Learning to Walk Dynamically: Optimal Control Parameterization

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1 Motivation

Articulated structures such as humans or humanoid robots (HR) have many joints and complex multibody and muscle dynamics. Control functions (neural signals to muscles) have to achieve optimal trade-off between, at least, three important but contradicting performance indices: locomotion speed, accuracy of steps, and energy consumption.

Performing a step in dynamic biped locomotion is characterized by three phases: taking-off, flying, and landing. The bipedal motion can be considered as a composition of several goal-directed movements with different dynamics structures, which implies different control structures for the corresponding phases.

For dynamic goal-directed movements, we can apply an efficient control learning (CL) scheme which has the following main steps, [1-2]:

1. *Choose a set of appropriate test control functions*

2. *Define the most relevant pairs of control parameters and controlled outputs*

3. *Solve shooting equations and perform control parameter optimization*

2 State of the Art

Most of the existing control schemes for walking bipeds are based on the so-called zero-moment point (ZMP) stability condition. Such schemes have three common characteristics: 1) bending at knees thus to avoid singular positions; 2) closed-loop controllers for trajectory tracking at the joints, 3) using higher power actuators, in particular at ankles, to compensate for the rotational motion (falling down) of the body above the ankle; This concept is in contrast with the concept of passive dynamic walking and cannot lead to energy efficient and naturally looking locomotion.

3 Our Approach

We have been developing [1-2], a generic control design approach for robotic systems that perform goal-directed and/or posture-stabilization motion tasks. Correspondingly, the controllers are open loop and closed-loop with bounded control functions. Correspondingly, we apply the CL scheme and optimal robust controllers. Our principal guideline in the control structure design is, for any task, to have a fully controllable system.

Of primary importance is to define a set of variables that best characterize the dynamic performance of the HR in the required motion task. Then, to enable the HR to fulfill the task, driving forces/torques are to be properly assigned. Our approach is based on the real robot/human dynamics and its control concepts are biologically plausible. Moreover, the proposed LC approach has the necessary mathematical guarantees for its feasibility and fast convergence.

4 Current Results

Our control concepts have been successfully verified in numerous computer simulations. We have considered two main tasks: upright posture stabilization with two controlled joints and 2D walking for a biped with six controlled joints. Satisfactory motion performance has been achieved in both case-studies.

We have found that that our approach is very promising and could be efficiently applied to the more complex, humanoid robots. We think that in order to achieve human-like locomotion, the biped has to have at-least eight links: trunk, pelvis, two thighs, two shanks, and two feet.

5 Best Possible Outcome

Our current research intention is to extend the proposed approach to meet the next challenge: optimal control synthesis of 3D humanoid locomotion to produce efficient and naturally looking walking. As the above proposed control concepts are biologically plausible, they could also be very useful in designing and controlling leg prostheses as well as in neuro-muscular rehabilitation of disabled people.

References

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[2] Kiryazov K. and P. Kiriazov, (2010) Efficient learning approach for optimal control of human and robot motion, in: Emerging Trends in Mobile Robotics, Eds: H. Fujimoto *et al* 2010, 1219-27.