Contents

Acknowledgements iii

Abstract v

Resumen vii

Resum xi

Contents xv

List of Figures xix

List of Tables xxi

Abbreviations and Acronyms xxiii

1 Introduction 1

1.1 Extracellular electrophysiology 2
1.2 Extracellular electrophysiology recording systems 5
1.3 Rodents in electrophysiology research 8
1.4 Closed-loop feedback experiments 9
1.5 Field-Programmable Gate Array (FPGA) devices 10

2 Motivation and Objectives 13

2.1 Motivation 13
2.2 Objectives 15

2.3 Thesis outline . . . 16

3 Open Ephys: Open source, closed-loop electrophysiology 19
3.1 Introduction . . . 20
3.2 Materials and Methods . . . 22
3.2.1 Intan RHD2000 integrated circuits . . . 22
3.2.2 Xilinx FPGA . . . 24
3.2.3 Connectors . . . 24
3.2.4 JUCE Library . . . 25
3.3 Results . . . 26
3.3.1 Headstages . . . 26
3.3.2 Open Ephys acquisition board . . . 28
3.3.3 Open Ephys Software . . . 31
3.3.4 Performance . . . 35
3.4 Discussion . . . 35
3.5 Conclusions . . . 36

4 Open Neuro Interface: High performance acquisition 39
4.1 Introduction . . . 40
4.1.1 High-bandwidth heterogeneous systems . . . 40
4.1.2 Tether issues . . . 41
4.1.3 Latency in closed-loop experiments . . . 42
4.1.4 Overview . . . 42
4.2 Materials and Methods . . . 43
4.2.1 Bus standards . . . 43
4.2.2 FPD-Link III devices . . . 44
4.2.3 FPGA devices . . . 44
4.2.4 3D Tracking . . . 46
4.2.5 Acquisition devices . . . 50
4.2.6 Stimulation devices . . . 51
4.2.7 Software . . . 51
4.3 Results and Discussion . . . 52
4.3.1 ONI specification . . . 52
4.3.2 ONIX hardware . . . 57
4.3.3 Tethers and torque-free commutator . . . 62
4.3.4 ONIX firmware . . . 64
4.3.5 Acquisition performance . . . 70
4.3.6 3D Tracking . . . 71
4.4 Conclusions . . . 72

5 Wireless electrophysiology compression 75

5.1 Introduction . . . 76
5.1.1 Wireless electrophysiology devices . . . 76
5.1.2 Data compression methods . . . 78
5.1.3 Objectives . . . 80
5.2 Materials . . . 80
5.2.1 Huffman Coding . . . 80
5.2.2 Delta compression . . . 83
5.2.3 Low-power FPGA . . . 83
5.2.4 Wireless processor . . . 84
5.2.5 Sample signals and acquisition hardware . . . 85
5.2.6 Development hardware and software . . . 86
5.3 Methods . . . 88
5.3.1 Software model . . . 88
5.3.2 Hardware design and validation . . . 89
5.3.3 In Vivo testing . . . 90
5.4 Results . . . 90
5.4.1 Compression algorithm . . . 90
5.4.2 Low-memory, Low-resource compression . . . 91
5.4.3 Compression performance . . . 94
5.4.4 Effect of dictionary on compression . . . 96
5.4.5 Transmission protocol . . . 96
5.4.6 Wireless prototype . . . 98
5.4.7 Power usage . . . 104
5.4.8 Resource usage . . . 105
5.5 Discussion . . . 105
5.6 Conclusions . . . 107

6 Conclusions and Outlook **109**
6.1 Implications for neuroscience research . . . 111
6.1.1 Effect of tools in the experiments . . . 111
6.1.2 Closed-loop and brain timescales . . . 112
6.1.3 Multi-source acquisition . . . 114
6.1.4 Modular approach . . . 115
6.2 Implications for the academic community . . . 115
6.3 Future steps . . . 117

7 Contributions **119**
7.1 Collaborations in the scope of the Thesis . . . 119
7.2 Publications . . . 120
7.3 Teaching . . . 120
7.4 Conference posters . . . 121

Bibliography **123**