

Contents

Glossary

Acronyms	I
List of Symbols	I
Mathematical Operators	II

1. Introduction 1

2. Fundamentals of Human Sound Localization and Binaural Technology 3

2.1. Human Sound Localization	3
2.1.1. Interaural Time and Level Differences	4
2.1.2. Monaural Spectral Cues	4
2.1.3. Influence of Head Movements on the Localization	5
2.1.4. Perception Thresholds of the Auditory System	6
2.2. Basics of Signal Processing	9
2.3. Head-Related Transfer Functions	11
2.3.1. Directional Transfer Functions	12
2.3.2. Pinna-Related Transfer Functions	13
2.4. Definition of the Coordinate System and Spatial Sampling	13
2.5. Reconstruction Techniques for Head-Related Transfer Functions	14
2.5.1. Representation as Poles, Zeros and Residua	14
2.5.2. Representation as Spherical Harmonics	15
2.5.3. Representation as Principle Components	16
2.5.4. Estimation of the Phase	18
2.6. Binaural Reproduction Using Headphones	19

3. Review of Individualization Techniques 23

4. Individual Head-Related Transfer Functions, Head and Ear Dimensions 27

4.1. Measurement of Head-Related Transfer Functions	31
4.2. Anthropometric Dimensions of the Head and Ear	34
4.2.1. Three-Dimensional Ear Models	35
4.2.2. Individual Dimensions of the Head and Ear	36

5. Interaural Time Difference	39
5.1. Ellipsoid Model	39
5.2. Interaural Time Delays	41
5.2.1. Estimation of the Interaural Time Delay	41
5.2.2. Adaptation of Interaural Time Difference	44
5.2.3. Reconstruction of Interaural Time Difference	45
5.3. Empiric Interaural Time Difference Model	46
5.4. Evaluation Standards of Interaural Time Difference Models . . .	46
5.4.1. Analytic Evaluation Standards of Interaural Time Differ- ence Models	47
5.4.2. Subjective Evaluation Standards of Interaural Time Dif- ference Models	47
5.5. Review of Interaural Time Difference Models	51
5.6. Comparison of Interaural Time Difference Models	53
5.6.1. Analysis of Interaural Time Difference Models in the Hori- zontal Plane	53
5.6.2. Angle-Dependent Analysis of Interaural Time Difference Models	56
5.6.3. Mean Angular Error of the Interaural Time Difference Models	58
5.6.4. Subjective Evaluation of the Interaural Time Difference Models	60
5.7. Influence of the Anthropometric Measurement Error on the Inter- aural Time Difference	61
 6. Interaural Level Difference	 63
6.1. Characteristics of the Human Interaural Level Difference	64
6.2. Influencing Anthropometric Dimensions	66
6.3. Modeling of the Interaural Level Difference	70
 7. Spectral Cues of Head-Related Transfer Functions	 73
7.1. Interference Effects of the Pinna	75
7.1.1. Detection of Resonances from Head-Related Transfer Func- tions	79
7.1.2. Detection of Destructive Interferences from Head-Related Transfer Functions	81
7.2. Evaluation Standards of Spectral Differences	84
7.3. Symmetry of the Ears	85
7.3.1. Symmetry of Anthropometric Dimensions	86
7.3.2. Symmetry of Head-Related Transfer Functions	87

7.4. Individualization of the Head-Related Transfer Function by Frequency Scaling	90
7.4.1. Optimal Scaling Factor	91
7.4.2. Anthropometric Scaling Factor	93
7.4.3. Frequency-Dependent Comparison of Scaling Factors . . .	95
7.5. Individualization of Head-Related Transfer Functions by Principle Components	96
7.5.1. Reconstruction of the Spectrum	97
7.5.2. Anthropometric Estimation of the Spectrum by Principal Components	105
7.5.3. Subjective Evaluation of the Individualization by Front-Back Confusions	108
7.6. Comparison of the Methods	113
8. Conclusion and Outlook	119
A. Kalman Filter for Minima Detection	123
B. Linear Regression Analysis	125
Bibliography	127
Curriculum Vitae	139
Acknowledgments	141