Spiking Neural Networks for Robot Locomotion Control

by

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Statement of Originality

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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.

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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.


To my grandmother Teresa and late grandfather Kazimierz
Contents

Abstract 3

1 Introduction 7
  1.1 Motivation ............................................. 9
  1.2 Aim and Objectives of This Thesis ................. 10
  1.3 Publications ........................................ 11
  1.4 Thesis Overview .................................... 12
  1.5 Summary ............................................. 14

I Spiking Neural Models and Networks 17

2 Spiking Neural Networks 21
  2.1 Biological Basis of Artificial Neural Networks ... 22
  2.2 Neural Network Structure ............................ 23
  2.3 Types of Artificial Neural Networks .............. 24
  2.4 Spiking Neural Networks ............................. 25
  2.5 Leaky Integrate-and-Fire Neurons .................. 27
    2.5.1 Discrete Time Simulation ...................... 28
    2.5.2 Event-Based Simulation ...................... 31
  2.6 Input and Output Coding ............................ 32
    2.6.1 Rate Coding .................................. 33
    2.6.2 Temporal Coding ................................ 40
  2.7 Learning ............................................ 45
    2.7.1 Supervised Learning ............................ 46
## 2.7.2 Unsupervised Learning ........................................ 47
## 2.7.3 Evolutionary Computation ............................... 48
## 2.8 Summary .................................................... 49

### 3 DEAFT Neurons 53

3.1 Model .................................................. 57
3.2 Refraction Types ....................................... 60
3.3 Other time-constant factors ............................. 63
3.4 Comparison to Existing Neuron Models ............... 64
3.5 Derivation of DEAFT from SRM ....................... 65
3.6 Summary ................................................ 66

### II Simulated Robot Applications 69

### 4 Acrobot 73

4.1 The Acrobot ............................................. 76
4.2 Controller ............................................ 79
  4.2.1 Motor and Sensor Neurons ....................... 79
  4.2.2 LQR Controller .................................. 81
4.3 Evolution ............................................... 83
4.4 Simulation Results and Discussion ................. 85
4.5 Summary ............................................... 88

### 5 Biped 93

5.1 Biped Robot Simulation ................................ 94
5.2 Spiking Neural Network Controller ................ 96
  5.2.1 DEAFT Neuron Model ......................... 97
  5.2.2 Network Input ................................. 98
  5.2.3 Network Output ............................... 99
5.3 Evolution Strategy ................................... 100
5.4 Results ............................................... 101
5.5 Summary ............................................... 103
CONTENTS

6  Spherical Cap Feet 107
   6.1 Motivation ................................................. 109
   6.2 Model ...................................................... 111
      6.2.1 Circular Base Radius ................................. 114
   6.3 LQR Balance Control ...................................... 115
      6.3.1 Balance Simulation .................................. 118
   6.4 Double Pendulum .......................................... 121
      6.4.1 LQR Balance Control and Simulation .............. 124
   6.5 Summary .................................................... 126

III  Conclusions 129

7  Discussion 133
   7.1 Summary .................................................... 133
   7.2 Main Research Contributions ............................. 136
   7.3 Future Work ............................................... 137
   7.4 Conclusion .................................................. 138

Bibliography 141
# List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Drawing of a biological neuron</td>
<td>22</td>
</tr>
<tr>
<td>2.2</td>
<td>Fire rate scales</td>
<td>36</td>
</tr>
<tr>
<td>2.3</td>
<td>Motor neuron output for a constant rate of received spikes</td>
<td>38</td>
</tr>
<tr>
<td>2.4</td>
<td>Motor neuron output vs received spike rate</td>
<td>38</td>
</tr>
<tr>
<td>2.5</td>
<td>Sampling the output neuron</td>
<td>39</td>
</tr>
<tr>
<td>2.6</td>
<td>Motor neuron output variability with sampling rate</td>
<td>41</td>
</tr>
<tr>
<td>2.7</td>
<td>Time coding input with a single spike</td>
<td>42</td>
</tr>
<tr>
<td>2.8</td>
<td>Time-encoding input with two spikes</td>
<td>43</td>
</tr>
<tr>
<td>2.9</td>
<td>Time-decoding spikes to output</td>
<td>46</td>
</tr>
<tr>
<td>3.1</td>
<td>Time evolution of membrane potential</td>
<td>58</td>
</tr>
<tr>
<td>3.2</td>
<td>Refraction with state zeroing</td>
<td>61</td>
</tr>
<tr>
<td>3.3</td>
<td>Refraction with membrane potential gradient preservation</td>
<td>62</td>
</tr>
<tr>
<td>3.4</td>
<td>A trace of the membrane potential of a bursting neuron</td>
<td>63</td>
</tr>
<tr>
<td>3.5</td>
<td>A trace of the membrane potential of a negative threshold neuron</td>
<td>63</td>
</tr>
<tr>
<td>3.6</td>
<td>Postsynaptic potential shape for various time constants</td>
<td>64</td>
</tr>
<tr>
<td>4.1</td>
<td>The acrobot showing directions for gravity, torque and joint angles</td>
<td>76</td>
</tr>
<tr>
<td>4.2</td>
<td>Network topology and synaptic weights</td>
<td>81</td>
</tr>
<tr>
<td>4.3</td>
<td>Stroboscopic sequences of each of the fittest candidates</td>
<td>85</td>
</tr>
<tr>
<td>4.4</td>
<td>The elite solution from each of the ten separate evolutions</td>
<td>86</td>
</tr>
<tr>
<td>4.5</td>
<td>Vertically aligned plots which depict the first 5 seconds of a 20 second simulation of an elite NN</td>
<td>87</td>
</tr>
<tr>
<td>4.6</td>
<td>Zoomed-in view of Figure 4.5(b)</td>
<td>88</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td>------</td>
</tr>
<tr>
<td>4.7</td>
<td>Stroboscopic sequences of candidates without LQR</td>
<td>88</td>
</tr>
<tr>
<td>4.8</td>
<td>Common swing-up trajectory</td>
<td>89</td>
</tr>
<tr>
<td>5.1</td>
<td>Biped morphology</td>
<td>95</td>
</tr>
<tr>
<td>5.2</td>
<td>Neural network topology</td>
<td>98</td>
</tr>
<tr>
<td>5.3</td>
<td>Vectors $u$ and $v$ used as input to the neural network</td>
<td>99</td>
</tr>
<tr>
<td>5.4</td>
<td>Fitness traces of each of the 5 evolution runs</td>
<td>102</td>
</tr>
<tr>
<td>5.5</td>
<td>First 12.6s of a walk, shown at 120ms intervals</td>
<td>102</td>
</tr>
<tr>
<td>5.6</td>
<td>Hidden layer neural activity during the biped walk</td>
<td>103</td>
</tr>
<tr>
<td>5.7</td>
<td>Top-down view of the centre of mass for the entire walk</td>
<td>104</td>
</tr>
<tr>
<td>6.1</td>
<td>Flat vs spherical foot</td>
<td>108</td>
</tr>
<tr>
<td>6.2</td>
<td>Flat base and spherical base inverted pendulum models</td>
<td>112</td>
</tr>
<tr>
<td>6.3</td>
<td>Inverted pendulum on a spherical base model</td>
<td>112</td>
</tr>
<tr>
<td>6.4</td>
<td>Distances between ankle and original centre of mass</td>
<td>116</td>
</tr>
<tr>
<td>6.5</td>
<td>Balancing of an inverted pendulum on a spherical base</td>
<td>119</td>
</tr>
<tr>
<td>6.6</td>
<td>Stability region</td>
<td>120</td>
</tr>
<tr>
<td>6.7</td>
<td>Inverted double-pendulum on a spherical base model</td>
<td>121</td>
</tr>
<tr>
<td>6.8</td>
<td>Balancing of an inverted double-pendulum on a spherical base</td>
<td>125</td>
</tr>
</tbody>
</table>
List of Tables

4.1 Acrobot parameters ........................................ 79

6.1 Single inverted-pendulum on a circular base parameters ...... 118
6.2 Double inverted-pendulum on a circular base parameters ...... 125
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.