A PC BASED MEASUREMENT SYSTEM FOR OBTAINING SPATIAL INFORMATION AND OBJECTIVE ROOM-ACOUSTIC INDICATORS.

A. Abdou and R. W. Guy
Centre for Building Studies (CBS),
Concordia University,
Montreal, Quebec, H3G 1M8, CANADA.

ABSTRACT

Over the last twenty years, many subjectively relevant objective room-acoustics quantities or indicators for evaluating the acoustical quality of an enclosure have been introduced. Whilst indicators give new insight into the acoustical goodness of a receiver position, there is still a need to quantitatively establish the extent that they are influenced by the interior physical features of the enclosure. The relationship between objective room-acoustic indicators and details of enclosure design from the point view of cause and effect are not fully understood; in order to contribute knowledge in this area, quality indicators must be obtained with directional information. A PC Based multiple channel measurement system under current development and designed to meet these demands is presented. The system involves software developments together with hardware interfacing. Its potential is discussed and example results are given.

SOMMAIRE

Au cours des vingt dernières années, on a introduit plusieurs quantités objectives subjectivement pertinentes ou paramètres pour l'évaluation de la qualité acoustique d'une enceinte. Bien que ces paramètres donnent des significations nouvelles à la qualité acoustique d'une position d'écoute, on eprouve qu'en même le beison d'établir quantitativement le degré de l'influence exercée sur eux par les caractéristiques physiques intérieures de l'enceinte. La relation causale entre les paramètres acoustiques objectives et les détails de conception des enceintes ne sont pas encore complètement compris; on doit obtenir des paramètres de qualité contenant de l'information directionnelle pour l'éclaircir. A fin de répondre à cette demande, on apporte une contribution originelle en utilisant un système de mesure multicanal basé sur ordinateur personnel. Le système comprend des développements de logiciel ainsi que d'interface. On explore le potentiel du système et on en donne des exemples.

1. INTRODUCTION

Over the last two decades, many subjectively relevant objective room-acoustics quantities or indicators for evaluating the acoustical quality of an enclosure have been introduced. Some of these indicators relate to reverberance and musical clarity, others to spaciousness or spatial impression, some to speech intelligibility and others to acoustic conditions at performer locations. These indicators are typically "Reverberation Time" (*RT*), "Early Decay Time" (*EDT*), "Definition" (*D50*), "Clarity" (*C50,C80*), "Centre Time" (*TS*), "Lateral Energy Fraction" (*LEF*), "Relative Strength" (*L*), "Speech Transmission Index" (*STI*), "Rapid Speech Transmission Index" (*RASTI*), "SUPPORT" (*ST*) and Modulation Transfer Function (*MTF*) [1; 7].

Most of the newer indicators are based on the room impulse response sound energy ratios and except for LEF do not touch upon the sound directional characteristics. Numbers of them are found to be inter-related and to some extent considerable overlap is exhibited;[3; 8] this implies that knowing a few will allow others to be deduced. They have also been correlated to overall geometric variables such as room width, height and wall angles; recently Gade [9] proposed empirical models for their prediction based on statistical analyses. Techniques for precise measurement of these indicators have become common however some of them are position dependent and more sensitive to the early reflection sequence, subsequently they are dependent on both the overall geometrical characteristics of the space and architectural details in the vicinity of the measurement location.

The value of such indicators give new insight into the acoustical goodness of a receiver position but in order to design halls, or to correct an acoustical defect in an existing enclosure, there is a need to quantitatively understand the extent to which they are influenced by the various physical design features of the enclosure. In order to develop this understanding, indicator values must be obtained together with directional characteristics information; thus a need exists for suitable comprehensive instrument development. The purpose is to link the measured indicators to the interior physical features and to assess diagnostic capability with respect to the effect and its cause.

2. INSTRUMENTATION REVIEW

With the advent of portable computers and signal analyzers, sophisticated analysis and data acquisition may be made in situ and there are already a few commercial and research PC based room-acoustics measurement systems. A well documented development is the four generations of measurement system developed at the National Research Council of Canada (*NRCC*) over the past 10 years and designed to measure and evaluate criteria concerning the acoustical conditions in auditoria. Bradley and Halliwell **[10]** review this experience in a comparative approach. The most recent of their systems the two microphone *RamSoftII* **[11]**, is based on using Maximum Length Sequence (*MLS*) as an excitation signal. The authors conclude that there is a need for a system giving more comprehensive directional information.

Another measurement system enabling the in-situ calculation of some room-acoustic parameters has been developed in Denmark **[12]**. The system uses a Bruel & Kjaer Modular Precision Sound Level Meter, type 2331 equipped with an IBM-compatible lap-top computer with a plug-in application software module. A powerful hi-fi amplifier and an omnidirectional loudspeaker constitute the sound source. The system is flexible, gives immediate results, is easy to setup and operate, but it is limited by being single channel therefore, indicators such as LEF cannot be measured.

Recently, a powerful single channel system analyzer,"MLSSA" **[13]** based on the MLS technique has been introduced. The system consists of a hardware component; a plug-in-Board (A/D-160), a software driver and signal processor. The system provides important functions needed in data acquisition, processing and analysis for room-acoustic investigations by post processing the impulse response. The system components and possible applications are discussed in some detail by Rife **[14,15]**.

Marshall **[16]** briefly described an other measurement system, "*MIDAS*", which performs room-acoustic measurements based on Fast Fourier Transform (*FFT*) techniques at full scale or at model scale using a variety of sound sources. The system is implemented on an Apple Mac-II computer and it can be operated either in a single or dual channel mode. A more complete description may be found in **[17]**.

Tachibana et al **[18]** demonstrated a measurement system using a technique for the measurement of the impulse response in real auditoria and in scale models. Their measurement system is described along with its application in both cases and some examples are also presented.

The foregoing systems have been developed primarily to measure existing indicators.

Endoh et al **[19]** have developed a technique by which they are able to grasp the spatial information specially of the early reverberation periods. The measurement technique developed by Yamasaki and Itow **[20]** employs a four channel input system to determine virtual image sources and directivity patterns. Powers of virtual image sources are calculated by a correlation technique. The technique gives new insight and valuable information about the directional characteristics of sound in enclosures however no attempt has yet been made to establish relationships between known room-acoustic indicators and the directional characteristics of the sound field.

Confining attention now to the systems described above which display the basic characteristics or potential for directional sensing, namely, digitized raw data capture, software driven and post processing, and two or more channel acquisition, an additional limitation is evident, that is, the current frequency range of application is restrictive. The systems are either low frequency limited (125 Hz) by a lack of low frequency energy content of the source or upper frequency limited (4 kHz) by the temporal length of the digital signal able to be captured and processed.

3. THE NEW MEASUREMENT SYSTEM

A comprehensive measurement system should possess certain features. It should be portable, efficient, and accurate whilst performing the following functions.

- Collect and process extensive time-frequency data in a routine manner over a full range of frequencies and durations.
- Calculate a number of potential useful room acoustic

indicators from the collected data in situ.
- Provide reproducible measurements.
- Provide directional and directivity information of sound in the enclosure in a manner which allows ready interpretation.

In addition the system must be flexible, easy to calibrate, update, set up and operate.

3.1 CBS-RAIMS Components' Description

The *CBS-RAIMS* (Centre for Building Studies-Room Acoustic Indicators Measurement System) is a comprehensive system for obtaining both known room-acoustic indicators and directional characteristic of the sound field. It involves software developments together with hardware interfacing.

The measurement system is based upon acquiring spatial information at the listener location by using an array of 3 microphone pairs arranged in cartesian coordinates or by sequentially measuring in three directions employing one microphone pair. By exciting the enclosure under test with a periodic and well defined signal i.e. MLS, 6 impulse responses can be calculated by Fast Hadamard Transformation and their results presented for preliminary examination at the point and time of measurement; this enables on site validation to be made. Post processing the calculated impulse responses yields the values of most room-acoustic indicators as well as providing a sufficient averaging base to futher enhance the signal to noise ratio. Subsequent signal analysis can also be perfomed which may involve:

- Digital Filtering.
- Energy Analysis.
- Intensity Evaluation.
- Correlation Analysis.
- Cepstrum Analysis.

An impulsive sound produced either by a blank pistol or via a loudspeaker can also be utilized; in the case of employing any non reproducible source, however the six microphone probe should be employed for signal capture.

The measurement system operates in two stages; *the first* is data collection, and *the second* is data processing and analysis. The system is based on a portable AT-386 computer 33 MHz and the main hardware components are shown in Figure 1. The system employs an eight channel signal conditioning board (SCXI-1140)*, and a data acquisition board (AT-MIO-16F-5)* both driven by a software driver. The signal conditioning board allows simultaneous channel sampling using the "Hold and Sample" facility. This feature is useful for preserving inter-channel phase relationships thereby enabling subsequent sound intensity evaluation. The analog input channels can be scanned simultaneously via the signal conditioning board in the HOLD/SAMPLE mode. At the same time as acquisition, the board analog output transmits an excitation signal (*MLS*) of length up to 32767 samples. The transducers currently used are B&K 1/4" pressure microphones Type 4135 mounted on an appropriate 3 dimensional intensity vector probe; in the case of one microphone pair, particular attention need be paid to maintaining the acoustic centre upon reorientation. The analog output channel is connected to a power amplifier which in turn feeds the signal to an isotropic sound source (i.e. loudspeaker). The loudspeaker, currently a B&K Type 4241, consists of a frequency unit composed of 12 high frequency loudspeakers mounted in a dodecahedral body and a low frequency unit. The sound source is isotropic within 3 dB for frequencies below 1000 Hz. Early tests indicate this sound source to lack power when employed in large volume enclosures and a more powerful replacement is currently under construction. The system is also equipped with a triggering device to be used if impulsive sound is desired to be generated while maintaining synchronized triggering with the data acquisition process.

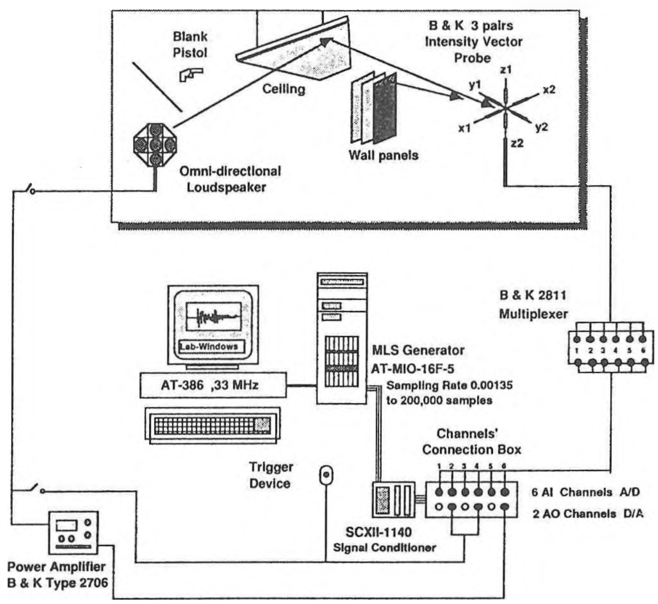

Figure 1. Block Diagram of "*CBS-RAIMS*" Hardware Components.

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* Products of National Instruments, Texas, USA.

3.2 Data Processing

Data processing involves first filtering the impulse responses in 8 octave bands from 63 Hz to 8 kHz using a standard qualifying 8-pole band-pass "ButterWorth" digital filter.Third octave or discrete frequency analysis is also available but not generally employed for enclosure evaluation. The average of the filtered impulse responses are then processed to yield the room-acoustic indicators. The Schroeder integrated impulse method [21] is used to obtain the decay curves from which "Early Decay Time" (*EDT*) and "Reverberation Time" (*RT*) values can be calculated. RT values are calculated via a standard regression analysis applied to that part of the decay between -5 and -30 or -35 dB. EDT values are obtained in the same manner but the decay is restricted to the first -10 dB. To minimize the problem of background noise effect and decay length, EDT and RT can be calculated with background noise compensation; this is done graphically in an interactive way by examining the impulse response.

Calculation of various sound energy ratios such as "Definition" (*D50*),"Clarity" (*C50,C80*) and "Running Liveness" (*R*) is done by integration. The "Centre Time" (*TS*) and "Relative Strength" (*L*) are also included. Indicators of speech intelligibility "Speech Transmission Index" (*STI, RASTI*) [22]."Useful-to-Detrimental Sound Ratio" (*U95*) are also calculated. All room acoustic indicators are then output in a comprehensive table for ease of assessment and comparison.

Several sub routines have been developed to achieve further signal analysis. Spectral Analysis using Fast Fourier Transformation involves Power Spectral Density calculation, Cross Spectrum and Complex Transfer Function calculations. Figure 2 shows a flow diagram of the data processing for the purpose of obtaining both objective room-acoustic indicators and directional characteristics of the sound field.

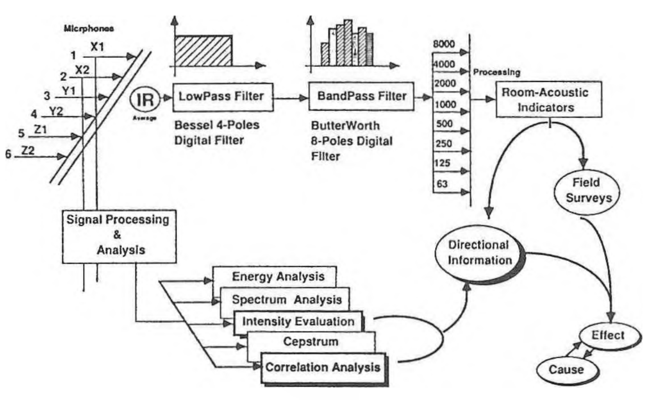

Figure 2. A Data Processing Flow Diagram for Calculating Room-Acoustic Indicators and Obtaining Directional Information.

4. DIRECTIONAL CHARACTERISTICS OF SOUND FIELDS

The objective now is to yield a visually detailed image of incoming sound intensity vectors on a base of time. The filtered 3 sets of impulse response X-X, Y-Y and Z-Z in each octave band allow 3 orthogonal intensity vectors components to be calculated using a finite difference approximation approach. The full record length for each set is used to avoid erroneous results from segmentation and time windowing procedures. This yields instantaneous intensity vectors which can change sign quickly and therefore may cause problems when investigating discrete reflection direction; to minimize this problem the envelope intensity technique could be used [23]. The resultant intensity vectors versus time are then calculated applying a conversion from rectangular to polar coordinates and displayed by employing "AutoCad"* software. An example result is shown in Figure 3.a., it shows the sound intensity vectors of a measurement conducted in the laboratory. Visualizing the temporal arrival, direction and magnitude, particularly of early sound reflections, will allow further detailed study with respect to the direct sound and in relation to each other, their intensity threshold and directions. Figure 3.b. shows only the discrete reflections received from a ceiling while Figures 3.c. and 3.d. display the full directivity patterns at the same location. In practice the graphical output of vectors is color coded for ease of interpretation.

With such information at hand along with values for room-acoustic indicators at the same listener location, it is now possible to attribute cause to effect with respect to the influence of spatial design details such as proscenium, cantilevered or recessed balconies, and facia as in the case of a concert hall or vaults, arches and pillars in a church, as they may effect the incoming early refections sequence. The contribution of left, right, up, down, back or front surface reflections can normally be separated and examined, however it must be accepted that some circumstances arise which might cause erroneous interpretation, for example two angular symmetric vectors of equal amplitude occurring at the same instant of time will be resolved to a single resultant along the axis of symmetry.

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* AutoCad ver. 10, AutoDesk, INC., USA.

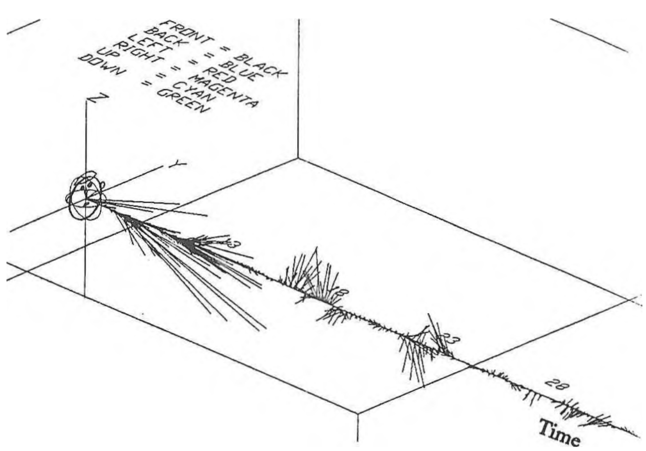

Figure 3.a Example presentation of sound field directional characteristics.

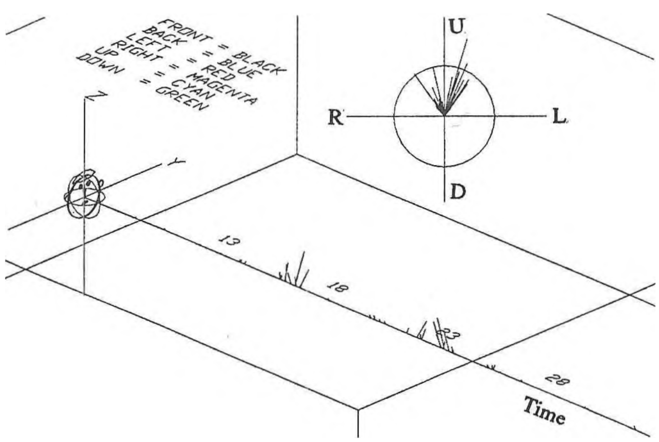

Figure 3.b Discrete reflections received from the upward direction i.e. the ceiling versus time.

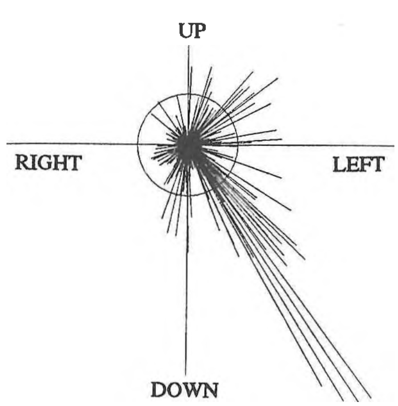

Figure 3.c Directivity Patterns of early reflections (first 50 ms after the direct sound)

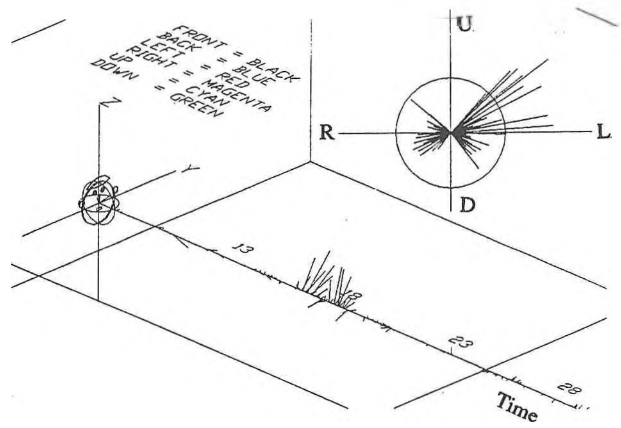

Figure 3.d Directivity Patterns for reflection received from left and right surfaces.

5. CONCLUSION

A knowledge of relationships between the objective room-acoustic indicators and enclosure design in terms of interior architectural details is not yet available. Such knowledge will be valuable for guiding the designer and the acoustician, for example spatial information would contribute towards diagnostic capability and when linked with measured values of the objective room-acoustic indicators for the same listener location, can provide a comprehensive picture of acoustical quality. The interpretation of their values in a more reliable way can lead to effective remedial treatments and possibly improved quality indicators.

The measurement system described here appears capable of providing the needed temporal and spatial information.

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