Bio-inspired controllers for dynamic walking: CPG enhanced with minimal feedback

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I. Motivation

In recent years there has been a growing interest in the field of dynamic walking and bio-inspired robots. However, while walking and running on a flat surface have been studied extensively, walking dynamically over terrains with varying slope remains a challenge.

II. State of the Art

Many of today's successful biped robots are controlled based on the Zero Moment Point (ZMP) method, which generates robust locomotion for flat-footed bipeds on a controlled environment. These controllers usually generate slow gaits with a low energy efficiency which do not look natural or human-like. In contrast, Passive Dynamic Walkers [2], [5] are fast, efficient and resemble human walking. Motivated by these capabilities, different passivity-mimicking dynamic walkers [1], [2], [3], [8] have been developed.

Most published works deal only with dynamic walking over flat terrain and only a handful investigate the effects of varying slopes on gait stability, usually remaining within the range of $\pm 5^\circ$ even when using complex models with knees or a torso. Goswami et al. developed a passivity mimicking controller that uses continuous feedback to maintain a predefined energy level and progression speed. This controller allowed a compass biped model to walk on slopes of up to $+12^\circ$.

Stable, dynamical gaits that are robust to disturbances can be generated by central pattern generators (CPGs), as shown in studies of animal locomotion [6]. CPGs are networks of coupled oscillators whose outputs are converted into control signals that drive the different muscles. CPGs are especially suited to control legged robots since they can take advantage of the robot's inertia and allow for free dynamic motion of the robot, utilizing minimal periodic actuation during the gait.

III. Own Approach

We applied a CPG based controller to a compass biped. The CPG generates a discrete, periodic signal which triggers a pre-planned parametric activation signal, such as a pulse defined by amplitude and duration. The bio-inspired controller generates stable walking gaits over a small range of slopes without any feedback, as detailed in [7]. While continuous feedback can improve the performance of the open loop controller, it may require excessive resources and may even hamper performance if the feedback is too noisy or delayed [4]. Hence we focus on strategies that involve minimal feedback, and in particular, once per step feedback using the terrain's slope.

IV. Current Results

Through numerical simulations we have demonstrated how the robustness of the open loop CPG controller [7] can be greatly enhanced by applying a minimal, once per step feedback that modifies the parameters of the activation pattern and the frequency of the CPG. The controller improves the robustness of the open loop controller ten-fold, allowing the robot to walk on slopes ranging from $+10^\circ$ to -10°, comparable to most slopes in human constructed environments.

V. Best Possible Outcome

The controller's open loop parameters and feedback gains where hand-tuned. We have recently used Multi-Objective Optimization (MOO) to systematically tune these parameters and improve energy efficiency. The algorithm found slow, efficient gaits as well as faster, less efficient gaits. We are currently extending the MOO to properly tune the feedback gains. Furthermore, we are extending the simple CPG controller to generate stable gaits for the ATLAS robot of the DARPA Robotics Challenge.

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References

[1] S. Collins, A. Ruina, R. Tedrake, and M. Wisse. Efficient bipedal robots based on passive-dynamic walkers. *Science*, 307(5712):1082–1085, 2005.
[2] A. Goswami, B. Espiau, and A. Keramane. Limit cycles in a passive compass gaitbiped and passivity-mimicking control laws. *Auton. Robots*, 4(3):273–286, July 1997.
[3] F. Iida and R. Tedrake. Minimalistic control of biped walking in rough terrain. *Autonomous Robots*, 28:355–368, 2010.
[4] A. D. Kuo. The relative roles of feedforward and feedback in the control of rhythmic movements. *Motor control*, 6(2):129–145, 4 2002.
[5] T. McGeer. Passive dynamic walking. *The International Journal of Robotics Research*, 9(2):62–82, 1990.
[6] R. H. Rand, A. H. Cohen, and P. J. Holmes. *Systems of coupled oscillators as models of central pattern generators*, chapter 9, pages 333–367. John Wiley & Sons, 1988.
[7] J. Spitz, Y. Or, and M. Zacksenhouse. Towards a biologically inspired open loop controller for dynamic biped locomotion. In *Robotics and Biomimetics (ROBIO), 2011 IEEE International Conference on*, pages 503–508, 12 2011.
[8] G. Taga, Y. Yamaguchi, and H. Shimizu. Self-organized control of bipedal locomotion by neural oscillators in unpredictable environment. *Biological Cybernetics*, 65:147–159, 1991. 10.1007/BF00198086.

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