
Contents

Introduction

Structured Audio	13
Controllability	13
Scalability	14
Compactness	14
Ideas to be Investigated	15
Structured Audio Event Representation	15
Feature Extraction	15
Structured Re-purposing and Control	15
Applications for Structured Audio	15
Automatic Foley	15
Producer and Sound Designer's Assistant	16
Low-Bandwidth Audio Representations	16
Auditory Invariants	18
Thesis Overview and Scope	20
Chapter 1: Ecological Acoustics	20
Chapter 2: Auditory Group Theory	20
Chapter 3: Statistical Basis Decomposition of Time-Frequency Distributions	20
Chapter 4: Structured Sound Effects using Auditory Group Transforms	21
Scope of Current Work and Results / Findings	21

Chapter I: Ecological Acoustics

1.1 Ecological Perception	23
1.1.1 Attensity and Affordance	24
1.1.2 Complexity of Percept versus Complexity of Stimulus	25
1.1.3 Everyday Listening and Reduced Listening	27
1.1.4 Persistence and Change as Perceptual Units	28
1.1.5 Persistence and Change in Sound Structures	29
1.1.6 Hierarchical Structure in Sound Events	30
1.1.7 Illusions of Affordance: The Example of Foley	33
1.1.8 Studies in Environmental Audio Perception	34
1.1.9 Summary: Implications of Invariants for Structured Audio	36

Chapter II: Auditory Group Theory

2.1 Exploitable Symmetries in Physical Acoustics	37
2.1.1 Physical Modeling of Acoustic Systems	37
2.1.2 Non-Explicit Physical Characterization of Sound Objects	38
2.1.3 Physical Evidence for Auditory Invariants	39
2.1.4 The Helmholtz Resonator	39
2.1.5 Modes of an Edge-Supported Rectangular Plate	40
2.1.6 The General Law of Similarity for Acoustic Systems	41

2.1.7 The New Family of Violins	42
2.1.8 Synthesis of Timbral Families by Warped Linear Prediction	42
2.1.9 Gender Transforms in Speech Synthesis	45
2.1.10 Practical Limits of Linear Dimension Scaling of Acoustic Systems	46
2.1.11 Acoustical Invariants	46
2.1.12 Force Interactions in Acoustical Systems	47
2.1.13 Higher-Order Force Interactions	49
2.1.14 Materials	50
2.1.15 Topology and Configuration	53
2.1.16 The Representational Richness of Affordance Structures	56
2.1.17 The Trace of Physical Symmetries in Auditory Energy Distributions	58
2.1.18 A Theory of Acoustic Information based on Ecological Perception	59
2.2 Auditory Group Theory	60
2.2.1 Formal Definition of Group-Theoretic Invariants	60
2.2.2 Representation of Auditory Group Invariants	62
2.2.3 The Local Lie Group Invariance Theorem	62
2.2.4 Time-Shift Invariance	63
2.2.5 Amplitude-Scale Invariance	64
2.2.6 Time-Scale Invariance	65
2.2.7 Frequency-Shift Invariance	65
2.2.8 Frequency-Shift Invariance Alternate Form	66
2.2.9 Summary of Invariant Components of Common Signal Transforms	67
2.2.10 Structured Audio Algorithm Analysis	68
2.2.11 Classes of Structured Audio Transform	69
2.2.12 The Tape Transform (An Unstructured Audio Transform)	69
2.2.13 Short-Time Fourier Transform (STFT)	69
2.2.14 The Phase Vocoder	70
2.2.15 Dual Spectrum Transformations (SMS, LPC)	73
2.2.16 Cepstral Transforms	75
2.2.17 Multi-Spectrum Time-Frequency Decompositions	76
2.2.18 Auditory Group Modeling of Physical Properties	77
2.3 Summary of Approach	78
2.3.1 A Note on Proper and Improper Symmetry	78
2.3.2 1. The Principle of Underlying Symmetry / Regularity	78
2.3.3 2. The Principle of Invariants Under Transformation	78
2.3.4 3. The Principle of Recoverability of Similarity Structure	79
2.3.5 4. The Principle of Representation Based on Control of Invariant Features	79
2.3.6 5. The Principle that Perception Uses the Above Representational Form	79
2.4 Summary of Chapter	80
Chapter III: Statistical Basis Decomposition of Time-Frequency Distributions	
3.1 Introduction	81
3.2 Time Frequency Distributions (TFDs)	81
3.2.1 Desirable Properties of the STFT as a TFD	82
3.2.2 Short-Time Fourier Transform Magnitude	82
3.2.3 Matrix Representation of TFDs	83

3.2.4 Spectral Orientation	83
3.2.5 Temporal Orientation	84
3.2.6 Vector Spaces and TFD Matrices	84
3.2.7 Redundancy in TFDs	85
3.3 Statistical Basis Techniques for TFD Decomposition	86
3.3.1 Introduction	86
3.3.2 Principal Component Analysis (PCA)	86
3.3.3 Previous Audio Research using PCA	86
3.3.4 Definition of PCA	87
3.3.5 Joint Probability Density Functions and Marginal Factorization	88
3.3.6 Dynamic Range, Scaling, Rank, Vector Spaces and PCA	88
3.3.7 The Singular Value Decomposition (SVD)	89
3.3.8 Singular Value Decomposition of Time-Frequency Distributions	91
3.3.9 A Simple Example: Percussive Shaker	91
3.3.10 Method	92
3.3.11 Results	92
3.3.12 A More Complicated Example: Glass Smash	93
3.3.13 Method	94
3.3.14 Results	94
3.3.15 Limitations of the Singular Value Decomposition	95
3.3.16 Independent Component Analysis (ICA)	98
3.3.17 The ICA Signal Model: Superposition of Outer-Product TFDs	99
3.3.18 ICA: A Higher-Order SVD	101
3.3.19 Information-Theoretic Criteria For ICA	103
3.3.20 Estimation of the PDFs	103
3.3.21 Parameterization and Solution of the Unitary Transform Q	104
3.3.22 Uniqueness Constraints	104
3.4 Independent Component Analysis of Time-Frequency Distributions	106
3.4.1 Method	106
3.5 Examples of Independent Component Analysis of TFDs	110
3.5.1 Example 1: Bonfire sound	110
3.5.2 Example 2: Coin dropping and bouncing sound	115
3.5.3 Example 3: Glass Smash Revisited	119
3.6 Summary	124
Chapter IV: Structured Sound Effects using Auditory Group Transforms	
4.1 Introduction	125
4.2 Resynthesis of Independent Auditory Invariants from Statistical Bases	125
4.2.1 Spectrum Reconstruction from Basis Components	125
4.2.2 Example 1: Coin Drop Independent Component Reconstruction	127
4.2.3 Example 2: Bonfire Sound	132
4.2.4 Signal Resynthesis from Independent Component Spectrum Reconstruction	135
4.3 Auditory Group Re-synthesis	137
4.3.1 Signal Modification using the LSEE MSTFTM	137
4.3.2 Efficient Structures for Feature-Based Synthesis	138

4.3.3 FIR Modeling	138
4.3.4 IIR Modeling	145
4.3.5 Characterization of Excitation functions	146
4.4 Auditory Group Synthesis Models	147
4.5 Future Directions	148
4.5.1 Orthogonality of ICA Transform	148
4.5.2 Weyl Correspondence and Transformational Invariant Tracking	149
4.5.3 On-Line Basis Estimation	149
4.6 Summary	149
Appendix I: Local Lie Group Representations	
1.1 Definition of Invariants	151
1.2 Transformations of points	152
1.3 Transformations of functions	154
Appendix II: Derivation of Principal Component Analysis	
2.1 Eigenvectors of the Covariance Matrix Derivation	157
2.1.1 Principal Component Feature Extraction	157
Bibliography	
	161