Energy-efficient planning for dynamic legged robots on patterned terrain

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Summary

Passive dynamics-inspired powered robots have demonstrated limited versatility which is defined as ability to walk on patterned terrain such as stairs or stepping stones. The gap in knowledge is that it is unclear how to create motion plans for such robots without compromising on the energy-efficiency. The proposed algorithm consists of two stages: (1) create a table of energy-efficient walking motions as a function of key gait parameters such as step length and step velocity; and (2) use a heuristic search to find the most energy-efficient solution based on terrain constraints. The table of energy-efficient motions was created using optimal trajectory control. The heuristic search is based on finding the best next-step by sorting the table in increasing order of energy usage. The approach is illustrated on a 2-D robot model and a terrain consisting of stepping stones.

Introduction

Bipedal robots inspired from passive-dynamics exploit their natural dynamics to achieve high energy efficiency [1, 2]. So far these robots have been limited to walking on flat ground at a single speed and step length. For these robots to be able to walk in human-like environments, they would have to be able to traverse patterned terrain consisting of ditches, stairs, and obstacles. The challenge then is to create motion plans for these robots to enable them to walk on patterned terrain without sacrificing energy-efficiency. In this paper, we present some preliminary results towards this objective.

Methods

First, we create a database of energy-optimal motion plans parameterized by step length and step velocity. Our metric for energy efficiency is the Cost Of Transport (COT) which defined as the energy used per unit weight per unit distance moved. To do this, we solve an energy-optimal trajectory control problem using a robot model and imposing various constraints such as actuator limits, periodicity, foot scuffing, etc.

Second, we use a heuristic search for motion planning. To do this, we sort the database in increasing value of the energy cost. Next, the terrain is scanned for location of the ditches and the most energy-efficient step and corresponding velocity is chosen from the database. The process is continued till the end of the terrain.

Results and discussion

We start the robot with an arbitrary initial velocity. Fig. 1 (a) shows the terrain with stepping stones in gray. The planned footstep locations are shown with a blue star. The velocity corresponding to a step is shown in (b).

We tried adding heuristic cost to the optimization that penalizes change in velocity between steps. This leads to a conservative walking strategy consisting of short steps and more or less uniform walking speed. We have also implemented a two-step planning algorithm that leads to an equal or slightly more energy-efficient motion plan compared to the one-step algorithm that we have described here.

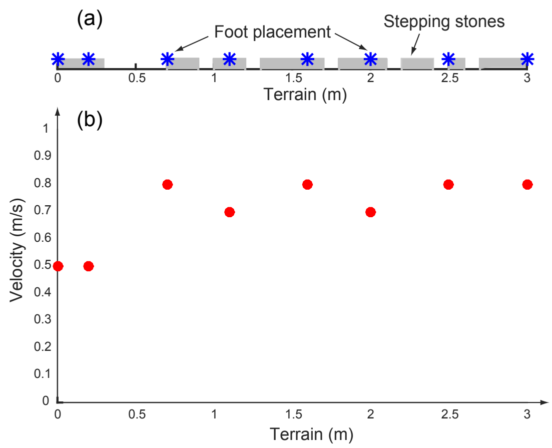

Figure 1: (a) Stepping stones in grey and foot placement strategy as blue stars. (b) Velocity at each step.

References

[1] S. Collins, A. Ruina, R. Tedrake, and M. Wisse. Efficient bipedal robots based on passive-dynamic walkers. *Science*, 307:1082–1085, 2005.

[2] J. A. Grimes and J. W. Hurst, The design of ATRIAS 1.0 a unique monopod, hopping robot *International Conference on Climbing and Walking Robots and the Support Technologies for Mobile Machines*, 548–554, 2012.