
Contents

Abstract	v
1 Introduction	1
1.1 Structure of the Thesis	3
2 Characterization of Mobile Devices and Use Cases	5
2.1 Application-Oriented Characterization	6
2.1.1 Device Classes	6
2.1.2 Definition of Use Cases	6
2.1.3 Reproduction of the Use Cases in this Thesis	8
2.2 Acoustic Characterization and Simulation of Linear Behavior	10
2.2.1 Acquisition and Evaluation of Device-Related Transfer Functions (DRTFs)	10
2.2.2 Quality Metric for Microphone Positions	14
2.2.3 Realistic Simulation of Use Cases of Mobile Devices	18
2.3 Characterization of Nonlinear Behavior	21
2.4 Conclusion	27
3 Self-Localization of Microphone Arrays for Blind Beamforming	29
3.1 Fundamentals of Self-Localization of Microphone Arrays	30
3.1.1 Introduction	30
3.1.2 Related Work	31
3.1.3 Proposed Approach	32
3.1.4 Signal Model and Pairwise Distance Estimation	33
3.1.5 Limitations of Time-Difference-of-Arrival based Self-Localization	34
3.1.6 Reference Algorithm: Classical Multi-Dimensional Scaling	35
3.2 Orthogonal Geometric Projection (OGP)	37
	vii

3.2.1	Basic Idea	37
3.2.2	Estimation of Coordinates from Pairwise Distances	38
3.2.3	Estimation of the Angle between Sources	40
3.2.4	Detection and Correction of Outliers	47
3.3	Evaluation	48
3.3.1	Performance Metrics	48
3.3.2	Analysis of OGP	49
3.3.3	Comparison with CMDS	52
3.3.4	Performance for Different Source Signals	57
3.3.5	Computational Complexity	58
3.4	Interim Conclusion	60
3.5	Beamforming based on Estimated Microphone Positions	61
3.5.1	Beamforming Basics	61
3.5.2	Analysis of Beamforming based on Artificially Disturbed Microphone Positions	66
3.5.3	Analysis of Beamforming based on Estimated Microphone Positions	71
3.6	Conclusion	76
4	Combined Beamforming and Acoustic Echo Cancellation	79
4.1	Processing Paradigms	80
4.1.1	Cascaded Structures	80
4.1.2	Joint Adaptation	81
4.1.3	Solutions without Beamforming	81
4.1.4	Proposed Approach	82
4.2	Digital System Model	82
4.3	Echo Canceller and Beamformer Design	85
4.4	Change Prediction (ChaP)	88
4.4.1	ChaP Core Algorithm	88
4.4.2	Improvements of ChaP	91
4.4.3	Application of ChaP to a GSC Structure	96
4.5	Evaluation	97
4.5.1	Performance Metrics	98
4.5.2	General Simulation Setup	99
4.5.3	Analysis of ChaP for Time-Invariant Echo Path	99
4.5.4	Comparison to AECfirst for Time-Variant Echo Path	102

4.5.5	Computational Complexity	104
4.6	Conclusion	105
5	Nonlinear Acoustic Echo Cancellation	107
5.1	Approaches to Nonlinear Acoustic Echo Cancellation	108
5.1.1	Physical Properties of the Nonlinear Echo Path in Mobile Devices	108
5.1.2	Digital System Model	110
5.1.3	Nonlinear Echo Path Models and Adaptation Algorithms . .	112
5.2	Linear-In-the-Parameters Nonlinear Filters	113
5.2.1	Definition	113
5.2.2	Simplification	114
5.2.3	Types of Nonlinear Expansions	116
5.2.4	Parameter Estimation	116
5.2.5	Analysis of Basis Functions	118
5.2.6	Digital Generation of Nonlinear Signals	124
5.3	Decomposition of the Nonlinear Echo Path	126
5.3.1	Parallel Decomposition	126
5.3.2	Serial Decomposition	128
5.3.3	Significance-Aware Decomposition	129
5.3.4	Interim Conclusion	130
5.4	Dual-Stage Multi-Channel Kalman Filter (DualStage-MCK)	131
5.4.1	System Model	132
5.4.2	Adaptation in the Block-Frequency Domain	134
5.4.3	Complexity Reduction by Decimation in Frequency	142
5.5	Evaluation based on Measured Data	145
5.5.1	Performance Metrics	146
5.5.2	Evaluation Setup	146
5.5.3	Steady-State Performance	147
5.5.4	Convergence Behavior for Room Acoustic Changes	149
5.5.5	Convergence Behavior for Far-end Level Changes	157
5.5.6	Evaluation of the Complexity Reduction	159
5.6	Conclusions	163
6	Summary	165

Contents

A Estimation of Process and Measurement Noise	169
A.1 Single-Channel Kalman filter	169
A.2 Multi-Channel Kalman filter	170
Mathematical Notation	171
Abbreviations	175
Bibliography	179