ITDG CALCULATION WITH A NON LINEAR ITERATIVE ALGORITHM.

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1 INTRODUCTION

The role of the *Initial Time Delay Gap* (*ITDG*) is well known in relation to subjective perception of a concert hall. Beranek[1] related the *ITDG* value to subjective attribute of "intimacy", on the basis of on listener's judgement statistics. The correlation between *ITDG* and "intimacy" has been confirmed in many studies[2,3].
In order to evaluate the subjective preference, Schroeder et Al.[4] analyzed several European concert halls and verified a low correlation between the *ITDG* value and the listener's preference. Ando[5] found a relationship between *ITDG*, diffuseness and factors extracted from short time autocorrelation function of the sound signal. In work[6] Ando identified the *ITDG* as one of the four normal factors contributing to the subjective preference in a concert hall.
Hidaka[2] fixed a limit of 20 ms as the preferred *ITDG* value which should be measured near the center of the main floor. For the same author the subjective attribute ''intimacy'' is observed only when the first reflection is immediately followed by a series of other reflections before the 50 ms time instant.
Cox et Al.[13] studying the contributes of lateral reflections in early sound field, showed that the *ITDG* is not significant to listener preference.
These different findings may be due to different interpretation of what *ITDG* really is and how camn be operationally defined.
In order to clarify the role of the *ITDG* in the subjective perception of a concert hall a correct measurement method is needed. The *ITDG* values may be inferred from the hall geometry, relying on optical methods or may be evaluated from the room impulse response. Both cases present some difficulties: in the first case, the evaluation of the amplitude of each reflections; in the second case the identification of the main peak of the early reflections. Moreover spurious reflections may be present in room impulse responses, due to floor reflections pit reflection in case of Italian opera houses[7]. These spurious reflections should not be considered in the *ITDG* measurement.

2 THE ALGORITHM

In the present work, the energy distribution instead of the hall geometry is used as criterion of choice of the significant reflection. The *ITDG* is assumed as the delay of the reflection group with the maximum energetic contribution instead of the reflection with the maximum of amplitude.
Fuji et Al.[10] proposed a similar interpretation of the *ITDG*, and proposed an extraction method based on short time integration of impulse responses. The algorithm proposed in this work is based on the Fuji's one with some improvements.
Two analysis are performed on the same impulse response: an iterative non linear processing extracts the arrival instant of each reflection and a short time integration defines the region of interest in which the maximum energy of the early reflection is concentrated.
The absolute value of the impulse response is preprocessed with an iterated sharpening, returning the local maxima, i.e. the arrival instant of each reflection. The non linear operation is described in figure 1.

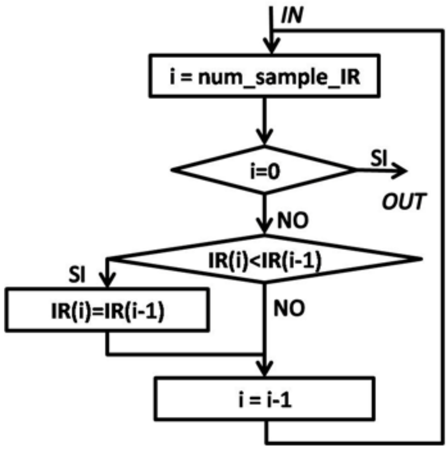


Figure 1: Block diagram of one iteration of the sharpening algorithm.

The basic algorithm of this iterated sharpening is as follows (see figure 1): at each iteration, the samples are compared two by two, from right to left, and for each comparison the smaller value is replaced by the higher.

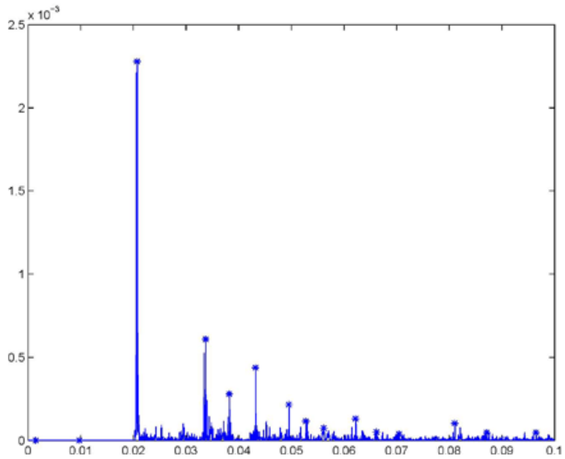


Figure 2: IR with identified reflections.

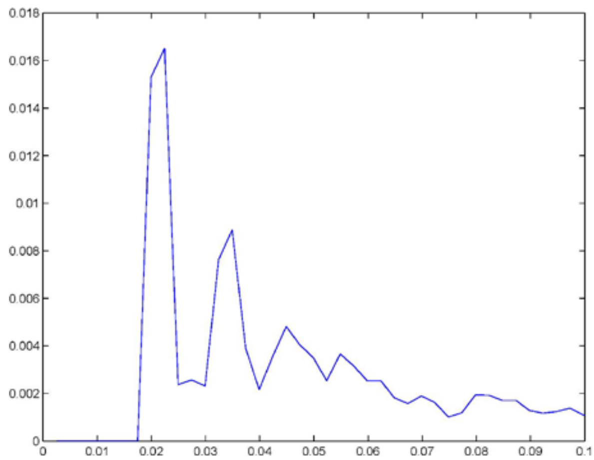


Figure 3: Curve of short time energetic integration.

A short-time integration is then performed on the squared impulse response (see figure 2) returning an energy curve:

$$D(t) = \int_{t-2.5ms}^{t+2.5ms} h^2(\xi)d\xi \qquad \textbf{(1)}$$

An example of a curve of short time energy is presented in figure 3.
The main maxima after the first one of this curve identify the region of the expected first reflection. It should be noted that the energy curve so calculated is smoothed and permits to not take into account the possible spurious reflections.
The maximum value of the local maxima calculated by sharpening (see figure 5) and located in the region were the first reflection expected (see figure 4) is assumed as the first reflection. The instant of the direct sound arrival is extracted in the same way selecting the main maximum of the energy curve (see figure 4) and founding the corresponding peak in the impulse response (see figure 5).

The delay time between the instant of the direct sound arrival and the instant of the first reflection arrival so calculated is the *ITDG*.

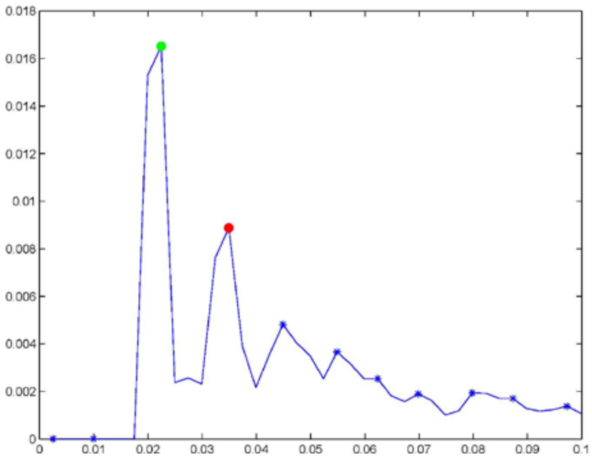


Figure 4: Selection of the maxima corresponding to the energy of the direct sound and of the first reflection.

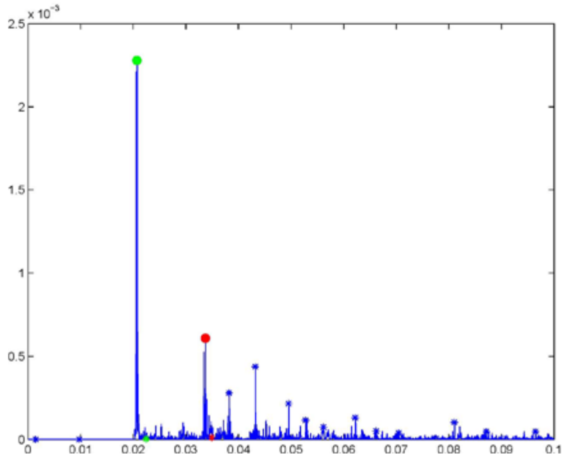


Figure 5: Extraction of the arrival instant of the direct sound and of the first reflection.

3 CASE STUDIES

The algorithm has been tested with the impulse responses of two different auditoria.
The first hall is the *Torri dell'Acqua* auditorium in Budrio[8], Italy, an octagonal hall (V=2000 m^3) with concrete on surfaces and octagonal shape. The impulse responses has been measured by the authors of this work.
The second hall is the *Promenadikeskus* Concert Hall in Pori, Finland (V=9300 m^3). The use of the impulse response, is permitted for research purposes[9].

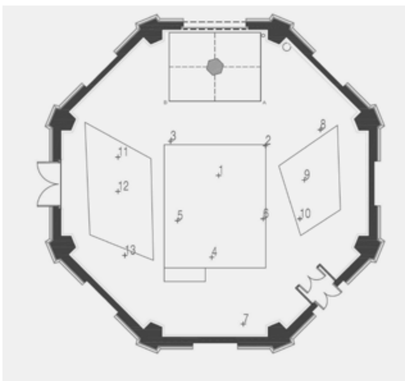


Figure 6: *'Torri dell'Acqua'* plant with microphones and source positions.

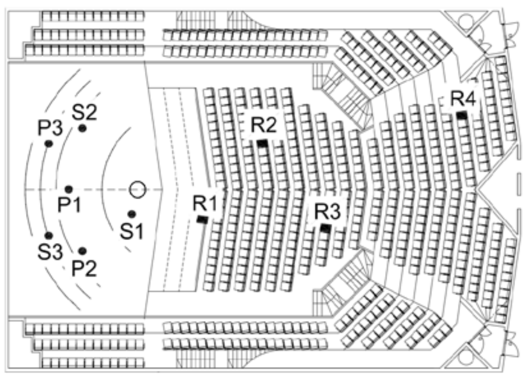
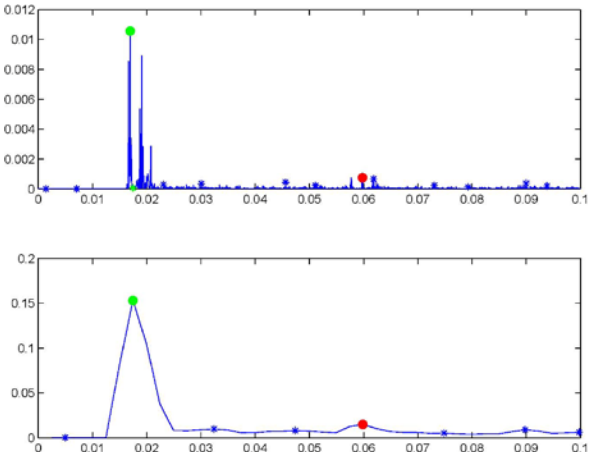
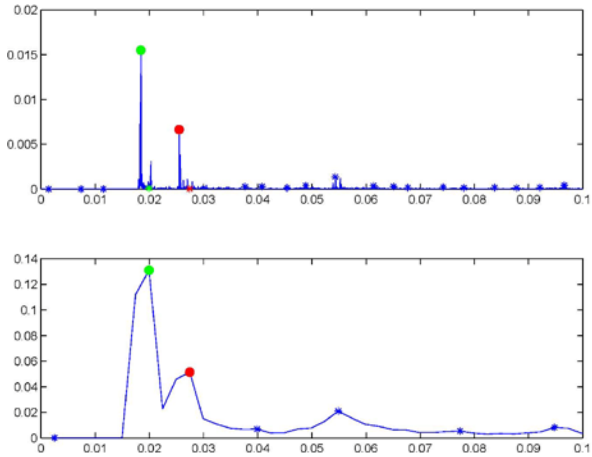


Figure 7: *'Promenadikeskus'* Concert Hall plant with microfones and sources positions. After[9].

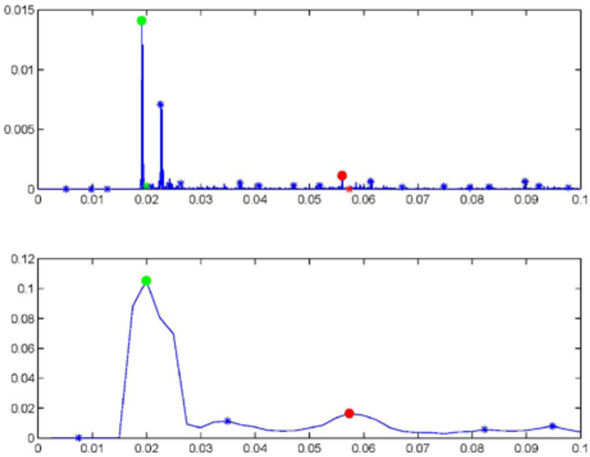
The two auditoria have different dimensions, shapes and diffusion of the surfaces and so may be considered useful case studies to testing the algorithm. In figures 6 and 7 are presented the plants and the microphones and sources positions. In figures 8 and 9 are presented the IR and the corresponding energy curve for a selection of measurement positions.



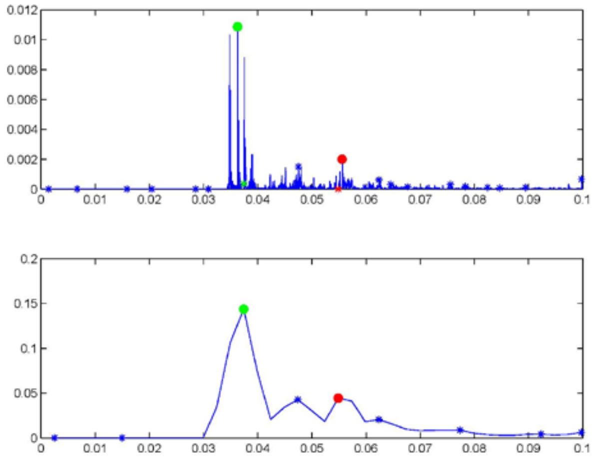
(a) S1, R1



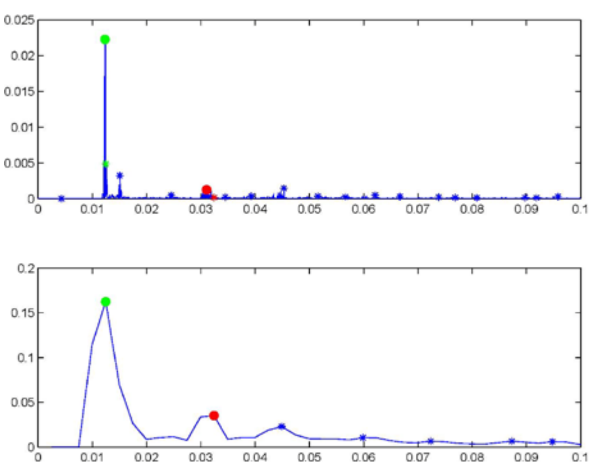
(b) S1, R2



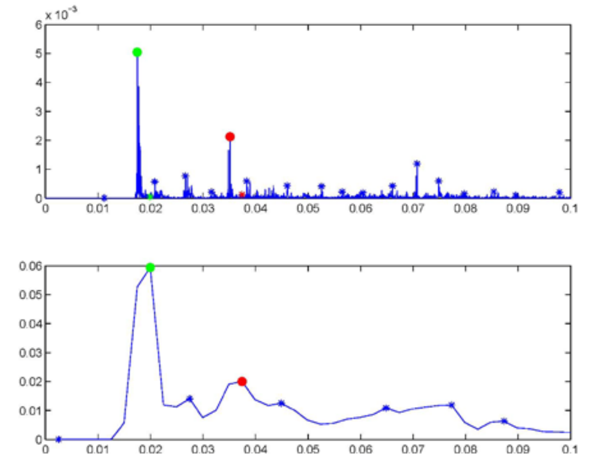
(c) S1, R3



(d) S1, R7

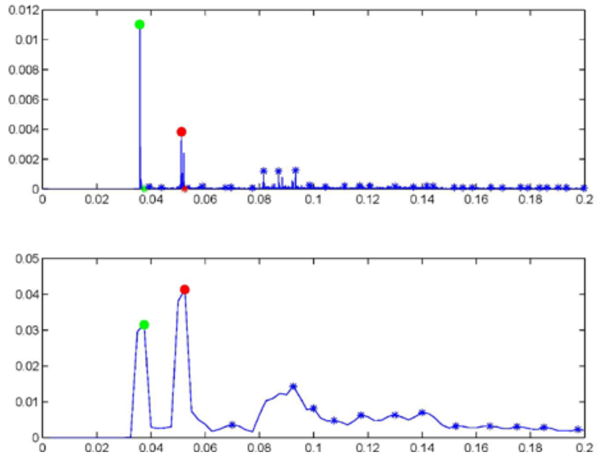


(e) S1, R8

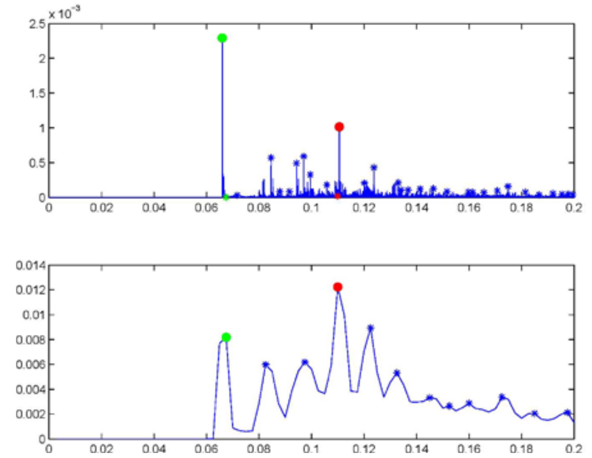


(f) S1,R9

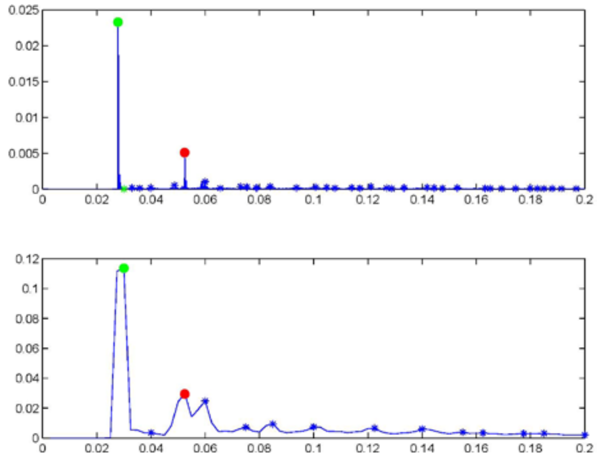
Figure 8: Measurement of *ITDG* values in *'Torri dell'Acqua'* auditorium. See figure 6 for source (S) and receivers (R) positions.



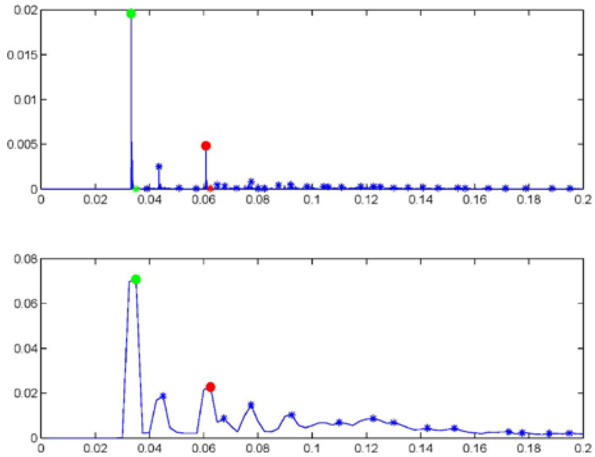
(a) S1, R2



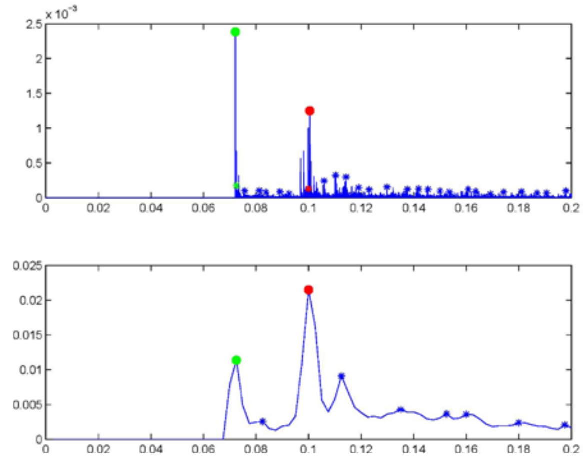
(b) S1, R3



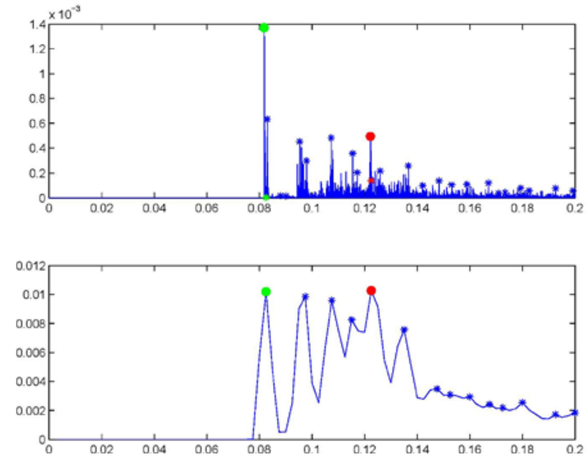
(c) S1, R4



(d) S2, R1



(e) S2, R3



(f) S3, R3

Figure 9: Measurement of *ITDG* values in *'Promenadikeskus'* Concert Hall. See figure 7 for source (S) and receivers (R) positions.

In all the figures is possible to note the property of the algorithm to masking the spourious reflection. Moreover, as can be noted in figure 8(d), the algorithm select the main peak in the IR graph corresponding to the same region of interest defined from the energy curve. Is important to note that in these figures the maximum corresponding to the first reflection is assumed as the one that correspond with the main energy region after the first, but the algorithm is able to identify the maximum corresponding to the second energy region, because it can define exactly all the maxima both in the energy curve and in the IR graph. Furthermore, in some case (see figures 9(a)(b)(e)(f)) the amplitude of the maximum corresponding to the first reflection in the energy curve may be higher than the one corresponding to the direct sound. Also in these particular cases the algorithm identify the arrival time of the direct sound and of the main reflection.

4 DISCUSSION

It is assumed that all the diffraction effect and the other waveform alteration are included in the temporal window of the running integration. The value of 5 *ms* (see equation 1) results effective for small or medium hall but could be increased for large hall evaluations.
On one hand the choice of this values permits an adequate smoothing of the energy curve. On the other hand the windowing process provides an high pass filter for the energy spectrum of the reflection, so that this model analyzes only the frequency components of reflection above 200 *Hz*. In order to evaluate the arrival instant of each reflection these components may be assumed as significant.
As noted by Hidaka[13] early reflections may be treated in deterministic mode and statistical hypothesis are meaningless. The quality of the iterated sharpening depends on the number of iterations. When this number is higher than necessary the selection criterion is too strict, so that few peaks are selected, on the other hand when this number is lower than necessary the algorithm selects not only the maxima but also other points.
The “ideal” number of iterations is function of the mean free path, and of sample rate. With a sample rate of 44100 *Hz*, for the cases under consideration the number of iterations which permits to obtain an almost correct envelope is 10.
The use of the sharpening, in this optics, may result more useful and robust that similar method for the peak identification, based on statistical analysis[11].
As recalled in the introduction, the *ITDG* have several interpretations in literature: the proposed algorithm permits to adapt the *ITDG* extraction to the different definitions with slight modifications. Following Beranek’s definition only the no more than 10 dB lower than the direct wave should be evaluated. Moreover some authors proposed the measurement of the delay of the “first significant” reflection, other the delay of the “main” reflection. The proposed algorithm can be adopted to each of these criteria of evaluation.

5 CONCLUSIONS

An efficient algorithm for the extraction of the *ITDG* value has been presented. The algorithm is based on an iterated non linear processing and on a short time squared integration. Impulse responses measured in two different auditoria have been used for testing the efficiency and the robustness of the proposed method.

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