Dynamic Gait Generation for a Humanoid Using Stereo Vision

Anjana MN
Department of ECE
PES University
Bangalore, India
mna3807@gmail.com

Ashwathi Subramanian
Department of ECE
PES University
Bangalore, India
ashwathisubramanian@gmail.com

Athindra Bandi
Department of ECE
PES University
Bangalore, India
athindra.bandi@gmail.com

Rajasekar Mohan
Department of ECE
PES University
Bangalore, India
rajasekarmohan@pes.edu

***Abstract*—Dynamic walking, empathizing and grasping an object are some of the hardest problems in robotics that involve trying to replicate things that humans can do easily.The goal has always been to create a general purpose robot rather than a specialized one for specific industrial machines. Making a humanoid walk on an even plane is something that does not find many applications.To mimic a human-like walking trajectory in a humanoid, especially over the inclined and uneven planes, is something challenging and unique when it comes to implementing the cost-effective and dynamic solution.The aim of this paper is 'To develop a dynamic gait generation for a humanoid robot using stereo vision with a capability to walk with small obstacles on an uneven/rough surface and to verify the same using ROS Gazebo simulation environment'.**

***Index Terms*—robotics, humanoid, dynamic walking, ROS Gazebo**

I. Introduction

This project came in reaction to realize dynamic gait for small sized humanoid robots.This process includes utilizing the stereo vision yield (the slant point) as the input to the as of now existing model, so that the pre-planned walks can be self-adjusted such that the humanoid can walk with stability. Zero Minute Point (ZMP) and support polygon play critical parts in guaranteeing the steadiness and stability[1].

The two of the most important features of bipedal humanoid robots are the shape and movements that are very much human-like. The Bipedal humanoid robots consists of two human-like legs. [5]These legs will help the humanoids walk with stability and they should be capability to be on various types of floors such as uneven floors or steps also. Two main methods of using motion planners to generate dynamically balanced robotic motions are as follows[6]:
1. In one of the methods, the humanoid movements are preplanned. The area of the space that needs to be explored can be decided based upon the speed of the humanoid and the position of its footprints.
2. In another method, a geometric route is decided. The humanoid is supposed to follow this geometric path. In the second step, the geometric path is estimated again.
Hence, we propose a method to make the humanoid walk with stability on uneven terrains, like inclined plane or rough surface. The aim here is to make use of the vision sensor,attached to the head of the bot, in a way that it can compute the slope of a fixed inclined plane. After the slope detection, the humanoid should be to adjust the servos without manual intervention(dynamically) and hence the gait patterns.

II. Related work

Prasanna Venkatesan K S,Prajwal Rajendra Mahendrakar,Rajasekar Mohan[1], have worked on a way to generate the gaits by solving inverse kinematics using geometric analysis in a small-size humanoid robot. The robot has 17 Degrees of Freedom, 5 on each leg and rest in arms. Section II will throw some light on related work that has been accomplished.The TONY Robot that was used for experimentation. A 3D linear inverted pendulum model is used to find the trajectory of the center of mass.

A. Inverse Kinematics

Kinematics is the theory which analyses the interrelation between the joint angles and position and attitude of a link. Kinematics lays a basic foundation for robotics.It includes mathematics which deals with rendering a dynamic object in 3D space. If the joint angles are known, and the final orientation of the robot tool tip is calculated,it's known as Forward Kinematics. If the required position is known and the joint angles need to be calculated, it's called Inverse Kinematics. Inverse kinematics is a field where the constraints define whether or not the equations are solvable. Hence, the approach in representation of links of a robot decides the effectiveness and solution of the problem.

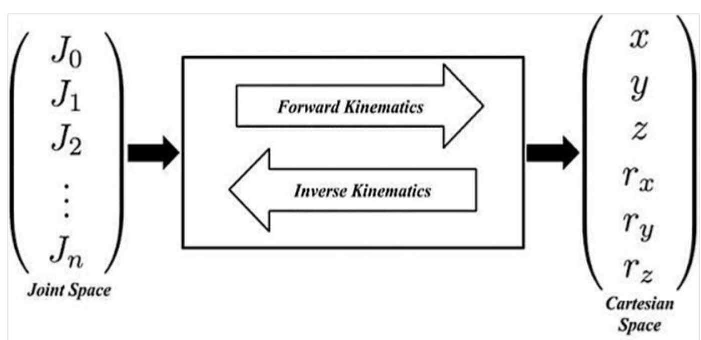

Fig. 1. Forward and Inverse Kinematics

B. 3D Linear Inverted Pendulum Model

3D linear Inverted Pendulum Model is an algorithm to generate a gait pattern that realizes the biped gait by producing a track. A gait pattern is nothing but a set of joint angles to achieve the required gait[1] .The 3D Inverted Pendulum Model consists of a few assumptions. They are listed down below[1]:
1. The entire mass of the robot is concentrated at its center of mass.
2. It is assumed that the legs of the robot are mass-less. The tips of the leg contact the ground at single rotating joints.
3. The end of the joint is only capable of moving in a single constrained plane, which has to be parallel to the ground. The important parameter in the 3D LIP model is R – supporting distance, G – gravity, f-kick force.

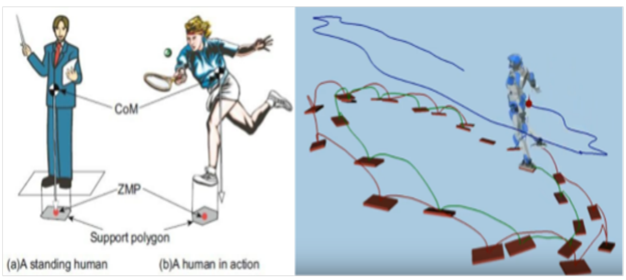

Fig. 2. CoM,ZMP and Support Polygon [1]

C. Few Definitions

1. Zero Moment Point : In static state, a point on the ground is predicted to be the COG based on some calculations. This is the Zero Moment Point or the ZMP. In the dynamic state, the entire force of inertia which comprises of gravity and mass goes though this point. If the ZMP continuously falls within the supporting polygon made by the humanoid feet, it will never fall down. Several research groups use ZMP as a criterion for stable walking of bipedal dynamic walking and the robot is controlled so that the ZMP is maintained within the supporting polygon.
2. Centre of Mass : point where the entire mass of the humanoid is concentrated. A point is called center of mass if it moves in the direction of the force without rotating.
3. Centre of Gravity : It is the point where the entire weight of the body is assumed to act. It is considered to be equal to the CoM in uniform gravity.
4. Support Polygon : Support Polygon is the region formed by enclosing all the contact points of the robot and ground using some elastic cord.

D. Static walking vs Dynamic walking

Till date, numerous methods to control the gait of a humanoid have been created considering the condition that the strolling surface is completely even and leveled without any slant. Till now several bipedal humanoids have walked on properly planned level floors with stability. However, in reality, though a typical room floor appears to be level, it will have nearby and worldwide slants of around 2 degrees at least. It is

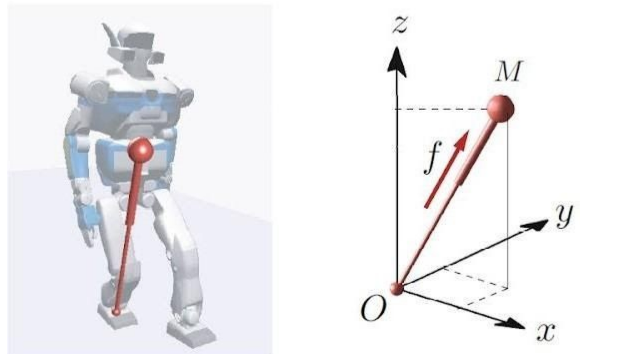

Fig. 3. 3D-Linear Inverted Pendulum Model

very crucial to keep in mind that even a little slant in the floor can result in the biped humanoid falling and collapsing[4].
Numerous and intense research on biped walking robots have been performed since 1970. During that period, biped walking robots have changed into biped humanoid robots through clever and innovative improvements. Moreover, the bipedal humanoid robot become as one of the agents to investigate subjects within the brilliantly robot investigate society. Numerous analysts expect that the humanoid robot industry will be the pioneer industry pioneer of the 21st century and we in the long run enter a period of one robot in each domestic. The solid center on biped humanoid robots comes from a long-established interest for human-like robots. Apart from this, it is really fascinating for a robot to have a structure like a human. This can be needed for a human-robot society.[4]
Developing a bipedal humanoid platform is not a very tedious task. However, making this humanoid walk on various types of surfaces with stability has always given a challenge. This is because of a lack of an understanding and knowledge on how human beings walk stably.
Early biped strolling of robots included inactive strolling with a small strolling speed. The step time of the biped humanoid was around 10 seconds per step and the technique to adjust the controls was performed by utilizing the Center Of Gravity (COG). The expected point of COG on the ground continuously seems to be within the support polygon that is made by two feet. While performing inactive strolling, the robot can stop its strolling motion at any point of time without losing its balance and avoiding falling down. The disadvantage of inactive strolling is that the movement is as well moderate and wide for moving the COG [4]. WABIAN-2 of Waseda College, ASIMO of HONDA, and HRP-3 of AIST are some of the famous bipedal humanoid robots.
Dynamic walking on a non-leveled, rough floor by a bipedal humanoid robot is really difficult to implement and appreciate. This is because the majority of bipedal humanoid robots use motors and gearing to perform hard position control of the joints. Hence, the response times of the actuators and sensors are low as a result of the reduction gear and sensor noise. So, it's not realistic for the robot to adapt to the ground conditions instantaneously. Also, it's not feasible for

the robot to respond properly even if the ground conditions are measured instantaneously. The human ankle can instantly adapt to changing ground conditions on the other hand[4].

E. Stereo Vision

In recent times, real-time camera monitoring from distant, isolated applications has had a lot of scope because of its capacity to strictly watch and monitor any place. But, there is a scarcity of realistic view because only 2D images are produced that don't contain any depth information and natural motion control[2].

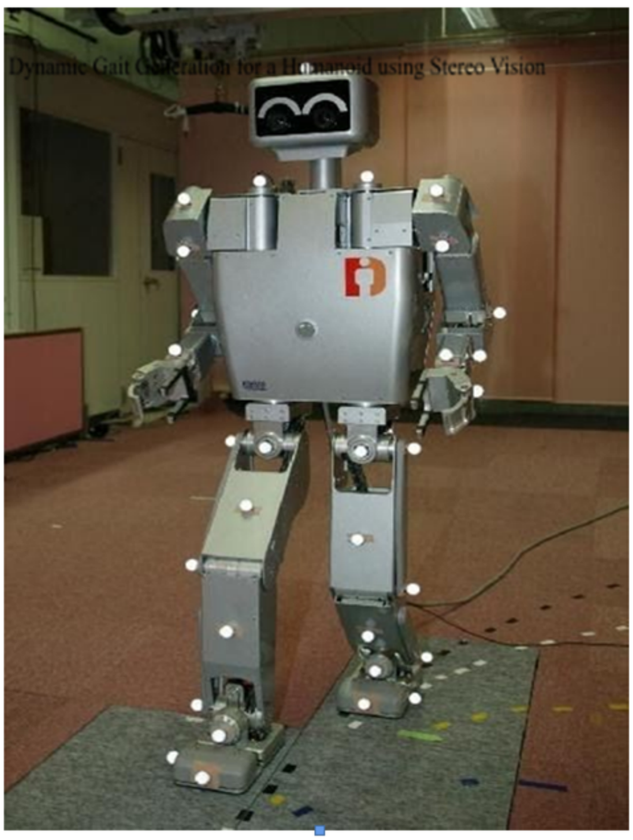

Fig. 4. Implementation of Stereo Vision on a Humanoid

The issue in stereo vision is based on the physical phenomena, that a 3-D object has different projections depending on the point of view. In this manner, it is conceivable to recreate the 3-D scene from at slightest two pictures of the same protest taken from two unmistakably, unique and distinct focuses [2] . Then comparing pixels from one picture are found within the other one and concurring to this data the difference outline is built. Afterward, the 3-D scene is recreated agreeing to the dissimilarity outline. The most complicated issue in stereo computation lies in plan of comparing focuses and points searching metrics and algorithms [2] .
Stereo application takes the input as stereo sets of 2-D pictures and produces the recreated 3-D information by finding the comparing focuses. The comparing issue requires a particular looking and coordinating method, the strength of which decides quality and accuracy of reproduced 3-D information .Most stereo recreation strategies are based on the utilization of the pinhole camera demonstration and parallel geometry. In these methods, two points are selected from each of the images, left and right, by using any procedure for stereo matching. Then the depth of the image will be calculated by looking at how inconsistent the two points are from each other(disparity). Depth can also be found by the partition of the two pixel points [2] .
As shown in figure 3.6, if (xL, yL) are the pixel coordinate in the left image and (xR,yR) are the pixel coordinates in the right images, then the 3D world coordinates (X,Y,Z) are computed as follows [2] :

$$X = (xL * b)/d \tag{1}$$

$$Y = (yL * b)/d \tag{2}$$

$$Z = fb/d \tag{3}$$

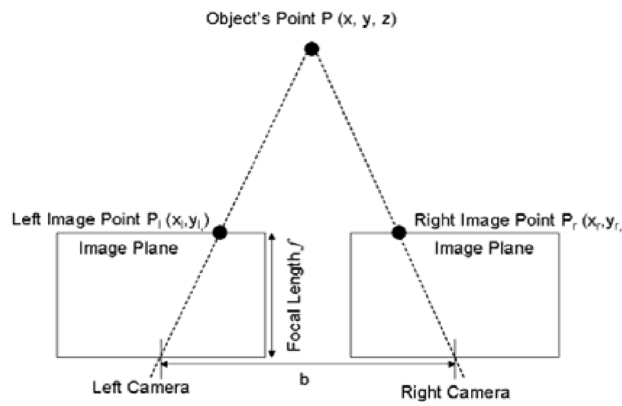

Fig. 5. Illustration of Stereo Geometry

F. About the Humanoid HRP-4

The simulation performed by importing HRP-4 robot in the ROS Gazebo environment. The most recent model in the HRP series is the HRP-3 humanoid. It is also one of the most advanced humanoid all thanks to the deep rooted partnership between Kawada industries. Kawada industries are led by Tadahiro Kawada, and Japan's National Institute of Advanced Industrial Science and Technology (AIST), headed by Tamotsu Nomakuch. HRP-2 was developed in 2002. HRP-3 then was developed in 2006[3]. After this, HRP-3 was developed. The aim of this project was to make the humanoid more light weight and hence secure for human interactions. In this project, engineers from Kawada focused on the humanoid robot hardware while the AIST researchers developed the motion-control software[3]. The goal was to make the new humanoid convenient and lighter making it safer for human interaction. But HRP-4 was created with aim to make it more capable than HRP-2 and HRP-3 humanoids in terms of manipulating objects and navigating human environments[3]. It was made sure that this objective was fulfilled. The final design was unveiled in September 2010.

 [3]

Fig. 6. HRP-4 Humanoid

Created by	**Kawada Industries and AIST**
Country	Japan
Year	2010
Type	Humanoids, Research
Features	Compact, lightweight design. Able to lift 0.5 kg (1.1 lb) with each arm. Equipped with low-power motors for improved safety.
Height	151 cm | 59.4 in
Weight	39 kg | 86 lb
Sensors	Cameras (in the head and arms), microphones.
Actuators	80-W motors and lower power motors
Computing	PC/104 Pentium M computer with Wi-Fi and speakers.
Software	Linux OS with RT-PreemptPatch and OpenRTM-aist middleware.
Degrees Of Freedom (DOF)	34 (Leg: 6 DoF x 2; Neck: 2 DoF; Chest: 2 DoF; Arm: 7 DoF x 2; Hand: 2 DoF x 2)
Materials	Plastic covers, aluminum alloy frame.
Official Name	HRP - 4

Fig. 7. Specifications of HRP-4 Humanoid [3]

III. Our Implementation

A. Simulation Work Flow

1. In ROS Gazebo, we have imported the rospy library that helps us to execute all the ROS related commands in Python.
2. There is a ROS node that is connected to all the leg joints. We know that ROS nodes connect the external environment to the humanoid and vice versa. Here the external environment is python. In the python code, the servo angles are being calculated. These servo angles are given as input to the humanoid with the help of ROS nodes.
3. There is a stereo vision camera sensor that has been attached to it. Hence, now the robot can perceive its surroundings. There is a cuboid that is kept in front of the humanoid. When the robot nears it, the robot calculates its slope and raises its leg to place it on the cuboid.
4. For calculating the slope, a simple equation,

$$tan^{-}1((y2-y1)/(x2-x1)) \tag{4}$$

has been used. Here x1, y1 are the coordinates of the lower rectangle and x2,y2 are the coordinates of the higher rectangle. The slope is calculated using this equation and the servo motors are adjusted accordingly.
5. So on perceiving the obstacles and while walking on non-smooth surfaces the robot plans its gaits accordingly and walks.

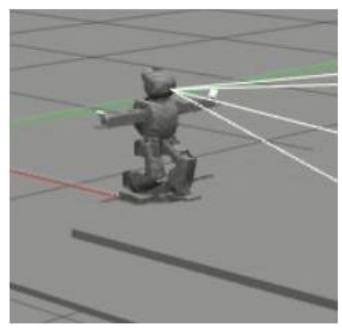

Fig. 8. HRP-4 in the simulation environment

B. Hardware Implementation

The following steps are to be followed for implementing dynamic walking on hardware.
1. The humanoid on which our logic will be implemented will have a stereo vision camera sensor attached to it. The camera provides the image data to the humanoid that is used for object identification, tracking and manipulation tasks. Hence this allows the humanoid to sense the obstacles around it and gets familiar with the environment. It computes its distance from the obstacles with respect to its own frame.
2. When the x, y coordinates of the obstacles are found then the slope are also calculated. This is given to the raspberry pi where the servo angles are calculated.
3. After the angles are calculated, they are given as inputs to the Arduino.
4. The Arduino in turn, controls the servos and the humanoid

adjusts its gaits and starts moving with stability.
This is how the logic can be successfully implemented on hardware.

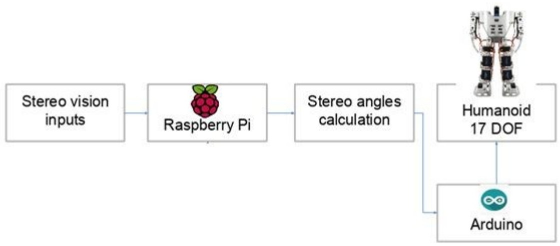

Fig. 9. Working of Dynamic Walking on Hardware

IV. Results and Discussion

Initially, the robot would fall whenever it would come across an obstacle since it was following a pre-planned gait. On attaching the camera sensor, the robot was able to get a knowledge about its local environment. Hence it was also able to find the coordinates of the cuboids that were placed in front of it. Using these coordinates, it computed the slope.
Accordingly, the joints and the servo motors of the humanoid were adjusted dynamically without any human intervention preventing the humanoid from falling down.
The generated gaits were tested on the imported humanoid model in ROS Gazebo. Whenever the robot moves from a lower step to a higher step, the slope is calculated and is displayed on the terminal as shown in the image above, thus allowing the robot to walk on non-smooth surfaces. The robot performed to match the expectations.
The figure below provides a glimpse of our implementation where the humanoid has successfully computed the slope and performed dynamic gait according to its calculations.
The main operations that were performed on the robot were, walking forward, turn left and right and also it was capable of walking on slopes and stairs.

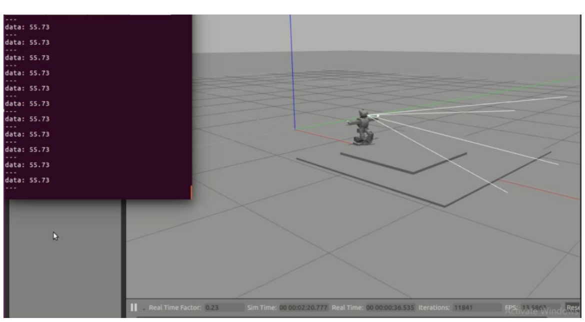

Fig. 10. Slope values computed by the vision sensor

The logic has been successfully implemented on ROS Gazebo. This can be further implemented on the hardware as well.

V. Challenges and Future Scope

We have come across the following hurdles during the entire course of this simulation:

1. Finding a suitable model for our project consumed quite a lot of time. We went through many websites and searched upon the specifications and features of various humanoids. Finally, HRP-4 consisted of the features and specifications that were needed for our simulation.
2. Finding a ROS version that was compatible for our system and OS was a tedious task.We encountered a lot of errors while installing ROS Kinetic, as the system was bound to low-graphics mode.

The results were obtained by using a single camera sensor. However, this can be extended to a stereo system also and can be implemented successfully using depth mapping, occupancy grids and localization algorithms.

VI. Conclusion

A noteworthy advance has been made towards steady mechanical and robotic bipedal walking, thus resulting in a big and interesting query about creating an independent route navigation methodologies custom-made particularly to humanoid robots. The capacity of the bipedal, humanoid robots to not only move around an obstacle but also to be able to walk over a few deterrents makes them apt for terrains and surfaces planned for the humans that frequently consist of a wide mix of objects and deterrents like furniture, entryways , stairs, and uneven ground. If the humanoid should be able to navigate and explore its environment with liberty, without any thought of falling down anywhere, it should be able to visualize the environment that it is present in from the information it receives from its sensors. Using this data, the route can be developed. So, in order to create the gait that will make the humanoid reach a destination, the robot's environment should be available to it in the form of global maps. This results in more productivity. In any case, on-body perception is solely restricted in extent and course.
Some approaches have focused on retrieving the information about the local environment that the humanoid is currently in. This only enables a few strategies for navigation such as reactive obstacle avoidance to be implemented. Some other approaches have used off-body visual sensing in order to compute the global maps. However the latter approach sacrifices some level of liberty of the robot. Through this approach, barriers like parallax and occlusions can be found.
Further study will focus on addition of toes to robot's foot and make it counteract the disturbances and use of an on-board computer for real time generation of sequences to get more realistic walk on this humanoid, TONY. The scope of possibilities for future work on the humanoid is endless and there are multiple ways of improvement in the robot whether be it improving the automatic gait-generating algorithm to upgrading the hardware.

VII. References

References

[1] "Solving inverse kinematics using geometric analysis for gait generation in small sized humanoid robots", Prasanna Venkatesan, Prajwal Rajendra M, M Rajasekar.

[2] "Using real-time stereo vision for mobile robot navigation", Don Murray & James J. Little.
[3] https://robots.ieee.org/robots/hrp4/
[4] "Walking Control Algorithm of Biped Humanoid Robot on Uneven and Inclined Floor", Jung-Yup Kim, Ill-Woo Park and Jun-Ho Oh.
[5] "Experimental realization of dynamic walking of the biped humanoid robot KHR-2 using zero moment point feedback and inertial measurement", Jung-Yup Kim,Ill-Woo Park Jun-Ho Oh
[6] "Dynamic Walking and Whole-Body Motion Planning for Humanoid Robots: an Integrated Approach", Sébastien Dalibard, Antonio El Khoury