Contents

1 Introduction **1**

1.1 Motivation 1

1.2 Speech disorders in selected populations 3

1.2.1 Parkinson's disease 3

1.2.2 Hearing loss 7

1.2.3 Aging 11

1.3 Hypotheses 11

1.4 Objectives 12

1.4.1 General objective 12

1.4.2 Specific objectives 12

1.5 Contribution of this thesis 13

1.6 Structure of the thesis 13

2 Speech production process **15**

2.1 Speech chain 15

2.1.1 Physiological processes of speech production 16

2.2 Impact of Parkinson's disease on speech motor control 18

2.2.1 Neuropathophysiology of motor control related to Parkinson's disease 18

2.2.2 Motor speech disorders in Parkinson's disease 22

2.3 Auditory system and speech control 22

2.3.1 Overview of the auditory system 22

2.3.2 Cochlear implants (CIs) 24

2.3.3 Auditory feedback and speech control 25

3 State-of-the-art **29**

3.1 Severity estimation of Parkinson's disease from speech 29
3.2 Speech analysis of cochlear implant users 35
3.3 Aging and speech 42
3.4 Smartphone-based applications for health care 44
3.4.1 Applications for Parkinson's disease 44
3.4.2 Applications for hearing loss 45

4 Automatic analysis of pathological speech signals **49**

4.1 Speech processing techniques-an overview 49
4.1.1 Short-time analysis 49
4.1.2 Time-frequency analysis 51
4.1.3 Filterbank analysis 55
4.1.4 Voice Activity Detection 61
4.2 Pathological speech modeling 63
4.2.1 Phonation analysis 63
4.2.2 Articulation analysis 66
4.2.3 Phonemic analysis 69
4.2.4 Prosody analysis 73
4.3 Machine learning methods 78
4.3.1 Support Vector Machine for classification 78
4.3.2 Support Vector Machine for regression 85
4.3.3 Neural Networks 88
4.3.4 Convolutional Neural Networks 93
4.3.5 Recurrent Neural Networks 95
4.4 Speaker models 103
4.4.1 Gaussian Mixture Models 103
4.4.2 i–vectors 107
4.4.3 x–vectors 108

5 Data collection **111**
5.1 Parkinson's disease 111
5.1.1 PCGITA (Spanish) 111
5.1.2 PD At-home (Spanish) 112
5.1.3 PD Longitudinal (Spanish) 112
5.1.4 Apkinson (Spanish) 113
5.2 Cochlear implants 114
5.2.1 LMU TAPAS (German) 114
5.2.2 LMU Onset (German) 114
5.3 Supporting datasets 115
5.3.1 Young healthy controls (Spanish) 115
5.3.2 PhonDat 1 Corpus (German) 116
5.3.3 Verbmobil subset (German) 116
5.3.4 TEDx Spanish Corpus - TSC (Spanish) 116

6 Experiments and results **119**
6.1 Models for speech analysis 119
6.1.1 Phoneme posterior probabilities 119
6.1.2 Automatic detection of voice onset time 128
6.2 Parkinson's disease patients 136
6.2.1 Automatic methods for the assessment of PD from speech 136
6.2.2 Speaker embeddings to monitor Parkinson's disease . 146
6.3 Cochlear Implant users 154
6.3.1 Quantification of phoneme precision to evaluate onset and duration of deafness 154
6.3.2 Segmental and suprasegmental speech analysis of postlingually deafened CI users 163
6.4 Aging and speech 172
6.5 Smartphone-based applications for health care 188
6.5.1 Apkinson 188
6.5.2 Cochlear Implant Testing App - CITA 193

7 Summary **197**
7.1 Automatic methods for speech analysis . . . 197
7.2 Parkinson's disease patients . . . 199
7.3 Cochlear implant users . . . 201
7.4 Aging and speech . . . 202
7.5 Smartphone-based applications for health care . . . 204

Appendices **205**

A Speech tasks **206**
A.1 Spanish speech protocol . . . 206
A.1.1 Vowel phonation . . . 206
A.1.2 Sentences . . . 206
A.1.3 Read text . . . 207
A.1.4 Speech diadochokinesia . . . 207
A.1.5 Monologue . . . 207
A.2 German speech protocol . . . 208
A.2.1 Read text . . . 208
A.2.2 Rhino sentences . . . 208
A.2.3 PLAKSS words . . . 209

B Publications **210**
B.1 Journal publications . . . 210
B.2 Conference publications . . . 212

List of Figures **216**

List of Tables **224**

Acronyms **229**

Bibliography **233**