Cerebellar Balance for Humanoids

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SUMMARY

We outline the goals of a seed design task at the Jet Propulsion Laboratory (JPL) for a search and rescue humanoid robot, including areas of direct relevance to Dynamic Walking. In preliminary work, we have begun simulation studies of passive-dynamic walking using a simple 2-D model on a noisy slope. A cerebellum-inspired neural network was trained on walking trajectories to predict falls several steps prior to their occurrence. This cerebellar network is expected to scale well to help dynamically balance a high DOF humanoid performing a variety of behaviors.

INTRODUCTION

The Robotics and Mobility Section at JPL has been involved in a number of studies for highly dexterous/ coordinated robots. Under a new seed task we are working towards a preliminary design for a humanoid robot. Such a biped robot would be able to assist crew in various surface operations and act in search and rescue missions. Dynamic Walking studies can play an important role because one of the major requirements is power efficient legged locomotion. However, a practical humanoid requires much more than efficient walking – it has to balance power efficiency with other capabilities and constraints. For example, objectives will include stable and power efficient walking over smooth or rough terrain, combined with sensing and manipulation for lifting and carrying heavy payloads, and practical power storage.

One of the tasks to support the humanoid design study is to explore dynamic balance for stable walking and manipulation. As an initial candidate for balance control, we developed a neural network for dynamic state estimation and predictive control [1], inspired by the cerebellum, the brain's "engine of agility".

METHODS

The neural network is comprised of a 2-layer RBF network that combines Hebbian and reinforcement learning to correlate sensory, state, and motor variables. It acts as an associative memory to estimate and predict state space trajectories. To explore cerebellar state estimation for dynamic walking, we first simulated a simple 2D compass-gait biped model in MATLAB [2]. Each trial consisted of a sequence of up to 10 steps, the first at the ideal slope to initialize network variables, and the remainder at a non-ideal fixed slope chosen from a normal distribution about the ideal. The input state-space was reduced to two variables: pitch angle and pitch angular velocity. The network output cells were trained to remain at nominal firing rate during good steps, decrease firing during steps leading to backward falls, and increase firing during steps leading to forward falls. This activity was used to estimate probabilities of falling forwards or backwards.

RESULTS AND DISCUSSION

The preliminary cerebellar network successfully learned the state space for this simple walking model. On an unknown fixed slope, it can predict the fall and fall direction several steps ahead of ahead of time by looking at the pitch dynamics alone (Fig. 1). We will next increase the model complexity, beginning by varying the slope on each step to simulate "rough terrain" [3].

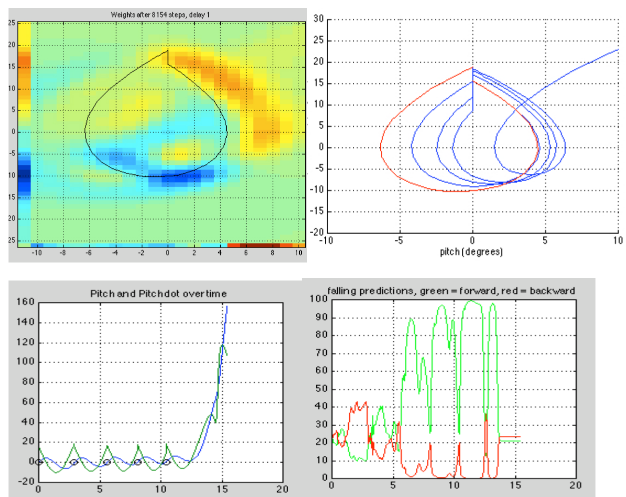

Figure 1. Top: Network weight map and a walking trial, in the state space of pitch velocity vs. pitch angle. Bottom: Falling direction is predicted 3 steps in advance.

The cerebellar network can learn to estimate state variables, predict trajectories, and modulate actuation. We will use it to explore critical issues: How to learn actuator responses to correct instabilities before a fall? How to scale up to handle high DOF 3D models? What is a minimal sufficient set of actuation/sensing to achieve dynamic balance? Ultimately, how to stably add functionality (turning, start/stop, carrying payload, etc.)? We look to the Dynamic Walking community to provide efficient, stable walking under a variety of postures and payload conditions – to help enable the first dynamically stable and practical walking humanoid.

REFERENCES

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