Additional Stability for Single-Unit Pattern Generators

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ABSTRACT

Legged robots have the potential to travel where wheeled robots cannot. While legged robots have many advantages that improve their maneuverability, they are notoriously difficult to control. However, neuroevolution, which combines the nature-inspired fields of neural networks with evolutionary computation, has shown promise in this task. The aim of this paper is to extend prior work that introduced an approach called single-unit pattern generators (SUPGs), which generate oscillatory patterns of activation for controlling the many moving parts of a legged robot. The extended SUPG approach employs a novel adjustment mechanism uniquely suited for SUPGs that allows fine-grained modulation of the SUPG oscillation pattern to potentially react effectively to more challenging conditions such as noise or rough terrain.

Introduction

Legged robot research has generated interest in a broad range of applications such as planetary exploration and military transportation. Legs offer advantages over wheels in environments with rough terrain or tight spaces. However, these advantages come at the cost of more difficulty in creating effective controllers, which must coordinate many degrees of freedom for each leg. In response to this challenge, Morse et al. [5] introduced a new kind of neuron called a single-unit pattern generator (SUPG) that exhibited superior long-term stability in evolved controllers for a simulated quadruped. This paper introduces a new method that further enhances the stability of the SUPG by allowing more fine-grained tuning of the control cycle, which creates the potential to handle more difficult environments. The method is tested in a preliminary experiment that hints at its potential applicability to unstable domains in the future.

Gait Generation with Neuroevolution

The idea of exploiting legged robot morphologies for locomotion was borrowed from nature and so it is natural to return to nature for the inspiration to effectively control legged robots. One such method for automatically generating gaits in legged robots is neuroevolution [4], which marries the complementary nature-inspired fields of neural networks and evolutionary computation. Because the leg motion in a regular gait is oscillatory in nature, one goal of many neuroevolution systems is to encourage some form of oscillation in the neural network.

One popular neuroevolution-based approach to generating gaits with oscillation is to encourage oscillations indirectly with central pattern generators (CPGs) based on continuous time recurrent neural networks (CTRNNs) [1, 2], which are inspired by mechanisms in the nervous systems of many animals. Another approach involves directly inputting a sine wave into a neural network in order to more strictly dictate oscillation [3]. The alternate approach enhanced in this paper directly enforces oscillation with a new type of neuron called a single-unit pattern generator (SUPG) that generates a pattern of activation over time and therefore produces an oscillatory pattern when it is repeatedly triggered [5].

The SUPG approach [5] involves creating a single SUPG for each degree of freedom (DOF) of the robot. Each SUPG therefore controls the motion of that DOF. The SUPG approach as a whole consists of three components: *shape*, *timing*, and *initiation*. The *shape* of the activation cycle for the SUPG is determined by a compositional pattern producing network (CPPN), which is evolved by a neuroevolutionary approach called NEAT [7]. CPPNs have shown the ability to produce complex and natural looking spatial patterns [6], a capability that is harnessed for generating temporal patterns by the SUPG. In particular, the SUPG contains a *timer* that is fed into a CPPN along with the coordinates of the SUPG to produce the activation for the SUPG at that point in time. In other words, the CPPN output is interpreted as a pattern of motion over time. The timing of the SUPG is also controlled by its *trigger*, which resets the SUPG's timer and effectively restarts the temporal activation pattern of the SUPG when the trigger activated (e.g. by a foot touching the ground). The repeated triggering of the SUPG therefore produces an oscillatory pattern of activation whose complexity is controlled by the CPPN. The *initiation* of the system is controlled by an offset that allows each SUPG to begin at any point within its activation cycle, which is necessary because a robot may start in a position that does not exist at any other point in its gait.

SUPGs have been shown capable of generating gaits that exhibit superior stability to CTRNNs and fixed oscillators over long periods of time. This stability is primarily from the trigger mechanism, which allows the activation cycle to reset in response to events in the robot's environment. The trigger for an SUPG is tied to a touch sensor on the foot of the leg to which the SUPG is attached. That way the timers for all SUPGs on a leg will have the same value at all times. This simple mechanism allows the SUPGs for a leg to restart precisely when the foot hits the ground, thus providing feedback to stabilize the gait.

Approach: Stabilization for SUPGs

While the SUPG trigger enables basic stability, the SUPG dynamics also enable other novel mechanisms to further improve stability. In particular, it would be beneficial if a mechanism could be discovered that allows modulation of

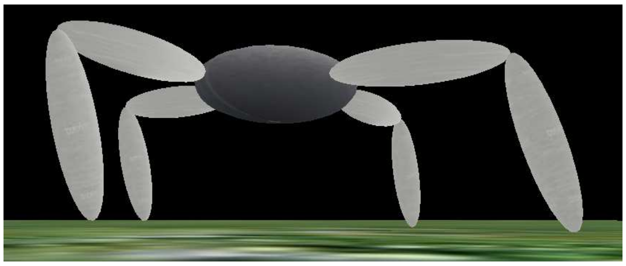

Figure 1: The simulated quadruped in the training environment. The environment is an unlimited flat plane with no obstacles. The quadruped starts in a standing position with all feet touching the ground.

the SUPG in between steps, which might increase balance in unstable situations, such as noisy environments or rough terrain. The stabilization method introduced here consists of evolving an auxiliary timing CPPN that can dynamically adjust the timers for each SUPG. This CPPN takes as input the timers for each of the legs and computes timing adjustments for each leg based on these inputs. The timing adjustment can force the SUPG timers to speed up or slow down as necessary, thereby facilitating more dynamic control over leg timing. This modulation of timers permits the SUPGs to calibrate in between steps rather than waiting until the foot hits the ground next to reset the timer.

Experiment and Results

The stabilization method is tested with a quadruped that has 3 DOF per leg. There is one DOF at the knee and two at the hip for lateral and vertical motion. The quadruped is evaluated on flat ground with the PhysX physics engine with a trial length of 60 seconds. An incremental evolution approach called staged evolution is employed to first evolve the primary CPPN that determines the SUPG activation cycle and then to evolve the adjustment CPPN for the best walker discovered in the first stage. This form of staged evolution forces the primary CPPN to learn to walk on its own so that it does not rely upon the adjustment CPPN from the start and the adjustment CPPN can be evolved to fine tune an existing evolved gait. Both stages of evolution (i.e. evolution of the initial gait and then evolution of the stability mechanism) are given 400 generations. This setup is compared against walkers who have no adjustment CPPN and whose primary CPPN is further evolved for another 400 generations in the second stage.

Table 1 shows the final training performance (averaged over eight runs) for the first stage of evolution and the second stage with both stabilization enabled and disabled. Evolution of the adjustment CPPN is as effective as further evolution of the primary CPPN in increasing the performance of the walkers during stage two. This result indicates that evolution of an adjustment CPPN can help stabilize an otherwise imperfect quadruped controller as effectively as additional evolution of the primary CPPN, with the added benefit of the stabilization not being dependent upon the coarse trigger timing. This more fine-grained adjustment mechanism thus has the potential to add stability in situations where waiting for the trigger of a leg is insufficient. Thus this initial result supports the idea that the stabilization mechanism may enable controllers in the future to be evolved to re-stabilize after destabilizing events like wind or slippage from rough terrain.

	Stage 1	**Stage 2**	
	Evolved 400 gens	**Stabilization mechanism**	**Additional evolution**
Distance	306.3	338.5	332.4
95% CI	58.5	58.5	69.1

Table 1: Training performance for quadrupeds evolved with and without stabilization during the second stage of evolution. Each result represents the distance traveled in a one minute trial averaged over eight runs. The stabilization approach is as good as additional evolution for improving quadruped stability.

Conclusion

This paper presented a new method for modulating single-unit pattern generators (SUPG) to allow fine-grained tuning of the SUPG in between trigger events. Results show that the stabilization method performs as well as additional evolution of the primary CPPN in stabilizing a quadruped in simulation. The increased granularity of SUPG adjustment opens the possibility of increased stability in more challenging environments and may also permit faster transfer from a simulated robot to a real world robot.

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