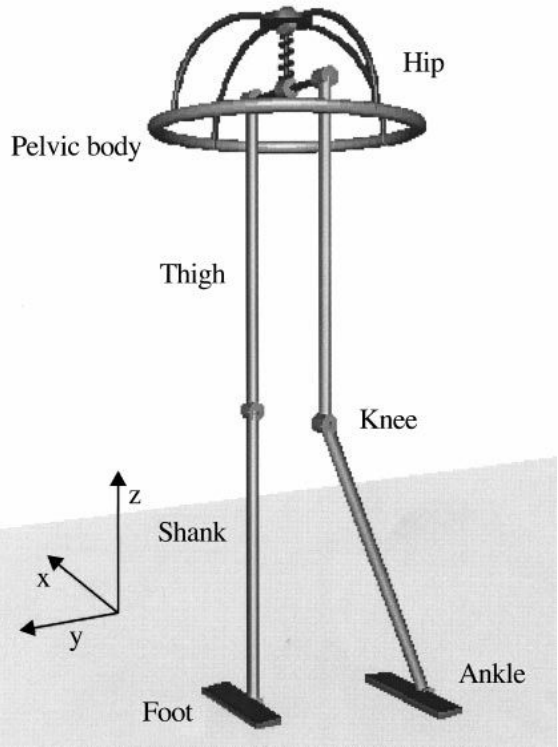
Biped Robot

Static and Dynamic Walking

Basic Terminology:

- **Hip:** There are three joints at the Hip. One for pitch, one for roll and for yaw.
- **Knee:** There is only one joint at the knee which is used for knee pitch. This is the most important factor in balancing and human walking.
- **Ankle:** The lower part which consists of two joints. One for roll and one for pitch.
- **Foot:** The foot is that part which is actually in contact with the ground.
- **DSP:** Double support phase (two legs in contact with ground)
- **SSP:** Single support phase (one leg in contact with ground)

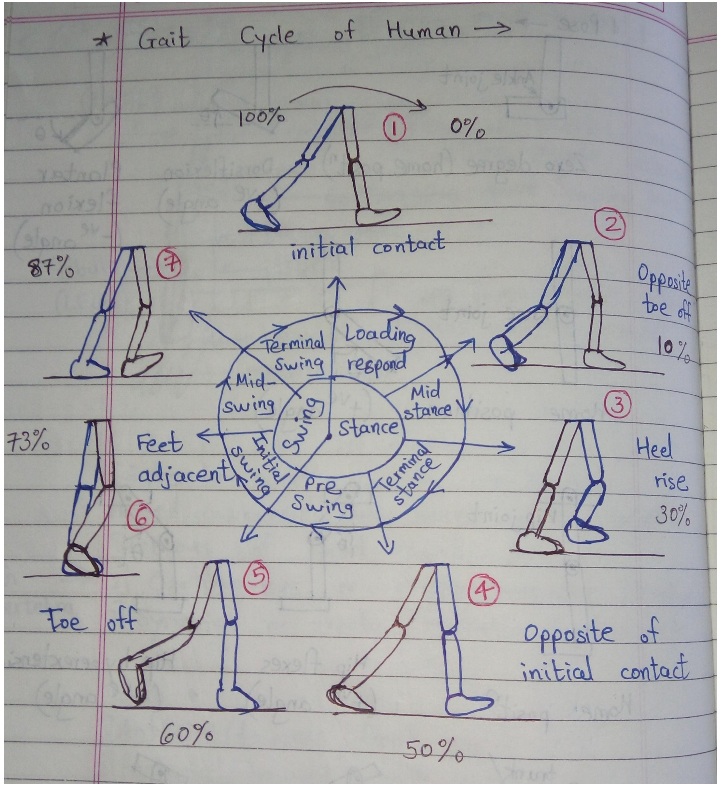


First Human then Humanoid!!

Gait cycle of humanoid:

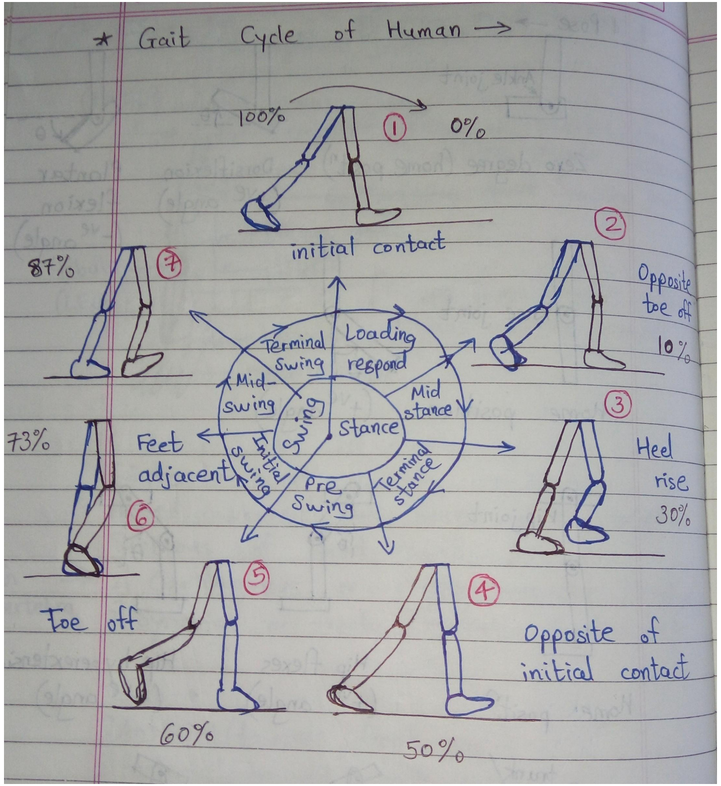
- **Stance Phase:**
  - Initial Contact
  - Opposite toe off
  - Opposite heel rise
  - Opposite of initial contact
- **Swing Phase:**
  - Toe off
  - Heel rise
  - Mid step
  - Initial Contact

(note: black colored leg is imp)



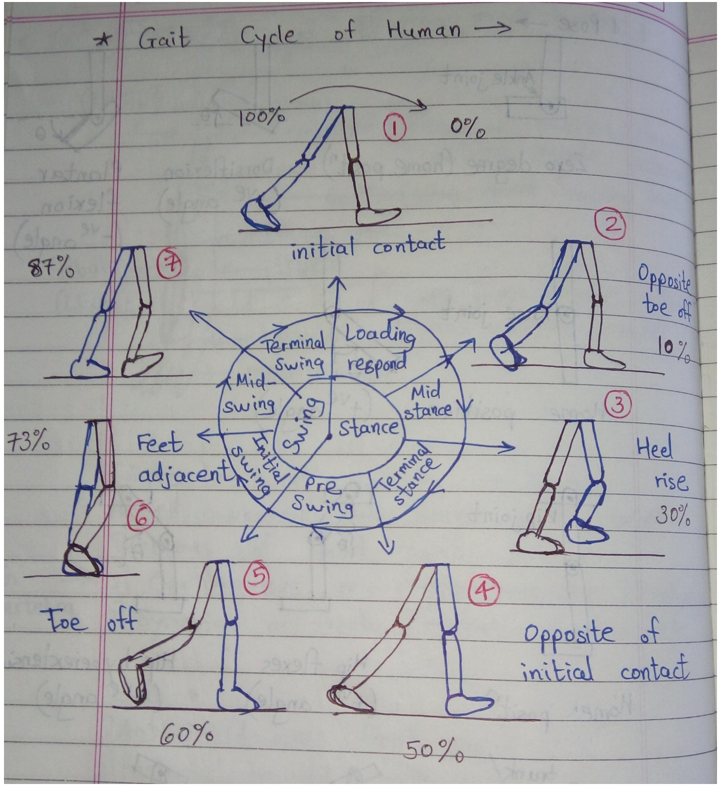
Stance Phase

- This phase contains the complete motion of the leg which is in contact with the ground during a step.
- Toe off is the state when just the toe is in contact with the ground.
- Heel rise is the state when the we balance on one foot and other foot is in air.
- In this phase the complete weight or CoM (center of mass) gets shifted on the black leg.



Swing Phase

- This phase contains all the information about the motion of the leg which swings about hip to take a step.
- It contains stages from the toe off to heel rise till the leg touches the ground.
- The trajectory of the foot of swing leg is almost a half wave.
- Motion of this leg can be treated as the motion of the manipulator with one end fixed at the hip joint.



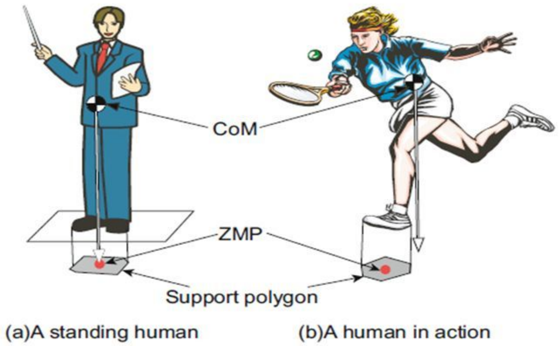
Human vs Humanoid!

- Unlike humans, kid size humanoid robot doesn’t have a toe off condition, which will not allow the foot to fall on ground with some pitch angle. So, the complete foot must create a contact with the ground after swing phase.
- This toe situation creates problems during the direction of ground reaction force.
- There is always a bending at the knees in the humanoid robot while walking. It is present in humans but it is so small that we ignore it or we can’t even see it.

Support Polygon

- It is a virtual area defined to find the stability of the body.
- It is a region in which the CoM must lie to achieve static stability.**Static Stability:** It is achieved when the CoM of the body is inside the support polygon.
- **Dynamic Stability:** It is achieved when the ZMP of the body is inside the support polygon even if the CoM is not inside the polygon.
- **ZMP:** Zero moment point. It is the point about which the resultant moment is zero. Some constraints and mathematics gives the equations for position of ZMP on the basis of momentum.

Relationship among CoM, ZMp and Support Polygon



CoG, ZMP, and Support Polygon

Projection of CoM on ZMP

Static Walking Gait Generation

Major Steps:

- First find the angles of motors to make the biped stand still without any movement.
- Bend the knees by providing angle to ankle pitch, hip pitch and knee pitch. (knee pitch angle = hip pitch angle + ankle pitch angle).
- This will give two benefits: One is the lowering of CoM which reduces the torque on the ankle motor and Other is the smooth and feasible motion from Heel rise to Opposite of initial phase.
- Find the optimum ankle roll angle so that the biped will not fall even if it is standing on one leg. (This ankle roll should be given to both feet of the robot)
- Increase the hip pitch and knee pitch while reducing the ankle pitch to take the swing leg further or in anterior direction.
- Next step is to give increase the roll pitch of ankle and hip of the stance leg so that the complete CoM will get shifted in anterior direction, ensuring that the CoM is inside the support polygon made by the foot of the stance leg.

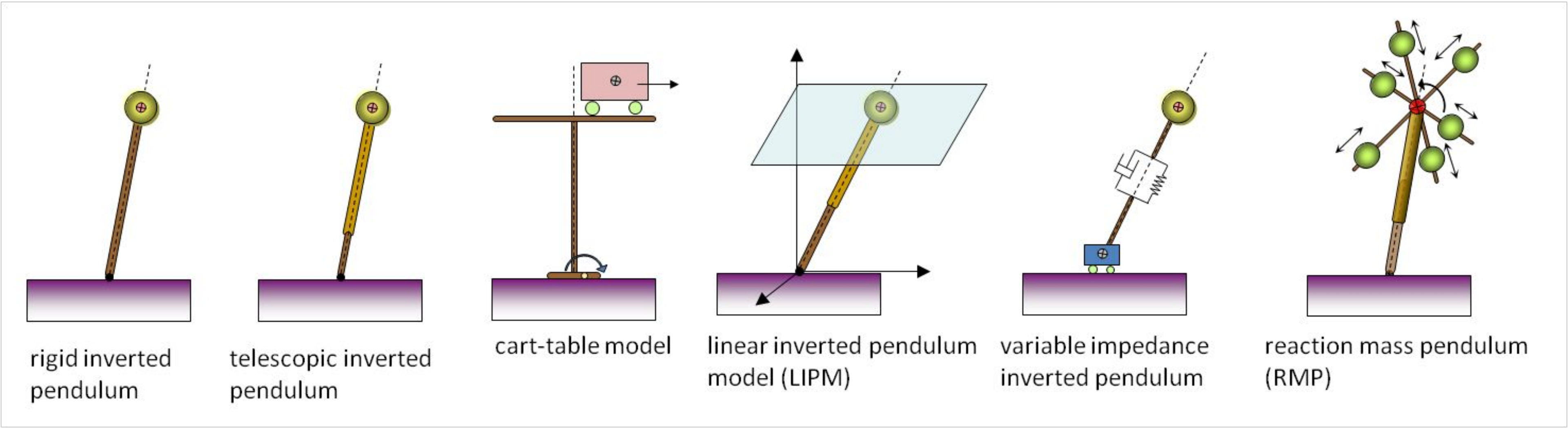
Static Walking Gait Generation

- After that, give a roll in the opposite direction so that both the legs will touch the ground and the robot will be stable in static conditions.
- After this, you just have to use a loop to continue the angles alternatively for the swing leg and the stance leg.
- This will produce a complete static walking motion of the biped.

How to Improve the Gait

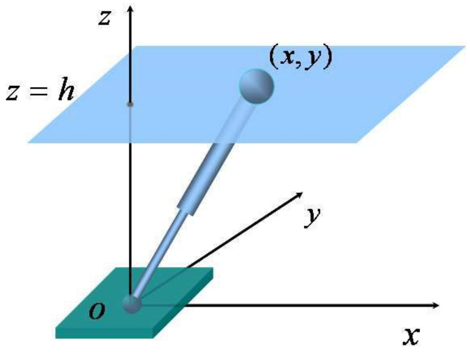
- Try to give the angles in steps with a sine nature to make the gait smooth.
- theta=(final_angle - initial_angle)*sin(t) + (initial_angle)
- t will be from 0 to 90 degrees and divide this 0 to 90 in the number of steps you want to find the required number of steps.

Pendulum Models (Dynamic Walking)



Dynamic Walking: (LIPM)

- LIP (linear inverted pendulum) model is used to model the dynamics of stance leg.
- Assumptions:
  - The CoM of the robot is assumed to be a pendulum.
  - The height of the pendulum is always constant with assuming a spring attached which will manipulate the height.
  - The pendulum will move only in x-y plane.
- Equation for LIPM: $\ddot{\theta} = -(g/l)\sin\theta$



Dynamic Gait Generation using LIPM

- Use the LIP model to get the equation in terms of x,y,z co-ordinates.
- Find the CoM of each joint in terms of the joint frame. Make a table with columns mass, X, Y & Z.
- Find the transformation matrices and DH parameters. Find location of CoM of every link in a global frame which is defined at the center of two legs of biped robot.
- Find the position of CoM of complete robot and then compare it with the equations of CoM from the LIPM. (in terms of x, y & z)
- Comparison of these equations will give us the equation for CoM in terms of theta of LIPM.

Global frame: frame at center of two legs.
Local frame: frame at center of torso.
T_{0i} *: Transformation of each joint frame w.r.t. frame associated with hip joint.*
piBody: Position of CoM of each link w.r.t. frame associated with joint above that link. (4x1 matrix)
iBody: Position of CoM of each link w.r.t. Global frame. (4x1 matrix)
ti: Transformation of hip frame to local frame.
WR: Transformation from Local frame to Global frame.

$$i: \begin{cases} r \text{ for right} \\ l \text{ for left} \end{cases}$$

mBody: Mass of each body link.

miBody: $\sum m_i * x_i$

$$A = \sum miBody_i$$

$$B = \sum mBody$$

$$COM = \frac{A}{B}$$

$$x_c = \frac{\sum m_i * x_i}{\sum m_i}, \quad y_c = \frac{\sum m_i * y_i}{\sum m_i}, \quad z_c = \frac{\sum m_i * z_i}{\sum m_i}$$

Parameters for My Biped Robot

Associate-d Joint	**Body**	**Mass (grams)**	**Co-ordinates w.r.t. Joint Frame (mm)**		
			x	y	z
Right Knee	Right Thigh	39.76	-38.06	0	1.53
Ankle Pitch	Right Leg	87.07	-67.13	2.62	-1.57
Ankle Roll	Right Ankle	75.77	-38.88	-2.39	5.75
Right Foot	Right Foot	92.63	-9.82	9.73	-3.55
Left Knee	Left Thigh	39.76	-38.06	0	-1.53
Ankle Pitch	Left Leg	87.07	-67.13	2.62	1.57
Ankle Roll	Left Ankle	75.77	-38.88	2.39	5.75
Left Foot	Left Foot	92.63	-9.82	-9.9	-3.35

(**Note1:** Add 1.25mm to y in Right Ankle Pitch. Add 1.25mm to z and multiply by -1 to y and z in Right Ankle Roll and Right Foot.)

(**Note2:** Difference of 1.25mm is due to offset in between y-axes which is not considered during DH parameters. Multiplication by -1 is due to change in orientation of frames. Errors while calculating DH)

Dynamic Gait Generation using LIPM

- Swing Leg trajectory is designed to using transformations to find the position of the foot. The foot is used to travel a desired curve.
- The distance travelled by the swing leg is optimized to get maximum possible step without fall of robot.
- In this way gait has been designed.