should also meet the cost requirement. Removing weight from products is an effective response to environmental concerns (energy efficiency, smaller carbon footprint) and economics (profitability of production and use). Lightness benefits not only the applications but also operations on the shop floor and working conditions, and means lower expenditures on material handling equipment.

Approximately The weight of the patient selected is60 kg and for the safety aspects 12kg is taken as the weight of one leg.For the selection standard dimensions , commercial availability and economical considerations are preferred. Hence we selected Grade 1, IS4923 CM/L , Bhushan steels.

Table 3.2 IS 4923: 1997 Specifications

Designation	Depth or Width D	Thickness	Weight	Area of Section	Moment of Inertia	Radius of Gyration	Elastic Modulus	Plastic Modulus
mm	mm	mm	kg/m	cm^2	cm^4	cm	cm^3	cm^3
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
180 × 180 × 4	180	4	21.9	27.9	1 434	7.17	159	184
180 × 180 × 5	180	5	27.2	34.6	1 755	7.12	195	226
180 × 180 × 6	180	6	32.05	40.83	2 036	7.06	226	280
180 × 180 × 8	180	8	42.5	54.1	2 633	6.98	293	346

3.4 SELECTION OF DRIVE

Compared with the hydraulic/pneumatic drives, the electric actuator has its unique features: It does not need a complete support system (pump, valve, pipe, filter etc), thus saving lots of space. Also it can work safely and reliably without any maintenance. It is free from oil pollution and keep a clean and quiet working environment by reducing the noise substantially. Specific functions are as follows: Self-locking: The majority of the electric actuator and screw jack with acme screw has the absolute self-locking function under dynamic load due the low transmitting efficiency, therefore, increasing the safety of the device.

Accuracy：

The in-line control can also be attained by matching with potentiometer

Synchronousness：

Through mechanical connection to multiple actuators, one single motor can drive the multiple actuators up and down simultaneously.

Driving system：

DC motor 12/24V; single phase AC motor ,three phase AC motor

Over-load protection：

It can be accomplished by matching with the safety clutch or the over-load sensor.

High load capacity：

Up to 250 ton.

Others：

Easy maintenance, low noise, work normally under the low/high temperature, corrosion-proof, explosion-proof environment.

In dc motors, a dc winding or a permanent magnet generates a fixed magnetic field in the stator. Speed and power in dc motors can be controlled very effectively, but the carbon brushes that are required to switch the current in this type of motor are subject to wear and tear. Hence for our small speed, medium load capacity and compact operation, we selected a dc motor over hydraulic and pneumatic drives.

3.5 SELECTION OF MOTOR

It is a proven fact that to design an actuator at hip position, it should satisfy following condition.

- Torque generated by the actuator > Torque generated by the weight of the limb and exoskeleton.
- Weight of the system (w) =Weight of leg + Weight of system

$$w = w_{leg} + w_{sys}$$

$$w = 12\ kg + 4.3kg$$

$$w = 16.3\ kg = 160\ N.$$

According to the book Human Body Dynamics: Classical Mechanics and Human Movement by Aydin Tozeren, the angle during walking varies as shown in Appendix figure 9.The angle is maximum at the start of stance phase (28.4°). But in the case of sitting the angle falls near to less than 90°.Hence the maximum toque generated will be at this position as shown in Appendix figure 10.

3.5.1 Procedure

- Torque generated by leg and exoskeleton will be, ($T_{sys} = W \times d$)
- The type of motor we are selecting is BOSCH FPG type(used for the automation of windows, curtains, door lock)
- Motors available are of following ratings:

Table 3.3 Motor Ratings

VOLTAGE(V)	POWER(W)	SPEED(RPM)
12	10	95
12	8.9	85
24	24	35

- Next step is to find the forces that can be handled by each motor, which creates torque at distance, d = l_{upper}.
- The general formula which relate torque and power is

$$P = T \times \omega$$

$$P = T \times \frac{2\pi N}{60}$$

$$P = W \times d \times \frac{2\pi N}{60}$$

- Calculated value of W for each motor is given in table 3.4

Table 3.4 Calculation of Force

MOTOR	POWER(**P**) (W)	SPEED(**N**)(rpm)	DISTANCE(**d**) (in m)	TORQUE (**T**)(N.m)	FORCE(N) **W**
M1	10	95	.04	1.005	25.142
M2	8.9	85	.04	1	25
M3	24	35	.04	6.5512	163.78

- Torque generated by the leg and exoskeleton = 160× 0.04
  = 6.4 Nm
- The torque generated by motor M1 > Torque generated by the System
- The motor M1 also consumes only 12 V.
- Thus the motor M1 is selected for the structure.

- Specifications are as follows:

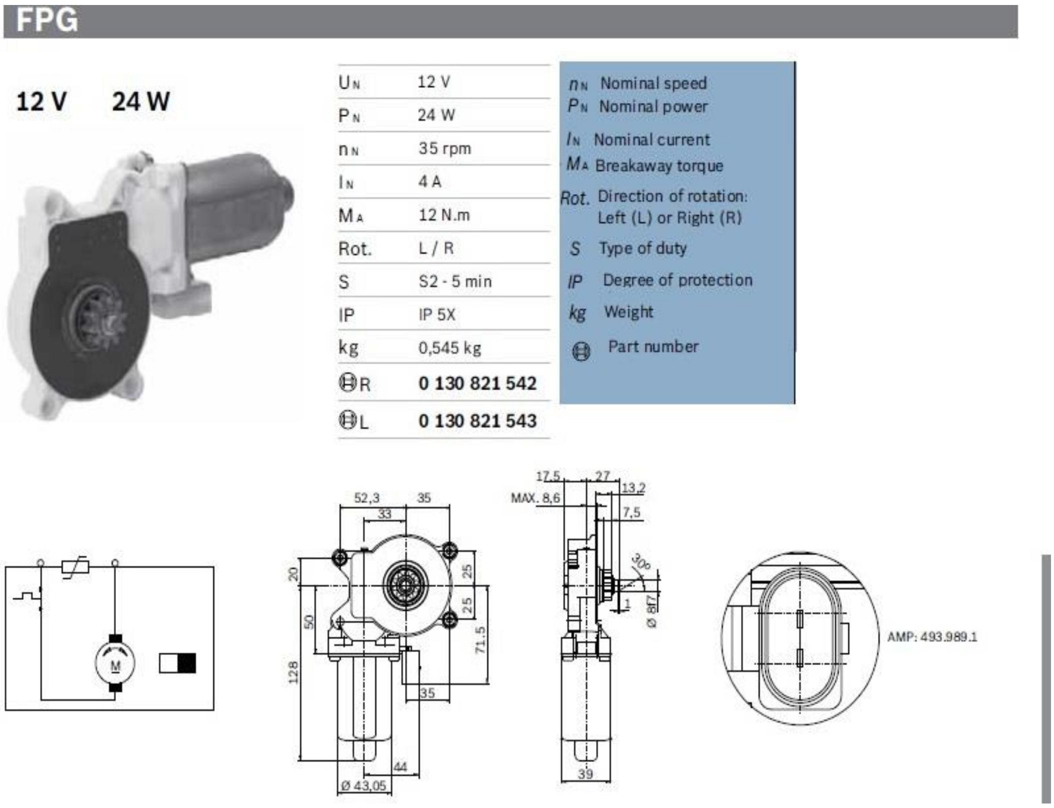

Figure 3.5 Bosch FPG12 Specifications

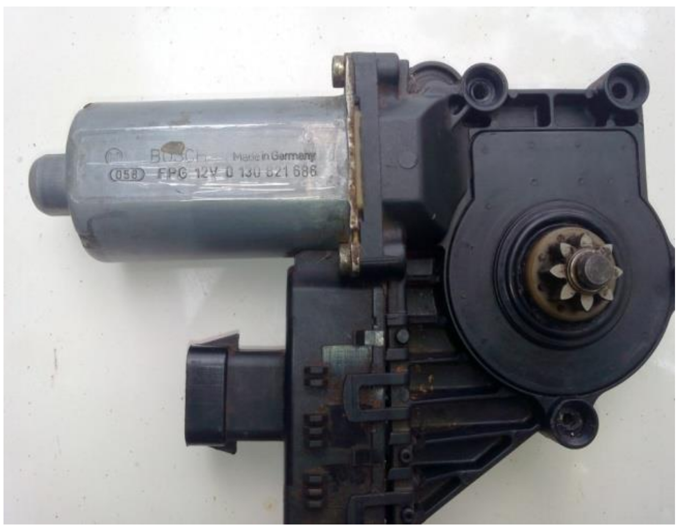

Figure 3.6 Bosch FPG12

3.6 FOUR BAR MECHANISM

The structure uses a simple four bar mechanism. This four bar linkage, makes the whole structure simple and of reduced weight compared to other walking aids commercially available. Hence we can avoid the use of an actuator at the knee position. This also improves the stability and rigidity compared to the walking aid with two actuators.

The simple four bar mechanism is as shown above. A,B,C, and D forms the four linkages; where D is the fixed linkage. Since A is connected to the motor extension it have a rotatory motion. So A is the crank. B is the longest link, the length can be adjusted according to the user and B act as the connecting rod.Since the link opposite to Aie C, osscilates or rocks this mechanism ca be considered as a Crank-Rocker mechanism.

The four bar mechanism is simulated in the Linkage software (including dimensions).Construction was based on the data and trial-and-error method.

The dimension are:

Link A- 17cm

Link B-55cm

Link C-40cm

Link D-19cm respectively.[Refer figure 11]

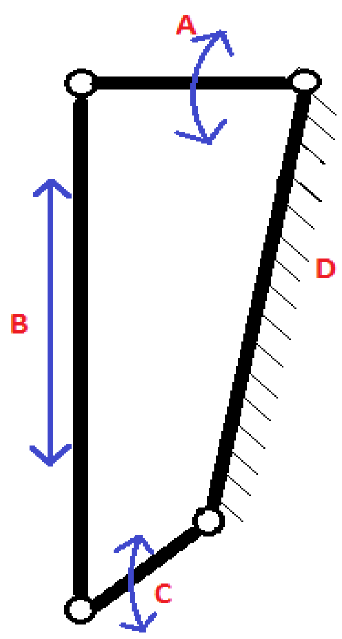

Figure 3.8 Four bar linkage

3.7CONTROL SYSTEM

3.7.1 Block Diagram

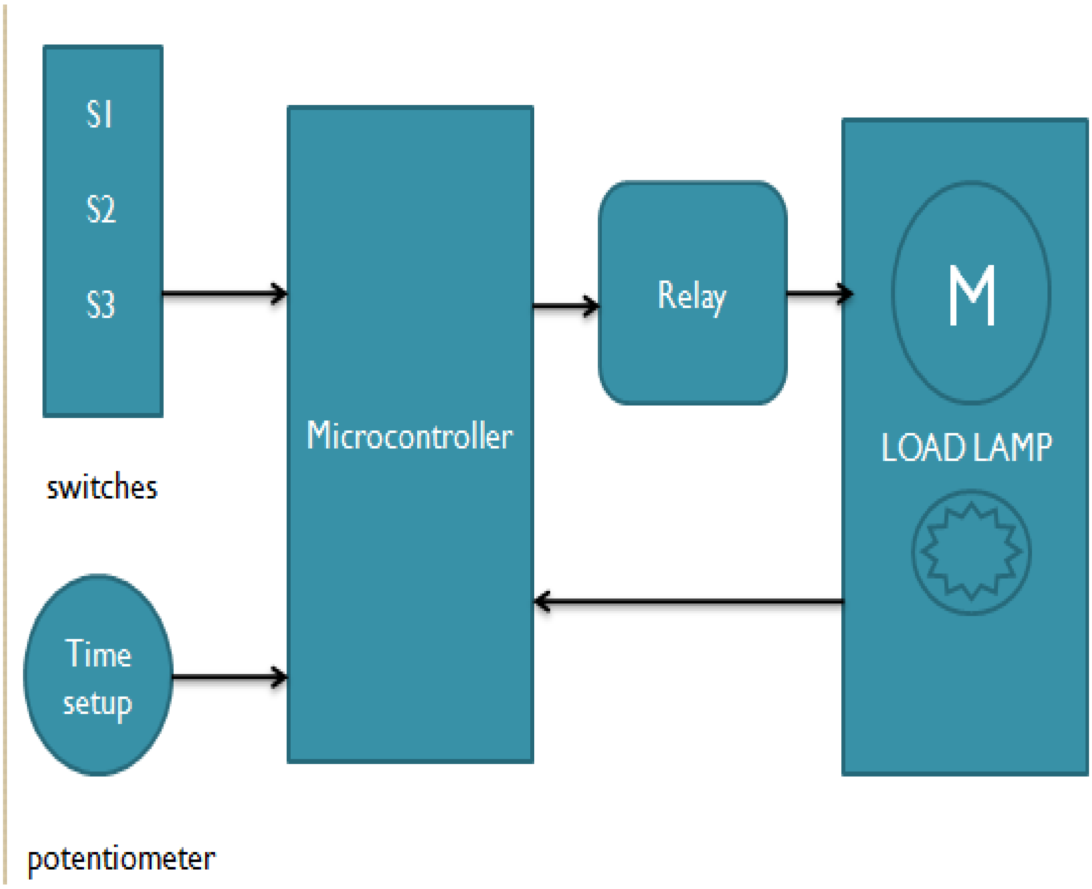

Figure 3.9 Block Diagram

The responses from each switch is given to the microcontroller. The microcontroller detects the required operations and passes the pulses according to the coded program on it. This program enables the relay to understand the required alternation in the rotation of motor, ie either clockwise or anti clockwise. The relay drive is also given for maintaining separate voltage for the operation of the relay. The time set up is given by the potentiometer. For the safety aspect motor overload bulb is given. It blows at the both extremes of motor rotations.

3.7.2 Component Specification

Table 3.4 Specification of Components

COMPONENT	SPECIFICATION	NO.
Relay	12V, SPDT	2
Microcontroller	µC76FS76	1
Relay Drive	ULN2003A	1
Voltage regulator	LM7805	1
Switch	Push type	3
Load bulb	12V	1
PCB	-	-

3.7.2.1 Battery Specification

Nominal Voltage- 12V

Nominal Capacity -7Ah

Weight – 5.86 lbs.

Dimensions (inch) – 5.95x2.56x3.74

3.8 FABRICATION

After all the required calculations and selection of material, motor etc fabrication was started. Different stages are :

3.8.1 Stages

Stage 1

Using dimensions from Linkage software as reference is selected a group members with average weight and height. The hip point and knee point are found out using long rods by bending the dummy in definite angles. Dimensions were taken and noted.

[Refer Appendix figure 12]

Stage 2

An approximate skeletal structure was modelled using wood which can give expected motion and of required dimensions.

Stage 3

Skeletal model was fabricated using MS rods, changes in dimensions were also noted.

[Refer Appendix figure 13]

Stage 4

Purchasing of motor and related accessories. Attachment of motor to the skeletal structure. Formation and fabrication of a four bar linkage mechanism for the expected motion.

Stage 5

Completion of model with bolting of belts, shoes for rigid support. Sponges and Rexene were used for both stress absorption and beautification purpose.

Stage 6

Purchasing of electronics components and completion of manual control circuit.

[Refer Appendix figure 14]

3.8.2 Completed structure

The exoskeleton structure is completed as shown in figure. The steel structure is fitted with sponges for taking the stresses acting on the user and is covered using Rexene for aesthetical purposes. The structure is bolted with five belts and a shoe for easy and rigid fixation.

Figure 3.10 Completed Exoskeleton Structure

4. RESULTS AND DISCUSSIONS

4.1 GENERAL

Completed structure of exoskeleton is used for semi paralyzed (situation in which people will receive the impulse but no achievement of human gate or possibility of sit-stand-support.) and aged people for walk assistance and physiotherapy .For fabrication one of the group member dimensions were selected as reference for the sake of easy trial run. The testing was completed successfully for various situations.

The controls are done completely for manual operation as automation may lead to technical difficulties to both the user and also the structure.
The exoskeleton structure must be tightened to the user using the five belts provided, three belts are provided to the upper body portion while the lower limb is rigidly fixed using the remaining two belts and shoe. For fixation the user must be in the sit position. Walking stick are provided for easy balancing and support. There are three switches provided on the walking stick for Stand, Sit, and Walk respectively. An overload bulb is provided to indicate the battery overload condition, which reduces the unwanted battery consumption. A power/circuit breaker switch is provided for emergency situations. During walking the hip must be slightly turned to achieve forward motion. This is to be done because the structure is limited to one leg.

4.2 WORKING

The working of the structure falls into following three operations sit, stand and walk. All these are controlled by three separate switches. Since the driven gear is designed in the shape of quarter of the circle , it helps us to easily achieve sit and stand positions. The switches are fixed on the hand support, so that the user can control it himself. The working is explained below considering the fact that walking aid is fixed for the right leg.

- Standing

The walking aid is attached to the user in sit position, for this the actuator is adjusted to make the limbs at sitting angle. The walking aid is now fixed to the body by the help of belts. The user should hold the support in his hand properly. As he presses the standing switch, the actuator pulls him to stand position. [Refer Appendix figure 15]

- Walking

The user should take his left leg to make a initial contact, then press the walk switch. This is the start of loading process. The user should fix his left foot flat to the groung. The actuator rotates back to the position till the sensor senses the maximum bending angle. At this position the actuator starts rotating in opposite position. This continues till the right foot becomes flat to the ground. For the next step the user should again make stance using his left leg, and there by repeat the process.

- Sitting

From the stand position, after keeping the toes at the same level the user can press on the sit switch. This makes the actuator to rotates in opposite position to extreme end, enabling the user to sit comfortably on the chair.

The speed of operation can be adjusted by using a potentiometer. Any problems during walking, can be adjusted by bring back to sit or stand positions.

5. SUMMARY AND CONCLUSIONS

5.1 SUMMARY

The study of possible motion of leg-exoskeleton suit is focused to construct the real hardware. The design of leg-exoskeleton suit is achieved by linkage and Siemens NX8software. By these softwares, the approximate motions and 3D design is done. In this work, stand ,sit and walk motions are achieved. Force analysis is covered using the previous works. The sensed force is used as input in control algorithm and the output as revolute angle, velocity and acceleration of hip, knee is given. Potentiometer is provided for timing adjustments and control switch is used for angular measurements. Suitable covering materials are used for aesthetic purpose. Structure was limited to one leg .

5.2 APPLICATIONS

In light of recent surge of interest in exoskeletons, much research has been made to developing exoskeleton systems. However most of the exoskeletons available in market are of robotics based. Robotics based exoskeletons are of high cost, cannot affordable by common people with walking disabilities. So we are aiming to construct an exoskeleton at low cost .It could provide sensation of walk to aged and paralyzed people. Also we are aiming to help user to carry heavy loads by transferring the load weight to the ground (not to the wearer).It could provide soldiers the ability to carry heavy loads such as food, communications gears, and weaponry without the strain typically associated with demanding labour. Thus major applications falls into:

- Walk assistance.
- In physiotherapy.
- Helps armed forces for carrying loads.
- Cost effective
- Low weight and complexity compared to existing structures.

5.3 LIMITATIONS

- Structure is only for single leg, so adjustments in walking are required.
- Limited angular movements.
- Sudden reflexes are not possible, even though emergency switches are provided.
- Little bulky at sides.

5.4 FUTURE SCOPE

The scope of the present work are as shown below :

- Study and examination of the key technologies required to successfully build an exoskeleton.
- Investigation of the control strategy and the exoskeleton to user interface.
- Force analysis of the associated linkage.
- Design and construction of an experimental prototype.
- Implementation of the control algorithm on the constructed prototype.
- Realization of the normal walking.
- The completion of the model for the two legs and with suitable supports for balancing.
- Maximum automation to the exoskeleton arrangement

5.5 CONCLUSION

The model was fabricated and found to work satisfactorily. Rehabilitation for paralysed and aged people is an increasing concern in the society .We were able to produce an exoskeleton walking aid for these people for the multiple uses of walking, physiotherapy and limited step climbing. Since this project is an experimental investigation, we limited the the structure for one leg. The change from two leg to one leg structure donot give much impact since the design is exactly same for the other leg, and suitable counter balancing back support is provided.

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APPENDIX

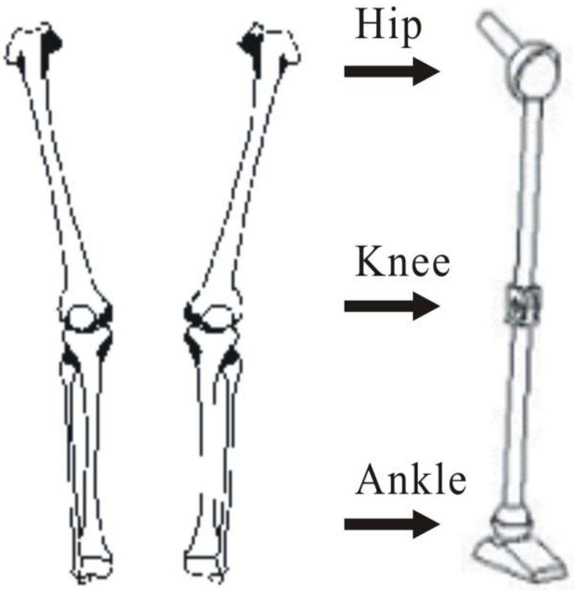

FIG 1

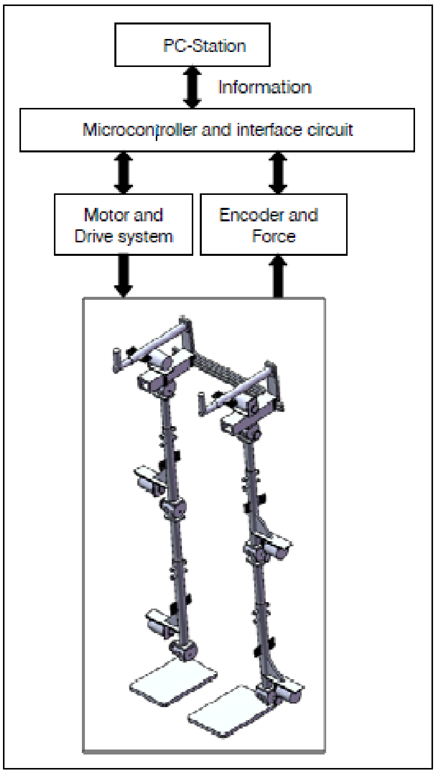

FIG 2

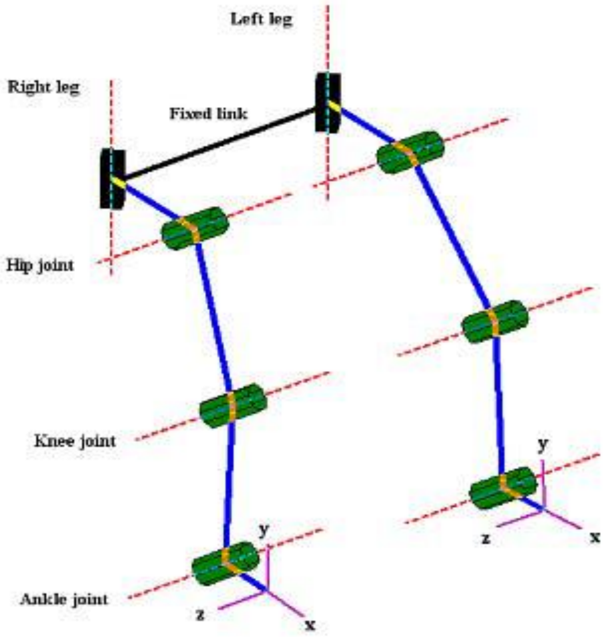
Left leg
Right leg
Fixed link
Hip joint
Knee joint
Ankle joint
y
z
x
y
z
x

FIG 3

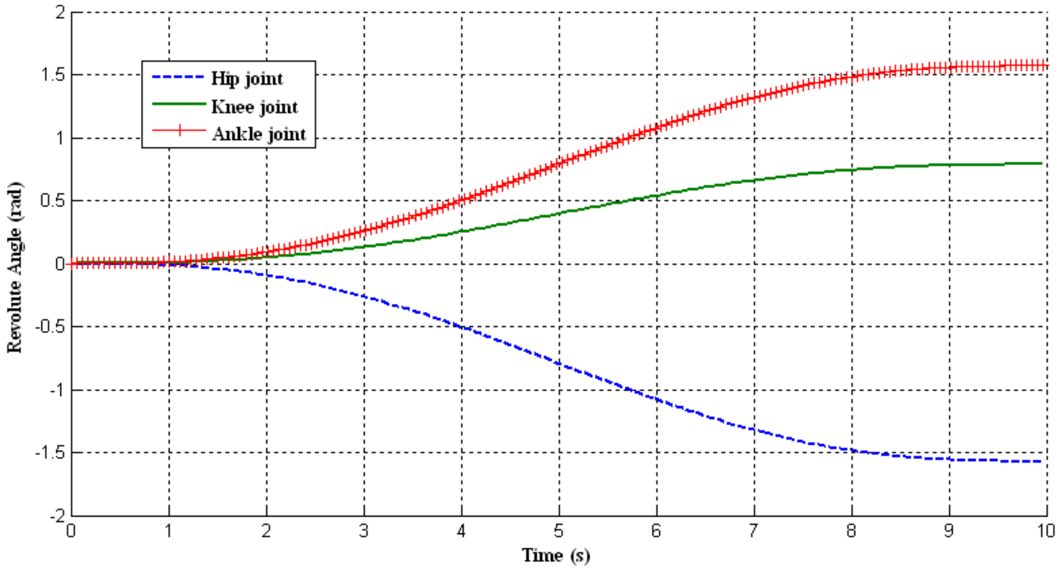
Hip joint
Knee joint
Ankle joint
Revolute Angle (rad)
Time (s)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
6
7
8
9
10

FIG 4

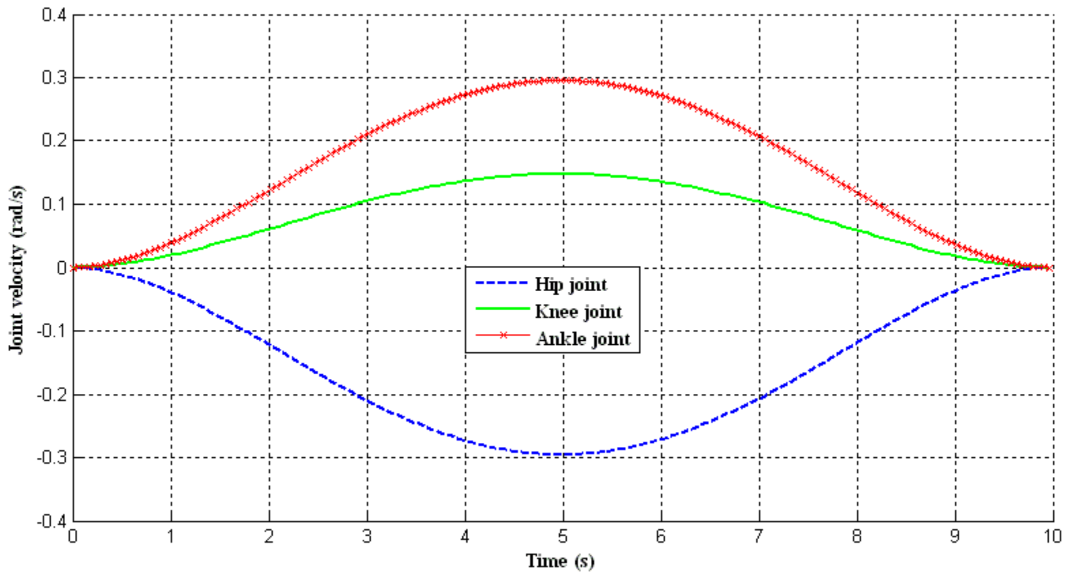
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
Joint velocity (rad/s)
0
1
2
3
4
5
6
7
8
9
10
Time (s)
Hip joint
Knee joint
Ankle joint

FIG 5

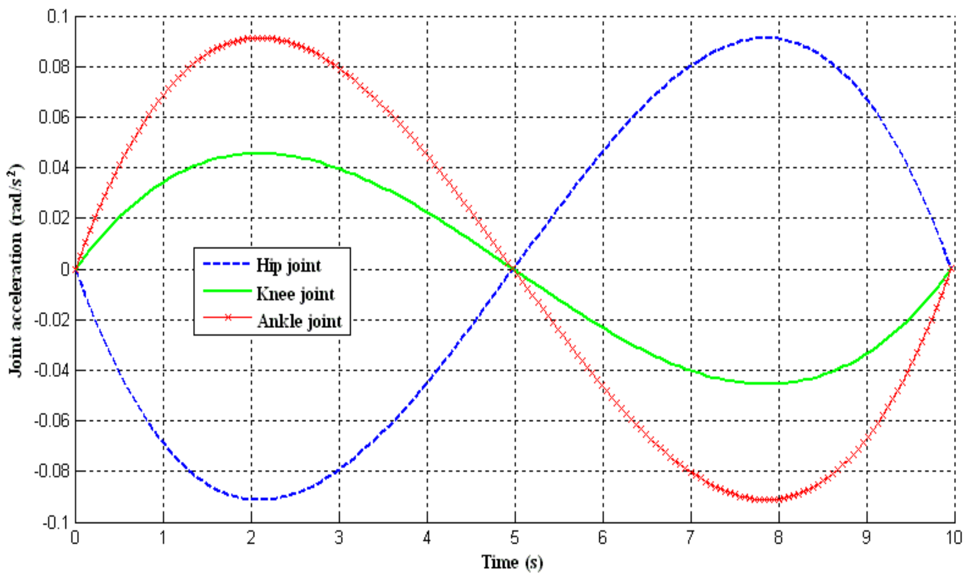
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
Joint acceleration (rad/s²)
0
1
2
3
4
5
6
7
8
9
10
Time (s)
Hip joint
Knee joint
Ankle joint

FIG 6

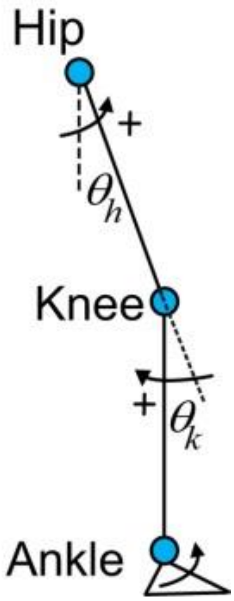
Hip
+
θ_h
Knee
+
θ_k
Ankle

FIG 7

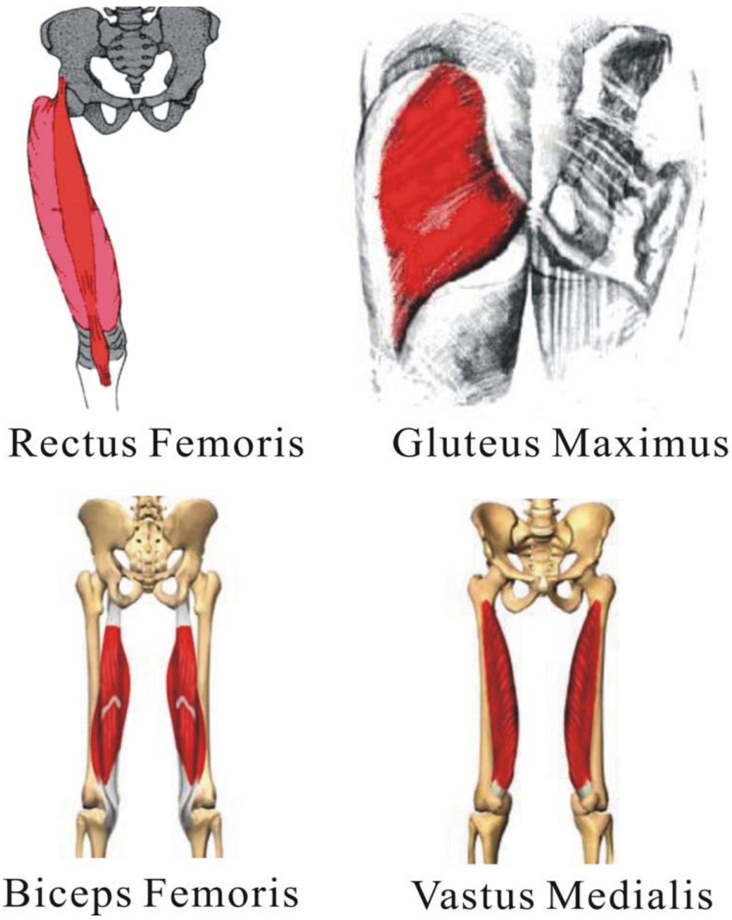
Rectus Femoris
Gluteus Maximus
Biceps Femoris
Vastus Medialis

FIG 8

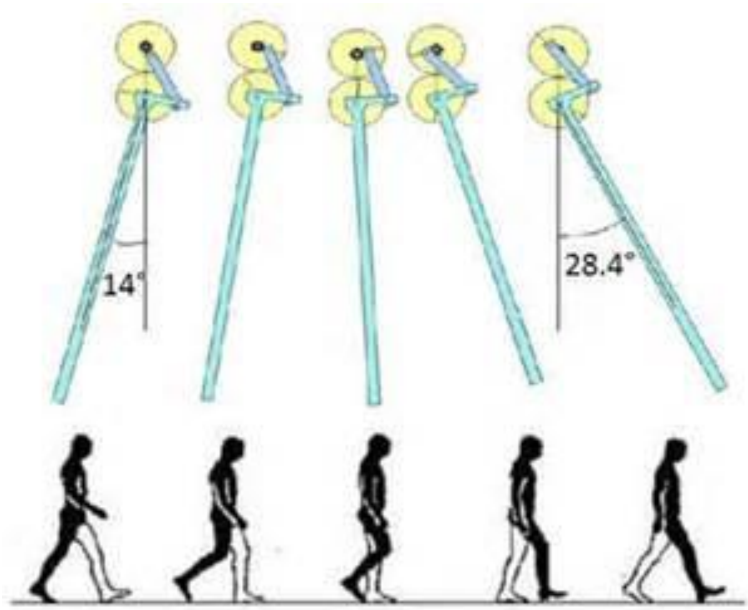

FIG 9

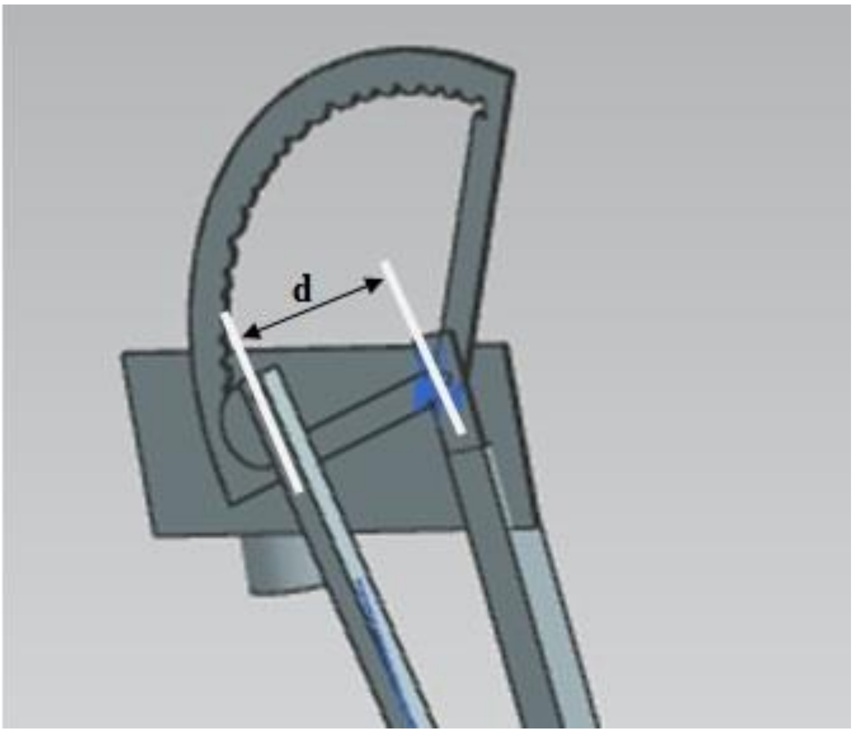

FIG 10

FIG 11

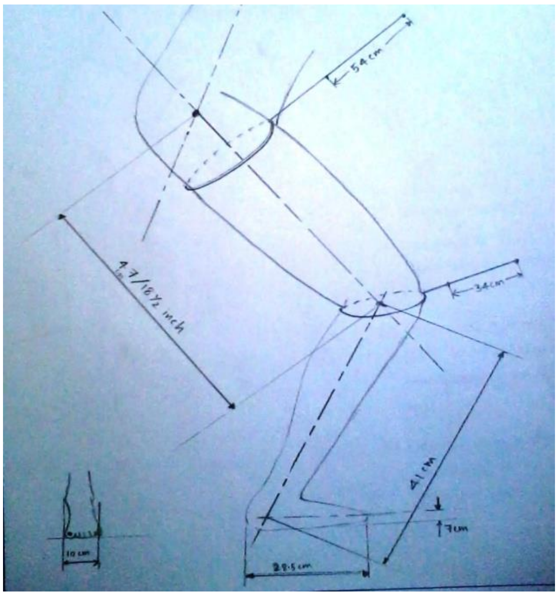

FIG 12

FIG 13

FIG14

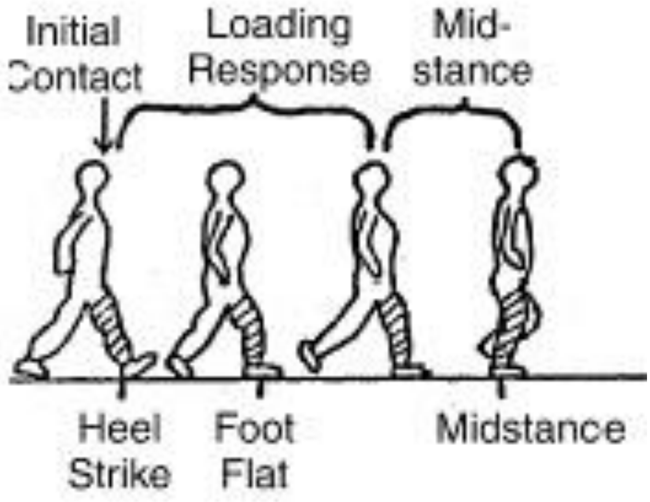
Initial
Contact
Loading
Response
Mid-
stance
Heel
Strike
Foot
Flat
Midstance

FIG 15