INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

SURGE-2022

PROJECT REPORT

"Kinematic Analysis and Balancing of 12 degree of freedom biped robot"

Submitted by:

Tushar Kumar

Surge Roll No. : 2230349

Department of Mechanical Engineering

Indian Institute of Technology Kanpur

Uttar Pradesh, India

Under the guidance of:

Dr. Ashish Dutta

Professor

Department of Mechanical Engineering

Indian Institute of Technology Kanpur

Uttar Pradesh, India

Contents

I. Acknowledgement

First and foremost, I would like to express my profound gratitude towars my institute IIT Kanpur, and my Project Supervisor and Mentor Dr. Ashish Dutta for selecting me in the prestigious internship program SURGE 2022 and giving me the opportunity to work under his guidance. I am deeply indebted to my Professor for emphasizing me and encouraging me to work on new domains, which opened new doors of opportunity for me and helped me explore a vast area I had left untouched. I am also thankful to Mr. Vyankatesh Ashtekar, Mr. James for constantly helping me out wherever I got stuck and also guiding me throughout the research project. I am extremely thankful to the Department of Mechanical Engineering, IIT Kanpur for providing me an environment, that helped me develop an interest in research and further studies. This internship would have been impossible without the constant support and inspiration of my parents, who had faith in me, much more than I could have. They guided and motivated me throughout, helping me go through difficult days and inspiring me to work harder. Lastly, I would like to thank my friends, Sachan and Gaurav for their constant support and wishes.

Tushar Kumar

II. Abstract

Research on robots with numerous degrees of freedom have always been a hot topic for robotics researchers. The project aims to construct a lower portion of a bipedal humanoid, followed by its kinematic analysis and then balancing while standing up from sitting position. As the first step in constructing this creature, we developed a novel mechanical structure comprising two legs, two feet and a pelvis. Following that, we investigated robot kinematics (both forward and inverse), which is the application of geometry to the chain of the robot. This was accomplished using DenavitHartenberg parameters, aka DH parameters. Forward kinematics can be used to identify the position of the end effector from known joint parameters, while inverse kinematics can be used to locate joint configurations that will be used to guide the end effectors of the robot to desired points in three-dimensional space. A bipedal robot walking simulation in the form of stick figure is further accomplished in MATLAB with the appropriately fed hip and ankle trajectory.

Keywords: DH parameters, Forward Kinematics, Inverse Kinematics, Bipedal Robot, Capture Point.

III. Introduction

ROBOT - A term which is hardly unfamiliar to any person in this era has a wide range of definition. It does not restrict itself to a type of automated machine that can execute specific tasks with little or no human intervention and with speed and precision. Now coming to Biped Humanoid Robot, which are designed to resemble and move like humans. They are a type of legged robot, meaning that they have legs instead of wheels for locomotion. Biped humanoids typically have two arms, two legs, and a head, although some designs may include additional features, such as wings or tails.

Biped humanoids are used in a variety of applications, including search and rescue, military operations, and space exploration. They are also used extensively in research and development in order to gain a better understanding of human movement and cognition.

One of the most famous biped humanoid robots is ASIMO, which was developed by Honda in 2000. ASIMO is capable of a variety of tasks, including walking, running, and climbing stairs. ASIMO has also been used as a platform for human-robot interaction research.

The design of complex dynamic motions can only be achieved through robot kinematics, which applies geometry to arbitrary robotic chains. Inverse kinematics and forward kinematics are both considered as part of robot kinematics. Inverse kinematics provides the means to find joint configurations that drive the end effectors of a robot to desired points in the three-dimensional space in which it operates, whereas forward kinematics allows the robot to map any joint configuration into the physical space where it operates, not just its own multi-dimensional joint space. Considering how complicated motions can be, kinematics is a necessity. For a robot to walk with a stable gait, its feet must follow planned trajectories; this is only possible with mechanisms that allow it to angle its joints in a way that drives the feet along the planned trajectory. As with balancing methods, balancing relies on knowing the exact position and orientation of each part of the robot in three-dimensional space to determine the robot's center of mass, which constantly changes as it moves; this is accomplished by applying forward kinematics. Furthermore, dynamic motions require any kinematics calculations to be performed in real-time.

IV. Kinematics

A. Forward Kinematics

Since there is not much information available from the joint space about the end effector's position and orientation, therefore using forward kinematics, one can map joint space to three-dimensional Cartesian space. Forward kinematics is referred to as finding the position and orientation of end effector of a serial-chain manipulator in which the position of all the joints and values of all the geometric link parameters are given. With a kinematic chain with m joints and a set of joint values (θ_1, θ_2, . . ., θ_m), the forward kinematics can determine where it is in three-dimensional space (px, py, pz) and where it is oriented (ax, ay, az). Whether the kinematic chain is simple or complex, forward kinematics is a domain-independent problem that yields a closed-form, analytical solution.

Developing of forward kinematics is a necessary step because it helps to us to write the manipulator coordination algorithms.

B. Inverse Kinematics

The ultimate aim of robot manipulators is typically to reach target points or follow trajectory in a three-dimensional spacefor which it is necessary to specify the values of the joints of the kinematic chain so that the end-effector reaches a certain point or follows a certain trajectory. Through inverse kinematics, the three-dimensional space can be transformed into the joint space. As the name suggests, it is just the opposite of forward kinematics but it should be handled with extra care. Now, inverse kinematics is the problem for a serial-chain manipulator to find the values of joint positions when the position and orientation of the end-effector relative to the base coordinate system and the values of all the geometric link parameters are given. Each inverse kinematic chain has a different solution because the problem is domain-dependent. An analytical, closed-form equation can be derived from the inverse kinematics problem, or a numerical, iterative approximation can be obtained. An object in the three-dimensional space may have more than one matching object in the joint space as the number of degrees of freedom increases, and it is due to this property that makes inverse kinematics a relation rather than a mapping.

V. DH Parameters

DH parameters or Denavit-Hartenberg parameters are a set of four parameters associated with a particular convention for attaching reference frames to the links of a spatial kinematic chain, or robot manipulator. In this the Z-axis of frame i is taken coincident to the joint axis i where as the origin if loacted where the a_i perpendicular intersects the joint i axis. X_i points along a_i in the direction from joint i to joint i+1. Subsequently Y-axis is taken in accordance with the right-hand rule. Generally, there are two conventions to follow the DH parameter rule - one is the classical convention while the other is the modified convention which is mostly followed nowadays. The difference between the classic DH parameters and the modified DH parameters are the locations of the coordinates system attachment to the links and the order of the performed transformations.Former has the coordinates of O_i put on the axis i, where as on the other side latter has the coordinates of frame O_{i-1} put on axis i-1 and not on the axis i.

Here, we would be using the modified DH convention which has the following definition of link parameters:

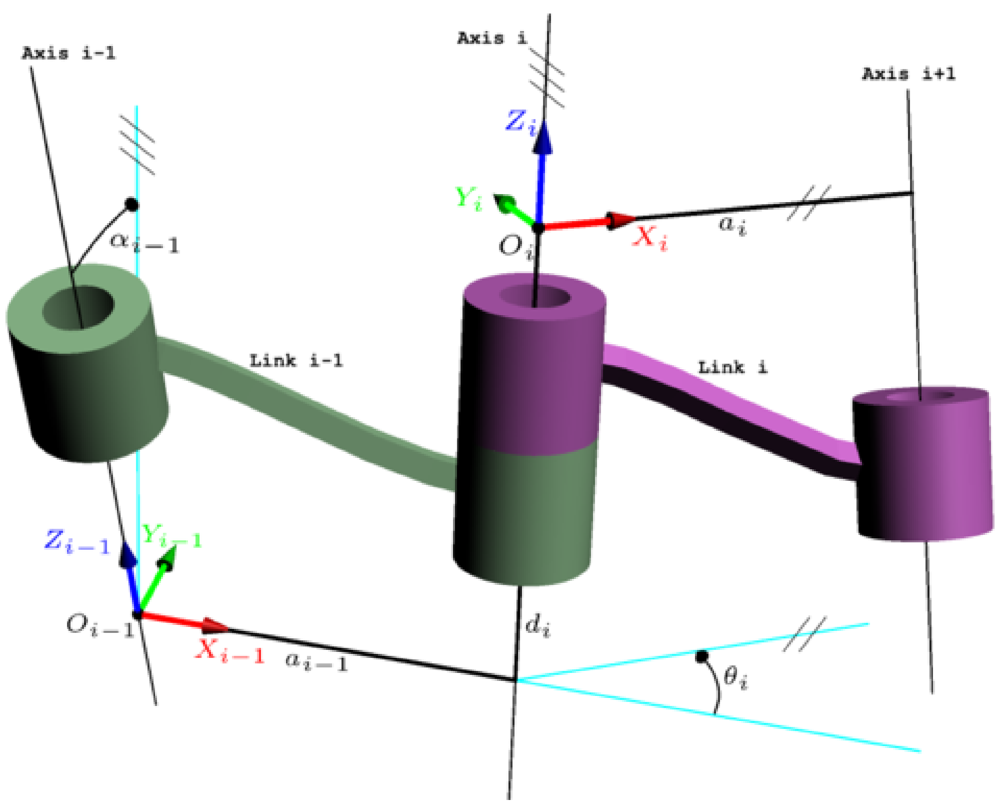


Fig. 1 Denavit-Hartenberg Parameters

a_i = the distance from Z_i to Z_{i+1} measured along X_i;

α_i = the angle between Z_i to Z_{i+1} measured along X_i;

d_i = the distance from X_{i-1} to X_i measured along Z_i;

θ_i = the angle between X_{i-1} to X_i measured along Z_i;

We can then transform the reference frame of some joint using the transformation matrix TDH, which consists of two translations and two rotations parametrized by the joint's DH parameters: The analytical form of the resulting matrix from the above composition is the following:

$$T_{DH} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 & a \\ \sin\theta\cos\alpha & \cos\theta\cos\alpha & -\sin\alpha & -d\sin\alpha \\ \sin\theta\cos\alpha & \cos\theta\sin\alpha & \cos\alpha & d\cos\alpha \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

VI. 12-Degree of Freedom Robot

Generally a simple humanoid robot can have 28 degrees of freedom with the following distribution: (i) 7 for each leg which consists of 3 at hip (yaw, roll, pitch), 1 at knee, 2 at ankle(roll, pitch) and 1 at toe , (ii) 7 DOF for each arm, including a single DOF gripper and (iii) 2 DOF at the neck. Nowadays, most of the humanoid robots mentioned above consist of two 6-DOF legs, namely 3-DOF hip, 1-DOF knee and 2-DOF ankle.

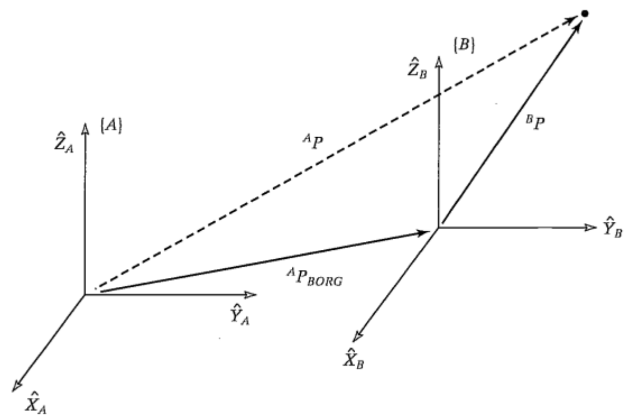
i	a_i	α_i	d	θ
1	0	0	0	θ_1
2	0	$\pi/2$	0	$\theta_2 - \pi/2$
3	0	$\pi/2$	0	$\theta_3 + \pi/6$
4	thigh	0	0	$\theta_4 - \pi/3$
5	calf	0	0	θ_5
6	0	-$\pi/2$	0	θ_6

Table 1 DH Parameters for 12-DOF Robot

Here, we take the length of **thigh** and **calf** as 100cms. The left hip

VII. Mappings: Changing from frame to frame

Very often in dealing with kinematics we need to change from frame to frame, for example we need to travel from the local frame to global or the vice-versa. Here, let us consider the general case of mapping where the origin of a frame B is not coincident with that of frame A but rather has a general vector offset which locates the B's origin denoted by P^A_{BORG} and is also rotated with respect to frame A which let us say is given by P^A_B. Also we are given a vector with respect to frame B denoted by P_B and we need to find out P_A.



The final expression which we obtain after relevant rotations and translation between origins is given by the following equation:

$$P_A = R^A_B\, P_B + P^A_{BORG}$$

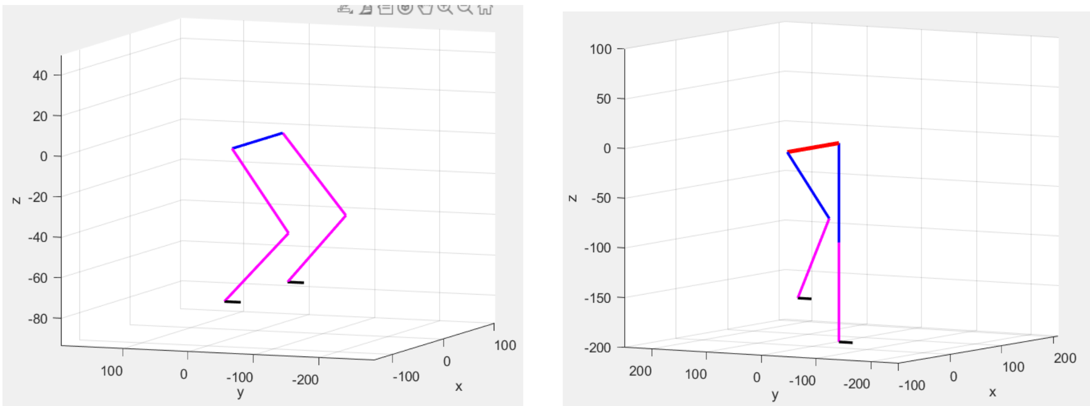
Hence, the above equation describes a general transformation mapping of a vector from its description in one frame to its description in another frame.

NOTE: In this paper we have used floating base coordinate system instead of fixed base coordinate system i.e., the base frame which is present at the hip centre has been given a path when simulation of the walking robot is carried out.

VIII. Case Studies

A. Standing Robot

As it can be seen in the below figure a static standing robot with an initial bending of 30° where as in the second one it can be seen that it is standing on one leg with some bend in the other leg.



B. Turning Directions

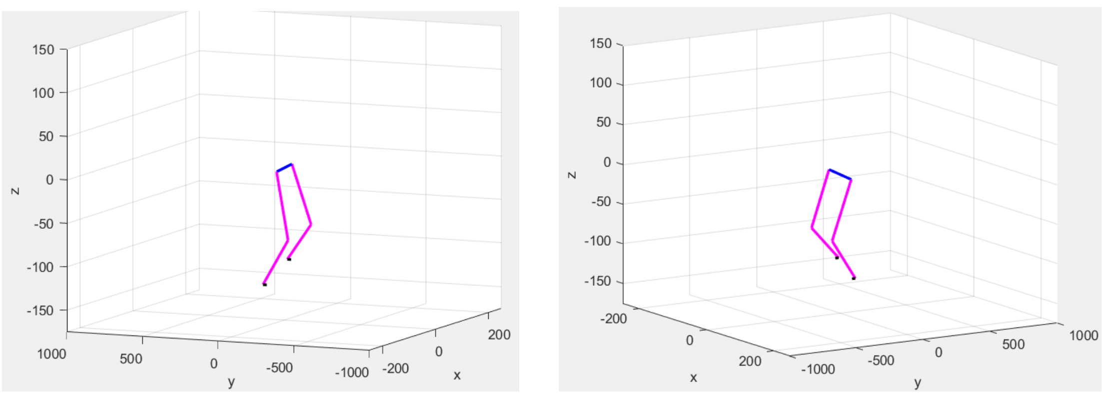
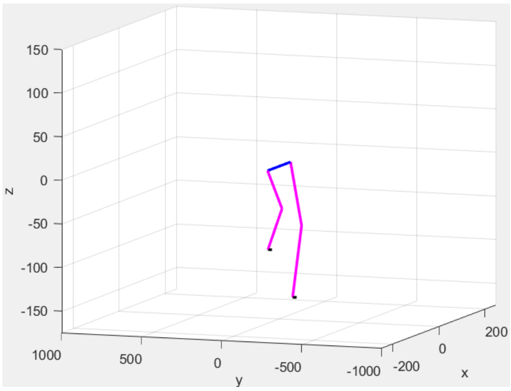


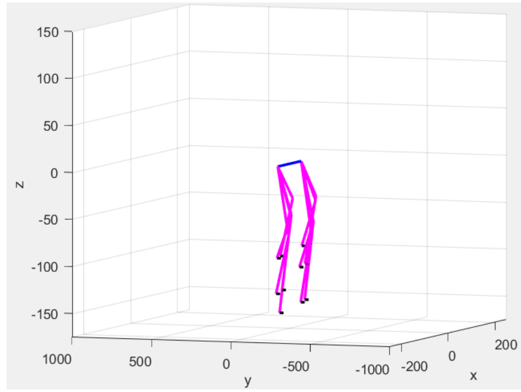
Fig. 2 (i)Left Turn (ii)Right Turn

As shown in the above figure are the turns taken by the robot in the left and right direction respectively. This is achieved by giving the appropriate torsoorient so that it can turn accordingly. Here it has been turned by 30 degrees in both the directions.

C. Cycling Robot

In this case the MATLAB code was fed with a circular trajectory for both the legs in the Y-Z plane with a phase π apart so that the cycling phenomena can be seen clearly. The first image shows the snap at a particular moment of the bicycling motion where as on the other hand the second image there are several such instants combined in a single image.





IX. Summary and Conclusion

Thus we conclude that kinematics is the base for several applications related to robot motion. It is the backbone of studying robotic structures and its motion. In this paper we successfully found out the DH parameters of the bipedal robot in accordance with the actual joint placement, assigned the appropriate floating base coordinate system, gave proper trajectory to the hip and both the ankles so that the robot can perform various movements and locomotion. We verified this experimentally using MATLAB where the robot turned, moved, cycled and performed other activities correctly. The work has been done in such a way that now the robot can perform any activity in a straight line motion or while standing at a single place.

X. Future Work

There has been left a wide range of topics to explore ahead of this like the walking in a circular path or walking on any irregular plane path or walking on an uneven surface. We can also explore how the robot can be made robust to minute disturbances or get up after falling down on the ground. Further there is a need for the dynamic simulations of the robot considering the mass factor of the links and various other factors of the robot.

References

[1] F. Sun, H. H. Ju and P. Y. Cui, "A new 12 DOF biped robot's mechanical design and kinematic analysis," Proceedings of 2011 International Conference on Electronic Mechanical Engineering and Information Technology, 2011, pp. 2396-2400, doi: 10.1109/EMEIT.2011.6023592.

https://doi.org/10.2514/1.16480

[2] Hun-ok Lim and Kensuke Tajima, "Development of a biped walking robot," 2007 International Conference on Control, Automation and Systems, 2007, pp. 1126-1131, doi: 10.1109/ICCAS.2007.4407070.

[3] C. Kilner, J. Monceaux, P. Lafourcade, B. Marnier, J. Serre, B. andMaisonnier, "Mechatronic design of NAO humanoid," inIEEEInternational Conference on Robotics and Automation, Kobe, 2009,pp. 769–774.

[4] M. Gienger, K. Loffler, and E. Pfeiffer, 2001, "Towards the design of biped jogging robot", Proc. of the IEEE International Conference on Robotics and Automation, pp. 4140–4145

[5] Y. Ogura, K. Shimomura, H. Kondo, A. Morishima, T. Okubo, S. Momoki, H. ok Lim, and A. Takanishi., 2006, "Human-like Walking with Knee Stretched, Heel-contact and Toe-off Motion by a Humanoid Robot", Proc. of IEEE International Conference on Robotics and Automation, pp. 3976–3981.

[6] John J.Craig, "Introduction to Robotics: Mechanics and Control, Third Edition.",Beijing, China Machine Press, 2006.6

[7] Xi Cao, Qun-fei Zhao, Pei sun Ma, "A closed-form Inverse kinematics Solution of a Biped Robot", in Mechanical and Electronic, 2006, pp.60-62.

[8]] P.R. Vundavilli, and D. K. Pratihar, 2011, "Balanced gait generations of a two-legged robot on sloping surface", Indian Academy of Sciences Sadhana, Vol. 36, Part 4, August 2011, pp. 525–550.

[9] Christine Chevalier, Guy Bessonnet, "Bipedal Robots Modeling, Design and Walking Synthesis", ISTE Ltd , 2009.

[10] Z.G.yu, Q. Huang, J.X. Li, Q. Shi, X.C. Chen, K.J.Li, "Distributed Control System for a Humanoid Robot", in Proc. IEEE Int. Conf. On Mechatronics and Automation, 2007, pp. 1161-1171.