Sensitivity of Impulse Response Measurements with Maximum Length Sequences and Sweeps

Student authors: Marko Ličanin, Ana Đorđević, Marko Jelenković
Mentor: Dejan Ćirić

Abstract – **Measurement of room impulse response can be affected by different disturbances appearing in the measured or measurement system. Thus, depending on the applied measurement technique, the disturbances such as noise and nonlinearity can cause certain degradation of the results. In this paper, sensitivity of the room impulse response measurement by two most widely used techniques (maximum length sequence and swept sine) is studied. The emphasis is given to certain imperfections of the measurement system causing time invariance in the reproduction of the excitation and recording of the response. The latency, repeatability and validity of the extracted impulse responses are analysed.**

Keywords – **Impulse response, MLS, swept sine, sensitivity.**

I. Introduction

An impulse response (IR) describes behavior of a linear time-invariant system. By definition, the IR is a response of a system when it is excited by the Dirac delta function [1]. In modern acoustics and its sub-areas, such as room acoustics, IR has become the only descriptor of the acoustic characteristics of a room since all acoustic parameters can be determined based on the room impulse response (RIR).

It is of great significance to select an adequate excitation signal for the measurement, which then implies the deconvolution technique for impulse response extraction. The most widely used excitation signals recently are maximum length sequence (MLS) and sine whose frequency varies in time (swept sine or sweep) [2-4]. The mentioned signals are stretched out in time enabling greater energy of the excitation and greater signal-to-noise ratio of the measured RIR.

In RIR measurement, some common problems, such as noise, nonlinearity and time variance limit the quality of the results including obtainable dynamic range of the extracted RIR. Thus, the achieved ranged can be insufficient for certain applications. This problem can be overcome applying adequate procedures for dynamic range increase including the averaging of RIRs measured in the repeated measurements [6-8]. However, if the measurement repeatability is too low, the averaging does not yield any improvement of the dynamic range. One of the reasons that can affect the repeatability is the latency present in the measurement. It can be caused by applied hardware or software [5]. In addition, the measurement results can be degraded due to sensitivity of a RIR measurement technique to certain factors.

The sensitivity of two RIR measurement techniques, MLS and swept sine technique, to hardware imperfections is investigated in this paper. These imperfections are related to lack of adequate synchronization and latency between reproduction of the excitation and recording of the response. For the purpose of investigation, several hardware configurations are applied for the measurements. Special attention is paid to the repeatability and latency of the estimated IRs.

II. Impulse Response Measurement

MLS technique represents a technique that has been widely used in various acoustical measurements. This technique uses a special type of white pseudo-random noise (MLS) as an excitation signal. MLS has a number of advantages in comparison to other excitation signals: it can be easily generated using shift register, it is stretched out in time enabling great excitation energy, its temporal content is known so that it can be precisely repeated, etc [2]. However, MLS technique has also certain drawbacks including sensitivity to time-variance and non-linearity that can severely degraded the obtained results.

Swept sine technique has been recently introduced in acoustic measurements [3,4]. The excitation signal used in this technique is so called swept sine or sweep. It represents a sine signal with frequency varying in time, e.g. linearly (linear sweep) or exponentially (logarithmic sweep). Swept sine technique is considered to be immune to some disturbances such as time variance or non-linearity [3,4]. Also, one of its advantages is that precise synchronization between the clock of signal generating (reproducing) and recording during the measurement is not required [4].

III. Methods of Analysis

The sensitivity of MLS and swept sine technique on hardware imperfections is investigated performing a number of impulse response measurements. In that regard, the impulse responses of pure electrical and acoustical system are measured applying both mentioned techniques on several diferent measurement configurations (systems). Here, a part of

Student authors:
Marko Ličanin, Ana Đorđević and Marko Jelenković are with the Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Nis, Serbia, E-mail: lichanin@elfak.rs, ana_djordjevic88@yahoo.com, virtus@elfak.rs

Mentor:
Ass. Prof. Dejan Ćirić is with the Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia, E-mail: dejan.ciric@elfak.ni.ac.rs

the measurement system consisting of a PC with the sound board (internal or external) represents the tested electrical system. The measurements on this system are carried out linking the output and input of the sound board. On the other hand, the measurements on the acoustical system (room in this case - one of the laboratories of the Faculty of Electronic Engineering in Niš) are performed using the whole measurement system including the acoustic transducers (dodecahedral omni-directional loudspeaker and condenser microphone B&K type 4144), Fig. 1. Different desktop and laptop computers with integrated sound board or with external sound board (M-Audio ProFire 610) are used as a central part of the measurement system.

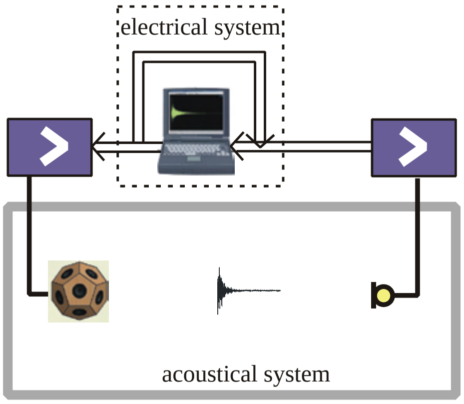

Fig. 1. Measurement of IR of electrical and acoustical system

The excitation signals, both MLS and logarithmic sweep of duration of 20 s, are generated by the developed MATLAB software module, used also for processing of the recorded responses. The analysis is based on determination of the latency and repeatability of the estimated IRs. Latency is determined in an automated procedure that requires starting point of the IR to be detemined. Repeatability is analysed observing and comparing the patterns of the obtained IRs. For each measurement configuration, the measurement is repeated 20 times in a series under the same conditions.

IV. Results

A. Latency

The extracted IRs of the electrical system measured with external sound board are presented in Fig. 2. The responses are grouped so that all twenty responses presented are not visible, but only seven of them. Besides, there is certain shift between them representing the latency. It has the smallest value among all other hardware configurations, but even in this case where specialised hardware component for reproduction and recording is used there is certain latency.

The latency has even greater values for the rest of hardware configurations. Some of the results are given in Fig. 3. While the measured IRs can be delayed for less than 50 samples (or about 1 ms for the sampling frequency of 44100 Hz) in Fig. 2, the IRs are delayed for a few hundreds of samples (several ms) in Fig. 3. The delay can be even greater in some other cases (not presented), e.g. it can be greater than a few thousands of samples (several tenths of ms).

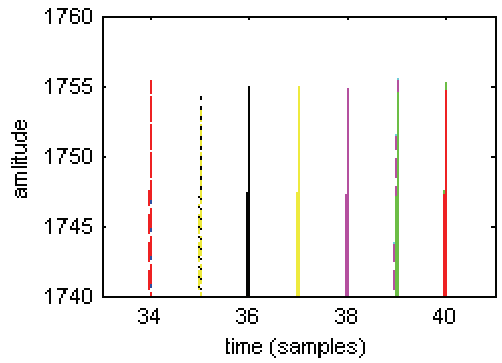

Figure 2. Zoom on the peaks of the IRs of electrical system measured with external sound board using *swept sine* technique

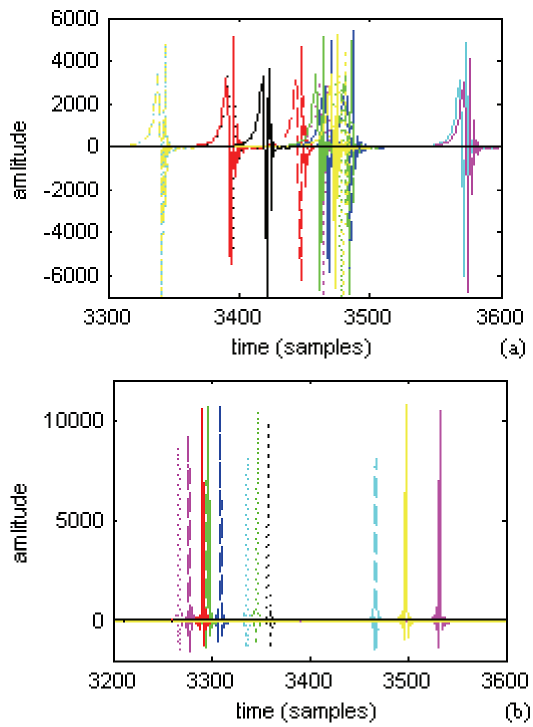

Figure 3. IRs of the electrical system measured with desktop (a) and laptop (b) computer using *swept sine* technique

The IRs of the acoustical system (room) are of much longer duration. However, the trend found in the electrical system exists also here. This is illustrated in Fig. 4. Thus, the extracted IRs are also delayed for certain variable time in relation to each other.

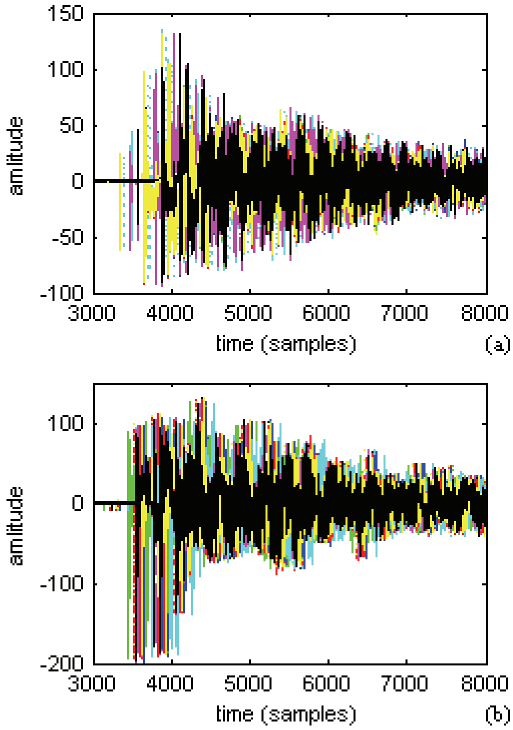

Figure 4. IRs of the acoustical system measured with desktop (a) and laptop (b) computer using *swept sine* technique

The latency does not depend on the applied measurement technique, so similar results are obtained for MLS technique independently on the measured system, Fig. 5.

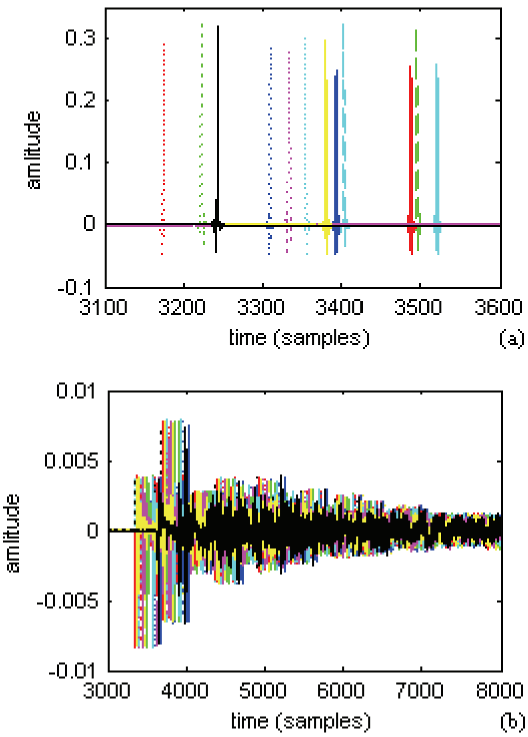

Figure 5. IRs of the electrical (a) and acoustical (b) system measured with laptop computer using *MLS* technique

B. Repeatability

The repeatability is tested so that a shift of the impulse responses caused by the latency is removed. In this way, all the responses begin in the same time point. Then, the responses measured with the same measurement technique and the same hardware configurations are compared first. Some of the results can be seen in Fig. 6. The IRs shown in this figure are without latency between them, so that their pattern can be compared. There is significant difference between the mentioned patterns for both electrical, Fig. 6(a) and acoustical system, Fig. 6(b). This difference is somewhat greater in the part of the response with greater amplitude, Fig. 6(c), and they can be even about 70 % of the maximum IR amplitude. Normalization of the IR amplitude does not reduce the difference between the IR amplitudes.

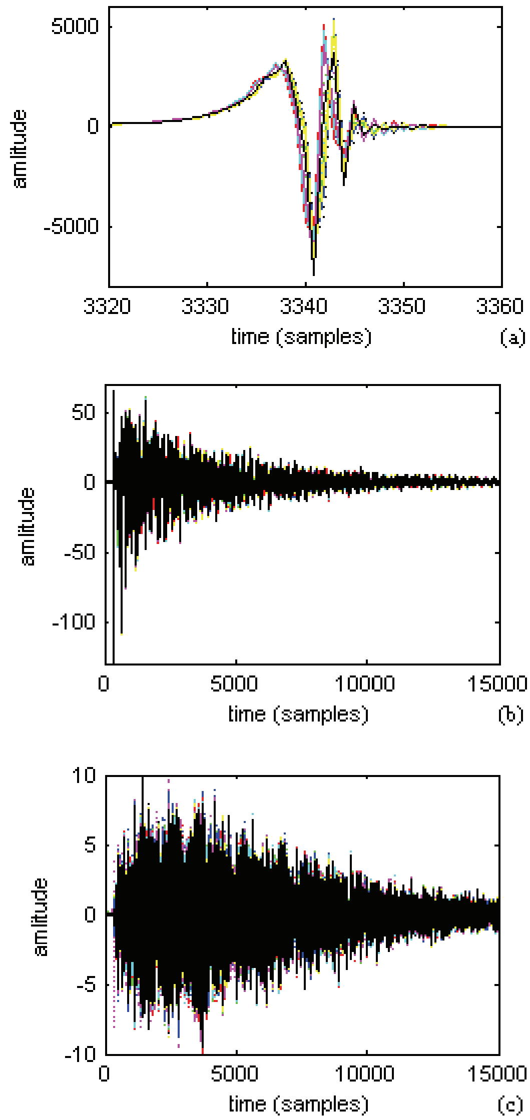

Figure 6. IRs (with removed latency) of the electrical system measured using *swept sine* technique applied on the desktop computer (a) and of the acoustical system measured with external sound board (b) together with the differences of the latter IRs (c)

The same analysis is carried out for the IRs measured using other hardware configurations and also another technique (MLS technique). The results are similar with the presented ones. Moreover, when the IRs of particular measured system (acoustical system) obtained by different hardware configurations are compared, the differences of the patterns are further increased. The same is observed when two measurement techniques are included in the comparison.

C. Sensitivity

Comparison of the results obtained by MLS and swept sine technique shows that MLS technique can be more vulnerable to some problems, which is not the case with swept sine technique. Thus, lack of synchronization between reproduction and recording as well as instability of sampling clock can cause significant degradation of the extracted impulse responses. In the extreme cases, especially when the response duration is relatively short, such as the case with the measured electrical system, the IRs can not be recovered at all. In less extreme cases the temporal shape of the extracted response is disturbed, and in further cases the dynamic range of the response is reduced. The representative examples are given in Fig. 7. The temporal shape of the IRs of the electrical system is completely degraded, Fig. 7(a), and it is completely useless. On the other hand, the dynamic range of the acoustical system IRs is significantly reduced, Fig. 7(b).

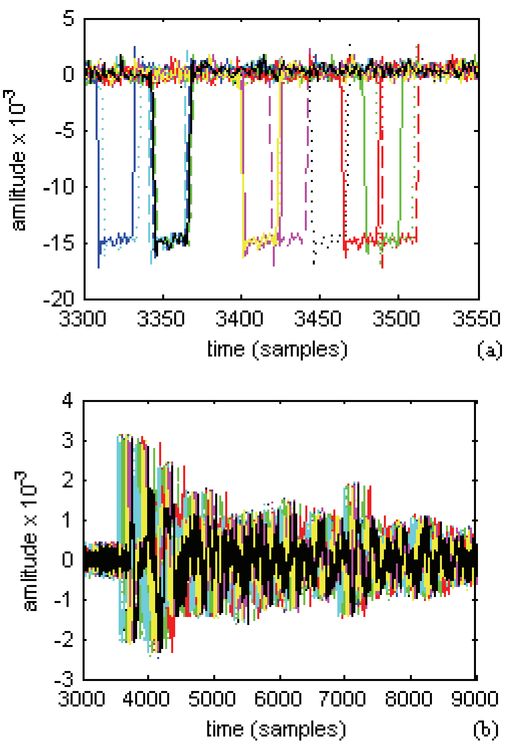

Figure 7. IRs of the electrical system (a) and acoustical system (b) measured whit desktop computer using *MLS* technique

V. CONCLUSION

Based on the results shown in this paper, it can be concluded that latency of the measured responses caused by the measuring system depends on system quality itself. However, it exists in all obtained results. What is even worse, this latency is variable and causes certain shift of the measured responses. In this way, direct averaging of responses is not possible, or the result of averaging would not lead to the dynamic range improvement. The latency can not be predicted. However, its effects can be minimized by additional processing.

Repeatability of the measured IRs is smaller than expected, especially when a hardware configuration of lower quality is used. The pattern of the IRs is usually kept, but the differences of the IR amplitude can be significant. The repeatability will be further explored in the future research.

MLS technique has shown some drawbacks compared to swept sine technique including vulnerability to certain imperfections of the measurement system. As a consequence, in some cases it can be even impossible to extract the IR.

ACKNOWLEDGEMENT

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