Robust 3D locomotion models using primarily reflex control

Seungmoon Song and Hartmut Geyer
Robotics Institute, Carnegie Mellon University
email: {smsong,hgeyer}@cmu.edu

1. Motivation

Understanding the neuromuscular control of human locomotion has the potential to deliver practical controllers for bipedal robots that robustly walk and run in unstructured environments. We aim to understand the control of human locomotion, develop neuromuscular control models that generate robust 3D locomotion, and transfer the resulting controllers to humanoid and rehabilitation robotics.

2. State of the Art

The functional relationships of the neural network that governs human locomotion are difficult to identify directly in experiments. Several research groups thus propose and develop computational models of neuromuscular control. In general, these control models consist of a central pattern generator that produces overall locomotion behavior and supplemental reflexes that add some robustness. The resulting neuromuscular controllers achieve steady state locomotion for human models in 3D environments; however, the models show limited robustness to, for instance, rough terrain ($\leq$2cm height difference, [1]) or physiological time delays ($\leq$5ms, [2]). As a result, they are generally not applied to controlling humanoid robots.

3. Own Approach

Instead of starting from complex representations of the human neural network, we synthesize a neural control by embedding dynamics and control principles of legged locomotion into muscle reflex pathways element by element. For instance, in our previous 2D model, reflex controls of the stance leg realize compliant leg behavior while avoiding joint hyper-extensions. More recently, we have identified swing-leg control principles that generate robust leg placement under large disturbances [3]. Following this systematic approach should lead to a neuromuscular control model of growing complexity that obeys the governing principles of legged dynamics and control, is highly reactive, is robust to environment disturbances, and tolerates time delays in the control system.

4. Current Results

In our current work, we have extended the neuromuscular model with an internal predictor of leg placement targets based on stance leg and trunk motion (Fig. 1). In the sagittal plane, this addition has resulted in the human model blindly negotiating up and down slopes of about 10% and random steps of about $\pm$10cm [4] (Fig. 1a). In addition, the sagittal plane controller well extends to 3D locomotion [5] (Fig. 1b).

5. Best Possible Outcome

The current results demonstrate that reflexive control of locomotion generates robust walking in the presence of large disturbances and delays (up to 20ms). We aim to generalize these controls to different locomotion behaviors and their transitions, and to apply them to humanoid and rehabilitation robots, leading to legged systems and assistance with human-like reactiveness and versatility.

Acknowledgment

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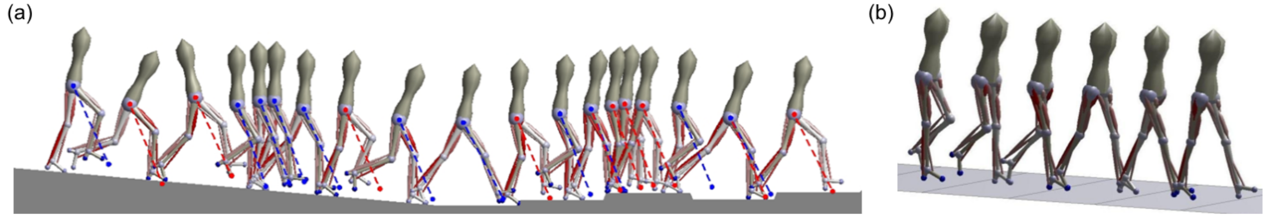

Fig. 1. Current results. (a) 2D walking on rough terrain(-10% slope and $\pm$10cm random steps). (b) 3D walking at 1.3ms^{-1}.