Tutorial on Modern Methods for Statistical Audio Signal Processing and Characterization

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1. OBJECTIVES

Musical signals contain many types of information, such as information about the sound color or texture, information about the type of the playing instrument(s), the notes being played, musical patterns and repetition structure, the style or mood of the musical piece and many more. In order to characterize, process or retrieve these different types of knowledge, many specific descriptors are proposed for each task and problem. In this workshop we will attempt to provide a unifying view of these problems in the context statistical data analysis and modeling. Our approach links the questions of signal modeling/representation to the question of information contents of the signal, extending it beyond linear models to non-Gaussian and non-linear signals and systems.

After a review of basic spectral estimation and signal modeling methods, we shall consider the role of information theory in problems of signal characterization, compression and classification. Geometric signal modeling is described by means of a low rank signal modeling approach. Higher Order Statistical (HOS) analysis is presented for problems of non-Gaussian and non-Linear signal analysis and is related to improved estimation of the information / entropy of such signals. Independent Component Analysis (ICA) is considered in the context of modeling natural sounds and provides an improved (non-orthogonal linear) basis for signal representation. Signal and spectrogram decomposition into ICA basis and ICA coefficients are described. Recurrence analysis is presented for detection of repeating patterns in musical signals. Phase coupling effects are described in the context of analysis of harmonic signal analysis and characterization of musical instruments.

1.1 Intended audience and expected level -

The workshop is intended for students and researchers in Music and Audio Signal Processing. No prior knowledge in statistical signal processing is assumed. Basic Mathematical background is required. Background in Signal Processing/Statistics is an advantage.

1.2 Course Material

Lecture handouts will be delivered during the tutorial. Course reader (papers and book references) will be published before the course.

1.3 Instructor's biography

Shlomo Dubnov graduated from the Jerusalem Music Academy in composition and holds a Ph.D. in Computer-Science from the Hebrew University, Jerusalem. In both institutes he served as a lecturer on computer music. The results of Dubnov's academic research are regularly published in musical and technical books and journals. In 1996 he received the Distinguished Paper Award from the International Computer Music Association (ICMA) for his work on Polyspectral Analysis of Musical Timbre. In 1996-1998, he worked as an invited researcher in IRCAM – Centre Pompidou (Paris). Since 1998, Dubnov has been heading the Multimedia track in Communication Engineering Department of Ben-Gurion University, Israel, where he conducts numerous researches on advanced audio processing and retrieval methods, computer music and other multimedia applications.

2. OUTLINE

2.1 Introduction

Open Problems in Audio and Music Signal Analysis:
- In search of a "Natural" basis for sound
- Randomly Modulated Periodicity and Harmonic / Noise Decomposition Problem
- When does a signal have structure? Spectral Flatness and Information Redundancy
- Music as a Non-Linear process

Principles of Linear Gaussian, Non-Gaussian and Non-Linear Time Series Analysis

2.2 Signal Representation:

Stochastic and Geometric Models, Non-Linear Systems and Generalized Dimensions

2.3 Information Modeling:

What is information? Application for Signal Compression and Retrieval

2.4 Linear Low Rank Modeling – Short Review:

Principal Components Analysis (PCA) and Singular Value Decomposition (SVD)

2.5 Non-Gaussian/Non-Linear Extensions:

Introduction to Higher Order Statistics, Independent Component Analysis (ICA), Non-Linear Systems and Recurrence Analysis, Effect of Phase Coupling in Harmonic Signals

2.6 Applications of HOS and ICA:

Structured Audio Representation:
- Independent Component Basis for Natural Sounds
- Harmonic+Noise Decomposition in Sustained Sounds
- Analysis of Music Structure by Recurrence Analysis

Sound Separation: Clustering IC (Independent Subspace Analysis)

Applications for Sound Retrieval:
- ICA Descriptors for Sound Effects
- Matching sound textures using HOS
- Kurtosis profile and phase coupling in sustained musical instruments

2.7 Conclusion and Summary