A Virtual Instrument for the Analysis of Objective Acoustic Parameters

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Abstract

In this paper a novel instrument for measuring objective acoustic parameters in acoustic concert halls is proposed. It has been realised by using the virtual instrumentation approach and attention has been devoted to the instrument flexibility. In particular it is possible to change various instrument parameters in accordance with the required information. Various objective parameters that allow to verify on line the hall acoustic quality are estimeted from the proposed instrument.

Introduction

In the last decades, in order to assess the acoustic quality of concert halls, several indexes have been formulated [1][2][3][4]. These parameters are known as *objective parameters.*

The concert hall can be considered as a dynamic system and therefore its performance can be obtained by recording the acoustic waves produced by the emission of particular acoustic signals. Pseudo-random solicitation signals are produced by a loudspeaker and the corresponding signals are recorded by using a microphone. The system input and output signals can be used to estimate the *objective parameters.* In Fig. 1 a schematic representation of the *acoustic hall system* is reported. In particular:

- X(t) represents the pseudo-random solicitation signal;
- Y(t) is the corresponding *output*, known as *impulsive response*;

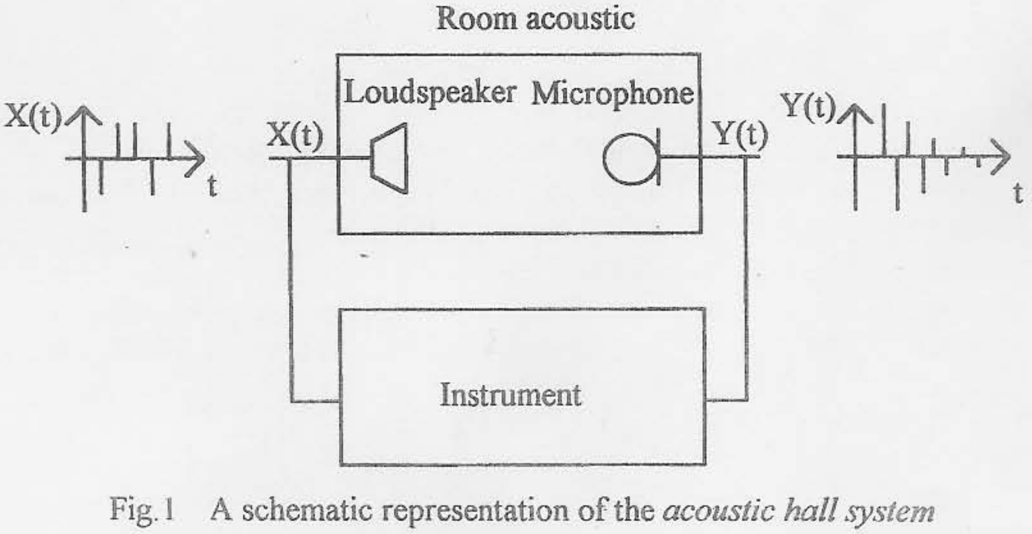


Fig. 1 A schematic representation of the *acoustic hall system*

The instrument reported in Fig. 1 is used for the estimation of the *objective parameters*.

Even though instruments for the estimations of these parameters do exist, generally they are custom products and therefore are not flexible devices. In this paper a novel kind of measuring instrument, known as *virtual instrument* is proposed.

A virtual instrument uses an acquisition card to sample the considered signals. The obtained data are therefore converted in digital form and are manipulated by using the software capabilities of a computer. The used approach allows to exploit the computational power of computer machines to obtain powerful and flexible instruments.

The objective acoustic parameters

The *objective parameters* allow to determine the acoustic quality of a concert hall. They are time-space variables and describe the sound energy reaching the listener in a acoustic room. As a first objective parameter, the *reverberation time* was introduced by W. Sabine. Afterward other researchers have introduced new parameters. These parameters allowed to describe different characteristics of the acoustic rooms as intelligibility, distinctness, spaciousness, etc..

In this paper the following parameters have been considered [5][6][7]:

- *reverberation time* RT;
- *early decay time* EDT;
- *early to late sound index* C80;
- *definition* D;
- *centre time* Tb;
- *signal to noise ratio* S/N;
- *speech transmission index* STI;
- *rapid speech transmission index* RASTI.

These parameters can been obtained by using a *Galois* sequence [8][9] as the sollecitation signal.

The virtual instrument

Generally, traditional instruments are self-contained and have defined all internally functionality; the user cannot change them. The virtual instrument is software that emulates the technological istrument, therefore it gives the possibility to realize flexible low-cost and high performance instruments.

To realize the proposed virtual instrument, the LabVIEW® [10] software was used. It allows to acquire data by using acquisition device cards and to create functional icons connected among them in a precise configuration.

The icons manipualate data, in accordance with adequate commands and produce the instrument outputs. The LabVIEW® shows the virtual instrument as formed from two sections: the "Front Panel" that realizes the instrument interface with the user and the "Block Diagram" that it is the functional part of the tool. The proposed virtual instrument is structured in five different parts, known *as sub-virtual instruments: Galois, Acqui, Hio, Filter and Io To.* The first section, *Galois*, allows to realize a Galois sequence and drives the loudspeaker to radiate the Galois signal. The second section, *Acqui*, aquires the *impulsive response* of the acoustic hall by using a microphone. The section *Hio* allows to determine some objective parameters as the STI, the RASTI, the D, the S/N, the U50 and the TC. The *Filter* section is used to filter the impulsive response. For sampling frequencies less than 23 kHz the considered bandwidths are eight, with central frequencies ranging from 31 Hz to 4kHz, for sampling frequencies above 23 kHz the select bandwidths are nine with central frequencies ranging from 31 Hz to 8 kHz. The last section has three different subsections *Filter1*, *Filter2* and *Filter3* that allow to calculate some acoustic objective parmeters as a function of the frequency. *Filter1* calculates C80, Tc and S/N. *Filter2* determines the D indicators and R. *Filter3* is used to calculate RT and EDT. In particular a brief description of the procedure to determine the *STI* parameter is reported. The *STI* parameter is defined by the calculations of the following variables:

1. The impulsive response, $h(t)$, by using a Galois sequence, as sollicitation signal.
2. The *real part* of the *complex modulation transfer function, m(F)*,:

$$m(F) = \frac{\mathrm{Re}\int_0^{+\infty} h^2(t)e^{j2\pi Ft}\,dt}{\int_0^{+\infty} h^2(t)\,dt} \qquad (1)$$

   where F is the frequency
3. The $(S/N)_{jk}$ *ratio matrix:*

$$(S/N)_{jk} = 10\log\frac{m(F)}{1-m(F)} \qquad (2)$$

   the j and k indexes depend on the number of the modulant frequencies and the octave-band frequencies, in this case 7 and 14 respectively.
4. Finally the *STI parameters* is obtained by:

$$STI = \frac{\left[\sum_{j=1}^{7}\omega_k\sum_{k=1}^{14}(S/N)_{jk} + 15\right]}{30} \qquad (3)$$

   where ω_k represents the octave band weighting factor.

The procedure reported above in the virtual instruments was employed. In figs. 2,3,4,5 some steps are reported. In fig. 2 the diagram panel of the subsection *Galois* is reported.

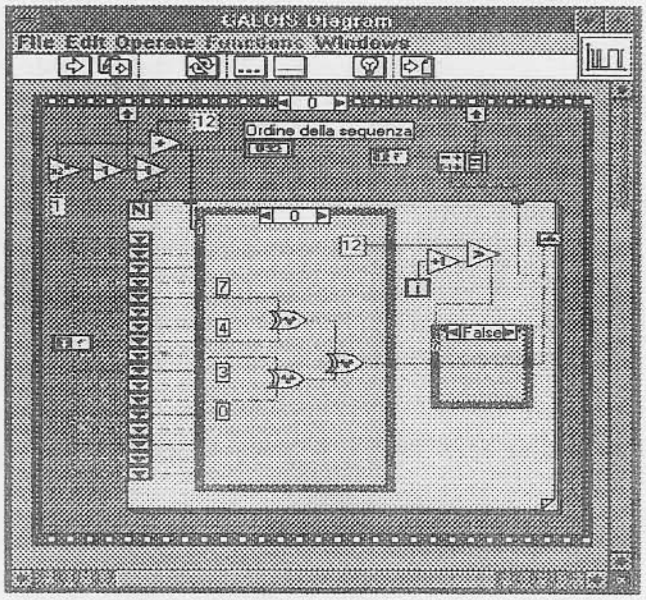
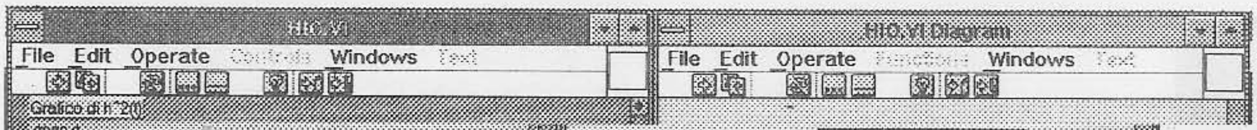


Fig. 2 The *Galois subsection* diagram panel

Fig. 3 shows the *HIO subsection*. As can be observed in the diagram panel the calculation of the *STI parameters* was choosen. In the *front panel* the *square impulsive response*, the *real part of FFT*, the *impulsive response* and the *echograme*, are shown respectively



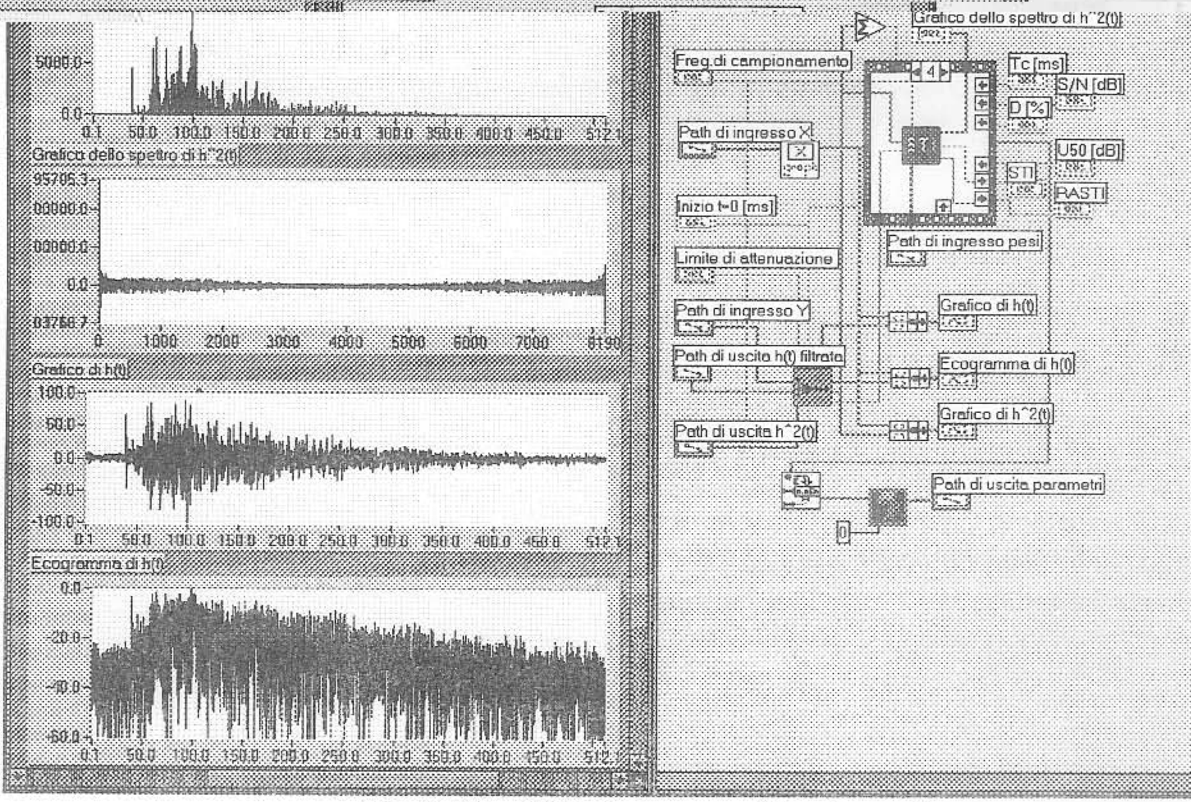


Fig. 2 The *HIO diagram and front panel*

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In fig. 4 the calculation of Eq. 3 is reported. The two diagram panels are employed subsection represented in the *symbol STI* in Fig. *(3)*.

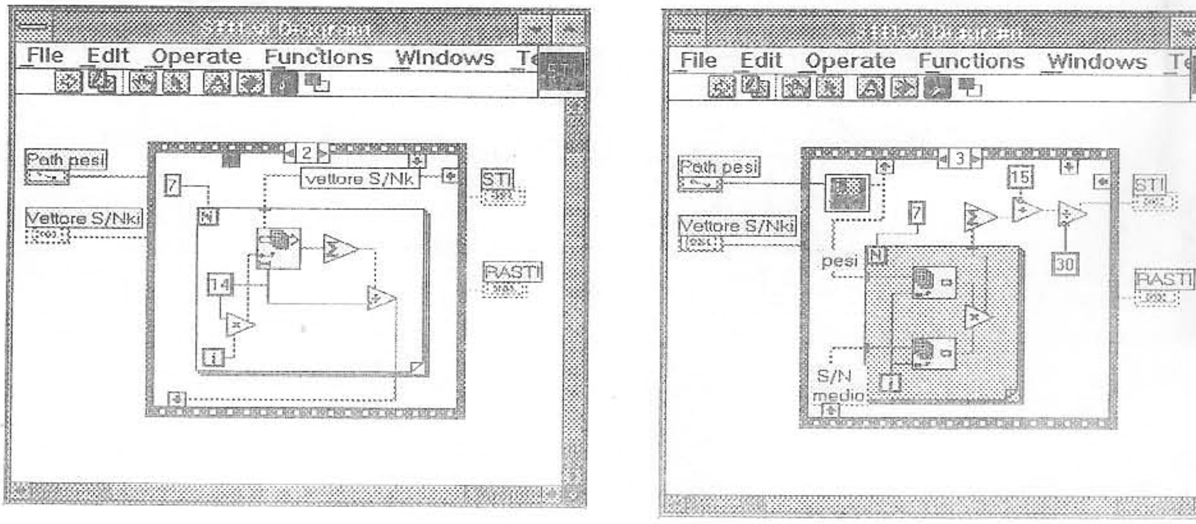
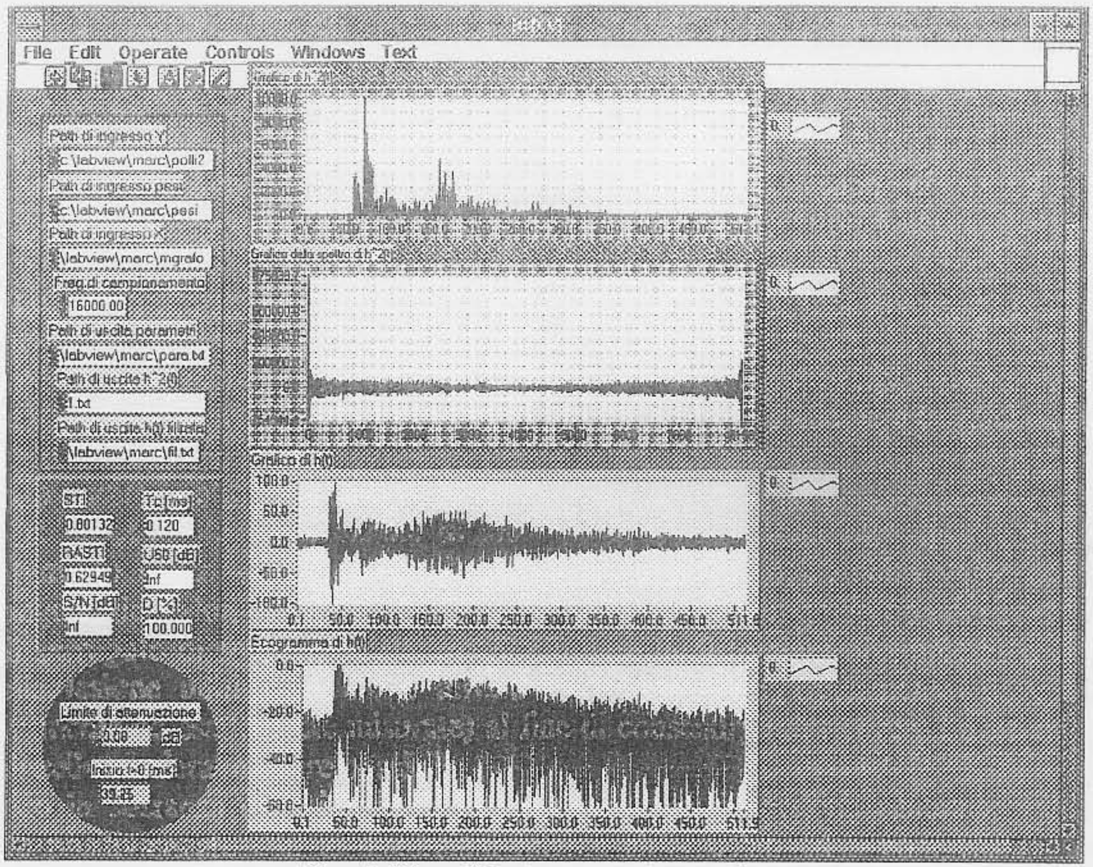


Fig. 4 The diagram panels refer to Eq. *(3)*

Fig. 5 shows the front panel where the *object parameters* values are reported.



Path di ingresso Y: c:\labview\marc\polli2

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STI: 0.80132

Tc [ms]: 0.120

RASTI: 0.62949

U50 [dB]: Inf

S/N [dB]: Inf

D [%]: 100.000

Limite di attenuazione: 0.00 dB

Inizio t=0 [ms]: 39.25

Fig. 5 The *object parameters values*

The Measurement Tests

A set of measurements in some acoustic Italian rooms has been performed to test the instrument. In this paper some results are shown. In particular the reported results concern the Verdi theatre in Padova. All measurements were made in unoccupied conditions and no correction for occupancy were made. For each theatre different seats were considered. In tab.1 and 2 the measured *objective parameters* are reported. In tab. 1 the *reverberation time* as a function of the frequency is reported; measurements in different seats of the room were made. As it can be observed, there are similar values of the *reverberation time* for each considered line. Referring to [7], the obtained data show a good attitude of the room to theatrical and musical opera performances.

Bandwidth [Hz]	middle last line	left last line	middle central line	left central line	right central line	middle first line
31.5	1.64	1.61	1.85	1.65	1.86	1.79
63	1.46	1.43	1.84	1.66	1.76	1.79
125	0.97	0.96	1.38	1.29	1.43	1.61
250	0.76	0.75	1.16	1.16	1.2	1.42
500	0.7	0.67	1.05	1.02	1.07	1.32
1000	0.65	0.64	0.98	0.99	1	1.27
2000	0.62	0.61	0.95	0.96	0.97	1.24
4000	0.6	0.59	0.93	0.94	0.96	1.23

Tab 1

In tab. 2 same objective parameters in the middle first line of the room were calculated.

In this case, as example, the C80 parameter has not a good distribution values [5].

Bandwidth [Hz]	RT (s)	EDT (s)	C80 (dB)	D (%)	Tc (ms)	S/N (dB)
31.5	1.79	0.85	3.23	40.87	79.58	2.94
63	1.79	0.88	8.96	83.83	48.93	9.02
125	1.61	0.78	-1.03	36.25	103.16	-1.53
250	1.42	0.57	-2.54	22.05	120.47	-4.35
500	1.32	0.65	1.89	55.04	78.64	1.95
1000	1.27	0.63	1.98	56.79	71.08	1.98
2000	1.24	0.61	1.25	52.57	78.08	1.18
4000	1.23	0.61	6.69	79.51	34.63	6.86

Tab.2

Conclusion

A novel instrument for measuring objective acoustic parameters in acoustic concert halls is proposed. The necessity to analyse acoustic concert hall and to use a flexible measuring instruments is the basic idea of the proposed virtual instrument.

The instrument were used to test some Italian acoustic concert halls and the corresponding results have been shown.

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