Control of Bipod Robot and its stability

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Abstract—**The ideology of biped robotics has a very wide range of application making it a very crucial one. In order to achieve this, the most important factor to take into consideration is its stability. The stability affects the aesthetic structure as well as the systematic functioning of it. The sophisticated robot can also be programmed the alter the speed of motion, direction change and obstacle detection and motion for inclination. Issues can be resolved by the utilizing the concept of Zero Moment Point (ZMP). It is defined as the point at which all of the system's moment and inertia cancel out, or when there is no net moment. Also, the influence of center of mass (CoM) trajectory on biped robot stability was studied in this research. The biped walking robot that receives ankle rotation assistance may have an additional non-performing degree of freedom situated between the toe of the foot and the surface of contact. The biped models under consideration are the revolute and the prismatic one and using the knowledge of kinematics, an inference is drawn in which the superior model will be considered.**

Keywords— crucial, stability, aesthetic, trajectory, revolute, kinematics, moment, inertia.

I. INTRODUCTION

The invention and development of legged motion resulted in a technological revolution in transportation; the most important concept of this motion was bipedalism, which was inspired by humans. Modern bipedal robots are developing to the area of interest in which it could be applicable to substitute mankind in a vast range of jobs performed in surroundings composed only for mankind (such as the usual commercial and factory workplace). Leg movement is distinguished by the availability of numerous collection of surface touch points that result in similar postures. This feature is extremely effective in unusual landscapes because the humanoid body position is less restrained by obstructions (if one collection of surface contact areas is not possible due to an obstacle, after which alternate solution sets are generally possible), as contrasted to wheeled locomotion, which has fixed points of contact that cannot overcome the hindrances. Bipedal robot integrate the adaptability of human movement with a minimal amount of surface touch area (which simplifies the designing of propulsion algorithms) at the price of increased motion stability challenges.

Biped robots are often investigated with the goal of imitating human-like movement skills while also taking animal biped locomotion [1-3] into account. Human movement is divided into two instances: such as the swing instance as well as double foot supporting instance. Throughout the swinging stage, one foot, known as the balance assistance foot, remains grounded on the surface. Meanwhile, the other leg, known as the balancing leg, swings forward at a speed that is sufficient to keep the user from toppling over. Movement on two feet has a number of challenges, prominent among them being stability.

Static stability necessitates such the bipedal robot must be steady in any static arrangement, and its measurement is solely dependent of the information of position. The related idea is dynamic stability, that demands that the bipedal robot not collapse on the walking surface when displacing without regard for stability at any point of the trajectory. [4,5] Velocity data is also used to calculate dynamic stability.

II. 3-D LIPM AND ZMP

The Linear Inverted Pendulum Model (LIPM) is used to potray the estimated displacement of the bipedal walking robot while stably assisting its structure on its one foot. A 3-D linear inverted pendulum is such a system in which the inverted pendulum that travels in one plane alone. The physics model may be expressed as follows if the restricted plane is considred as a landscape plane.[6]

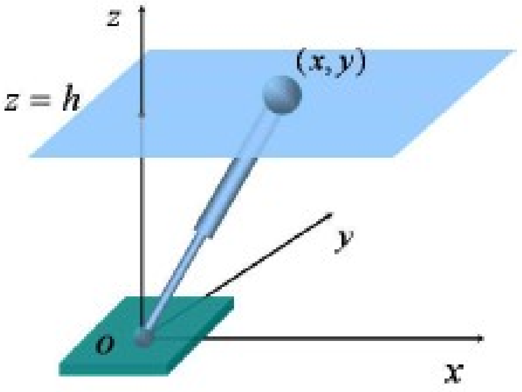

Fig. 1 3-D LIPM

$$\ddot{x} = \frac{g}{h}x + \frac{1}{mh}T_y \tag{1}$$

$$\ddot{y} = \frac{g}{h}y - \frac{1}{mh}T_x \tag{2}$$

Here the gravitational acceleration is considered to be g , the provided vertical height is h, the inverted pendulum has a mass of m, (x, y) as well as (¨x, ¨y) are considered as the location as well as the pendulum’s acceleration within the restricted plane, also the _x, _y are x-axis and the y-axis torque respectively.

Another key notion in biped walking is the ZMP. It is designated as the place lying on surface of the earth in which the moments cumulation (which can be considered as the inertia as well as the gravitational force) is a net zero [7].

Bipedal robot may walk in a steady way during which the ZMP lies in the limitation of the elliptic curve of the touchdown area within the leg and the surface of contact; the biped's feet will thoroughly contact the ground. It is especially important for humanoid bipod robots that have touch sensors positioned beneath their feet to be able to adjust their balance by using the input received from such sensor.

Calculating the ZMP in a three-dimensional LIP can be done by,

$$p_x = -\frac{1}{mg}T_y \tag{3}$$

$$p_y = \frac{1}{mg}T_x \tag{4}$$

where (px, py) are considered as the point of the ZMP. We can rewrite (1) and (2) as,

$$\ddot{x} = \frac{g}{h}(x - p_x) \tag{5}$$

$$\ddot{y} = \frac{g}{h}(y - p_y) \tag{6}$$

To accomplish full walking, the double-support phase might be scheduled in a lower-level planning based on ZMP decisions. Our simple bipedal walking model is as follows:

1) Consider the biped to be a linear inverted pendulum stably assisted with its anyone foot. The robot's combined mass is spread over the Center of Mass, and travels horizontally at a static and fixed height. Inertia's effects are disregarded.

2) The walking process is exclusively made up of single-support periods. Each of the robot's legs serves the stably assisting foot in each motion turn. In theory, one single-assisted moment might quickly move to the adjacent.

3) During the single-assistance moment, we employ a singular ZMP result rather than a ZMP trajectory.

III. CENTER OF MASS (CoM)

The information included in the center of mass states plays a crucial part with the management and steadiness of biped robots. The interference, expressed as the modelling fault as well as the acceleration fault, might have a negative impact on the optimization mechanisms. CoM conditions are employed in the standard of steadiness, either directly or indirectly through inertial and gravitational forces.[8-11]

Managing the biped CoM dynamics necessitates knowledge of the CoM states as well as the ZMP trajectory. The ZMP may be determined by utilizing constraint optimization to estimate the reaction forces and their placement.[12] The restrictions are caused by the leg coming into contact, friction, and the support polygon.[13] Process and measurement models are used to estimate CoM states. The perturbation might have a substantial impact on the system.[14] It may be approximated by representing it in the system model as an enhanced step disturbance state.

The position and the displacement speed states of the CoM are estimated.

To estimate the disturbance, the enhanced state approach is applied. Position and force measurements are included in the measuring model. Using accelerometer sensor and feet accelerometer sensor, the interference observation recored is utilized to measure the exterior factors. The ZMP interference observation divides the ZMP fault into the location as well as the acceleration fault focused on band of frequency, but it ignores the CoM states. [15]

The process dynamics of the prediction are formed using the LIPM dynamics as building blocks.

$$\ddot{c}_x = \frac{g}{z_c}(c_x - p_y) \tag{7}$$

$$\ddot{c}_y = \frac{g}{z_c}(c_y - p_x) \tag{8}$$

where c Z is the CoM's constant height. For the sake of simplicity, the subscripts x and y shall be ignored from now on. The following analysis applies to both the x and y dimension.

In an ideal setting, the force "p f" calculates the same p as the force "p".

$$p - c - \frac{z_c}{g}\ddot{c} \tag{9}$$

IV. BIPED MODELS

Both of the kinematic structures under consideration feature two feet also a rigid associating waist. Considering that the disposition of the biped examined within the study is limited to the sagittal surface, the feet that require that they displace within this surface, and therefore each of these have a smooth surface structure.

The initial structure's kinematics, in which each and every linkages are of the revolving type. Each leg contains three joints (all of which are systematically functioned) that correspond to the humanoid foot: the hip joint, the knee joint, and the ankle joint. A prismatic joint replaces the knee joint in the second construction. [16-18]

The modelling of each structure takes use of a significant notion that they are both sequential chain of kinematic, and therefore typical approaches for the kinematics as well as dynamical structuring of the sequential operators (6-dof sequential operators for each and every structure) may be applied. This process associates the manipulator's base with the assisting foot as well as the manipulator's end-effector with the balancing foot.

The influence as well as the surface response forces are represented as the exterior factors affecting on the manipulator's tip, i.e., the stability assisting foot.

The three joints of the 6R structure have and application to locate and organize the feet, but within the RPRRPR arrangement, the joint of the knee is solely utilized to place the legs, along with the joint of the ankle primarily employed for leg organization.

As a result, describing an associative disposition for the arrangement of the RPRRPR is less complicated than for structure 6R. [19-21].

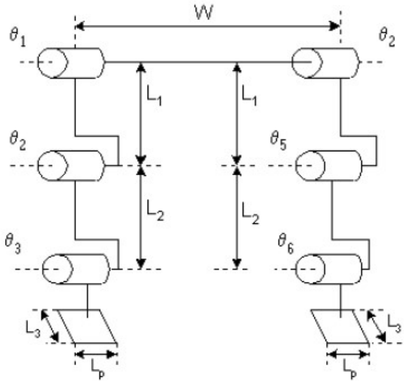

Fig. 1 Revolute Structure (6R)

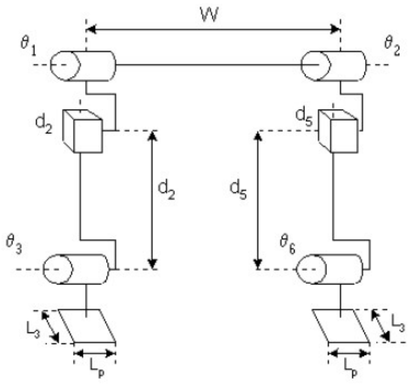

Fig. 2 Prismatic Structure (RRPRRP)

V. CONCLUSION

In this paper, we describe a novel approach for biped walking planning. We discussed the LIP model, the ZMP notion, and a simpler walking method. The control approach of managing the CoM trajectory to achieve a stable walking pattern was explored. Walking pattern generating system based on the notion of changing CoG ahead of time to respond to changes in road conditions as humans walk. Both of the structures that are shown cannot stand on their own because they are statically unstable, despite the fact that they are mechanically straightforward. In order to prevent the robot from toppling over, any maneuvers that are performed when it has just one foot grounded on the surface need to be performed quickly. Because of the rapid pace at which the robot moves, the actuators need to be powerful enough to provide significant torques and forces despite the rapid pace at which they operate. Also, the mobility description for the RPRRPR design is less restricted, with smaller amplitudes of hip and ankle joint motions than the 6R structure. As a result, the prismatic structure is selected for implementation.

REFERENCES

[1] M. Vukobratoviä, B. Borovac, " Zero-moment point -thirty five years of its life," International Journal of Humanoid Robotics (IJHR),vol. 01, pp. 157-173, 2004.

[2] A. Goswami, "Postural Stability of Biped Robots and the Foot-Rotation Indicator (FRI) Point," The International Journal of Robotics Research, vol. 18, pp. 523-533, June 1, 1999.

[3] A.I.Haldar and N.D.Pagar, "Predictive control of zero moment point (ZMP) for terrain robot kinematics", Materials Today Proceedings, vol. 80(15), 2022

[4] T. Sugihara, Y. Nakamura, and H. Inoue, "Real-time humanoid motion generation through ZMP manipulation based on inverted pendulum control," in Proceedings of IEEE International Conference on Robotics and Automation , pp. 1404-1409, 2002.

[5] S. Kajita, T. Nagasaki, K. Kaneko, K. Yokoi, and K. Tanie, "A Running Controller of Humanoid Biped HRP-2LR," in Proceedings of the IEEE International Conference on Robotics and Automation, pp. 616-622.

[6] K. R. Muske, T. A. Badgwell, "Disturbance modeling for offsetfree linear model predictive control," Journal of Process Control, vol. 12, pp. 617-632, 2002.

[7] H. Kobayashi, S. Katsura, K. Ohnishi, "An Analysis of Parameter Variations of Disturbance Observer for Motion Control," IEEE Transactions on Industrial Electronics, vol. 54, pp. 3413-3421, 2007.

[8] T. Sato, S. Sakaino, K. Ohnishi, "Parameter design for ZMP disturbance observer of biped robot," in 34th Annual Conference of IEEE on Industrial Electronics,pp. 1650-1655, 2008.

[9] G. A. Pratt, "Legged robots at mit: What's new since raibert." IEEE Robotics and Automation Magazine, 2000.

[10] Y. Nakajima, A. Yonemura, A. Kawamura, "Experimental approach for the fast walking by the biped walking robot mari-1. AMC", 2000.

[11] S. A. Takanishi, H. Lim, M. Tsuda, I. Kato, "Realization of dynamic biped walking stabilized by trunk motion on a sagittally uneven surface." In: Procs. of the IROS'90, 1990.

[12] K. C. Chanchai, C. Prabhas, "Automatic syn-thesis of robot programs for a biped static walker by evolution computation",. In: Procs. Second Asian Symposium on Industrial Automation and Robotics, 2001.

[13] Ching-Long Shi, "Ascending and descending stairs for a biped robot.", IEEE Trans. on Systems,Man and Cybernetics, Part A: Systems and Human, 1999.

[14] S. Kajita, F. Kanehiro, "Biped Walking Pattern Generation by using Preview Control of Zero-Moment Point", in Proc. of 2003 Robotics and Automation, vol. 2, pp. 1620-1626, 2003.

[15] N.D.Pagar, and S. H. Gawande. "Experimental investigations on meridional and circumferential stresses of bellows due to internal pressure." Gas Turbine India Conference. Vol. 83525. American Society of Mechanical Engineers, 2019.

[16] N. D. Pagar, S. S. Gawde, and S. B. Sanap. "Online condition monitoring system for rotating machine elements using edge computing." Australian Journal of Mechanical Engineering (2023): 1-14.

[17] B. K. Patle, N. Pagar, D. R. K. Parhi and S. Sanap, "Hybrid FA-GA Controller for Path Planning of Mobile Robot," 2022 International Conference on Intelligent Controller and Computing for Smart Power (ICICCSP), Hyderabad, India, 2022, pp. 1-6, 2022.

[18] N. D. Pagar "Influence of simultaneous optimisation to enhance the stress-based fatigue life of bellows joint." Australian Journal of Mechanical Engineering (2021): 1-16.

[19] Q. Huang, K. Yokoi, "Planning Walking Patterns for a Biped Robot", IEEE Trans. Robotics and Automation, vol. 17, pp. 280-289, 2001.

[20] S. A Darade., M. Akkalakshmi,, & N.D. Pagar, SDN based load balancing technique in internet of vehicle using integrated whale optimization method. In AIP Conference Proceedings (Vol. 2469, No. 1). AIP Publishing, 2022.

[21] S. Kajita, K. Tani, "Study of dynamic biped locomotion on rugged terrain-derivation and application of the linear inverted pendulum mode," in Proceedings of IEEE International Conference on Robotics and Automation, vol.2, pp. 1405-1411, 1991