Spiking Neural Networks for Robot Locomotion Control

by

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Statement of Originality

The thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository[1], subject to the provisions of the Copyright Act 1968.

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Statement of Authorship

I hereby certify that the work embodied in this thesis contains published papers of which I am a joint author. I have included as part of the thesis a written statement, endorsed by my supervisor, attesting to my contribution to the joint publications.

Lukasz Wiklendt　　　　Date

Contribution to Joint Publications

During the course of the candidature, the following publications have been coauthored with my academic supervisors based on normal candidate-supervisor practice.

- Lukasz Wiklendt, Stephan K. Chalup, and Rick Middleton. A small spiking neural network with LQR control applied to the acrobot. *Neural Computing & Applications*, 18(4):369–375, 2009a
- Lukasz Wiklendt, Stephan K. Chalup, and María M. Seron. Simulated 3D biped walking with an evolution-strategy tuned spiking neural network. *Neural Network World*, 19:235–246, 2009b
- Lukasz Wiklendt, Stephan K. Chalup, and María M. Seron. Quadratic leaky integrate-and-fire neural network tuned with an evolution-strategy for a simulated 3D biped walking controller. In Fatos Xhafa, Francisco Herrera, Ajith Abraham, Mario Köppen, and Jose Manuel Bénitez, editors, *Hybrid Intelligent Systems, 2008. HIS08. Eighth International Conference on*, pages 144–149. IEEE, 2008
- Lukasz Wiklendt and Stephan K. Chalup. Balance control of a simulated inverted pendulum on a circular base. In Steve Scheding, editor, *Australasian Conference on Robotics and Automation 2009*, 2009

To my grandmother Teresa and late grandfather Kazimierz

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Abstract

Spiking neural networks (SNNs) are computational models of biological neurons and the synapses that connect them. They are chosen for their characteristic property of information exchange via the timing of events called *spikes*, in contrast to earlier-developed models such as sigmoid neural networks which have no explicit timing component. SNNs are often applied to tasks in artificial intelligence by using existing models of biological neural networks that were used in neuroscience in the past, and that are detailed enough to contain the timing-property. Neurons can be modelled at many levels of detail, and often a neuron model is chosen with scant consideration of the most appropriate level of detail for the given task. This thesis presents a novel spiking neuron model developed to retain the timing-property, including proposed favourable characteristics for application to artificial intelligence tasks, while removing the unnecessary detail for achieving those characteristics that current SNN models contain. The result is a computationally powerful neuron model with an analytically solvable spiking-time calculation.

While SNNs have been applied to various tasks in artificial intelligence, including robot control, the types of control problems faced have been primarily of a stable nature. This thesis focuses on unstable control problems, that is, problems where the dynamics governing the motion of the robot under control are such that small disturbances, inaccuracies, or pauses in control can lead to a rapid acceleration away from a desired state. Concretely, simulation experiments are conducted (i) on a planar underactuated inverted double-pendulum called the *Acrobot* for the swing-up and balance task which, combined with linear quadratic regulation (LQR) control for balance, was able to achieve the task, and (ii) to a 1.5m tall biped for the distance locomotion task, where it walked 16m without collapsing. In the interests of automatically developing bipedal dynamic walking behaviour, via the stochastic tuning of spiking neural network parameters, a new spherical-foot model is presented that exhibits favourable dynamical properties.

Existing physical biped robot morphologies can be clustered into three main groups based on their feet and ankle configurations. One group contains large flat feet with actuated ankles, and is most often seen in environments and tasks requiring moving in both sagittal (forward-backward) and coronal (left-right) planes, such as robotic soccer. The second group contains point feet with no ankles, and finds success in fast locomotion such as running, where coronal motion is limited. The third group consists of passive-dynamic walkers, that contain rounded feet and are able to walk in the sagittal plane along a slight decline without any control input. In this thesis a new biped feet-angle configuration is proposed which is a marriage of these groups, with relatively small (second group) rounded feet capable of smooth continuous ground contact (third group), and actuated ankles (first group) that aid in standing balance control. An analysis of this novel type of foot configuration is presented here for the planar case, and a controller for standing balance is included.