

# Contents

---

<b>Abstract</b>	<b>iii</b>
<b>Acronyms</b>	<b>xv</b>
<b>Notation</b>	<b>xvii</b>
<b>List of Figures</b>	<b>xxiii</b>
<b>List of Tables</b>	<b>xxvii</b>
<b>List of Algorithms</b>	<b>xxix</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Motivation . . . . .	1
1.2 Objectives . . . . .	3
1.3 Structure of the thesis . . . . .	3
<b>2 Background</b>	<b>5</b>
2.1 Personal Sound Zones (PSZ) systems . . . . .	6
2.1.1 Description and problem definition . . . . .	6
2.1.2 Requirements . . . . .	7
2.1.3 Approaches for creating PSZ . . . . .	7
2.2 Loudspeaker array processing . . . . .	10
2.2.1 Superposition of sources . . . . .	12
2.2.2 System model and formulation . . . . .	16
2.2.3 Filter optimization . . . . .	20
2.2.4 Review of algorithms . . . . .	24
2.2.5 Control metrics . . . . .	32
2.3 Performance evaluation . . . . .	35
2.3.1 Setup and methodology . . . . .	35
2.3.2 Impulse response truncation for wPM-F . . . . .	38

2.3.3	Influence of the regularization factor . . . . .	43
2.3.4	Comparison of wPM-T and wPM-F . . . . .	45
2.4	Summary . . . . .	54
<b>3</b>	<b>Least Squares solvers for PSZ systems</b>	<b>57</b>
3.1	Least Squares (LS) problem . . . . .	58
3.2	Literature review . . . . .	59
3.2.1	Classic solvers . . . . .	59
3.2.2	Fast solvers . . . . .	60
3.2.3	Superfast solvers . . . . .	61
3.3	Cholesky solver . . . . .	62
3.4	Fast a Posteriori Error Sequential Technique (FAEST) . . .	63
3.5	Superfast solver . . . . .	65
3.6	Performance evaluation . . . . .	73
3.6.1	Setup and methodology . . . . .	73
3.6.2	Accuracy of solvers . . . . .	74
3.6.3	Performance of solvers for PSZ . . . . .	77
3.6.4	Computational complexity . . . . .	79
3.7	Summary . . . . .	81
<b>4</b>	<b>Subband filtering for PSZ systems</b>	<b>83</b>
4.1	Filter bank theory . . . . .	85
4.1.1	Basic multirate operations . . . . .	85
4.1.2	Filter bank analysis . . . . .	88
4.1.3	Design considerations . . . . .	93
4.1.4	Generalized Discrete Fourier Transform filter bank .	98
4.2	Subband decomposition . . . . .	100
4.2.1	Sufficient conditions . . . . .	101
4.2.2	Optimal subband components . . . . .	102
4.2.3	Efficient computation . . . . .	104
4.3	Optimization of subband filters for PSZ . . . . .	106
4.3.1	Previous works . . . . .	106

---

4.3.2	System model . . . . .	107
4.3.3	Formulation . . . . .	108
4.3.4	wPM-S . . . . .	110
4.4	Performance evaluation . . . . .	113
4.4.1	Setup and methodology . . . . .	113
4.4.2	Influence of the filter bank configuration . . . . .	115
4.4.3	Comparison of subband filters . . . . .	120
4.4.4	Comparison of broadband and subband filters . . . . .	123
4.4.5	Subband-dependent configuration for wPM-S . . . . .	128
4.4.6	Computational complexity . . . . .	134
4.5	Summary . . . . .	138
<b>5</b>	<b>Weighted Pressure Matching with windowed targets</b>	<b>141</b>
5.1	Target selection . . . . .	142
5.1.1	Non-windowed targets . . . . .	143
5.1.2	Windowed targets . . . . .	144
5.2	Kurtosis as a measure of diffuseness . . . . .	147
5.3	Performance evaluation in an office-like room . . . . .	148
5.3.1	Setup and methodology . . . . .	148
5.3.2	Kurtosis of RIRs . . . . .	150
5.3.3	Evaluation of windowed targets . . . . .	151
5.3.4	Robustness to perturbations . . . . .	159
5.4	Performance evaluation in a listening room . . . . .	160
5.4.1	Setup and methodology . . . . .	161
5.4.2	Kurtosis of RIRs . . . . .	162
5.4.3	Evaluation of windowed targets . . . . .	163
5.5	Summary . . . . .	166
<b>6</b>	<b>Conclusions and future work</b>	<b>169</b>
6.1	Main conclusions and contributions . . . . .	169
6.2	Future work . . . . .	173
6.3	List of publications . . . . .	174

<b>A</b>	<b>Computational complexity analysis</b>	<b>177</b>
A.1	Computational complexity of wPM-T . . . . .	178
A.1.1	Cholesky solver . . . . .	178
A.1.2	FAEST . . . . .	182
A.1.3	Superfast solver . . . . .	184
A.2	Computational complexity of wPM-F . . . . .	185
A.3	Computational complexity of wPM-S . . . . .	186
A.3.1	Subband decomposition . . . . .	187
A.3.2	Computation of subband filters . . . . .	191
A.3.3	Total computational complexity . . . . .	195
<b>B</b>	<b>Prototype filter design for GDFT filter banks</b>	<b>197</b>
B.1	Formulation . . . . .	197
B.1.1	Alias-To-Signal Ratio . . . . .	198
B.1.2	Reconstruction Error . . . . .	200
B.2	Optimization . . . . .	203
B.3	Design examples . . . . .	204
	<b>Bibliography</b>	<b>207</b>