Chapter 35
Prototyping and Real-Time Implementation of Bipedal Humanoid Robots:
Dynamically Equilibrated Multimodal Motion Generation

Barkan Ugurlu
Toyota Technological Institute, Japan

Atsuo Kawamura
Yokohama National University, Japan

ABSTRACT

This chapter is aimed at describing a contemporary bipedal humanoid robot prototyping technology, accompanied with a mathematically rigorous method to generate real-time walking, jumping, and running trajectories that can be applied to this type of robots. The main strategy in this method is to maintain the overall dynamic equilibrium and to prevent undesired rotational actions for the purpose of smooth maneuvering capabilities while the robot is in motion. In order to reach this goal, Zero Moment Point criterion is utilized in spherical coordinates, so that it is possible to fully exploit its properties by the help of Euler's equations of motions. Such a strategy allows for characterization of the rotational inertia and therefore the associated angular momentum rate change terms, so that undesired torso angle fluctuations during walking and running are well suppressed. It enables prevention of backwards-hopping actions during jumping as well. To validate the proposed approach, the authors performed simulations using a precise 3D simulator and conducted experiments on an actual bipedal robot. Results indicated that the method is superior to classical methods in terms of suppressing undesired rotational actions, such as torso angle fluctuations and backwards-hopping.

INTRODUCTION

Starting from 1970s, humanoid robots have evolved in many aspects and they are still expected to be adapted within the dynamic human environment. Considering such an environment, people may walk, run, jump and interact with others in various cases. Therefore, a well-adapted bipedal humanoid robot should function this kind of human-like dexterity for the purpose of providing compatible human-humanoid interaction capabilities. Some futuristic aspects regarding this matter are discussed by Kajita & Sugihara (2009), within an extensive manner.

In humanoid robotics technology, bipedal trajectory generation is known to be one of the most challenging issues. Formally speaking, humanoids interact with the outer environment through floating base points, i.e., through their feet and hands. These unilateral contacts make them underactuated and thus nonlinear. Besides this structural property, yet another nonlinearity arouses from the motion interference between sagittal and lateral planes through intrinsic angular momentum (Ugurlu, 2010) rate change terms. All together with other unmentioned nonlinearities, bipedal trajectory generation may be regarded as a complicated task.

In general, bipedal motion planning algorithms bifurcate into two main approaches: a) Multi-mass based approach; b) Abstracted dynamics approach. The first approach is known to be accurate and usually utilized to build dynamic and precise simulation environments (Fujimoto, & Kawamura, 1998; Kanehiro et al., 2004). On the other hand, its real life applications on actual robots may suffer from various deficiencies. For instance, inaccurate CAD (Computer Aided Design) data of mechanical hardware and unmodelled dynamics -such as joint frictions and inherent compliance- can be listed in this matter. In addition to these difficulties, multi mass approach is considered to be computationally expensive and it has inherent drawbacks during the online implementation on built-in computers, which are usually placed in humanoid robots.

In the second approach, the overall humanoid dynamics are usually abstracted by employing different modeling tools, such as, planar and spatial inverted pendulum (Kajita, &Tani, 1991; Kajita et al. 2001), spring-loaded pendulum (Poulakakis, &Grizzle, 2009), variable impedance (Jafari et al. 2010) pendulum and so on. The basic idea is to capture the essence of dominant humanoid dynamic characteristics, so that researchers can obtain applicable motion generation and control techniques. Even though there may be no clear and quantitative way to express the actual accuracy of these methods in representing the dynamics, it is possible to quantify their effectiveness through experimental studies. What is more, dynamic error compensators (Takenaka et al., 2009a) might allow us to regulate some of the unmodelled aspects in these approaches.

ZMP (Zero Moment Point) (Vukobratovic, &Borovac, 2004; Kajita, &Espiau, 2008) appears to be a de facto standard while indicating the dynamic balance of a humanoid robot. Some other ground reference points can be examined in (Popovic et al., 2005) and (Hirukawa et al., 2006) as well. By the definition, the ZMP is a point on the floor, in which the total moment acting on the robot due to gravity, centroidal torques and inertial forces equals to zero. In order to ensure the dynamic balance, the ZMP response must be within the convex hull of the support polygon. If the actual ZMP reaches to the edge of the support polygon, the robot is considered to be losing its dynamic equilibrium. Three different scenarios are illustrated in Figure 1.

In comparing ZMP equations with inverted pendulum's mathematical model, one may easily think that they resemble to each other. Oftentimes, ZMP's mathematical model is considered to be forced pendulum equations. In other words, ZMP equations become equivalent to inverted pendulum equations in case of zero ZMP values, both for x-axis and y-axis (the homogenous case). Gener-

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