DETERMINATION OF TRUNCATION POINT OF ROOM IMPULSE RESPONSE

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Ciric Dejan[a)]
Faculty of Electronic Engineering, University of Nis, Beogradska 14, 18 000 Nis, Yugoslavia
[a)] Current address: Department of Acoustics, Aalborg University, Frederik Bajers Vej 7B 5, DK-9220 Aalborg, Denmark, Tel: (+45) 96 35 87 24, Fax: (+45) 98 15 21 44, E-mail: dc@acoustics.auc.dk

ABSTRACT

Theoretically obtained optimal truncation point of impulse response is located at the intersection of main decay slope and noise floor. Precise determination of this point is made more difficult in practise. So, the algorithm for truncation point determination representing automatic, accurate and fast procedure is proposed here. It is based on iterative determination of difference between set preliminary truncation point and obtained cross-section of estimated impulse decay slope of truncated response and noise level. This algorithm is compared with the existing ones using simulated and measured impulse responses. The results confirm validity of proposed algorithm indicating its advantages.

INTRODUCTION

The reverberation time can be determined from integrated impulse response obtained by backward integration of room impulse response [1]. However, the decay range of integrated impulse response representing the range between initial maximum of the curve and the knee – the intersection of main decay slope and noise floor level, can be insufficient for reliable determination of reverberation time [2]. This decay range is increased by implementation of various procedures. One of common procedures is the truncation of impulse response before integration [3]. Theoretical analysis has shown that optimal time or point for truncation is located at the knee [4]. However, the deviation of decay from exponential one, curvatures and the fluctuations of impulse response make the determination of optimal truncation point more difficult in practise. This point is usually determined by simple implementation of its definition as a cross-section of the estimated slope of main decay and noise level. Such method will be called here method I. Its disadvantages are overcome using more sophisticated algorithms such as iterative algorithm proposed in ref. 3 (method II).

New algorithm for accurate, fast and simple determination of truncation point of room impulse response is proposed in this paper. It is also based on iterative procedure, but the concept of iteration is different from that one in method II. Elementary advantages of both mentioned methods

(I and II) are incorporated in proposed original algorithm. It is compared to these two methods using simulated and measured impulse responses.

TRUNCATION OF IMPULSE RESPONSE

Background noise is almost uniformly distributed throughout the room impulse response. On the other hand, the energy of reverberant sound decays exponentially, so that this energy is concentrated in the beginning of response. As a result of this, reverberant sound energy is usually considerably bigger than noise energy in the response beginning, and the noise influence is relatively small here. It becomes more important toward the end of response. However, overall noise energy in response influences the integrated impulse response since this energy is cumulatively added starting from the end of response toward its beginning [2]. This cumulative adding of noise energy reduces the decay range. The noise problem can be counteracted by truncation of the part of response containing only noise. However, it is well-known that such truncation of response before integration can influence the slope of the integrated impulse response, Fig. 1.

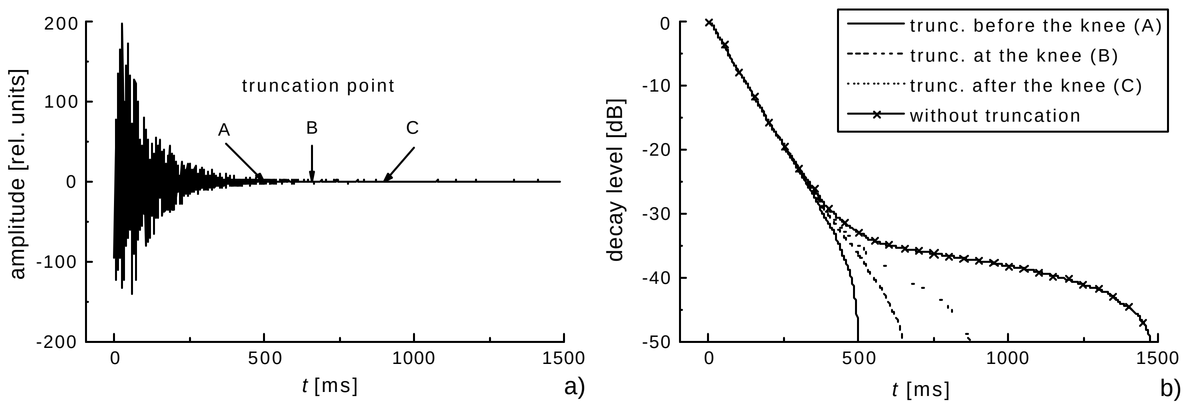

Fig. 1. Impulse response with truncation points a), and integrated impulse response obtained with and without truncation at the indicated points b)

In the beginning of implementation of this method, various points were used as truncation point, such as *T*/2, where *T* is the reverberation time [4]. Somewhat later, the point of estimated intersection of decay slope and noise level was intuitively proposed as truncation point. Theoretical analysis quantitatively confirmed that the mentioned intersection of decay slope and noise level (knee) represents optimal truncation point leading to correct reverberation time and relatively small sensitivity of this time on truncation point [4]. In spite of reduced sensitivity, dislocation of truncation point from the knee can cause deviation of decay slope, especially for bigger dislocation, and in such a way, deviation of reverberation time. Thus, it is necessary to determine the truncation point at the knee as precisely as possible.

PROCEDURES FOR TRUNCATION POINT DETERMINATION

<u>Existing Methods</u>

Since optimal truncation point has been theoretically obtained, it can be thought that all problems concerning impulse response truncation have been solved. However, curvatures of impulse response decay, that is, the deviation of decay from true exponential decay as well as the fluctuations of response make the truncation point determination more difficult. Thus, the determined truncation point can be dislocated from the optimal one.

The simple procedure for determination (method I) sets the truncation point at the cross-section of estimated decay slope and noise level, where this estimation is performed using subjectively chosen ranges. However, above mentioned curvatures and fluctuations influence that the estimation of decay slope, that is, slope approximation by straight line, is dependent on the part of decay used for estimation. Besides, the estimation of noise level can also show a kind of dependence on used estimation range. The main disadvantage of this simple method is just lack of objective references for setting the ranges used for estimations of decay slope and noise level. The more sophisticated method (method II) based on iterative procedure of mutually dependent estimation of decay slope and noise level is presented in ref. 3. Before iteration, the averaging is performed. In each iteration step, preliminary truncation point is determined as a cross-section of estimated decay slope and noise level. It is very important here that the preliminary truncation point and noise level in current step determine the ranges for estimation of decay slope and noise level in this step.

Proposed Algorithm

Using advantages of both mentioned methods and incorporating new concept of iterative procedure, the authors have developed fast and accurate iterative algorithm for truncation point determination. This algorithm can be implemented with or without averaging. But, in order to reduce the influence of fluctuations, better solution would be to average the response. The algorithm is based on procedure whose purpose is to make the point of cross-section of estimated slope of truncated impulse decay (curve obtained as result of logarithm of squared truncated impulse response) and noise level equal to preliminary truncation point or to enable their difference to be below defined value of convergence.

This iterative procedure can be described by the following steps (Fig. 2):
a) defining of preliminary truncation point;
b) defining of ranges for estimation of decay slope and noise level based on preliminary truncation point or previously determined noise level;
c) estimation of the decay slope of impulse decay obtained after truncation of impulse response at preliminary truncation point;
d) estimation of noise level using defined range in the last part of response containing only noise;
e) determination of cross-point of estimated slope and noise level;
f) determination of difference between preliminary truncation point and obtained cross-point Δt;
g) analysis of this difference; if it is equal to zero or if defined accuracy is obtained – procedure is finished, but if this difference is less (greater) than zero, that is, its absolute value greater than defined value of convergence, preliminary truncation point is dislocated toward the end (beginning) of response for corresponding value and procedure is repeated from step b);
In order to speed up the iterative procedure, the dislocation of preliminary point is not performed for the same value in each step, but it varies depending on previously obtained differences of this point and cross-point.

In the presented version of proposed algorithm, the estimation of decay slope is performed up to the preliminary truncation point. This practically means that even the last part of decay is used for slope estimation. So, the curvature, which usually appears in that part of the decay, can negatively influence the result, that is, the truncation point can be dislocated. Due to this, it would be better not to use the very last part of decay, but to define slope margin and dislocate the slope estimation range toward the beginning of response for this margin from preliminary truncation point if it is set in the part of main decay, that is from noise level if the preliminary truncation point is set in the part of response where noise is dominant, Fig. 2.d). The noise level can be estimated in fixed range, as it is shown in Fig. 2. However, similarly as in method II, the range for noise level estimation can also be variable. Thus, in each step of iteration, the beginning of this range is dislocated from the current preliminary truncation point for the noise margin.

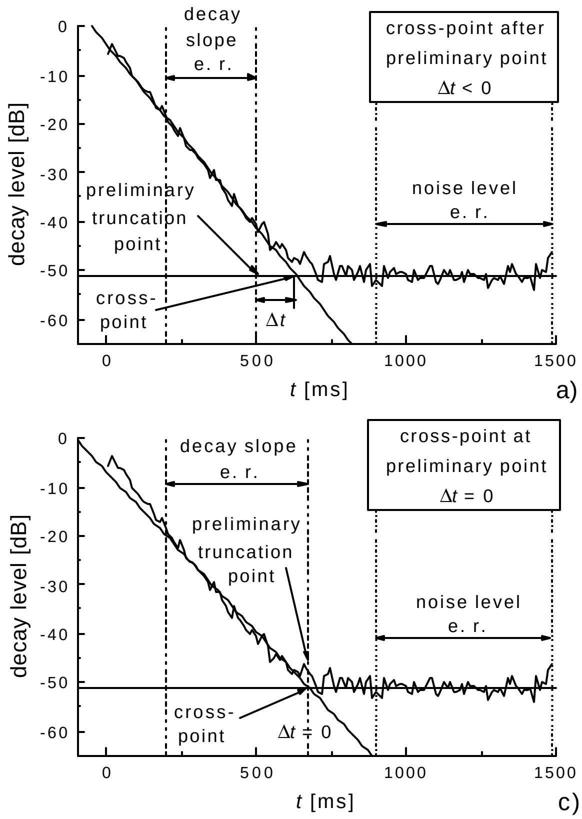

Fig. 2. Determination of truncation point by implementation of proposed algorithm a), b) and c), and modification of this procedure introducing slope and noise margin d) (e.r. is estimation range)

This procedure is opposite in direction in reference to the method I. Namely, here the preliminary truncation point is first set, and then the decay slope is estimated based on truncated impulse decay. In this way, in each step of iteration, corresponding range for estimation of decay slope is determined. This range is not known before the beginning of iterative procedure.

COMPARISON OF RESULTS

Used Impulse Responses

Comparison of three mentioned methods is performed using two types of impulse responses: the theoretical response whose all parameters are known and the decay is true exponential, and measured response representing real response with existing decay curvatures. The theoretical response, here called simulated impulse response, is generated by following mathematical model:

$$h(t) = \mathrm{sgn}(n_1(t))\left|e^{-kt/2T} r(t) + \sqrt{a} n_2(t)\right|, \tag{1}$$

where $r(t)$ represents a unit-mean multiplicative random process modelling fluctuations, which are the consequence of multiple reflections from boundaries, a represents noise floor power, $n_1(t)$ and $n_2(t)$ represent the unit-variance noise processes and k is the constant equal to 13.81551 [5]. The noise level excluding fluctuations is defined by a, that is, the value $10\log a$ represents noise level.

So, the optimal truncation point, that is the knee, can be simply calculated by $t_k = (-T \cdot 10 \log a)/60$. The measurements of responses were performed in one particular laboratory. For this purpose, the simple measurement system based on PC was used implementing Maximum Length Sequence (MLS) technique [2]. The reverberation time of this room on middle frequencies is about 0.8 s.

Analysis of Results

Already mentioned influences of curvatures and fluctuations as parameters of response are translated on influences of parameters of procedure implemented for truncation point determination, such as estimation ranges, slope and noise margin, averaging interval etc. It is indicated that the range used for slope estimation should be 10-20 dB, range for noise level estimation should be at least 10 % of impulse response, and slope and noise margin 5-10 dB [3]. The influences of these parameters have been investigated in more details by authors [6]. It has been shown that relative deviation of determined truncation point from the optimal one of even 8 % can appear as a result of the mentioned influences.

In order to adequately compare results obtained by existing procedures and proposed algorithm, it is necessary to use the same values for procedure parameters. While these parameters are conceptually similar in method II and in proposed method so that adequate values can be used for them, there are some difficulties in setting of parameters in method I. Namely, since this method is not based on iterative procedure, there is not any preliminary truncation point or current value of noise level that can be used as reference for setting procedure parameters. Preliminary point can be set here approximately, and based on it, the estimation ranges and margins can be set. However, as a result of this approximate setting, determined truncation point becomes dependent also on preliminary point. This is not the case in two other compared methods, since preliminary truncation point (cross-point) as well as decay slope and noise level are determined in each iteration step.

The first type of response used for comparison, simulated response, decays exponentially and decay slope remains unchanged almost up to the knee, that is somewhat before the knee excluding fluctuations. Thus, the importance of the mentioned disadvantages of method I is reduced and considerable deviation of determined truncation point doesn't appear even in this method. For the same values of procedure parameters, the method II and proposed method give the truncation points which deviations from true truncation point (1 s) are rather small, Fig. 3.a). Here, the beginning of slope estimation range is variable and it is located at points corresponding to the decay levels of impulse decay presented on horizontal axis of the mentioned figure. The size of estimation range varies since its end is fixed at the point dislocated from the knee (noise level) for the slope margin, where the knee is at 1 s or –60 dB of decay level.

In using measured impulse responses, the implementation of method I is significantly dependent on approximate setting of estimation ranges as it is mentioned earlier. Proposed algorithm and method II give almost identical results for the same procedure parameters. Relative difference of truncation points determined by these methods is below 0.5 % (3 ms) for used impulse response when the slope estimation range is bigger, that is, when this range begins in the interval from the response beginning up to the point corresponding to decay level of –28 or –25 dB depending on slope margin, Fig. 3.b). In this response, the knee is located at about 680 ms and it corresponds to decay level of about –51 dB. So, for slope margin of 5 dB, the end of estimation range is located at the point corresponding to decay level of –46 dB. The mentioned relative difference of 0.5 % is relatively small, so that it will cause no changing in reverberation time. Somewhat bigger relative difference (up to 3 %) is obtained when the beginning of slope estimation range is closer to the truncation point (below the decay level of –28 or –25 dB), that is, when this range is smaller. Nevertheless, latter difference is also relatively small, and its influence on reverberation time is not so important.

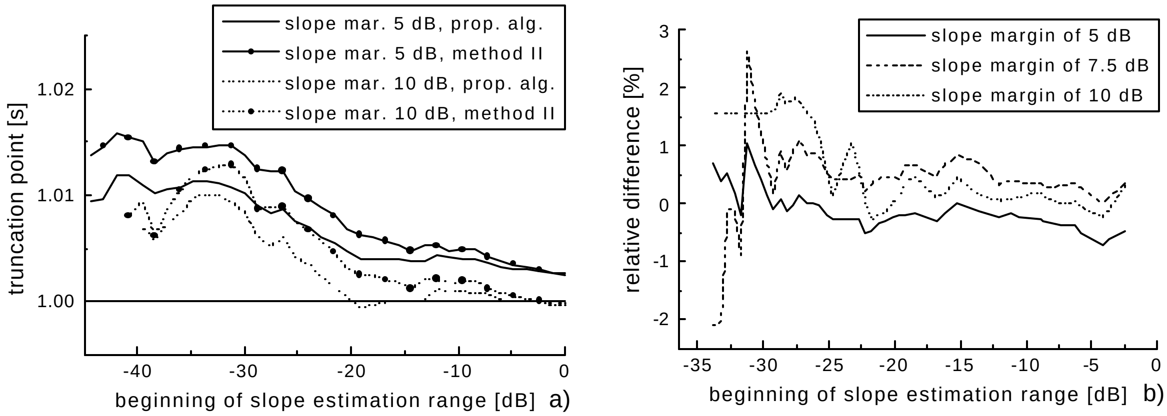

Fig. 3. The truncation points determined by proposed algorithm and method II using simulated impulse response a) and relative difference between truncation points determined by these methods using measured response b) for noise margin of 5 dB

CONCLUSIONS

Although theoretical analysis shown that optimal truncation point is located at the knee, some difficulties due to the impulse decay curvature and fluctuations appear in determination of this point in practise. The algorithm for simple and accurate determination of impulse response truncation point is proposed in this paper. It can be easily implemented by designing corresponding programme module, so that truncation point is obtained automatically.

Based on comparison of results obtained by proposed and existing procedures, it can be concluded that simple procedure (method I) shows significant dependence on approximate setting of procedure parameters. On the other hand, the situation is improved in iterative procedures. Almost the same truncation point is obtained by existing and proposed iterative procedure using the same procedure parameters. Practically, the values of these parameters including ranges for estimation of slope decay and noise level as well as slope and noise margin have bigger influence on difference in obtained truncation points. The results confirm the validity of proposed algorithm.

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