STRUCTURAL DESIGN AND KINEMATIC ANALYSIS OF A HUMANOID ROBOT

Project Report

Submitted in partial fulfillment of the requirements for the award of

Bachelor of Technology Degree in

Mechanical Engineering

of the APJ Abdul Kalam Technological University

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CERTIFICATE

This is to certify that this project report entitled ***"STRUCTURAL DESIGN AND KINEMATIC ANALYSIS OF A HUMANOID ROBOT "*** is a bonafide record of the Project work done by **ANOOP K R, GANESH S, JASEEL HASSAN K and HARI SANKAR VIJAY** of 8th semster B.Tech under our guidance towards the partial fulfillment of the requirements for the award of **B.Tech Degree in Mechanical Engineering** of the APJ Abdul Kalam Technological University during the year 2019.

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CET.

ABSTRACT

Humans have always been extremely adroit and are adept at intricate motion which is nearly impossible for any other animal on the planet. The main objective of the project is to design and fabricate a humanoid robot with natural walking capabilities based on simulations and balancing controls. The 3D model was designed in Autodesk Fusion 360 and simulated in MATLAB®.The parts were fabricated in acrylic using Laser cutting and bend using hot air gun. The joints are actuated using servo motors. Inverse Kinematic analysis is performed at the joint level and the resulting joint angles are used for generating a lookup table. This technique is tested through both simulation and hardware on a 12 DOF bipedal model and the results obtained are satisfactory.

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Chapter 1

INTRODUCTION

1.1 Background

A humanoid robot is a robot that has human-like shape. Humanoid robots are one of the captivating autonomous systems in human society as they can work well in indoor environment designed for humans. The environment of the modern society is designed for humans, the width of corridor, the height of stair and the position of a handrail are determined to fit the size and motions of humans. Thus a more economical solution is to develop humanoid robots than to modify the whole environment. Most of the tools for humans are designed to be used by humans.Thus anthropomorphism helps for proper interaction within human environment.

Bipedal robots are able to move in areas that are normally inaccessible to wheeled robots and areas filled with obstacles that make wheeled locomotion impossible. An uneven floor has to be made flat, a narrow passage should be removed and a lift must be available for a robot on wheels.
Also it may be easier for people to interact with walking robots with human morphology rather than robots with non-human shape. Robots should be able to do tasks alongside humans being our partners enjoying communications. These days humanoids mainly finds scope in amusement and entertainment
Recently, many studies have focused on the development of humanoid biped robots.

Among the robots HRP, WABIAN and ASIMO are the most famous ones.

1.2 Problem Statement

The design and development of human-like robots has been one of the main topics in advanced robotics research during the last years. The aim of the project is to design and fabricate a Humanoid with natural walking gait and human interaction capabilities. In order to mimic the human like walking, a dynamically stable model has to be realized. Dynamic equation and dynamic system modeling is used to predict the position, velocities and acceleration to achieve the same. Thereby obtaining the overall stability of the robot is the main objective.

1.3 Motivation

Humanoid robots are envisioned as the ideal but probably most complex service robot. Human-like structure allow them to perform well in human environments, they would be able to navigate anywhere inside a house, to go up and down by stairs, to use human tools and machines , or assist people in their daily life. An anthropomorphic design with human social characteristics is believed to increase the acceptance of robots for people. In some aspects humanoid robots can over perform human capabilities since they do not feel fatigue, sleepiness, boredom. This can act as an advantage in safety as disastrous scenarios need robots with capability of acting in dangerous places without risking human life.

1.4 Objectives

- To develop a humanoid robot with bipedal walking capabilities.
- Designing and implementing a dynamically stable humanoid robot
- Design of structure limbs which mimics human motions
- Realisation of kinematic model for a robot with natural walking gait
- Finding the optimum range of torques, speeds and angles for the joints, so that the humanoid is stable for a given range of positions and orientations.

- Indoor navigation using efficient path planning algorithms, avoiding obstacles.

1.5 Outline of the Project

Chapter 1 gives a brief introduction into our project. In chapter 2 a literature survey is conducted. Chapter 3 discusses the various existing control algorithms widely used in humanoids. Chapter 4 gives an idea about the proposed system used. Chapter 5 deals with the methodology of the system. The hardware design is given in chapter 6. The simulation is discussed in chapter 7. List of components is discussed in chapter 8. Results and discussions are conducted in chapter 9. Finally, the report is concluded with the conclusions and future scope in chapter 10.

Chapter 2

LITERATURE REVIEW

The advances in robotics and the expanding significance of humanoid robots led to a growing business interest in this field. There are different control algorithms proposed to different type of robots. Each control algorithm has its own pros and cons. The selection of the control algorithm depends on the type of robot to be developed and the number of degrees of freedom(DOF). Some of the control algorithms widely used are zero moment point method, minimal actuation method, hybrid zero dynamic model, foot capture point method and hybrid state driven autonomous control. The control techniques were identified and a comparison study was conducted on their performance and feasibility.

Passive dynamic walking was proposed by T. Mc. Geer[McGeer, 1990].It was a fully dynamic walking on sloped surface. Due to the action of gravity alone the robot will walk down the slope. After a few steps passive walking will stop due to the lose in energy. Inorder to compensate for the lose energy actuated joints should be used. There was different control methods proposed for passive dynamic walker. To ensure a stable walking constant contact between foot and the surface is needed. By providing appropriate dynamics of humanoid it is possible to maintain constant contact between feet and the surface.So the overall forces and moments acting on the feet can be assumed to act in a single point just like the definition of centre of mass. This point is known as ZMP. Inorder to attain stability ZMP must reside inside the support polygon of the humanoid. Which will be stance foot in single support phase and control polygon formed by two feets in double support phase.

Zero moment point (ZMP) specifies the point with respect to which dynamic reaction force at the contact of the foot with the ground does not produce any moment. At ZMP, the total inertia force equals zero. It is an indicator of the stability of the robot. If ZMP point is in the foot shadow then the biped is stable and else unstable. Minimally actuated serial robot is a serial rigid structure consisting of movable actuators and multiple links connected by passive joints. These actuators are freely moved through the links to desired positions. So, more the number of links, more is the area that can be covered by the robot.

actuated robot.png

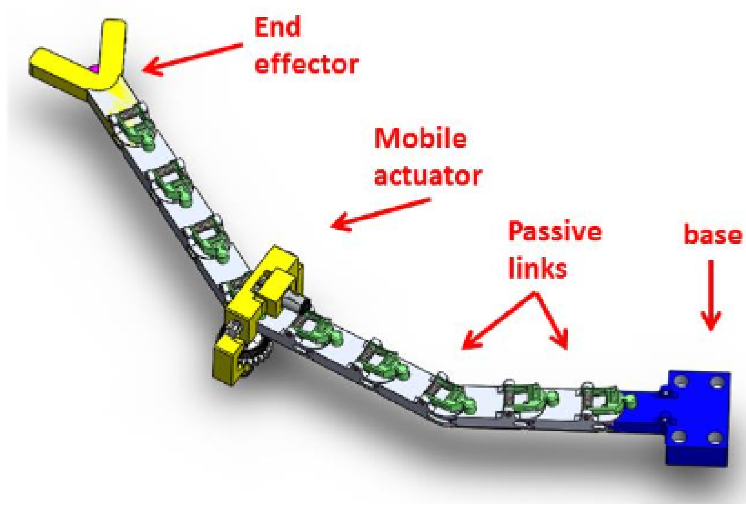


Figure 2.1: Minimally actuated serial robot

Chapter 3

PROPOSED SYSTEM

Kinematic configuration (6+6DOF) Figure shows the Kinematic configuration of the robot. For a human each leg provides 7 degrees of freedom on each leg. But for achieving stable human like gait on a humanoid robot minimum 6 degrees of freedom(DOF) is required on each leg. Proposed Kinematic configuration consists of 3DOF, 2DOF and 1DOF at each hip, feet, knee respectively.

Human hip consists of ball and socket joint. To mimic the joint, 3 DOF joint is designed to provide the roll, pitch and yaw motions. Knee joint is limited to 1DOF. Knee motion is limited to only one direction from the mean position.The knee joint is similar to the hinge joint and the knee joint rotation is also limited. Pitch and Yaw motions at feet is required for human gait. Human has pitch, roll and yaw motions at feet. Due to the difficulty in implementation and cost constraints of 3DOF at feet, roll motion is dropped and only 2DOF is implemented. The motor was downsized which decreased the overall cost but also decreased the maximum available torque. So the overall size of the robot was scaled down .

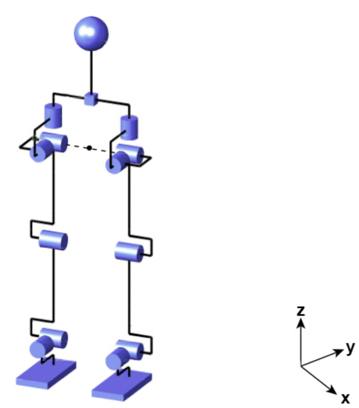


Figure 3.1: Kinematic configuration

Walking gait of a humanoid is to be realized. There are different control methods to attain walking gait for a humanoid.

ZMP (Zero-Moment Point) method plays an important role in the control of a humanoid robot. According to ZMP method, the humanoid is stable as long as the ZMP lies inside the control polygon of the robot. Waling pattern can be generated using 3D LIPM (Linear Inverted Pendulum Method). Kinematic analysis and simulation are to be conducted on MATLAB. We will use Matlab to do this calculation. One walking cycle of a stick man figure is to be realised in Matlab. After carefully completing simulation joint angles are plotted. After completing this simulation on matalb we will move along to Simscape multibody, where the simulation is to be completed using our CAD model. We will import our CAD model to Simscape multibody and simulate the model in that environment. It will result in joint angles and joint torques. After obtaining the results from Simscape multibody these joint angle values are made into a lookup table, and will directly use to control the robot actuators in real time.

Chapter 4

METHODOLOGY

The project was done by studying the corresponding motion study in human walking movements including the joint angles, joint type etc. After this the kinematic configuration required for walking gait was formulated.The design of the humanoid structure is an iterative process. The design of the actuators was based on the torque and weight requirements. The parts were designed based on the static structural analysis at different positions while walking. The project includes the design,simulation, fabrication and testing of the humanoid robot.

4.1 Mechanics of Human movement

Mechanics of human movement is the study of the internal and external forces that act on the body and the effects of these forces on the movement of the body.

A biped can be positioned in the three dimensional space with a base-frame-origin and three mutually perpendicular planes. Frontal plane The plane parallel to the yz-plane is called the Frontal plane. Sagittal plane The plane parallel to the xz-plane is called the Sagittal plane. The plane parallel to the Sagittal plane and containing the Center of Mass (CoM) is called the Median plane. Figure 4.1 shows the maximum angle limits for different joints in the human body. These joints are provided for a larger set of applications and are not specifically for walking.

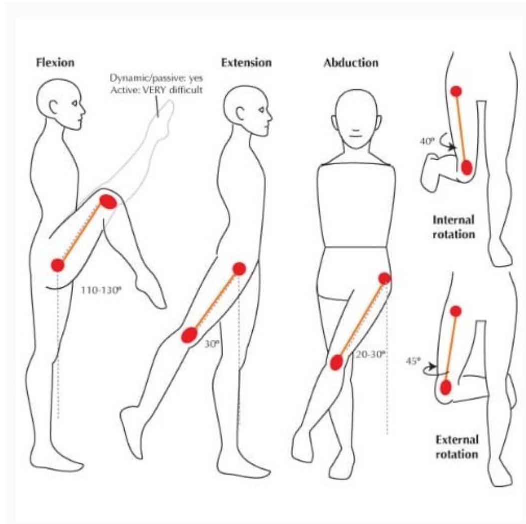


Figure 4.1: Limits of angles at various human joints *(Mechanics of human movement, NPTEL online course)*

4.2 Human Gait Cycle

Gait Analysis For studying the human gait cycle one needs to be familiar with some specific terms, which are defined below. Figure 4.1 shows the human gait cycle.

Walk: Walk is the movement by putting forward each foot in turn, not having both feet off the ground at the same time.

Gait is the manner of walking or running.

Periodic gait A gait that is performed by repeating the steps in an identical way, it is a periodic gait.

Double Support (DS): This term is used for situations where the biped has two isolated contact surfaces with the floor. This situation occurs when the biped is supported by both feet, but it is not necessarily that both feet are fully supported with the floor.

Single Support: (SS) This term is used for situations where the biped has only one contact surface with the floor. This situation occurs when the biped is supported with only one foot.

Support Polygon (SP) The Support Polygon is formed by the convex hull about the floor support points. This term is widely accepted for any support area .

Swing leg, swing foot The leg that is performing a step (moving forward

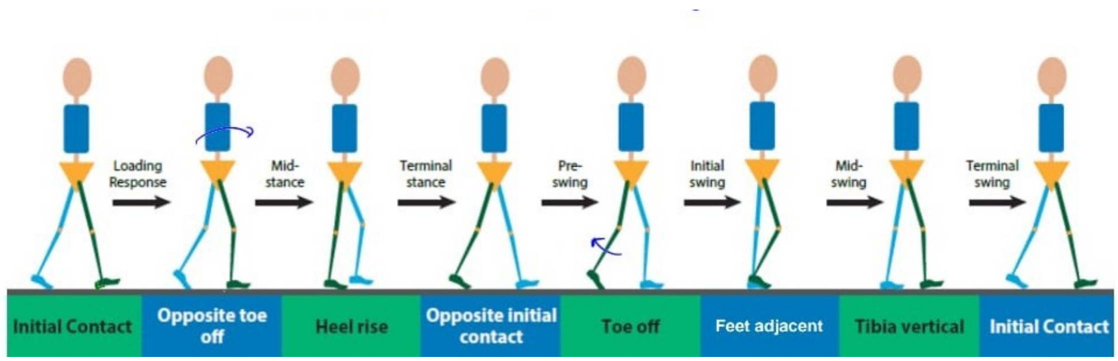


Figure 4.2: Human Gait Cycle, *(Mechanics of human movement, NPTEL Online course)*

through the air) is denoted with the term swing leg. The foot that is attached to this leg is called the swing foot.

Stance leg, stance foot While the swing leg is moving through the air, the stance leg is fully supported with the floor by the stance foot and supports all the weight of the biped.

Gait Phases: When the biped is in periodic gait, the gait can be divided into four phases:

1. Double Support Phase (DSP) This is the phase where both feet are fully supported with the floor. 2. Pre-Swing Phase In this phase the heel of the rear foot is lifting from the floor but the biped is still in double support due to the fact that the toes of this foot are still on the floor . 3. Single Support Phase (SSP) The phase where only one foot is fully supported with the floor and the other foot swings forward. 4. Post-Swing Phase In this phase the toe of the front foot is declining towards the floor. The biped is in double support because the heel of this foot is contacting the floor.

4.3 Structure Design

The structure is designed for 40 cm tall humanoid robot with the body parts with dimensions according to Indian Anthropometric Dimensions for Ergonomic Design Practice by Debkumar Chakrabarti.The lengths were determined using the above method whereas the other details were determined based on the strength and rigidity of the brackets that were designed to connect between two joints.The dimensions between two joints were implemented in the robot configuration and the motions required at each joint were decided and thus the Kinematic configuration was made.The parts were modelled in Autodesk Fusion 360 and structural analysis was performed.

4.4 Kinematics

Position and orientation of each link is to be known in order to do forward kinematics. We first define an origin for the world coordinate. The x-axis of the world coordinate faces forward direction. Z-axis is along with the height of the robot. Y-axis is directed along the left. This coordinate system named as W. Absolute position, absolute velocity, and absolute rotation of each link is defined with respect to the world coordinate. A local coordinate system is defined for each link of the robot.

Chain rule of homogeneous transformation is used to connect different local coordinates carefully to find the position and orinentation of a point in world coordinates. Chain rule reduces the complexity of kinematic calculations.

4.4.1 Conceptual Separation of the robot.

We virtually divide the robot into smaller parts to make the analysis easier. Instead of following Denavit–Hartenberg parameters, we divided the robot carefully and allocated local coordinates accordingly. We avoided D-h parameter notation due to the complexity and chances of making errors while programming. We divided the robot in such a way that each joint gets included with the link that follows it. For example, instead of associating knee joint with the upper leg, we associated it with the lower leg. It was to make sure that every link will get only one joint. It helps to use the same code for every joint. It is to be noted that this separation is only a conceptual one. Our humanoid robot has 12 DoF, 6 on each leg. Each link has given name as shown in the figure.

Now in order to connect each link to get a whole humanoid robot, we use a connection rule as shown in the Figure 4.3. The connection rule we used is similar to a family tree. Left arrow of each link indicates its child link and right arrow indicates the sister link. This family structure can make use of recursive programming to access all links.

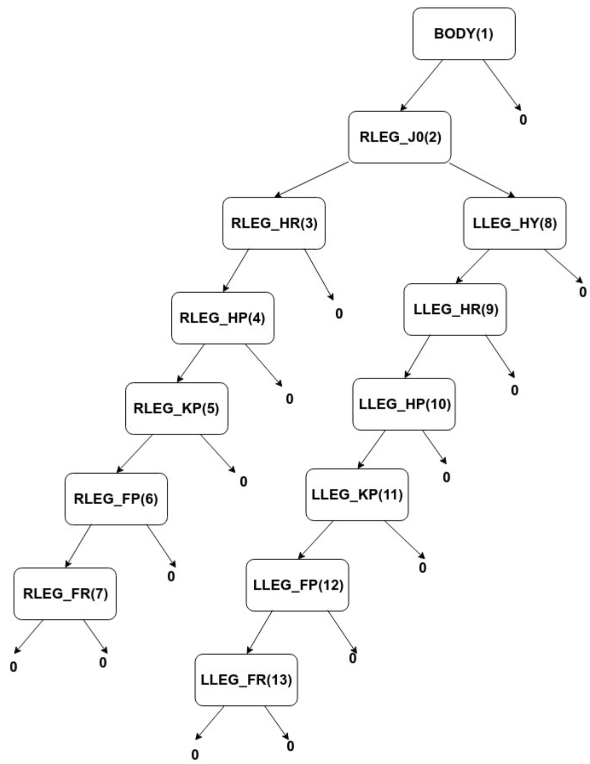


Figure 4.3: Humanoid Link Connection

Now we need to define local coordinate for each link. We define the origin of the local coordinate of each link at the joint. For the hip joint, it is easier to define the origin of all the three frames at the same point. The same condition follows for the ankle joint.

Now we assign rotation matrices for each coordinate system.(Figure 4.5) Initially, we set these coordinate systems to match that of world coordinates. So we set 13 rotation matrices as,

$R_1 = R_2 = R_3 = R_4 = R_5 = R_6 = R_7 = R_8 = R_9 = R_{10} = R_{11} = R_{12} = R_{13} = E$

where E is the unit matrix. The local coordinate defined is shown in the figure. We defined joint axes along the axis of rotation of each joint.

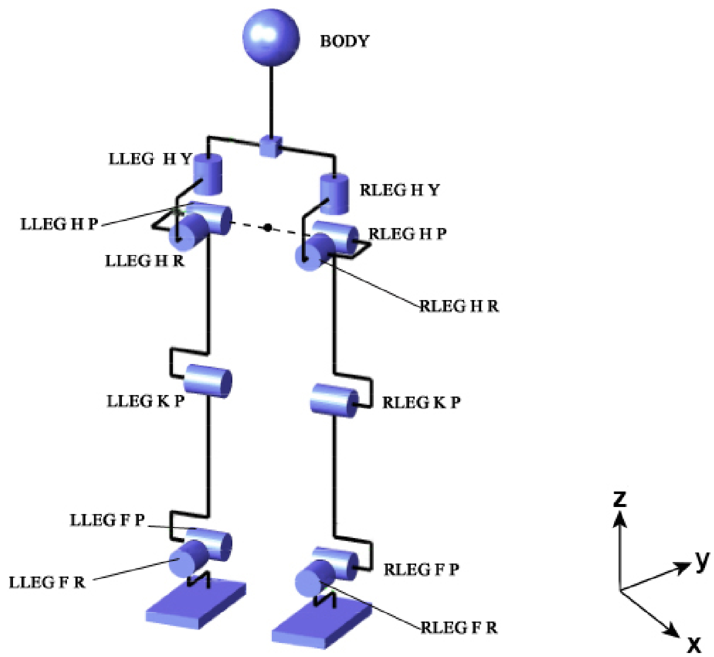


Figure 4.4: Joint Diagram

4.4.2 Forward Kinematics

Forward kinematics is calculated using the chain rule of homogeneous transformation, the first step of which will be calculation of homogeneous transformation of a single link. The homogeneous transform of a link relative to the parent link is given by:

$$T_j^i = \begin{bmatrix} e^{\widehat{a}_j q_j} & & & b_j \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Now considering two links as shown in Figure 4.6, the homogeneous transform of Σ_i becomes

$$T_i = \begin{bmatrix} R_i & & & p_i \\ 0 & 0 & 0 & d \end{bmatrix}$$

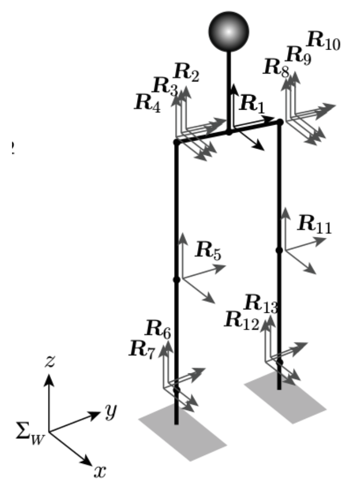


Figure 4.5: Rotation matrices of Local Coordinates

From the chain rule of homogeneous transform Σ_j is

$$T_j = T_i T_j^i$$

The absolute position (p_j) and attitude (R_j) of Σ_j can be calculated using:

$$p_j = p_i + R_i b_j$$
$$R_j = R_i e^{\widehat{a}_j q_j}$$

Similar to Forward Kinematics, we can also compute the velocity of a link which is connected to its parent link. Given the joint speed $\dot{q}_j$, its linear and angular velocity can be calculated by:

$$v_j = v_i + \omega_i \times R_i b_j$$
$$\omega_j = \omega_i + R_i a_j \dot{q}_j$$

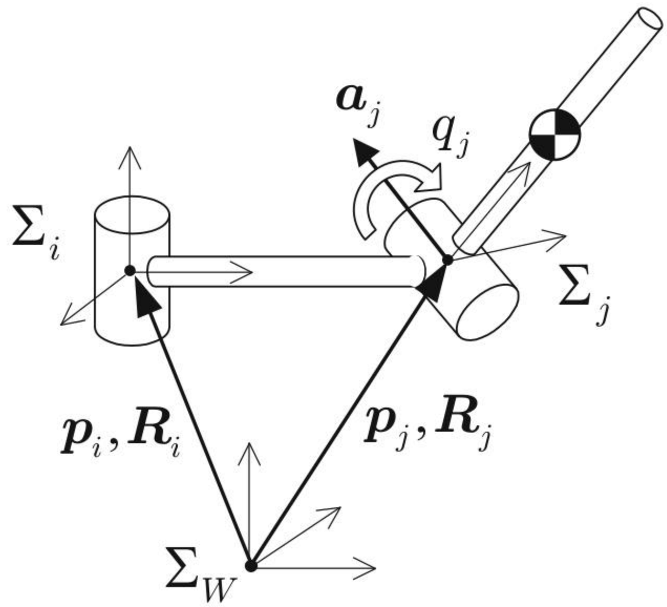


Figure 4.6: Relative position of 2 links

4.4.3 Inverse Kinematics

Since analytical solution to Inverse Kinematics is too complex, a numerical solution strategy is being adopted. We can solve the inverse kinematics problem by doing trial and error method using forward kinematics. The steps involved in this method is given below

1. Set the position and orientation of base.(p_o, R_o)
2. Set the position and orientation of end effector.(p_o, R_o)
3. Define a vector q which have the values of joint angles from base to end effector.
4. Calculate position and orientation of end effector using forward kinematics.(p, R)
5. Calculate change in position and orientation (error in position and orientation).(Δp, ΔR) = (p_o-p, $R^T R_o$)
6. If error(Δp, ΔR) is small stop calculation

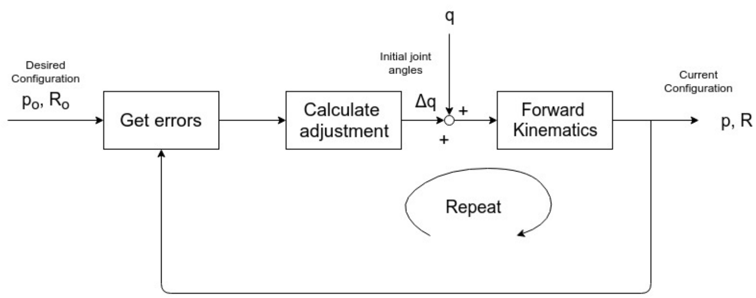


Figure 4.7: Numerical Approach of Inverse Kinematics

7. If error(Δp, ΔR) is not small enough calculate Δ q which would reduce the error.

8. Update joint angles by q := q + Δq and return to step 4.

when there is a momentary change in joint angle δq, which can be mathematically expressed as:

$$err(p, R) = ||p||^2 + ||\theta||^2$$

$$\Delta\theta = (ln\Delta R)$$

This function becomes zero only at both position and attitude error is zero. You can say the position and attitude errors are small enough when err $(\Delta p, \Delta R)$ becomes smaller than predefined value, for example 1x10^6.

We need to do come up with a set of joint angles q which lowers err$(\Delta p, \Delta R)$. For that we use the Newton-Raphson method. We start off by considering what happens to the position and attitude $(\delta p, \delta\theta)$ when you change the joint angles using a minute value of δq.

$$\delta\theta = X_\theta(q, \delta q)$$

$$\delta p = X_p(q, \delta q)$$

Here, X$_p andX_\theta$ are unknown, but when δq is small let us say that we can describe it simply with addition and multiplication.

$$\begin{bmatrix} \delta p \\ \delta \theta \end{bmatrix} = \begin{bmatrix} J_{11} J_{12} J_{13} J_{14} J_{15} J_{16} \\ J_{21} J_{22} J_{23} J_{24} J_{25} J_{26} \\ J_{31} J_{32} J_{33} J_{34} J_{35} J_{36} \\ J_{41} J_{42} J_{43} J_{44} J_{45} J_{46} \\ J_{51} J_{52} J_{53} J_{54} J_{55} J_{56} \\ J_{61} J_{62} J_{63} J_{64} J_{65} J_{66} \end{bmatrix} \delta q.$$

Here $\mathrm{J}_{ij}, (i, j = 1...6)$ are constants which are defined by the current position and attitude of the robots links. There are 6 because of the number of links in the leg. It is too much to write all the components each time so we will simplify it by

$$\begin{bmatrix} \delta p \\ \delta \theta \end{bmatrix} = J \delta q$$

$$\delta q = \lambda J^{-1} \begin{bmatrix} \delta p \\ \delta \theta \end{bmatrix}$$

This adjustment is added to the old joint angle configuration which is then passed to the robot.

$$q_{new} = q_{old} + \delta q$$

4.5 Zero Moment Point

Fig. 4.6 shows an example of force distribution across the foot. The load has the same sign all over the surface, ergo it can be reduced to a resultant force R, the point of attack of which will be in the boundaries of the foot. The point on the surface of the foot, where the resultant R passed is defined as the zero-moment point, or ZMP in short.

4.5.1 Calculation of Center of Mass

If the center of mass of the j^{th} link in local frame is $\bar{c_j}$, then the center of mass of the j^{th} link in world frame is given by:

$$c_j = p_j + R_j \bar{c_j}$$

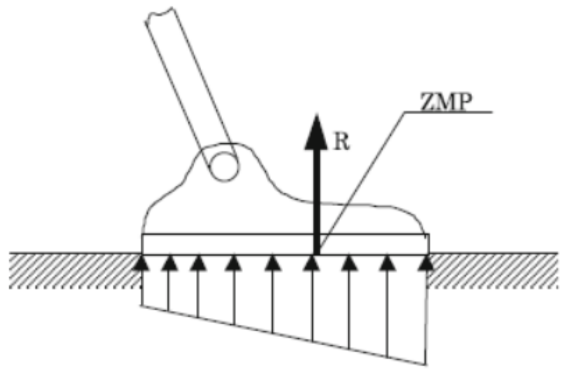


Figure 4.8: Understanding ZMP

where (p_j ,R_j) denotes the position and orientation of the link. We can obtain the body's center of mass by dividing the sum of moments by the total mass M as shown:

$$c = \sum_{j=1}^{N} m_j c_j / M$$

4.5.2 Calculation of Linear and Angular Momentum

The linear moment of the robot depends only on the external forces and not internal forces. The linear momentum of a robot having N links is given by:

$$P = \sum_{j=1}^{N} m_j \dot{c}_j$$

where velocity of the j^{th} link $\dot{c}_j$ is calculated as:

$$\dot{c}_j = v_j + \omega_j \times R_j \bar{c}_j$$

The equation is independent of the structure of the robot. // The angular momentum of a robot having N links is given by:

$$L = \sum_{j=1}^{N} L_j$$

where angular momentum of the j^{th} link L_j is calculated as:

$$L_j = c_j \times P_j + R_j \bar{I}_j {R_j}^T \omega_j$$

4.5.3 Calculation of ZMP

The ground reaction force can be expressed by using the ZMP (p), the force (f) and the moment (τ_p) about the vertical line including the ZMP as:

$$\tau = p \times f + \tau_p$$

Substituting the equations for linear and angular momentum, we get:

$$\tau = \dot{L} - c \times Mg + (\dot{P} - Mg) \times p$$

Solving for p_x and p_y, we get:

$$p_x = \frac{Mg_x + p_z \dot{P}_x - \dot{L}_y}{Mg + \dot{P}_z}$$

$$p_y = \frac{Mg_y + p_z \dot{P}_y - \dot{L}_x}{Mg + \dot{P}_z}$$

where p$_z denotes the height of the ground. For walking on the flat ground, we have p_z =$ 0.

4.6 Linear Inverted Pendulum Model

Walking dynamics of a humanoid robot can be analyzed using LIPM. The model make use of some assumptions to make the robot as coarse grained(simplified) model. LIPM uses fewer parameters to represent walking dynamics.
The stance foot of the humanoid act as an origin for the inverted pendulum. The legs are assumed to be massless and one end of the leg and ground contact point is assumed to be connected by a revolute joint.The other end is connected to the CoM. connected by stance foot and CoM of the humanoid. Humanoid walk in such a way that the height of centre of mass kept constant.(Figure) LIPM eqution is given by

$$\ddot{x} = \frac{g}{z_c}(x - p_x^*)$$

On solving the force and moment equation as in figure it will yield

$$x(t) = (x_i^{(n)} p_x^*) cosh(\frac{t}{T_c}) + T_c \dot{x}_i^{(n)} sinh(\frac{t}{T_c}) + p_x^*$$

$$\dot{x}(t) = \frac{(x_i^{(n)} p_x^*)}{T_c} sinh(\frac{t}{T_c}) + \dot{x}_i^{(n)} cosh(\frac{t}{T_c})$$

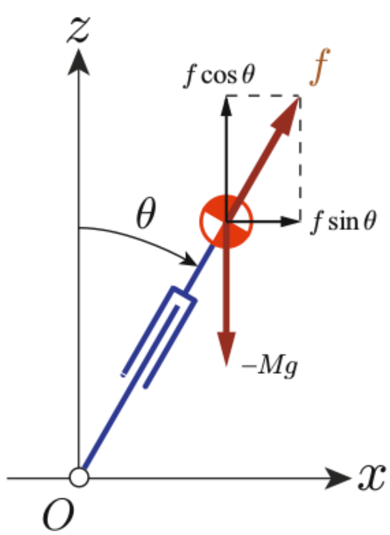


Figure 4.9: LIPM

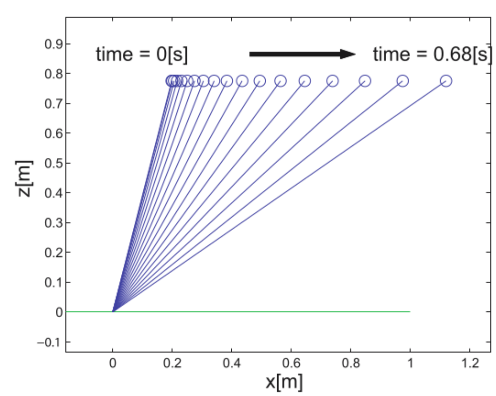


Figure 4.10: CoM moving keeping height constant

Chapter 5

HARDWARE DESIGN

The fundamental step towards humanoid biped walking is a meticulous hardware design with specific requirements of the robot. Special care must be given for the selection of appropriate actuators as oversized motors increase the total weight of the robot, thereby deteriorating the walking performance.

5.1 Parts design

The robot is assumed to be 400mm tall from feet to head and weighs 1000 grams.

The dimensions for the links are taken as corresponding proportions as that of a 400mm imaginary human. The distance is taken from the centre of rotation of one motor to the other.

Brackets are designed to be simple in construction. The brackets came with the motor is taken as the standard for the positioning of holes. FTDI cables are used for communication in AX-12A. So provisions are provided in the brackets so that the wires can be disconnected even in the assembled state.

For the robot, total of 16 parts are required to be designed for the full functionality. To reduce the cost of fabrication and the complexity, symmetry is opted to reduce the number of parts. Hip and feet is given the same set of design; and is symmetric about knee. Thus the number of component to be designed gets reduced to 7. The bracket named Frame F3 which is provided with dynamixel AX-12A is used.

For designing the bracket, the load is assumed accordingly. Considering the impact that might occur while walking, a thumb rule of 3 times the weight is taken for the study. Though the loads that occur at various orientation is different for different,parts robot is designed within a close range of orientations which are just enough to provide the required walking gait obtained from the simulation.

It is assumed that this impact is evenly distributed among two legs, which comes near 15 Newtons per leg. Considering uncertainty of 5 Newton load in addition to this, 20 Newton load is taken for the study of links that directly bear the load.

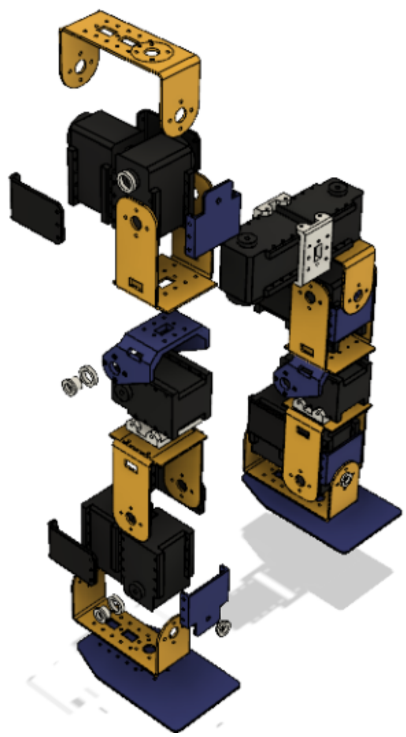


Figure 5.1: Exploded view of robot

In the exploded view, all the components of the robot (excluding FTDI cables and control boards) can be seen in place.

For the brackets, the height of flange is taken from the required limp length; and the distance between the flanges are fixed according to the dimension of the motor and the clearance for washers. No bearings are used; instead sliding contact is given between the plastics of the bracket and the washer.

The modelling and structural analysis is done in Autodesk Fusion 360. The study results are given below.

5.1.1 Hip and Feet connection links

This part is designed to be used both in the hip and feet. This joint is designed to provide yaw motion in hip joint and roll motion in feet.For the hip this part provides yaw motion and for feet it is for roll. Structure is 1.5mm thick and the material is assumed to be Aluminium.

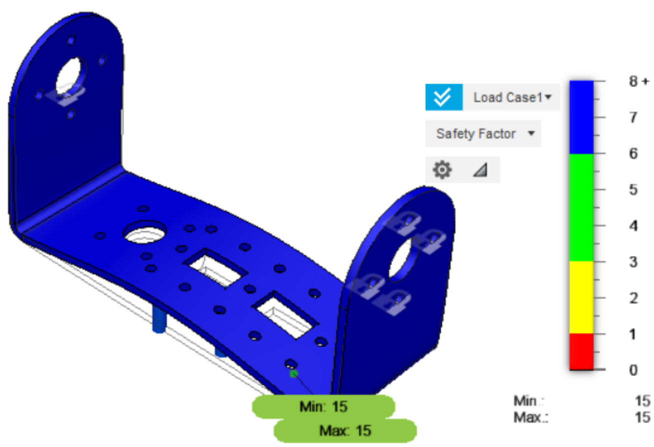


Figure 5.2: Feet roll link with aluminium

In the hip yaw joint, motor head is attached to the circular hole provided on the bracket. A minimum safety factor of 6.492 is obtained.

For feet, flanges are fixed and a load of 20 Newton is applied at the bottom face. Minimum safety factor of 15 is obtained.

Since metal laser cutting was expensive and unavailable and acrylic can be easily formed into the required shape study was done for acrylic. The loading is similar to that given with aluminium.

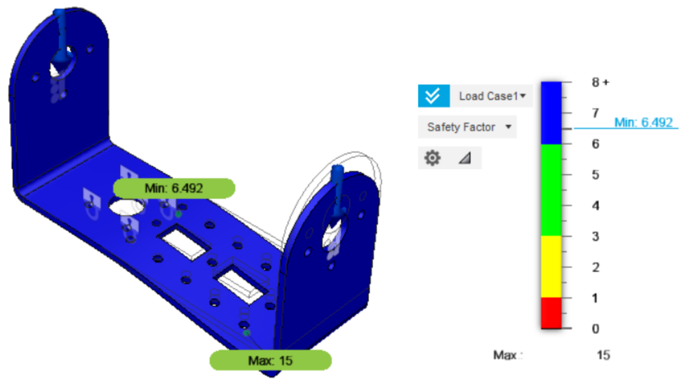


Figure 5.3: Hip yaw link with aluminium

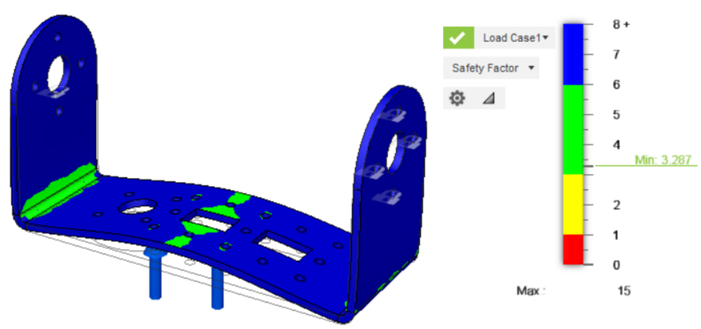


Figure 5.4: Feet roll link with acrylic

Minimum safety factor of 3.287 is obtained for feet roll joint on acrylic part.

Minimum safety factor of 1.152 is obtained for hip yaw joint; which is much below the required minimum safety factor of 3. So the recommended material for hip yaw with the current design is aluminium.

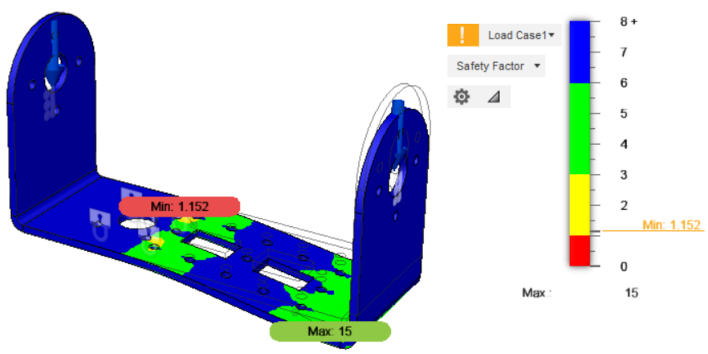


Figure 5.5: Hip yaw link with acrylic

5.1.2 Thigh and hip link

This link provides the pitch motion is both at hip and feet. 42mm gap is provided between the flanges so as to accommodate a motor. Flange height is taken as 63mm from the base to the top.

Material used for study is acrylic sheet of 1.5mm thick. With a load of 20 Newton provided at the base assuming the top circular holes of flanges are fixed 4.678 is obtained as the minimum safety factor.

5.1.3 Motor binder Joint

The only function of this joint is used to bind two motors together; so that pitch and roll motions can be achieved side by side. So connected motors are used at hip and feet.

While binding the motors together, the joint will be having a tendency to resist twist in a plane parallel sagittal plane. Two brackets are required to fully constraint two motors. So the load is divided among the two. For the study, the holes at smaller flanges are assumed to be fixed and a load of 8 Newton is applied in the holes of larger flange in a direction as shown in the figure. The material used for study is acrylic of 1.5mm thick and a minimum safety factor of 3.254 is obtained.

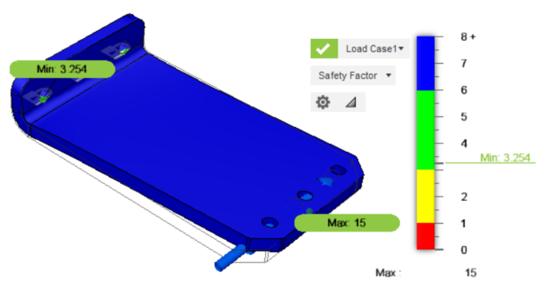


Figure 5.6: Motor binder joint

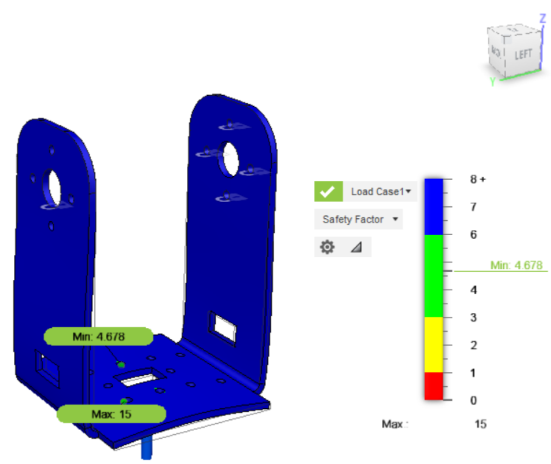


Figure 5.7: Thigh and Hip link

5.1.4 Knee Joint

Knee joint is designed so as to prevent forward bending when the legs are laid straight; just like human. Base is designed similar to that of FRAME F3. The holes for attaching motors are at an offset of 15mm offset from the centre of the base. The material used in the study is Polylactic acid (PLA), which is the common material used in 3D printers.

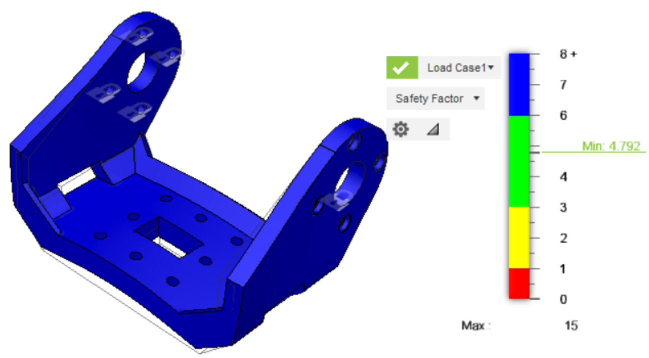


Figure 5.8: Knee Joint

20 Newton is applied at the base in the normal direction keeping the holes provided for connecting motors as fixed. From the structural analysis done in Fusion, 4.79 is obtained as the minimum safety factor. Ribs are provided so as to make the minimum safety factor above 4.

5.1.5 Connector for hip and feet

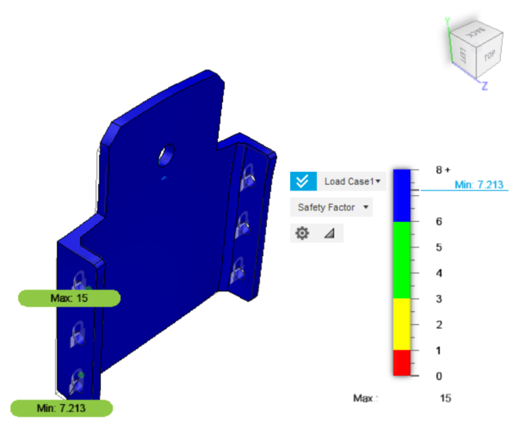


Figure 5.9: Connector for hip and feet

One end of hip and feet connection link is supported by the motor; the other side is supported on washers which in turn needs support on motors. This joint provides that support.

Polylactic acid (PLA) is used as the study material. 20 Newton is taken as the load acting on it, so that the robot will not fail even if the connection on the other side of hip and feet connection fails; which occurs while assembling and dissembling of robot. Part has a thickness of 1.5mm.

The holes at the small flanges are for attaching to the motor. These holes are assumed to be fixed and the load is applied in the main face in vertical direction. 7.213 is the minimum safety factor obtained for the part.

5.1.6 Feet

3mm Acrylic is used for the study and has an area of $5600mm^2$. Hip and Feet connection link is connected on the feet. A rectangular patch of dimensions that of hip and feet connection link is assumed to be fixed and 20 Newton load is applied normal to the base. Minimum safety factor above 8 is obtained.

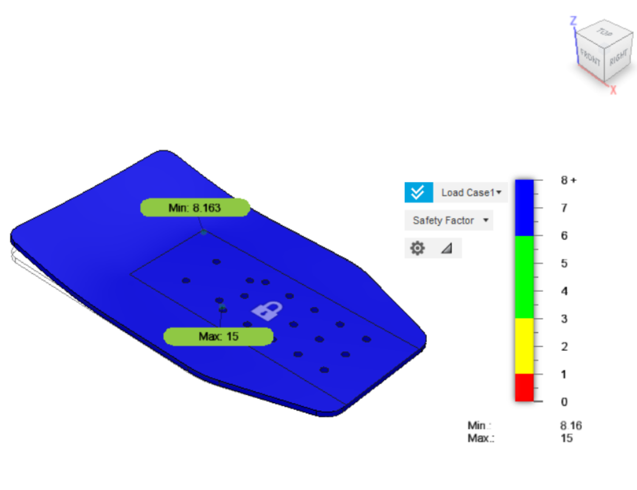
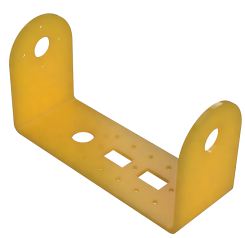


Figure 5.10: Feet

5.2 Fabrication

The parts were initially planned to be fabricated using Aluminium sheet metal by laser cutting and CNC bending. But Aluminium laser cutting being expensive and inaccesible we tried acrylic laser cutting and 3D printing fabrication methods. The design was modified and the parts were fabricated in FABLAB at College of Engineering Trivandrum. Two parts were 3D printed using PLA material using Ultimaker2+. The remaining parts were laser cut on Acrylic sheet and bend after heating it using hot air gun and bend over a die which is an Aluminium block machined to the required dimensions at the mechanical workshop.The parts were later assembled and the parts having relative motion were connected using lock nuts and bolt. The motor and other control boards were purchased. The actuators used were Dynamixal AX12A motors which is a servo motor with a stall torque of 1.5Nm.The feet is provided with a rubber padding to provide friction with the ground and the feet to obtain the required motion. The structure has a total weight of 975 grams.

The details of fabrication methods and specifications of each parts are tabulated below.

 Hip and Feet connection links	Material: Acrylic Fabrication: Laser Cutting, Bending Weight: 6.72g Volume: 5.652cc No. of parts needed: 4
 Thigh and Hip link	Material: Acrylic Fabrication: Laser Cutting, Bending Weight: 2.8g Volume: 2.293cc No. of parts needed: 4

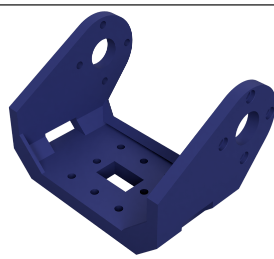
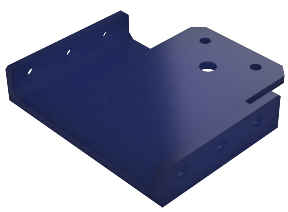
 Motor binder joint	Material: Acrylic Fabrication: Laser Cutting, Bending Weight: 8.98g No. of parts needed: 8
 Knee Joint	Material: PLA Fabrication: 3D Printing Weight: 9g Volume: 7.885cc No. of parts needed: 2
 Connector for Hip and Feet	Material: PLA Fabrication: 3D Printing Weight: 2.17g Volume: 2.042cc No. of parts needed: 4
 Feet	Material: Acrylic Fabrication: Laser Cutting, Bending Weight: 9.98g Volume: 8.398cc No. of parts needed: 2

Table 5.1: Parts and Specifications

Chapter 6

SIMULATION

6.1 Dynamic Simulation

Dynamic Simulation was performed by importing our CAD model into Simscape multibody and controlling it using Matlab Simulink

6.1.1 Matlab and Simscape Multibody

MATLAB is a multi-paradigm numerical computing environment and proprietary programming language developed by MathWorks. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, C, Java, Fortran and Python. Simscape Multibody™ (formerly SimMechanics™) provides a multibody simulation environment for 3D mechanical systems, such as robots, vehicle suspensions, construction equipment, and aircraft landing gear. You can model multibody systems using blocks representing bodies, joints, constraints, force elements, and sensors. Simscape Multibody formulates and solves the equations of motion for the complete mechanical system. You can import complete CAD assemblies, including all masses, inertias, joints, constraints, and 3D geometry, into your model. An automatically generated 3D animation lets you visualize the system dynamics.

Simscape Multibody provides some tools to calculate kinematics and Dynamics. By carefully utilising these tools and gving a reference path to follow it is possible to simulate the robot in similar to real conditions. Forward Dynamics, Trimming, and Linearization In the Forward Dynamics mode, a Simscape Multibody simulation uses the Simulink suite of ordinary differential equation (ODE) solvers to solve Newton's equations, integrating applied forces/torques and obtaining the resulting motions. The ODE solvers project the motion of the DoFs onto the mathematical manifold of the kinematic constraints and yield the forces/torques of constraint acting within the system.

Trimming. The Trimming mode allows you to use the Simulink trimming features to search for steady or equilibrium states in mechanical motion. These states, once found, are the starting point for linearization analysis.

Linearization. You can use the Simulink linearization tools to linearize the forward motion of a system and obtain its response to small perturbations in forces/torques, constraints, and initial conditions.

Inverse Dynamics A Simscape Multibody simulation can solve the reverse of the forward dynamics problem, determining the forces/torques needed to produce a given set of motions that you apply to the system.

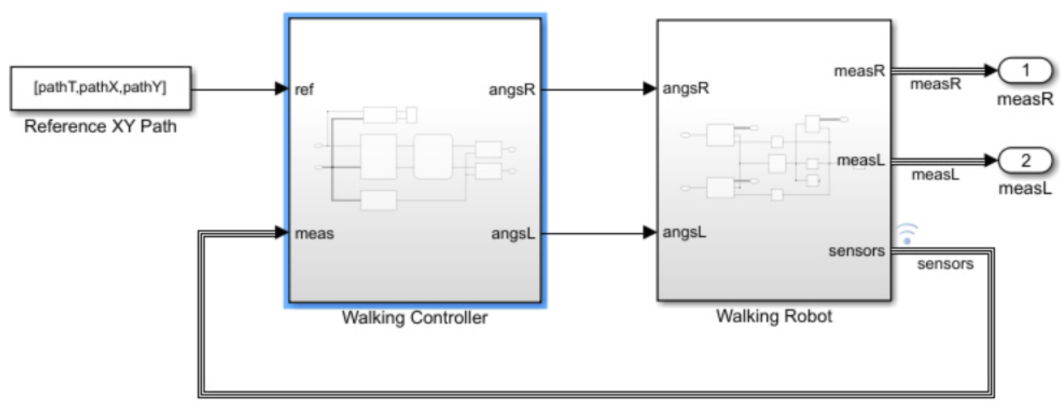


Figure 6.1: Walking controller and Humanoid Block Diagram

Cad model of our robot is imported into this block diagram as shown below.

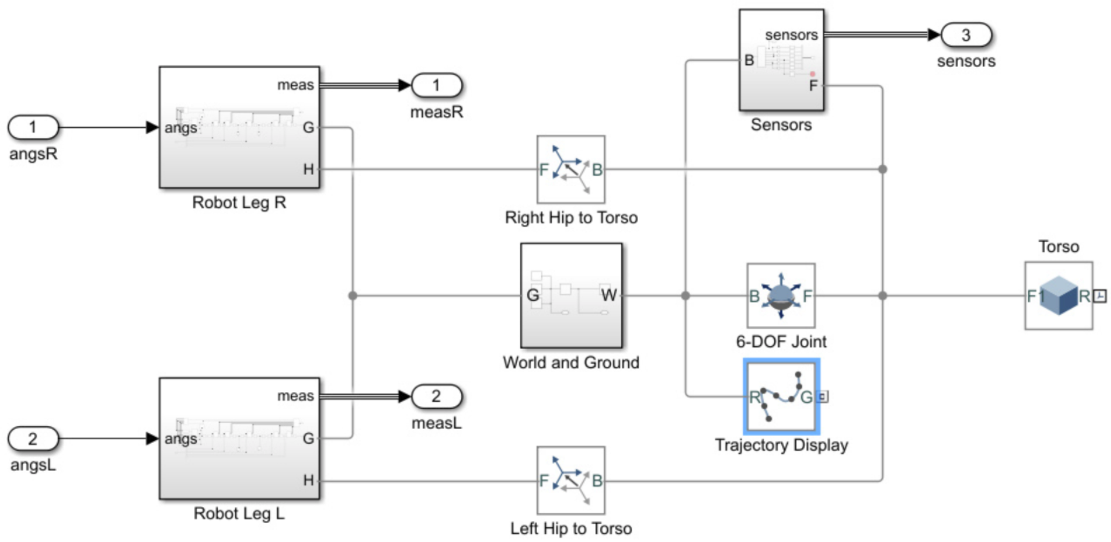


Figure 6.2: Humanoid Robot Block Diagram

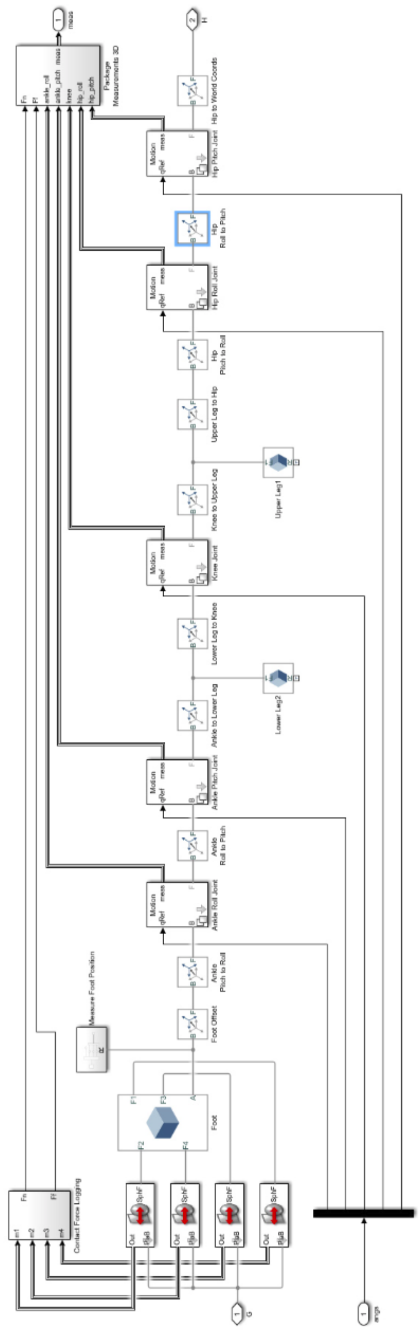


Figure 6.3: One leg of the Humanoid

Chapter 7

RESULTS AND DISCUSSIONS

The overall structure was designed, fabricated, assembled and tested.

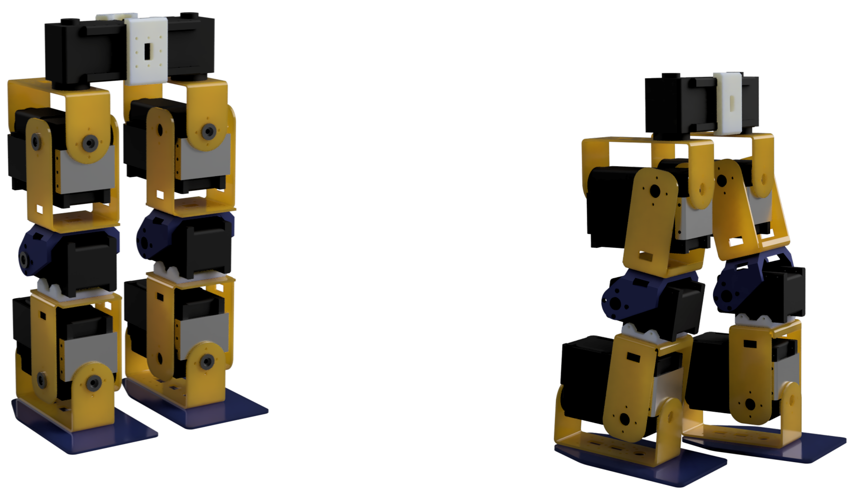


Figure 7.1: Assembled views in Autodesk Fusion 360

The developed hardware was tested by conducting experiments on a smooth surface.The developed prototype was found to implement bipedal locomotion with stability. The walking pattern was similar to that obtained in the simulation.

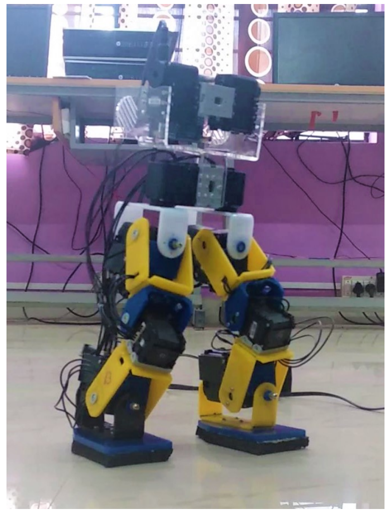


Figure 7.2: Actual Prototype

Matlab simulation after kinematic analysis looked like in figure

Joint angles are obtained for one walking cycle. The plot of joint angles for one walking cycle is shown in fig 7.3

Fig 7.1 shows the 3D model designed for the humanoid robot. The fabricated robot which was tested is shown in fig 7.2. The joint angles of the robot in one complete cycle is shown

Dynamic simulation done in Simscape mutlibody resulted in Dynamic simulation resulted in a plot of torque for each joint. Joint angle values are obtained in the form of a look up table and these values are used for real walking.

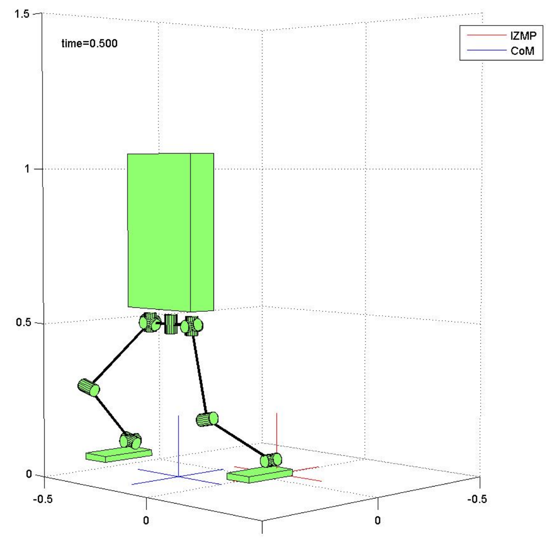


Figure 7.3: Matlab simulation

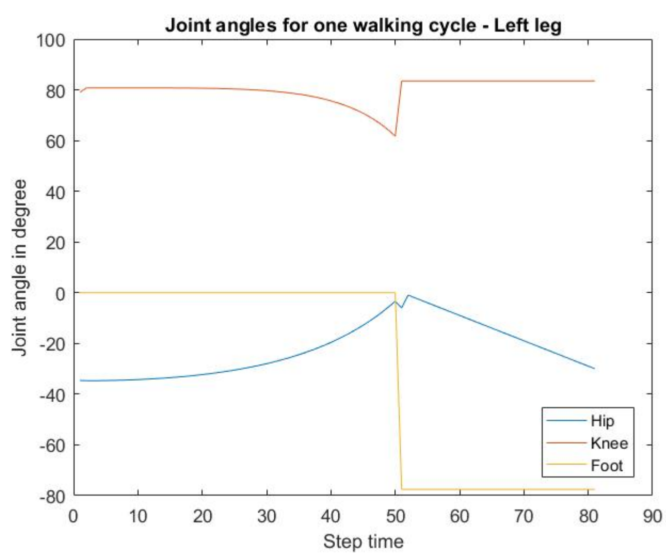


Figure 7.4: The plot of joint angles for one walking cycle

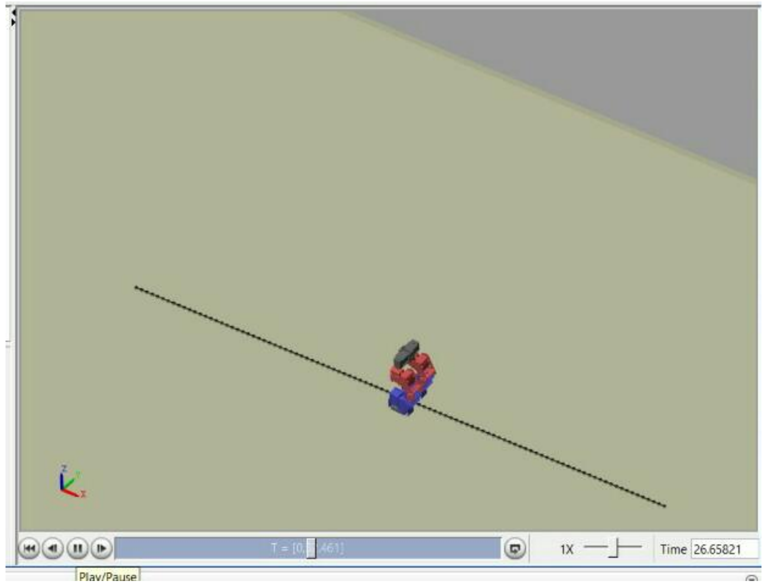


Figure 7.5: Simscape Multibody simulation

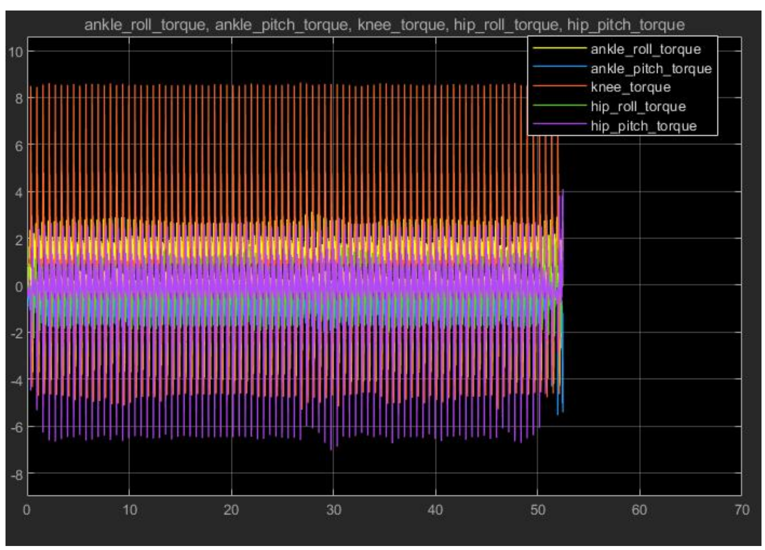


Figure 7.6: Torques for each joint

Chapter 8

CONCLUSION AND FUTURE SCOPE

Humanoid robots are envisioned as the ideal but probably most complex service robot. Indoor navigation for the visually impaired is a common problem that is addressed by many means conventionally. But with disruption in technology , engineers came up with much more viable and attractive methods using RFID, Camera based image processing, WiFi etc. But the practicality of these methods are often questioned with respect to their cost, implementation and ease of access.The power consumed by these robots are still far more than that of human beings. The proposed design detailed in this report will be able to act as a retrofit kit and gain more access. Apart from the ease of access, this method makes use of light as a medium of localization as well as illumination in the indoor space.

Future scope of this system is indoor navigation for normal peoplle inside huge indoor locations like malls etc. Hence the application can be extended beyond the use by visually impaired people.It has been well documented that there will be increase in number of humanoid robots over the next decade. According to the Boston Consulting Group, by 2025, robots will perform 25 percentage of all labour tasks. Wide applications of humanoid robots are possible in airport manufacturing facilities, companion robots in medical industry

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