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Overview of Gait Synthesis for the Humanoid COMAN

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Abstract

This paper focuses on the developments of a generic gait synthesis for the humanoid robot COMAN. Relying on the essential Gait Pattern Generator (GPG), the proposed synthesis offers enhanced versatilities for the locomotion under different purposes, and also provides the data storage and communication mechanisms among different modules. As an outcome, we are able to augment new abilities for COMAN by integrating new control modules and software tools at a cost of very few modifications. Moreover, foot placement optimization is introduced to the GPG to optimize the gait parameter references in order to meet the robot's natural dynamics and kinematics, which enhances the synthesis's robustness while it's being implemented on real robots. We have also presented a practical approach to generate pelvis motion from CoM references using a simplified three-point-mass model, as well as a straightforward but effective idea for the state estimation using the sensory feedback. Three physical experiments were studied in an increasing complexity to demonstrate the effectiveness and successful implementation of the proposed gait synthesis on a real humanoid system.

Keywords: humanoid robots, bipedal locomotion, gait synthesis, dynamic walking

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1 Introduction

Humanoid robots have been gaining an increasing attention in the recent years due to their improved technological readiness and the potential to have real outdoor applications. With the anthropomorphic morphology, humanoids possess a great potential of completing the tasks undertaken by humans[1–3], such as using human-oriented tools, driving vehicles, traversing unstructured terrains where the wheeled robots cannot go, operating in hazardous environment, rescue/repair in disaster responses, and the like. In short, humanoid robots or their variants, as a question of time, earn good motivations under the context of our aging society, and can be deployed as general machines with a fairly large spectrum of skills. The scenarios of exploring humanoid robots as a universal machine are illustrated in Fig. 1 from some research works conducted on the COMAN robot[4].

To achieve the completion of tasks in real world, a physical mobility is the fundamental basis. Therefore, a reliable and robust locomotion skill shall be addressed first. Hence, researchers have made tremendous efforts in the past to improve bipedal walking for humanoids. A widely implemented class of gait pattern generations are developed based on the Zero Moment Point (ZMP)[8], such as HUBO[9], ASIMO[10], HRP[11] and the Atlas[12]. The generated gait patterns are then combined with feedback controllers to stabilize the motion of the robot by either tracking the planned references at very time

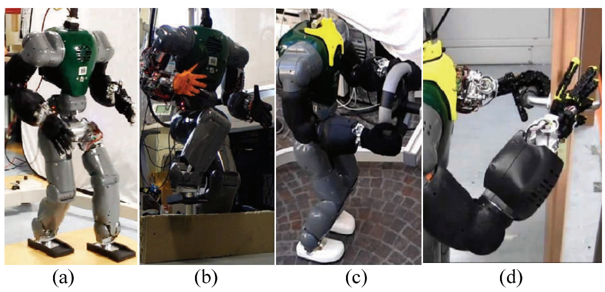

Fig. 1 COMAN's demonstration as a general machine with versatile skills for solving complex tasks in real world scenarios. (a) Fast dynamic walking; (b) obstacle negotiation[5]; (c) valve turning[6]; (d) door opening[7].

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instant[13,14], or reactively replanning the references[15–17]. For this class of control, we have a number of options of classical and modern linear controllers to improve the performance and realize different functionalities[18–20]. Pratt *et al*.[21] have presented a capturability-based framework for balance and walking control of legged robots. Englsberger *et al*.[22] have successfully implemented the Divergent Component of Motion for realizing the dynamic bipedal gaits. Some other robots, such as MABEL[23] and ATRIAS[24], have adopted a different approach where nonlinear control plays an important role and the finite state machine approach is commonly used. This alternative solution often offers an interesting feature in terms of agility and energy efficiency. However, in turn, its nonlinear feature makes the stability analysis very difficult, and the implementation of 3D walking is rather rare to date.

Research efforts are made on the humanoid robots for improving their adaptability in human daily environment. This trend is been accelerating after the disaster happened at Fukushima Daiichi nuclear power plant in 2011. The DARPA Robotics Challenge (DRC) was heavily influenced by the events at Fukushima, thus it imposed a big challenge for the locomotion by requiring every robot to operate in outdoor environment without a safety harness. Complex tasks such as stair-climbing, vehicle egress, rough terrain traversal *etc*. demand advanced locomotion ability. It is critical that every team concentrates in not only developing algorithms for specific tasks[25,26], but also integrating different controllers[27–30].

During the preparation of the WALK-MAN team for the DRC finals, we were motivated by the tasks requirements, and learned the importance of having a generic locomotion module that can be easily adapted to tasks without too much modifications of an existing framework, which could significantly facilitate system integration. Therefore, in this paper, we present an overview of our gait synthesis which is developed and validated on the COMAN platform that targets on the advanced locomotion skills for humanoid robots. The inherent expendable structure of the proposed synthesis offers enhanced versatilities for the locomotion under different purposes by introducing plug-in modules, and also provides the data storage and communication mechanisms among different modules. As an outcome, we are able to augment new abilities for COMAN by integrating new control modules and software tools at a cost of very few modifications.

The rest of this paper is organized as follows. Section **2** briefly introduces the components of the proposed gait synthesis. Section **3** presents the modules of GPG, such as the optimization of foot placement and step time, the Center of Mass (CoM) and foot trajectories generation, as well as the three-mass model used for analytically generating the pelvis motion from the CoM/feet trajectories. Section **4** elaborates the main concepts of Interactive Data Server and explains two most frequently used services. Section **5** demonstrates the effectiveness of the proposed gait synthesis from three different locomotion tasks. We summarize and conclude our study in section **6**.

2 Overview of the gait synthesis

As shown in Fig. 2, the proposed gait synthesis mainly consists of four parts: the essential GPG, High Level Controllers, Walking Plug-in Modules, Interactive Data Server (IDS). The COMAN is the test bed for hardware implementation and validation.

The GPG takes the sequence of desired foot placements as inputs and generates reference trajectories to perform dynamic walking. It firstly solves a nonlinear constrained optimization problem to adjust the foothold location and time in order to warrant both kinematic and dynamic feasibilities, then generates ZMP references including gait initiation and termination phases. The horizontal CoM references are therefore produced using a predictive control scheme, combined with the body orientation and vertical CoM motion in the case of non-straight/non-at walking. The references of CoM will then pass into a simplified dynamics filter in order to obtain the pelvis motion. By solving the inverse kinematics given the pelvis and feet references, the joint angles of lower body are obtained and then sent to the robot. Details of this controller will be explained in section **3**.

The High Level Controllers are the modules that provide global settings, environmental information or autonomous decisions that considered as the higher hierarchy in the whole control framework, compared to the GPG and Walking Plug-in Modules. For example, user commands, perception, navigation *etc*. are within this scope, especially the footstep planner, which generates a sequence of desired foot placements, is a higher