

1	Introduction	1
1.1	Motivation and Applications	1
1.2	Problem Statement and Literature Review	3
1.3	Thesis Outline	11
2	Fundamentals of HOA Signal Processing	13
2.1	Spherical Harmonics and Spherical Harmonics Transform	13
2.1.1	Coordinate System Definition	13
2.1.2	Spherical Harmonics	16
2.1.3	Spherical Harmonics Transform	18
2.1.4	Windowed Spherical Harmonics Transform	19
2.1.5	Discrete Spherical Harmonics Transform	21
2.2	Higher Order Ambisonics	22
2.2.1	Spherical Harmonics-Based Description of Sound Fields	23
2.2.2	Order Truncation and Higher-Order Ambisonics	25
2.2.3	Stochastic Signal Modeling	27
2.2.4	Spherical Harmonics Rotation Operator	28
2.2.5	Beamforming	30
2.2.6	Reproduction of Sound Fields	32
2.3	Baseline Approaches to Sound Field Translation	34
2.3.1	Plane-Wave Translation (PWT)	35
2.3.2	Virtual Ambisonics (VA)	37
2.4	Measures and Tools for Investigating HOA Signals	39
2.4.1	Instrumental Measures	39
2.4.2	Psychoacoustical Assessment	42
2.4.3	Visualization of Linear Operations	44
3	Non-Adaptive Sound Field Translation	47
3.1	Plausible Sound Field Translation	47
3.2	Space Warping	48
3.2.1	Warping into $\vec{e}_z$ -Direction	48
3.2.2	Natural Equalization Function	49
3.2.3	Energy-Preserving Equalization Function	51

3.2.4	Generalization to Arbitrary Directions	52
3.3	Space Warping Based Sound Field Translation	53
3.3.1	Geometric Model	53
3.3.2	Proposed Translation Method	54
3.3.3	Relation to Sound Field Theory and Far Field Approximation	58
3.4	Evaluation	61
3.4.1	Comparison of Approaches: Resulting Sound Field	61
3.4.2	Comparison of Approaches: Operator Matrices	66
3.4.3	Artifacts of Space Warping due to Finite SH Order	67
3.5	Computational Aspects	72
3.6	Discussion	78
3.7	Chapter Summary	79
4	Adaptive Sound Field Translation	81
4.1	Motivation	81
4.2	Signal Model	83
4.2.1	Input Signal Model	84
4.2.2	Output and Target Signal Models	85
4.2.3	Expected Error	85
4.3	Covariance Estimation in Time and Frequency	86
4.4	Adaptive Space Warping	88
4.4.1	Hard-Decision Adaptive Space Warping	89
4.4.2	Soft-Decision Adaptive Space Warping	90
4.4.3	Expected Error of Soft-Decision Translation	92
4.4.4	Primary-Ambient Extraction and Covariance Matrix Decomposition	93
4.5	Evaluation of Adaptive Space Warping	95
4.5.1	Experimental Setup	95
4.5.2	Impact of Primary-to-Ambient Ratio	97
4.5.3	Filter Analysis with Oracle Covariance Information	98
4.5.4	Adaptive Space Warping Angular Bias	102
4.5.5	Filter Analysis with Estimated Covariance Matrices	103
4.6	Adaptive Beamforming	104
4.6.1	Refined Parametric Signal Model	104
4.6.2	Processing Chain	105
4.6.3	Primary-Ambient Extraction Error Considerations	108
4.6.4	Optimality of Adaptive Beamforming	109
4.6.5	Parameter Estimation	109
4.7	Evaluation of Adaptive Beamforming	112
4.7.1	Filter Analysis	112
4.7.2	Parameter Estimation	114
4.8	Formal Comparison of ASW and ABF	114
4.8.1	Primary-Ambient Extraction	116
4.8.2	Sound Field Translation	120

4.9	Discussion	123
4.10	Chapter Summary	128
5	Perceptual Study	131
5.1	Objectives	131
5.2	Test Signals	131
5.2.1	Generation of Input and Reference Signals	132
5.2.2	Methods Under Test	133
5.2.3	Objective Evaluation of Test Conditions	134
5.3	Listening Experiment	136
5.3.1	Test Design	136
5.3.2	Results	140
5.4	Discussion	143
5.5	Chapter Summary	145
6	Conclusion	147
Appendices		
A	Additional Remarks	153
A.1	Practical Considerations: Spherical Sampling	153
B	Mathematical Derivations	157
B.1	Limit Values for Far-Field Approximations	157
B.2	Limit Values of Spherical Hankel Functions	158
C	Additional Investigations and Experiments	159
C.1	Robustness of Geometric Model against Distance Misestimation . .	159
C.2	Space Warping Monte Carlo Simulation	161
C.3	Artifacts of Space Warping due to Finite SH Order	164
C.4	Correlation of Instrumental and Subjective Localization Ratings .	166
Mathematical Notation & Abbreviations		169
Bibliography		173
Curriculum Vitae		191