# Preface

Acoustic metrology has long presented the problem that sound measuring instruments are very expensive. This is due to two types of components: the transducer, i.e., the microphone, and the electronics required to perform signal conditioning and processing (filtering, analysis, comparisons) and display the results.

At the beginning, both the microphone and the electronics were intrinsically expensive. The microphone, because it was a sophisticated electromechanic device which required a complex manufacturing process and high-quality materials to ensure robustness, flat frequency response, low distortion, and stability over time. The electronics, because of the need of highly trained labor as well as expensive high-quality components.

Nowadays, instrumentation grade microphones are still expensive, but the cost of electronics has dropped several orders of magnitude. So one would expect that acoustical instrumentation prices had dropped as well. However, they tend to rise! For instance, a decade ago it was possible to purchase a first-brand sound level meter for about $2000. Today, the cheapest instrument that replaces that one is twice as expensive, even considering that the international inflation of the dollar has been only 30 % during the same time span, and the manufacturing cost has been further reduced by offshoring in countries like China and by the replacement of many discrete components by a small count of custom integrated circuits. In contrast, the computer industry exhibits the opposite trend: the price of what at a given time is considered to be a state-of-the-art computer not only does not increase but is actually falling below the dollar inflation.

Measurement instrument manufacturers try to imply that the price rise pays for a lot of exciting new features that are now possible through the use of sophisticated microprocessing units. However, the real cost of hardware and software is a very small fraction of the retail price. Moreover, they have adopted a commercial policy from the software industry, which is to license different software (firmware) modules that run on a single hardware platform. From the manufacturer standpoint, this reduces even further the manufacturing cost since the same hardware can be used to provide the functionality of several instruments as well as the promise of future updates (which certainly are not cheap). In some cases, firmware modules are preinstalled and all that is needed is to buy the code that unlocks the desired function.

In this scenario, the idea to exploit the potential of personal computers arises. Any user with some programming experience has at their fingertips the possibility to replace or emulate the signal processing that takes place inside a typical advanced sound level meter or analyzer. A sine qua non prerequisite is to have the signal available in digital format. This is accomplished by means of an external digital audio recorder which records the calibrated audio output signal that almost any sound level meter provides. Once digitized, the signal may be subject to many different processes, from computing any of the classic parameters and indicators to any possibility deserving to be investigated that our imagination can think of.

The traditional measuring paradigm is, hence, starting to change. Instead of recording a reading as an abstract translation of some property of a given phenomenon with no possibility of further verification, we record the very object to be measured. It is true that the original object is a sound field with complex spatial, temporal, and spectral distribution, and that by capturing it by means of a single microphone a severe abstraction process has been already performed. But it is the same abstraction process that the sound level meter carries out prior to the actual measurement!

The proposal put forward in this book is to examine traditional measurement processes and to present alternative approaches to be implemented using mathematical software running on a general purpose personal computer. Compatibility with International Standards in the field of acoustical measurements is also analyzed to ensure that the algorithms to be used comply with relevant standards. Several examples of parameters that are usually absent even in sophisticated commercial instruments are also given. In all cases, the proposal involves the minimum hardware and software investment, which is why all the examples use free, open source, and multiplatform software.

While every effort has been made to render the book reasonably self-contained, some prerequisites should be fulfilled to profit the most from its reading: (1) A fluent working knowledge of algebra and calculus of several variables, including the complex variable and the basics of differential equations. (2) A fair acquaintance with the theory of signals and systems, including the Laplace and Fourier transforms, the concept of spectrum and basic filter theory. (3) At least an elementary knowledge of Acoustics. (4) A good command of computers. (5) Some programming experience. (6) A grasp of elementary probability and statistics (though there is an appendix covering the basics).

Chapter 1 introduces the general concepts of acoustical measurements, such as equivalent levels, time and frequency weighting, statistical descriptors, and spectrum analysis, with emphasis on the process of measurement stabilization. Chapter 2 covers the most distinct aspect of measurement quality: uncertainty. While measurement uncertainty is extensively treated in many books and standards, the particular case of acoustical measurements is often neglected or presented in a fragmentary way. An in-depth treatment is provided here. This chapter may be skipped in a first reading without loss of continuity. Chapter 3 covers many aspects of digital recording, from sampling and analog/digital/analog conversion to audio file formats, recording media, and long-term preservation. This chapter can also be skipped or presented in a different order if starting earlier to program algorithms is the priority and the reader has a practical acquaintance with digital recording. Chapter 4 is an introduction to digital audio editing with special reference to its applications to measurement postprocessing. Chapter 5 covers several aspects of transducers that are relevant to their use in a measurement system, such as frequency response and directivity. Chapter 6 introduces digital signal processing, covering the main standard techniques such as convolution, discrete systems, difference equations, Z transforms, and stability. This chapter can be skipped if the reader is already acquainted with the basic theory of digital signal processing. Chapters 7 and 8 cover specific techniques and algorithms used in acoustical measurements. Finally, Chap. 9 presents the test methods to be applied to digital recorders to ensure the hardware complies with the relevant standards.

Each chapter includes a problem set in which the main ideas are applied to practical situations. In several problems, additional or advanced methods related to the subject of the chapter are introduced.

Finally, the book contains sixteen appendices covering supplementary material, derivations, and basic theory or examples.

Because of space restrictions, it is not possible to include here but short excerpts of some programs implementing the general ideas that are studied herein. That is why full-length examples are to be included in the Web site of the Acoustics and Electroacoustics Laboratory of the National University of Rosario. They will be available for download from http://www.fceia.unr.edu.ar/acustica/measurements.

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