Stable Locomotion of a 12 DoF Biped by Planning Centre of Mass Motion

Hurath Ramkumar, Garima Bansal, Alinjar Dan and Subir Kumar Saha

May 31, 2024

Stable Locomotion of a 12 DoF Biped by Planning Centre of Mass Motion

Hurath Ramkumar*, **Garima Bansal#**, **Alinjar Dan†**, **Subir Kumar Saha†**

* Mechanical Engineering
NIT Trichy
Tiruchirappalli, 620015, Tamil Nadu, India.
rhurathnitt@gmail.com

Agricultural and Food Engineering
IIT Kharagpur
Kharagpur 721302, West Bengal, India.
garimabansal.stem@gmail.com

† Mechanical Engineering
IIT Delhi
Hauz-Khas, 110016, New Delhi, India
alinjardannitdgp2014@gmail.com, saha@mech.iitd.ac.in

ABSTRACT

This work presents a stable locomotion of a 12 DoF biped using motion planning of its Centre of Mass (CoM). The biped is modelled as a 3-D Linear Inverted Pendulum (LIP). The walking pattern is generated using the CoM motion planner and foot pattern generator so that the CoM stays inside the Support Polygon (SP) created by feet during the locomotion. Ultimately, simulation and hardware results of biped locomotion using the proposed methodology are presented.

1 INTRODUCTION

Biped locomotion has inherent challenges because of its hybrid dynamics, effective underactuation and joint space control [1]. There exists more than one stability criterion which researchers have followed to achieve stable locomotion over the year, such as Zero Moment Point (ZMP) [2], limit cycle [3], Capture Point(CP) [4] etc. All criteria have limitations, e.g., ZMP [5] based criterion cannot be used straightforwardly for non-level surfaces, and limit cycle criterion is best suited for periodic locomotions. etc. However, a CoM-based criterion can be applied universally if the walking speed is sufficiently low. In the present work, stable locomotion of a biped is generated based on its CoM motion and foot pattern generator. Here, we have presented locomotion on level ground only, but the same criteria can be applied to walking on any surfaces because of using the CoM planner. This criterion was used earlier for quasi-static motion. However, it can also be used for locomotion with high speed if we can choose allowable CoM locations more conservatively.

2 METHODOLOGY

In the present work, we have generated CoM and, subsequently, the hip joint motion of a biped using the LIP model. The equations of CoM motion are

$$x_c(t) = x_c(0)\cosh(\frac{t}{T_c}) + T_c\dot{x}_h(0)\sinh(\frac{t}{T_c}), \qquad y_c(t) = y_c(0)\cosh(\frac{t}{T_c}) + T_c\dot{y}_h(0)\sinh(\frac{t}{T_c}) \tag{1}$$

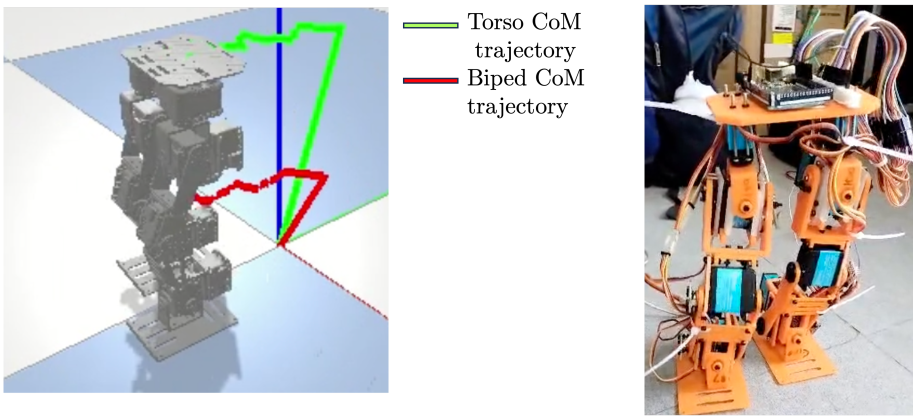
where $x_c(t)$ and $y_c(t)$ denote x and y- coordinate of the biped's CoM at time t, and $T_c = \frac{z_c}{g}$ (z_c is z-coordinate of CoM). From the CoM trajectory, torso CoM motions and, subsequently, hip joint motions are obtained with an assumption that the distance between the torso's CoM and the biped's CoM remains the same throughout the locomotion. The foot-pattern generator equation for n-th step is written as

$$x_f^n = s_x^{(n+1)}/2, \qquad y_f^n = (-1)^n s_y^{(n+1)}/2, \qquad z_f^n = 0, \tag{2}$$

Using equation (2), the ankle motion of the support leg is obtained. The swing leg's ankle motion is obtained as

$$x_a = -s_l\cos(\frac{\pi}{T}t), \qquad z_a = \frac{h_f}{2}[1-\cos(\frac{\pi}{t}t)] \tag{3}$$

where x_a and z_a are x and z coordinates of the ankle joint respectively. The variables s_l, h_f, and T denote step length, swing leg clearance and step time, respectively. After obtaining ankle and hip motion, inverse kinematics is performed to obtain the required joint trajectories. The joint trajectories are input to the system using position control. The generated biped locomotion using this methodology is shown next.



(a) (b)

Figure 1. Snaps from Biped locomotion: (a) Simulation in Pybullet, (b) Hardware.

3 RESULTS

Figure 1 shows snaps from the locomotion in simulation and hardware, respectively. The simulation is performed in Pybullet. For the hardware, Pybullet communicates the joint trajectories to an Arduino Microcontroller in real time. Then, Arduino sends the PWM signal to servo motors. The videos for the same is available here.

4 CONCLUSIONS

Using the proposed methodology, stable quasi-static locomotion of a biped on a level ground is shown in this work. This work will be extended to locomotions with larger step lengths, higher walking speeds, and various surfaces.

REFERENCES

[1] Eric R Westervelt, Jessy W Grizzle, Christine Chevallereau, Jun Ho Choi, and Benjamin Morris. *Feedback control of dynamic bipedal robot locomotion*. CRC press, 2018.

[2] Miomir K Vukobratović. Contribution to the study of anthropomorphic systems. *Kybernetika*, 8(5):404–418, 1972.

[3] Kyosuke Ono, Ryutaro Takahashi, and Toru Shimada. Self-excited walking of a biped mechanism. *The International Journal of Robotics Research*, 20(12):953–966, 2001.

[4] Jerry Pratt, John Carff, Sergey Drakunov, and Ambarish Goswami. Capture point: A step toward humanoid push recovery. In *2006 6th IEEE-RAS international conference on humanoid robots*, pages 200–207. IEEE, 2006.

[5] Shuuji Kajita, Hirohisa Hirukawa, Kensuke Harada, and Kazuhito Yokoi. Biped walking. In *Introduction to humanoid robotics*, pages 69–101. Springer, 2014.