Contents

List of Figures ix

List of Tables xi

Glossary xiii

1 Introduction 1
- 1.1 AI-enhanced Signal Processing . . . 1
- 1.2 Radar Processing . . . 6
- 1.3 Publications . . . 9

2 Background 11
- 2.1 Artificial Intelligence and Deep Learning . . . 11
  - 2.1.1 Deep Learning and Artificial Neural Networks . . . 11
  - 2.1.2 Supervised Learning . . . 12
  - 2.1.3 Convolutional Neural Networks . . . 14
  - 2.1.4 Long Short-Term Memory . . . 16
  - 2.1.5 Quantization of Neural Networks . . . 18
- 2.2 Spiking Neural Networks . . . 19
  - 2.2.1 Biological Neurons and Synapses . . . 19
  - 2.2.2 Leaky Integrate-and-Fire Neuron . . . 21
  - 2.2.3 Surrogate Gradients . . . 23
- 2.3 SpiNNaker 2 Neuromorphic Hardware Platform . . . 24
  - 2.3.1 SpiNNaker 2 Hardware . . . 25
  - 2.3.2 SpiNNaker 2 Software . . . 27
- 2.4 Radar . . . 28

3 Experimentals 35
- 3.1 Simulation of Spiking Neural Networks in Deep Learning Frameworks . . . 35
- 3.2 Radar-based Gesture Recognition Datasets . . . 36
  - 3.2.1 Soli dataset . . . 37

3.2.2 IFD dataset 38
3.3 Entry Points for SNNs in the Radar Processing Chain 39
3.3.1 Neural Networks after Range-Doppler Pre-Processing 39
3.3.2 Processing Time-Domain Data with Convolutional Neural Networks . 43
3.4 Efficiency estimation of Neural Networks 45
3.4.1 Estimating the Computational Cost of Neural Networks 46
3.4.2 Energy Measurement of Neural Networks on SpiNNaker 2 46

4 Training and Comparison of Network Architectures on Von-Neumann Hardware 49
4.1 Neural Networks after Range-Doppler Pre-Processing 49
4.1.1 Training Results of SNNs compared to DNNs 50
4.1.2 Hybrid Neural Networks 56
4.2 Neural Networks on Time-Domain Data 61

5 Porting and Evaluating Network Architectures on SpiNNaker 2 65
5.1 Implementing Neuron Models on SpiNNaker 2 65
5.1.1 Implementing required Neuron Models for SNNs 66
5.1.2 Implementing Neurons Models for DNNs 69
5.1.3 Implementing Neuron Models for HNN 73
5.2 Mapping of Neural Network Architectures 74
5.3 Evaluating Accuracy Results On SpiNNaker 2 76
5.4 Evaluating Latency 78
5.5 Measuring and Evaluating Energy Consumptions on SpiNNaker 2 79

6 Discussing the Efficiency of SNN-based Architectures 89
6.1 Interpretation of Findings 89
6.2 Implications of Results 95
6.3 Limitations and Recommendations for Future Research 97

7 Summary and Outlook 99
7.1 Summary 99
7.2 Outlook 100