Toward an open room acoustics measurement system:
I: Overview and Hardware

Robert Essert
and
Eckhard Kahle

Artec Consultants Inc
114 W 26 ST, New York, NY 10001

Essert now at Sound Space Design
2 St George's Court, 131 Putney Bridge Road
London SW15 2PA
bobessert@soundspacedesign.co.uk

Presented as Paper 5pAA7 at the third joint meeting of the
Acoustical Society of America and the Acoustical Society of Japan
Honolulu, Hawaii, 4-6 December 1996

Abstract

Recent development of PC based acoustical measurement systems has allowed separation of hardware and software development. It is often no longer necessary to buy new hardware in order to add new features, but only to add or change the software algorithm. Having measured and stored room impulse responses (mono, directional, binaural, 3D) one can use the same raw data later with new computer analysis routines. The CHRG room measurement project and the Alex round robin test have drawn attention to the differences between systems; different measurement teams have a variety of goals and priorities. We wish to measure and analyze far more than reverberation times. On the one hand, we need to provide specifications that will guarantee comparable data for certain standard measurements, and on the other hand, we need to accommodate future development. Starting with a superset of goals, we outline an approach to defining which parts of the system should be subject to standards, still retaining the flexibility for unique or experimental measures.

INTRODUCTION

At meetings of the Concert Hall Research Group we spend a lot of time discussing measurement systems. Everyone has their own system, own priorities, own interests. We have different budgets. An initial thrust of the Concert Hall Research Group was to compare and contrast three representative measurement systems and techniques in several halls, and eventually to normalize them to each other or to a nonexistent standard.

A long term goal of the CHRG is to assemble a shared library of data on halls. For that to be of any use, the data needs to be useful for some years.

Many of us have considered these issues as we develop our own measurement systems, but most of us give a higher priority to expediency than to overall consistency and long term interest. Let us today step back and look at the bigger picture.

Generally, we are not keen on "standards for standards' sake". We are interested in developing a framework into which specific measurement systems can fit, with flexibility and extensibility. This paper is a first outline for discussion by the CHRG and possibly TCAA on a road to develop such a framework..

Perception and diagnostics – different needs

We are convinced that the future of acoustical measurement, analysis and evaluation must include strong *perceptual* component. In performing arts acoustics perception is everything. The performers and audience are (if all is going well) *actively engaged* participants in the concert, opera or play. In concerts, especially, sound quality is at the forefront of the listening and performing endeavor. Our next generation of measurement and analysis tools must be a capable platform for perceptual judgments.

We also need data and analysis techniques to help us more directly understand the causal relationship between the source, the architecture and the resultant sound field. Single channel responses with an omni mic and omni speaker do not help much; we can now contemplate capturing 3D information.

Researcher vs practitioner priorities

There are diferences in priorities between researchers who want flexibility in the measurement and analysis systems and practitioners who want turnkey systems, accepting the "closed box" nature of the system. Most commercial systems are designed with the practitioner priorities first. We believe the "open system" strategy can and should fold in the requirements of both.

The rest of this paper will focus on measurement systems for performing arts and assembly spaces, though some portions may apply to other acoustical measurement needs. I will give an overview and focus more on hardware issues. My colleague Dr. Kahle will follow in the next paper with a more specific discussion of the software issues.

OBJECTIVES

What follows below is the first outline of objectives for concert hall/theatre acoustics measurement systems.

Occupied hall (as well as unoccupied)
- Presence of audience and performers (orchestra) have a profound effect on the acoustics.
- What the audience experiences in performances is the occupied condition, so the relationships between objective and perceptual testing ought to be established in the occupied condition.

Data quality adequate to span perceptual domain
- Bandwidth
- Dynamic range
- Spatial definition

Binaural for auralization
- Full audio bandwidth
- Wide dynamic range
- “Standard” pinnae, or individual pinnae?

Space-time full impulse response
- Full audio bandwidth
- Wide dynamic range
- 3D spatial info – for diagnostics and for resynthesis of sound field in lab for further study

Long data usability / life
- Audio characteristics – useful for future analyses
- Storage media – ubiquity, stability, cost, ease of use
- Storage format – “open”, easy to access

Modularity
- Separate hardware from software
- Separate various modules

“Open” System
- Encourage new measurement, analyses.
- Flexibility of systems to allow “mix and match” of various components
- NOT standardized <u>measurements</u>, but measurement <u>systems</u>.

Portability
- Avoid wiring
- Quick in and out for occupied measurements

Scalability
- Add recorders/mics at linear cost
- Add sources at linear cost

Use with scale modeling

- Computer capture and analysis tools can be used for scale models as well as with full size spaces
- Auralization “back end” should work for scale modeling

MODULARITY

A primary objective is to separate the components of the system into independent elements. This will allow development by different parties in different areas, yet allow each to incorporate the work of the others. The divisions between modules might logically be as follows:

Acquisition

- Source
- Receiver
- Signal
- Acquisition system
- Raw Storage

Processing/analysis

- Signal Processing
- Processed Storage
- Analysis

Presentation

- Numerical
- Graphical
- Auralization
    - Binaural
    - Transaural
    - Ambisonic

SOUND SOURCE

Directivity

- Simple directivity
  - Omni
  - Multi-direction – reconstruct omni
  - Emulate musical instrument and voice directivity?

- Bandwidth
  - Full audio bandwidth

- Dynamic range
  - Impulsive sources -- efficiency/ power handling / linearity
  - Continuous noise
  - TDS
  - Deconvolution

- Repeatability
  - Explosive or chaotic – multiple averages
  - Deterministic and "well behaved"

- Linearity
  - Low crest factor signals put less stress on the transducers, and can therefore be operated at higher levels and achieve better S/N ratio.

Additional Criteria For Occupied Halls

- Speed of setup/capture
- Portability
- Scalability
- Ease on the ears in occupied halls – typically an orchestra on stage

Source Signal Characteristics

- Impulse - balloon, gunshot
  - Poor repeatability (esp. balloon)
  - Band-filtered impulse: Gade, et al.

- Continuous noise
  - Typically used with real-time analyzer, but can also be deconvolved.

- MLS
  - Susceptibility to time variance – difficult w/ audience
  - White power spectrum – not a good match for hall background noise

- Sweep -- flexible
  - Power spectrum can be tailored to suit the task

Equalization with both time and amplitude
Can be tailored for low distortion

Can we, should we, outline a “standard” source? Should we specify tolerances? We contend that the answers to these questions should be driven by perceptual relevance.

Source Transducers

Below is a comparison of general characteristics for commonly used source transducers. They fall into two basic groups: the chaotic/impulsive ones (balloon, gunshot) and the loudspeakers.

SOURCE CHARACTERISTIC	***Balloon***	***Gunshot***	***omni loudspkr***	***multi-directional***	***model voice/ instrument***
Directivity	omni (-)	omni	good (lo f) fair (hi f)	flexible	specific
Bandwidth	lacks lo/hi	lacks lo/hi	good	good	good
Dynamic Range	good at mid-freq	good at mid-freq	fair	good	poor
Repeatability	poor*	fair*	excellent	excellent	excellent
Speed	excellent	excellent	good	poor	fair
Portability	excellent	excellent	good	good	good
Human factors	excellent	poor	good	good	excellent

Source Signals

Below is a comparison of general properties of several commonly used source signals. They fall into two categories: explosive/chaotic (first 3) and deterministic/repeatable (last 3).

SOURCE CHARACTERISTIC	***Balloon***	***Gunshot***	***Random Noise***	***TDS/TEF***	***MLS***	***Sweep***
Bandwidth	lacks lo/hi	lacks lo/hi	full	full	full	full
Dynamic Range	good at mid-freq	good at mid-freq	good	excellent	good	excellent
Repeatability	poor*	fair*	fair*	excellent	excellent	excellent
Speed	excellent	excellent	poor	poor	good	excellent
Portability	excellent	excellent*	fair	good	good	good
Human factors	excellent	poor	poor	poor	fair	excellent
Impulse Response	yes*	yes*	no/yes**	no	yes	yes

* requires averaging to achieve decent S/N, bandwidth and portability
** Traditionally continuous noise has been used with real-time analyzers, but today it can be used as a stimulus and deconvolved from the measurement to get the impulse response

RECEIVER

Types in use today:
- Omni-directional - size/polar tolerance
- Binaural – standardize?
- Directional mics: fig8, supercardioid?
- 2ch for omni+fig8 (lateral fraction)
- 2ch for binaural
- 3-dimensional
  - 4 spaced mics – 4ch
  - Intensity – 4ch
  - Soundfield microphone – 4ch
  - Larger, synthetic arrays

Considerations:
- Calibration of reference level
- Noise floor low enough that it is not perceptible as either noise or increased reverberation
- Bandwidth for full relevant audio perception
- Portability for occupied hall measurements
- Scalability for adding measurement positions without large incremental cost

ACQUISITION SYSTEM

- Bandwidth: 20-20kHz
- Dynamic range: 90dB
- # channels Up to 4 for 3D impulse responses, 2 otherwise
- A/D Linearity Especially relevant for MLS measurements. What is an appropriate value?
- Portability We sacrifice immediacy of results for ease and speed of capture with Portable DAT machines
- Cost PC based solutions need not cost much. One can
- Ease of use Unoccupied measurements are often made late at night, where it's easy to make mistakes. The system should actively help to avoid them.

STORAGE

Stored data should first and foremost be useful for some time in the future. We get into the halls so rarely to measure them. The data should be have a long and useful life. With digital storage systems now, the physical properties of the medium need not be a limiting factor.

- Long term storage
- Sharing
- Allow independence of acquisition and analysis software
- File naming, annotation

<u>Proposal</u>: CD-ROM

SOFTWARE

- Standard A/D capture software in OS to industry std file.
  16bit minimum dynamic range.
  Sample rate?

Proposal: 16-bit audio files

- Intermediate storage format
  Condensed time domain
  What is enough resolution? What is too much?

- We are now using Matlab for processing, analysis

- Standard OS D/A software for playback of WAV files

- Interactive vs batch operation

Proposal for low-cost, portable, "open" system:

- Precomputed signal on portable DAT -> Source

- Record on multiple DAT machines in hall – running in parallel

- Capture to PC:

2-ch: High quality PC "Windows" board capture only
4-ch: more costly acquisition board
Standard sound recorder software

- Matlab analysis, w/supplements

- Matlab file formats for metafiles (time, freq, space)
  Numerical results in text files

- Processed time series audio in OS/platform standard sound files (wav, snd…)