

# Preface

Sounds create an evolving signal of the events occurring around us in our daily lives. The field of acoustics is that branch of natural science concerned with the physical and psychological properties of such sounds. As with other areas of natural sciences, the properties of sound can be described by mathematics. As mathematics is an abstract science, sound is also analyzed in terms of abstract spaces. However, the primitive structures contained with the sounds encountered in our real lives are left without one's notice. The motivation of this book is the return to the nature of sound from the perspective of time structures.

Fourier transforming a function into its image function has been the fundamental and historical approach to the science of waves and particularly the field of acoustics. Given a function that depends on the time variable, the Fourier transformation provides a means to extract the spectral properties of the function. The spectral properties are normally represented by the frequency variable. Thus, the spectral function can be characterized by relating each spectral component to a sinusoidal function. Any function of the time variable or waveform can be represented as a superposition of sinusoidal functions. This approach by decomposition in treating the waveform as a sum of sinusoidal functions has been heavily exploited in signal analysis of waves and particularly sound in the frequency domain using Fourier transformation theory. Consequently, the behavior of sound waves in the time domain has had less attention although sound waveforms can be normally recorded in the time domain.

This book focuses on the characteristics of sound waves in the time domain. This time domain approach provides an informative and intuitively understandable description of various acoustic topics such as sound waves traveling in an acoustic tube or in other media where spectral or modal analysis can be intensively performed. The effects of reflection from the boundary on propagating waves are explicitly manifest, for example.

The envelope or the signal dynamics is representative of sound signatures in the time domain. The global behavior of the waveform defined by the envelope is determined by local structures related to the spectral characteristics including the phase of the waveform. The signal dynamics as represented by envelopes provide

the main cues in speech intelligibility. This fact has oriented the author's research to the time domain approach and reestablished the importance of the phase of the wave, which has been given less attention in the frequency domain.

The periodic nature of sound is another typical signature associated with the time domain that relates to the harmonic and nonharmonic structures in the global spectral properties that are independent of the phase. Sensation of pitch that mostly relates to the period of sound is a historical topic in sound perception; however, it seems still a very attractive topic to the author. Sound generated by a musical instrument such as a piano looks nonharmonic. Such sound waveforms may be interpreted through period analyses in the time domain to be subject to the missing fundamental condition where the fundamental is out of auditory range.

Alternatively, sound waves travel in media basically governed by the theory of linear system as described by linear equations. Here the impulse responses and convolution are key concepts. The solutions of the linear equations are superposition of the particular and general solutions. This decomposition reminds the author of the decomposition of sound waves into direct and reflected (or reverberation) sound waves in the time domain. This type of decomposition would be informative not only for room acoustics but the study of musical sounds such as those from piano string vibrations, where the waveform can be understood as a superposition of the direct wave resulting from the excitation by the hammer and the resonant modal waves generated in the string vibration.

Sound propagation in a medium or radiation from a sound source can also be formulated in accordance with convolution theory. This formulation has also motivated the author to take up the time domain approach. In addition to that, the analysis of room reverberation in the time domain has historical roots in the field of acoustics.

This book deals with the signature analysis of sound from the view point of the time domain. The author has tried to make this book self-contained and useful as a textbook for graduate and undergraduate courses offered at universities. The book starts from the very introductory topic of sinusoidal waves basing the material on the formal relationship between the time and frequency domains. For that purpose, the fundamental notions of Fourier or  $z$ -transformations and linear systems theory are summarized along with interesting examples from acoustical research. Research engineers and scientists might also have interest in this book for its different approach. In particular, the expressions concerning waveforms including the impulse responses might be informative to audio engineers who are familiar with digital signal analysis.

Exercises have been prepared for every chapter. These exercises are very simple and designed to be solved straightforwardly by hand without the need for a computer. Thus, they assist in reconfirming the fundamental ideas and notions present in every chapter. However, the author has had to assume some prior knowledge on acoustics and signal processing so that from a practical point of view the finished book remained concise. For readers who are not familiar with acoustics in general including signal analysis, the references below have been found to be useful.

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