Braitenberg Control of a Seven-Link Walking Model

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SUMMARY

Control of Limit Cycle Walking robots is challenging because of the complex dynamics involved. However, recent research has shown that simple, linear control principles can serve as an effective framework for enabling stable, efficient walking. Embracing this linear approach, the present study applies a fully-connected, linear control architecture, inspired by Braitenberg vehicles, to the task of locomotion over unpredictable, rugged terrain with a seven-link walking model. Stable and efficient walking performance is achieved.

INTRODUCTION

Control of bipedal robots is difficult due nonlinear, non-stationary, discretely-changing, underactuated dynamics, in combination with high-dimensional state and action spaces. Although these characteristics may motivate application of nonlinear control principles, relatively simple linear control laws have had significant success, both in simulation and in hardware [1]. Inspired by these results, we decided to investigate the efficacy of a linear, "Braitenberg-style" control architecture in the control of Limit Cycle Walking.

Braitenberg vehicles are classic two-wheeled mobile robots that compellingly demonstrate how surprisingly sophisticated behaviors can emerge as a simple agent following simple rules interacts with its environment [2]. In one popular instantiation, the motor on each wheel is directly connected to each of the vehicle's sensors (e.g., light, temperature, proximity), and the motor speed is proportional to the weighted sum of the sensor inputs. In this study, we show that a form of the Braitenberg control architecture is remarkably well-suited for Limit Cycle Walking.

METHODS

The 2D biped model has seven links, including feet, shins, shanks, and an upper body (total leg length = 65cm), and the goal is for it to stably traverse rugged terrain, with a step-to-step ground height standard deviation of about 3.3 cm (5.0% leg length; see Figure 1). A total of seven Braitenberg-style neural networks are used, one to control each of the following: upper body angle, inter-leg angle, stance knee angle, swing knee angle, stance ankle angle, swing ankle angle, and the duration of push-off. The stance leg is determined using a simple heuristic, based primarily on binary foot contact sensor information. The neural network inputs include the angle and speed of each joint, a binary "in push-off phase" variable, and a bias. The outputs of the six neural networks for controlling the joint angles are sent to Proportional-Derivative (PD) controllers to compute torque.

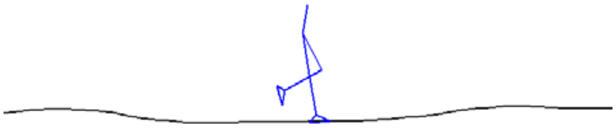

Figure 1: The seven link model, walking along a typical terrain profile.

A standard real-valued genetic algorithm was used to optimize the neural network weights and PD gains. The optimization criteria used (the "fitness function") is the distance *d* the biped walks before expending a fixed amount of energy (2000J) or falling down, thus encouraging the evolution of a controller that is both stable and efficient. The terrain was randomly regenerated each generation to ensure that the controller evolved to be effective over unpredictable terrain.

RESULTS

A total of 15 runs of the genetic algorithm were completed, all evolving stable controllers. To assess the general performance of the best controller from each run, it was tested over 100 terrain profiles. The average fitness (distance traveled) was $d = 95.0$m, and the biped fell down on an average of 15.4% of the test terrains. For the highest fitness run, the biped achieved $d = 108.4$m, fell down on 12% of test terrains, and exhibited a specific cost of transport of 0.173. This is quite efficient considering humans walking *on level ground* have a specific cost of transport of 0.2.

DISCUSSION

The Braitenberg control architecture has shown to be extremely effective when applied to the Limit Cycle Walking control of a 2D, seven-link walking model. The results are noteworthy considering the level of stability and efficiency that was achieved over rugged terrain. The next phase of this research will involve application to a 3D walking model, and subsequently an actual bipedal robot.

REFERENCES

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