

# A General Framework for Dynamic Walking Control

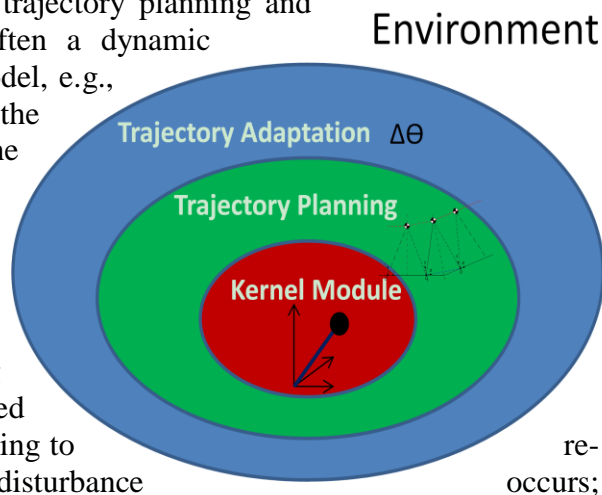
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Dynamic walking control remains a challenging problem due to complex models and underactuated foot-ground contact. Common approaches simplify the dynamics and apply modern control techniques for trajectory generation. Typical simplified models include LIPM (linear inverted pendulum model) [1], flywheel model [2] and planar based 5-link model [3]. Stability criteria such as ZMP (zero moment point) are often considered to maximize the stability margin. Since the early days of bipedal robot development, most powered bipedal robots walk with offline predefined trajectories with little adaptation to external disturbances. Consequently, these bipeds could not survive maneuvering in a dynamic human environment where unpredicted disturbances may occur at any time. To be able to walk in an unpredictable environment, the biped needs a flexible trajectory for adaptation ability.

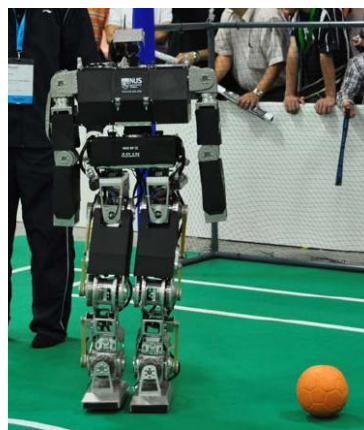
To enable a flexible trajectory for adaptation ability, we proposed a control framework. The framework includes three parts: kernel module, trajectory planning and trajectory adaptation. The kernel module is often a dynamic function which based on simplified dynamics model, e.g.,

LIMP, flywheel or 5-link planar model. Based on the kernel function, trajectory planning part of the framework generates the reference trajectory according to the stability criteria and constraints such as motion types, joint limit and step length.

Trajectory adaptation part modifies the reference trajectory if an unpredicted disturbance occurs. A trajectory adaptation is needed for the following reasons: 1) it is impossible to model the unpredicted disturbance; 2) it may be computationally demanding to compute the reference trajectory whenever disturbance and; 3) the adaptation can often be computed in a simple and intuitive way.



We have implemented this concept on our robot ASLAN which participated in Robocup 2010 under Team RO-PE. The kernel module is a 3D LIPM [1]. The advantages of LIMP for the kernel selection are: 1) solution of the linear differential equation could be obtained with relative ease; 2) low computation cost makes LIMP attractive for real-time application. In the trajectory planning part, a preview control method is adopted to generate the reference trajectory while keeping the ZMP in a safe zone. Two methods are adopted for trajectory adaptation: 1) tile compensator by modifying the stance foot ankle joints; 2) foot landing compensator by modifying the swing foot ankle joints. These strategies enable the robot a robust ground walking even with tiny stone or little inclination. The robot achieved the first prize in the adult-size humanoid league in Robocup 2010.



[1] S. Kajita, F. Kanehiro, K. Kaneko, K. Fujiwara, K. Harada, K. Yokoi, and H. Hirukawa, "Biped walking pattern generation by using preview control of zero-moment point," in *IEEE International Conference on Robotics and Automation (ICRA)*, Taipei, Taiwan, pp. 1620–1626, 2003.

[2] J. Pratt, J. Carff, S. Drakunov, and A. Goswami, "Capture point: A step toward humanoid push recovery," in *6<sup>th</sup> IEEE-RAS International Conference on Humanoid Robots*, December 2006, pp. 200–207.

[3] E.R. Westervelt, J.W. Grizzle, D.E. Koditschek, "Hybrid zero dynamics of planar biped walkers" *IEEE Transactions on Automatic Control*, Volume: 48 Issue 1, pp.: 42 – 56 2003.