Contents

Chapter 1

Biped Design and Simulation

1.1 Introduction

This project aim is to build a biped-design for our humanoid-project which can resemble human like walking. Generally there are two types walking styles i.e. Static Walk and Dynamic Walk. Static Walking can't be used to achieve faster walking speed, further details are explained in upcoming section. We planned to first proceed with a static design and then with a future plan to make a dynamic design as well, for which we had decided to use Cart-Table model to calculate ZMP and use it as a stability criteria.

1.2 Walking Analysis

1.2.1 Cart-Table Model for ZMP

This is a simplified model to compute the ZMP. Which gives position of ZMP in terms of acceleration and position of COM. The relations are as follow:

$$x_{ZMP} = x_{COM} - \frac{\ddot{x}_{COM}}{g} z_{COM}$$

$$y_{ZMP} = y_{COM} - \frac{\ddot{y}_{COM}}{g} z_{COM}$$

1.2.2 Static Walk

Static walking assumes that the robot is statically stable. This mean that, at any time, if all motion is stooped the robot will stay indefinitely in a stable position. It is necessary that the projection of the COM of the robot on the ground must be contained within the foot support area. This can be seen from the Cart-Table model of ZMP that when the COM acceleration will be zero in ground plane the ZMP will come out to be COM projection.

1.2.3 Dynamic Walk

Biped dynamic walking allows the center of gravity to be outside of the support region for limited amounts of time. In this case COM is not considered to be with constant acceleration therefore COM will not be ZMP in this case and stability criteria is that ZMP must be contained within the foot support area.

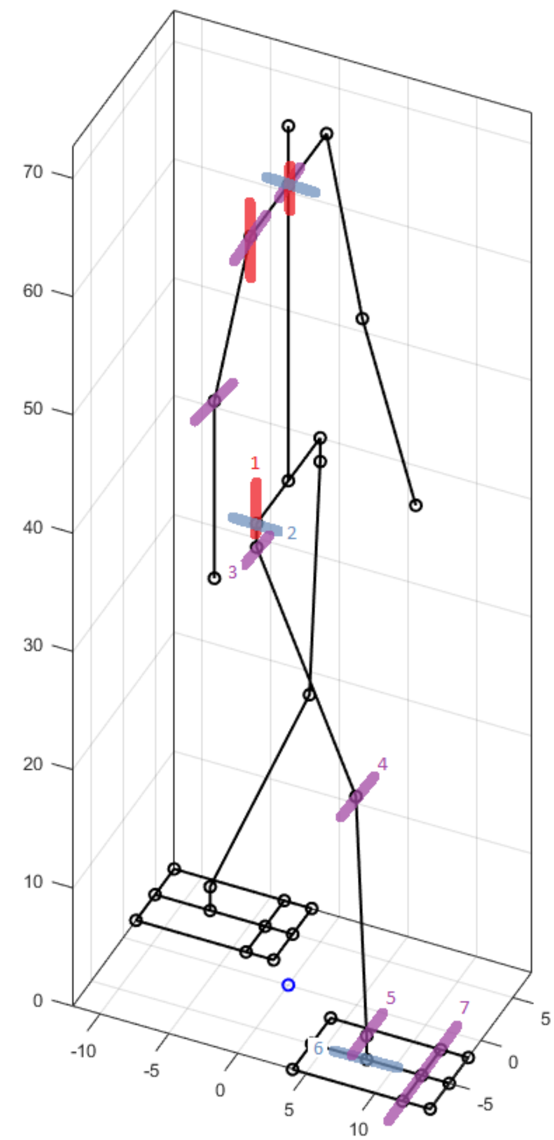
1.3 Description of Our Model

What we aimed is to design the walking algorithm such that it somehow resembles the motion of human walk i.e. following different joint trajectories which resembles with that human. Simultaneously we have to also look at the stability during the walking phases. To achieve these all targets we designed the algorithm in following steps:

- Using ZMP as a stability criteria we planned a reference trajectory for COM which is discussed in details in section 1.3.2
- As discussed in section 1.3.3 the ankle will follow a trajectory according to the motion of the foot in both the Double Support Phase duration. After that these points were used to get a 3rd order polynomial to get the Ankle trajectory during the Single Support Phase for the stance leg. (This was for the stance leg)
- The trajectory constraints of ZMP and Ankle was used to find the solution to different joint angles for the stance leg. For the swing leg as the foot will be in rest with respect to ground during all the three phases so we used this and COM to find other angles.

1.3.1 Kinematic Structure

The figure below shows the kinematic structure of our model. There are total 23 DOF for the complete humanoid model consisting of



- 7 DOF for each leg and foot.
- 3 DOF for each hand.
- 3 DOF for neck.

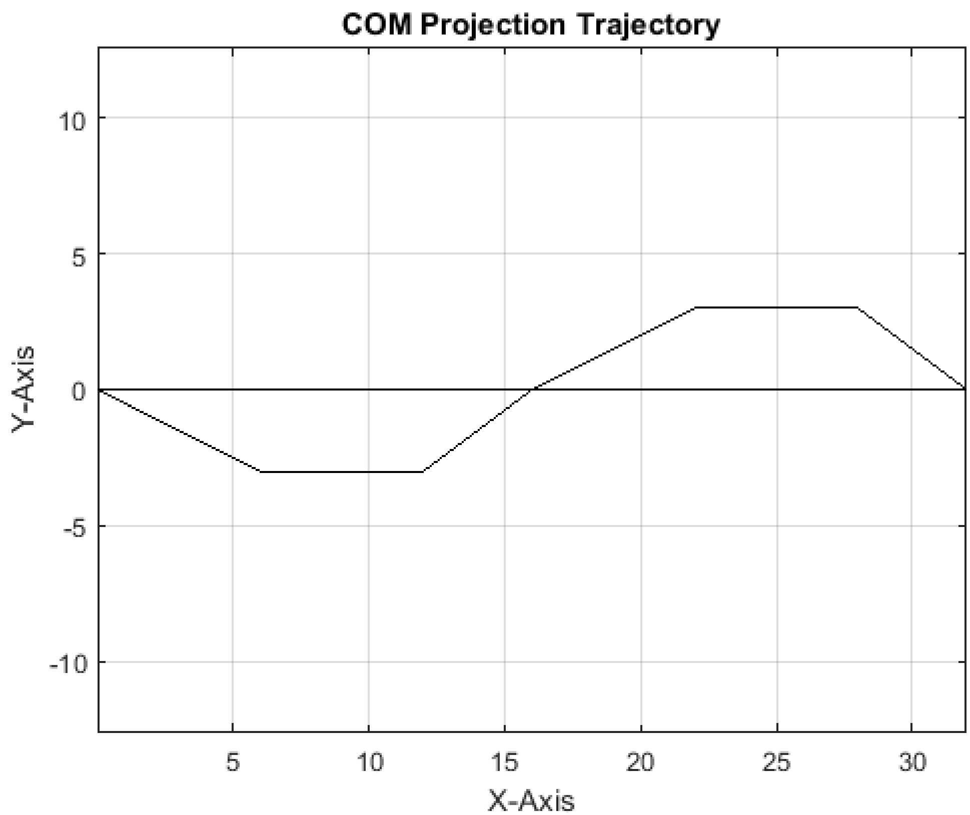
Dimensions

- length (link 3 - 4) = length (link 4 - 5) = 20 units.
- length (link 1 - 3) = length (link 5 - 6) = 2 units.
- foot length = 10 units.
- toe length = 2 units.

- foot width = 3 units.
- length of hip = 10 units.

1.3.2 Reference Trajectory for COM

We have decided to shift the COM by 16 units and the ankle of stance leg will shift by 32 units in the direction of walking. We have divided half walk cycle in three phases which are Double Support Phase-1 (DSP1, $x = x_0 : x_0 + 6$, $y = 0 : 3$), Single Support Phase (SSP, $x = x_0 + 6 : x_0 + 12$) and Double Support Phase-2 (DSP2, $x = x_0 + 12 : x_0 + 16$, $y = 3 : 0$). (where x_0 is the initial position before the walking starts, x axis is the direction of walking and y axis is perpendicular to direction of walking in transverse plane). This is kept like this keeping in mind that ZMP lies within the foot support area.



The motion was devised such that it causes a very slight displacement in z direction of COM which ranges from about (0, 0.1) units.

1.3.3 Walking Phases

Double Support Phase 1

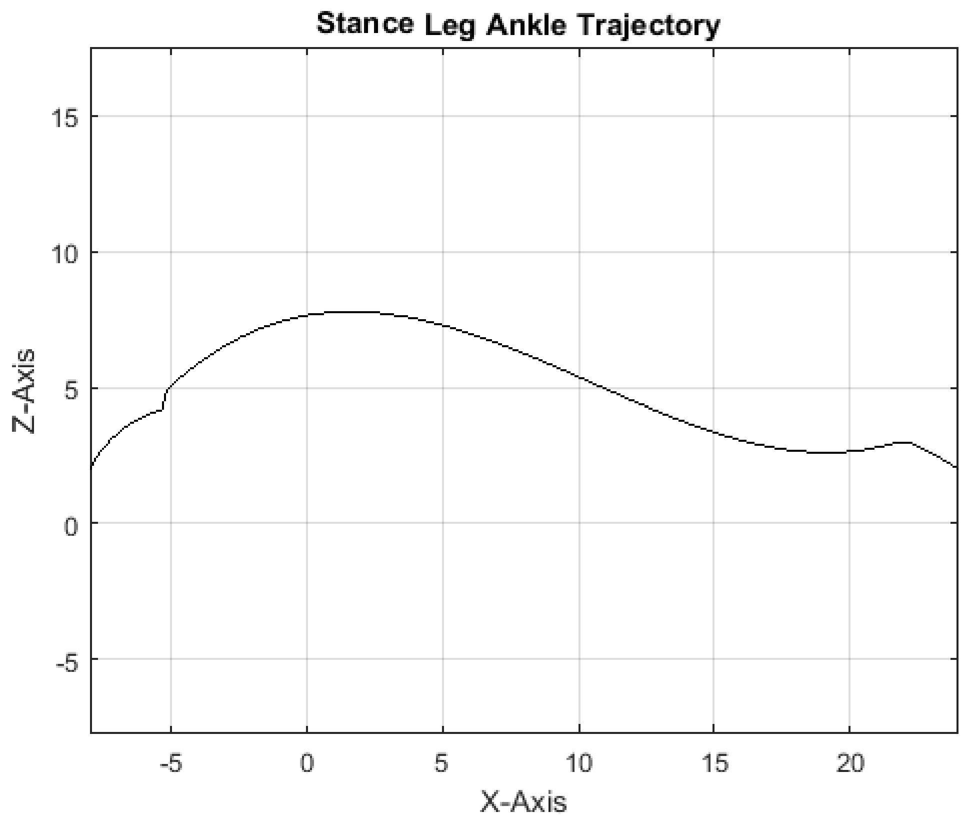
In this phase, ankle (joint no.5) follows a circular trajectory with respect to the point of the joint between the foot and toe (joint no. 1). In which the toe angle of stance leg varies from 0 to 45 degree during this period what we do is shift COM projection (i.e. ZMP in case of static walking) to the foot support area given by the swing leg. Actuation at point 1, 2 and 6 were used to move ZMP in y direction.

Double Support Phase 2

In this phase the stance leg again touches the ground after the Single Support Phase and the foot makes an angle of 15 degree with ground when it touches it again which is followed by circular trajectory of the ankle about the end point of the foot till the foot lie again flat on the ground.

Single Support Phase

In this phase stance leg loses contact with the ground and body comes in single support phase . And follows a defined ankle trajectory which resemble the trajectory of human ankle.



1.3.4 Regression for Ankle Trajectory

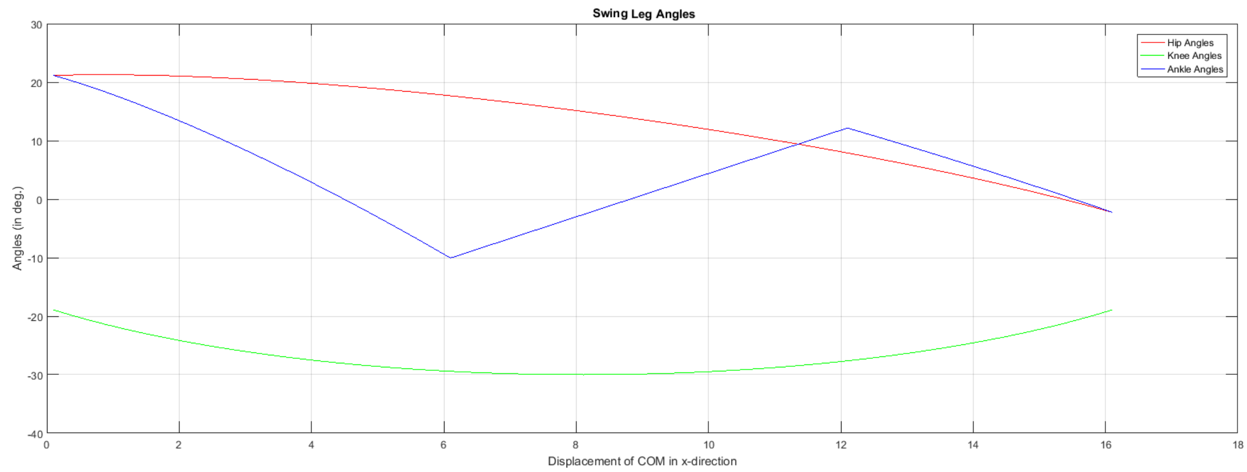
Considering that human ankle trajectory somehow follows a 3rd order polynomial equation in between the step length. We had approximated the single support phase trajectory for the stance leg ankle using regression technique for the date points which were obtained during double support phases. The equation which we got is:

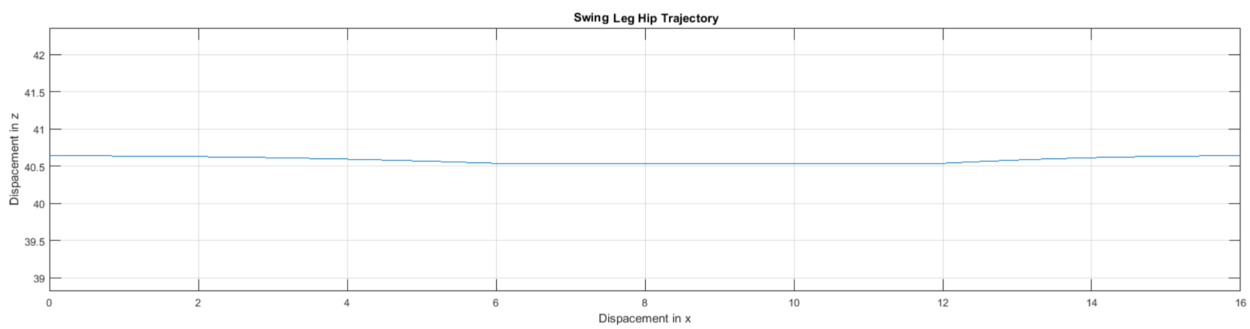
$$z_{ankle} = 7.805745 - 0.004895957 * (x_{ankle} - 1.5) - 0.05288801 * (x_{ankle} - 1.5)^2 + 0.00189056 * (x_{ankle} - 1)^3$$

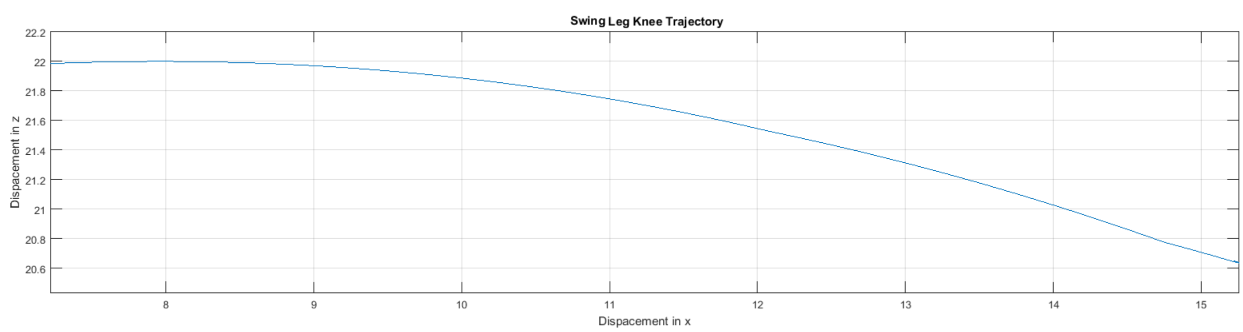
1.3.5 Implementation

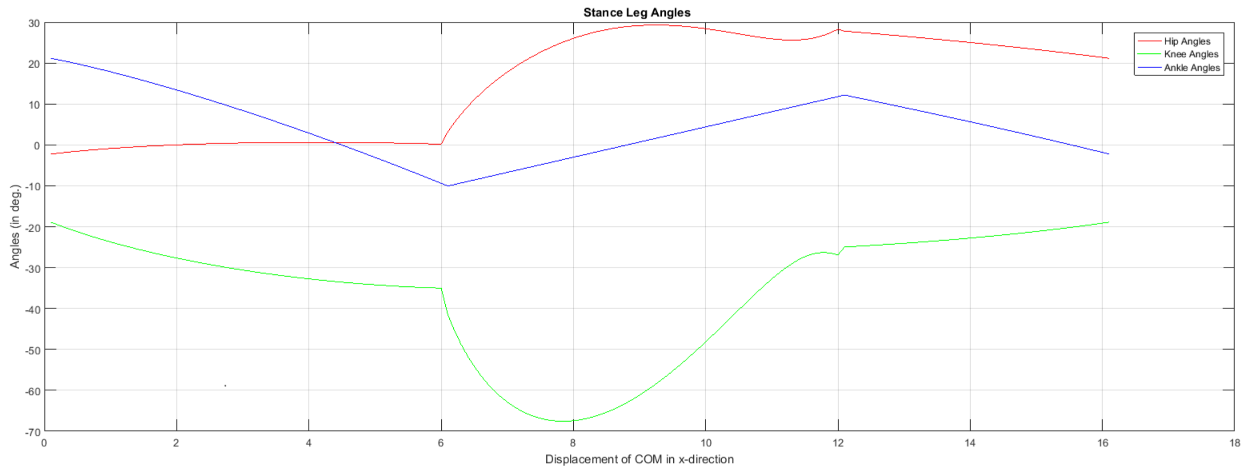
Simulation part is done in Matlab by plotting all the different joints and links in 3D Space. Joint angles were solved using the trajectory equations (for all walking phases) and forming equation for angles using trajectory constraints. Matlab sims function was used to solve those relations in terms of x_{COM}. Finally all the changes in joint angle and different joint trajectories were plotted which are shown in sec 1.4

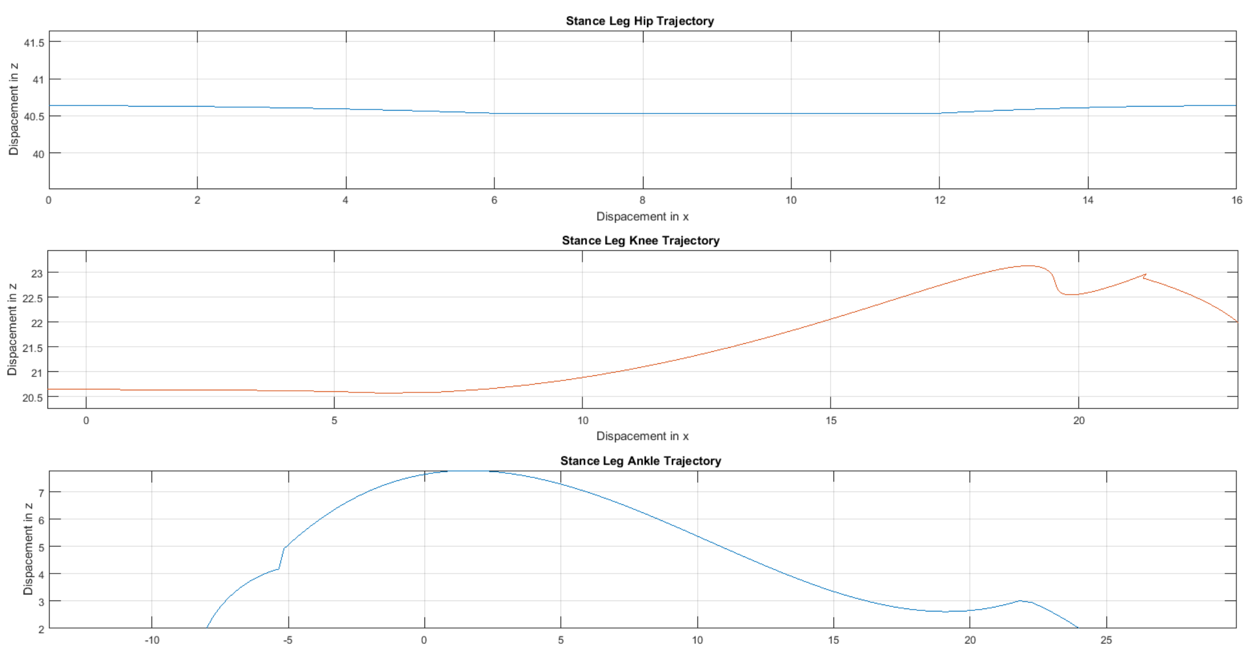
1.4 Simulation Results








Stance Leg Angles
Hip Angles
Knee Angles
Ankle Angles
Angles (in deg.)
Displacement of COM in x-direction


Stance Leg Hip Trajectory
Dispacement in z
Dispacement in x
Stance Leg Knee Trajectory
Dispacement in z
Dispacement in x
Stance Leg Ankle Trajectory
Dispacement in z
Dispacement in x