Walking Generator and Stabilizer for Hephaestus

Haitao Wang and Mingguo Zhao[1]

[1] Tsinghua University, Beijing 100084, China
mgzhao@mail.tsinghua.edu.cn

Abstract. Some details about Walking Generator and Controller of Team Tsinghua University.

Keywords: Divergent Component of Motion, Inverted Pendulum.

1 Framework of Control System

To realize robust bipedal walking in RoboCup, we utilize the ZMP trajectory from Footprints as input to generate the Divergent Component of Motion(DCM) and Center of Mass Trajectory(CoM). The motivation and more details could be found in[1], we actually plan the DCM instead of CoM.

Fig. 1. UBTECH's newly developed multi-core heterogeneous processor hardware platform

Thanks to UBTECH's hardware platform WALKER+, with Harmonic gearbox, PMSM servo motors and 6-Axis force/torque sensors. We realize an accurate joint position controller and a compliant body and foot based on the admittance controller. The structure of our control board is the same as 2019[2], we have a DSP core to running gait planning and ARM core to control the joint servo based on EtherCAT. This year we update the control board(Fig.1) for high scalability, and optimization-based methods such as quadratic programming(QP) for low level control and model predictive control(MPC) for a high-level gait generator can be realized on it.

The Frame of walking is divided into two layers in Fig.2. We confirm the algorithm can be executed real-time in our own control board.

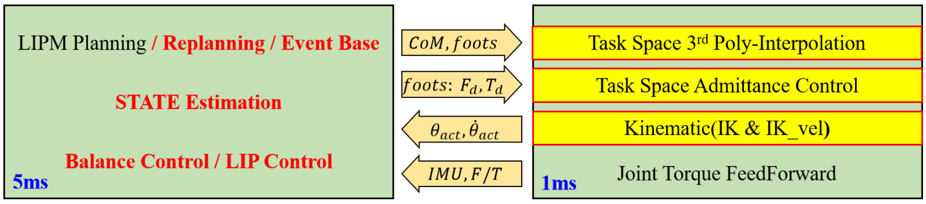

Fig. 2. Walking module frame work

2 Gait Generation

In this part, we mainly introduce the generation of ZMP and DCM from the high-level footprint command using piecewise polynomial. In our omnidirectional gait generator, we define foot center point as the middle of two feet while robot standing. Then we generate the position and orientation of footprint in next N steps by command message compatible with speed mode. More details can be seen in [1].

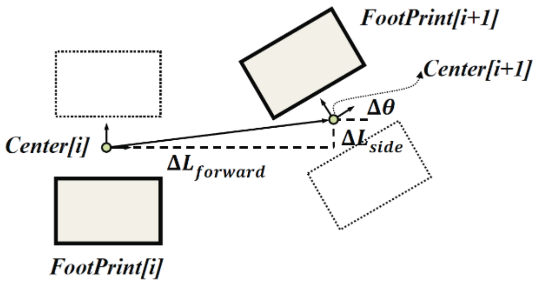

Fig. 3. Footprint Generation from high-level cmd.

We first compute the discrete ZMP or VRP in each footprint, then we can generate DCM initial points using backward iteration [3]. Finally, the piecewise polynomial can help to smooth both the VRP and the DCM trajectories due to the continuity relationship between DCM and VRP.

$$\dot{\xi} = \omega(\xi - \mathrm{vrp}) \quad (1)$$

Then we can get the trajectory of CoM following DCM, with a stable first-order dynamic:

$$\dot{x} = -\omega(x - \xi) \quad (2)$$

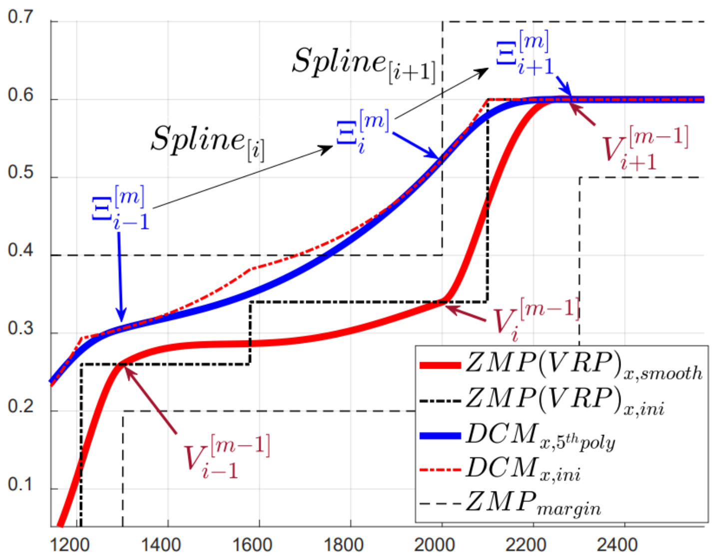

Fig. 4. ZMP and DCM generator based on piecewise polynomial

When we get the CoM trajectory, we have several ways to transform it into real robot kinematic joint angle: CoM inverse kinematics (RoboCup 2019), 3-Mass model (RoboCup 2018) or just fixed offset between CoM and waist. There is a trade-off between CoM inverse kinematics and the computation time, for we use an iteration based algorithm to search waist position to meet the right CoM.

The swing foot trajectory is designed as the 3rd polynomial in position (XYZ) and Euler angles (Pitch, Yaw) with different parameters in each state: normal walking, kick in walking, dribbling, high kick, etc.

3 Feedforward and Feedback

We test our inverse dynamic algorithm to compensate for the feedforward current (torque) of each joint, based on Recursive Newton-Euler Algorithm (RNEA).
And the feedback is mainly divided in three parts [1]: DCM tracking controller (5ms), DCM re-planning (100ms) and Foot landing complaint controller (1ms).
To reject small error of DCM, we generate the additional CoM acceleration according to a PD controller.

$$\ddot{x} = K_1(zmp_{est} - zmp_{ctrl}) + \ddot{x}_{ref} \quad (3)$$

$$\mathrm{zmp_{ctrl}} = zmp_{ref} + PD(\xi_{est} - \xi_{ref}) \quad (4)$$

However, due to the limited foot area, the modification of ZMP cannot too much. We have to take step adjustment to keep balance when large push occurs or ZMP meet the limits, the DCM trajectory and the swing foot should be re-planning at the same time.

4 Conclusion and Further work

The ZMP based gait generation has shown its stable performance in RoboCup2018 and 2019, however, the speed of walking is still too slow for the 9mx14m field. We are trying to use a more accurate whole-body controller to replace the DCM PD controller. And momentum-based optimization will generate a better high kick and high jump motion.

References

1. Wang, Haitao, et al.: Human-Like ZMP Generator and Walking Stabilizer Based on Divergent Component of Motion. In 18th International Conference on Humanoid Robots (Humanoids), pp. 1–9. IEEE, Beijing (2018).
2. Mingguo, Zhao, et al.: Tsinghua Hephaestus 2019 AdultSize Team Description," Humanoid League Team Descriptions, Robocup 2019, Sydney, (2019).
3. J. Englsberger, C. Ott, and A. Albu-Sch¨affer, "Three-dimensional bipedal walking control based on divergent component of motion," IEEE Transactions on Robotics, vol. 31, no. 2, pp. 355–368, (2015).