ACÚSTICA 2000 TECNIACÚSTICA MADRID 2000

ROOM IMPULSE RESPONSE USING SEGMENTED MAXIMUM LENGTH SEQUENCES (MLS) FOR ANNOYANCE MINIMIZATION

PACS REFERENCE: 43.55.Br

J. V. C. P. Paulo[1], C. R. Martins[1], J. L. Bento Coelho[2]
1 Escola Náutica Infante D. Henrique
Av. Eng. Bonneville Franco
2780 Oeiras, Portugal
E-Mail: joelpaulo@enautica.pt
2 CAPS - Instituto Superior Técnico,
P-1049-001Lisboa, Portugal,

ABSTRACT

The technique using Maximum Length Sequences (MLS) for the measurement of room impulse responses gives the possibility to achieve large signal-to-noise ratios. For auditoriums or public environments, the ultimate measurements must be carried out with people inside for a better representation of the internal acoustical conditions.

In order to reduce or even avoid the perception of the MLS sequences by the people in the audience, a new scheme for MLS based measurement techniques is presented herein. This technique uses the total MLS sequence segmented into a set of several pieces, maintaining the Signal to Noise Ratio (SNR). At the receiver point, all the parts are combined together to constitute the MLS sequence, before the cross-correlation calculation. The improved performance is illustrated by experimental results.

1. INTRODUCTION

The impulse response of a room allows the estimation of its internal acoustical conditions and sound quality parameters, namely the frequency response and the reverberation time. In order to guarantee reliable results, the ISO 140 Standard recommends 6 dB as the minimum acceptable value for the Signal to Noise Ratio (SNR).

The impulse response of a room is usually measured with the room empty. In most cases, even when the background noise in the room assumes significant levels within certain limits, one can increase the test signal level to a value of the same order of magnitude. In case of auditorium events both the mean absorption coefficients and the air relative humidity values are constantly changing. As such, significant deviations occur in the room impulse response. Therefore, the tests must be carried out during the performance. If some parameters change during the event, namely the reverberation time and the high frequency response, the sound technician is able to compensate for them.

This paper deals with the measurement of the room impulse response during a performance. In this sense, the test signal level must be

(i) significant low, not to be perceived by the audience;

(ii) as high as possible to increase the SNR at reception.

With the classic techniques, it is virtually impossible to achieve reasonable values of the SNR. The recent method of Pseudo Random Sequences (Maximum Length Sequences - MLS) is becoming very popular because of its noise immunity properties.

2. BRIEF THEORY OF MAXIMUM LENGTH SEQUENCES

Maximum Length Sequences are a special kind of correlation signals. The sequences are periodic binary (+1 and -1) pseudo random signals. The auto-correlation function of these sequences result in a Dirac impulse (excluding a very low DC value). In this sense, the room impulse response is evaluated with the cross-correlation between the MLS and the signal at the reception point, as it is shown in Figure 1,

$$\underbrace{S_{MLS}(n) * h(n)}_{y(n)} * S_{MLS}(-n) = \quad (1)$$

$$= \underbrace{S_{MLS}(n) * S_{MLS}(-n)}_{\Phi_{SS}} * h(n) = \delta(n) * h(n) = h(n)$$

Figure. 1. Scheme of the impulse response calculation in a Linear Time Invariant System using the MLS technique.

where Φss stands for cross-correlation between the emitted and the received MLS's. The sequence length is $L = 2^N - 1$, where N denotes the order of the sequence, i. e., the number of the shift registers used for its generation. Each peak (Dirac impulse) contains the same energy of the total length of the MLS. Care must be taken in choosing the sequence length to avoid time aliasing [1]. This can be achieved by using a sequence duration (L / fs) corresponding to a value higher than the reverberation time of that room [2].

The cross-correlation is calculated by using the Fast Hadamard Transform - FHT [3, 4]. Figure 2 illustrates the MLS method for the measurement of the room impulse response.

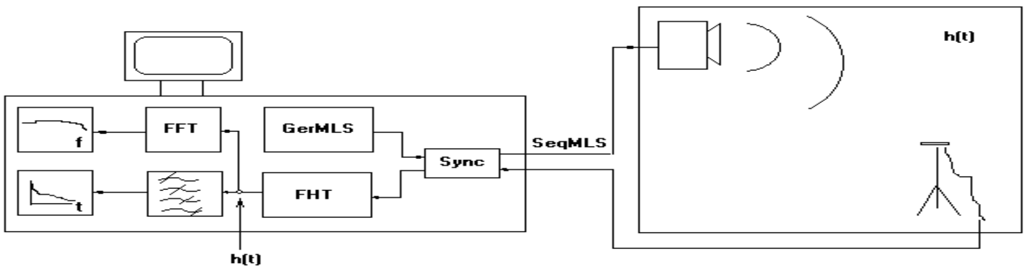

Figure 2. Minimal configuration for measuring the impulse response using the MLS method.

In order to guarantee reliable results, it is very important to synchronize the input and the output signals. Furthermore, for adequate equalization purposes of the whole chain, it is convenient to have proper knowledge of the frequency response of every piece of the measuring equipment.

3. BEHAVIOUR IN THE PRESENCE OF NOISE

The disturbance noise is in general stationary and has an additive character [1]. The SNR can be evaluated from

$$SNR = \frac{MS\,(y(n))}{MS\,(N(n))}$$

where MS stands for the Mean Square value [5] and N for the noise signal.

4. SEQUENCE PARTITION

This technique consists in breaking the MLS sequence into a set of short sequences and spread them through the noise environment with a convenient level to maintain a constant SNR [8]. At the reception point, a complete MLS sequence is constructed from the received sub-sequences. This technique is depicted in figure 3,

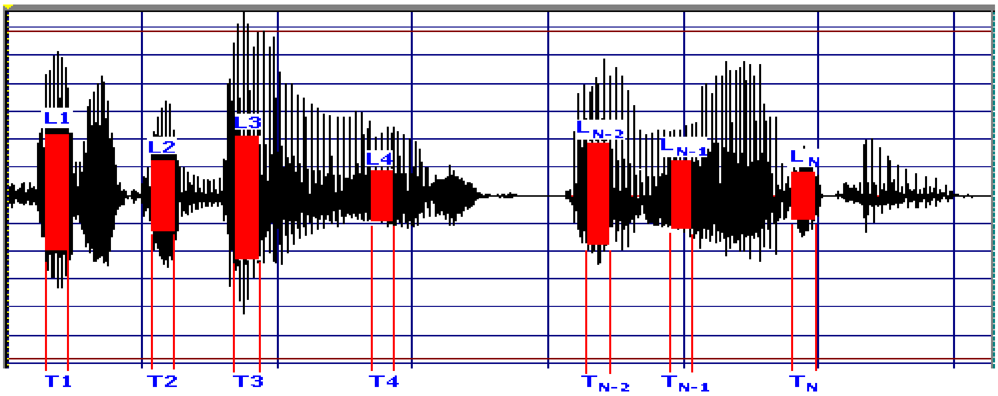

Figure 3. Implementation of the sequence partition technique, before emission.

where $\sum_{i=1}^{N} Ti = (2^L - 1)T_s$

and T_s stands for the sampling period.

This is a possible scheme by application of the associative property of the convolution operation.

$SeqMLS_1(t) * h(t) + SeqMLS_2(t) * h(t) + ... + SeqMLS_N(t) * h(t) = SeqMLS(t) * h(t)$

where $SeqMLS(t) = SeqMLS_1(t)$ <u>concat</u> $SeqMLS_2(t)$ .... <u>concat</u> $SeqMLS_N(t)$

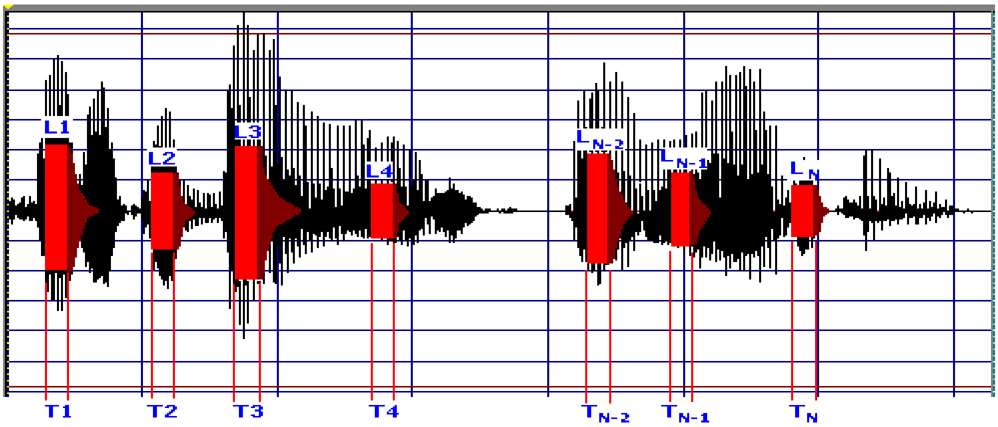

Figure 4. Resulting signal at the reception point.

Special care must be taken regardless to the synchronization between the incoming and outgoing sub-sequences and the sub-sequences overlap (energy decay of each sub-sequence) [6,7]. A proposed scheme is shown in the figures 5 and 6.

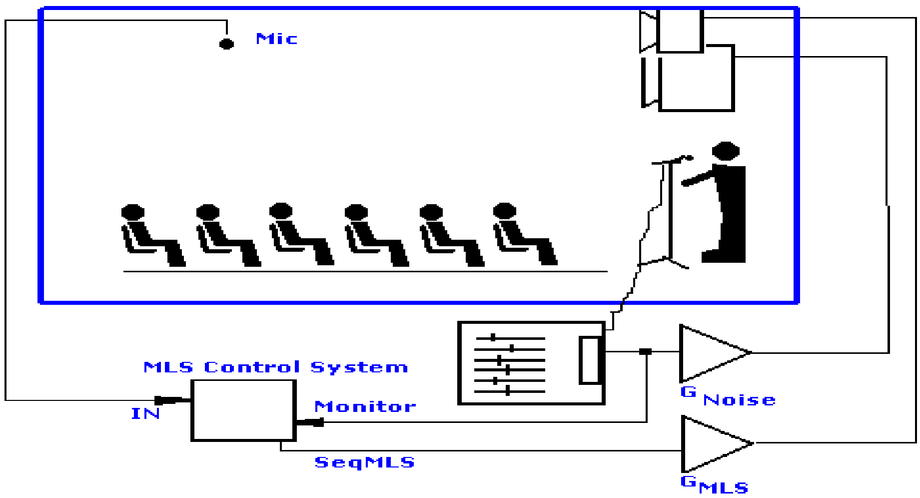

Figure 5. System lay-out for the sequence partition measurement technique.

.

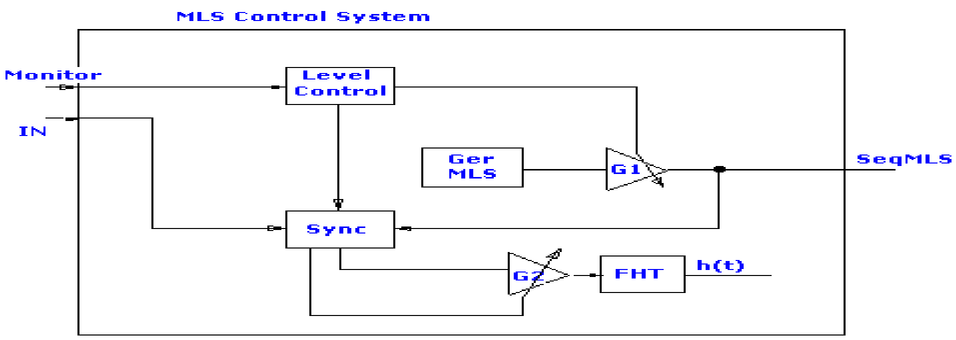

Figure 6. The basic control system for the sequence partition technique.

5. EXPERIMENTAL RESULTS

Experimental tests were conducted by using pop music, speech tracks and with masking signals. The tests were done in a small room with a reverberation time of less than 0.6 s. To avoid time aliasing, an MLS of order 15 was used at a sample rate of *fs* = 44.1 kHz, which corresponds to a period of about 0,7 s.

Sub-sequences with length of 2000 samples were used, which corresponds to a period of about 45 ms for the chosen *fs*. This delay is about the human auditory processing time.

Two types of signals were used for comparison proposes. The first test signal is just 1 whole MLS sequence. The second test signal consists of 17 adequately delayed MLS sub-sequences. Both the test signals were added to the noise signal at zones of maximum energy. For initial synchronization, a special signal was used at the beginning of the signal.

The SNR varies in the range of 0 to –24 dB in steps of –6 dB. The composed signal corresponding to an SNR of 0 dB is depicted in Figure 7.

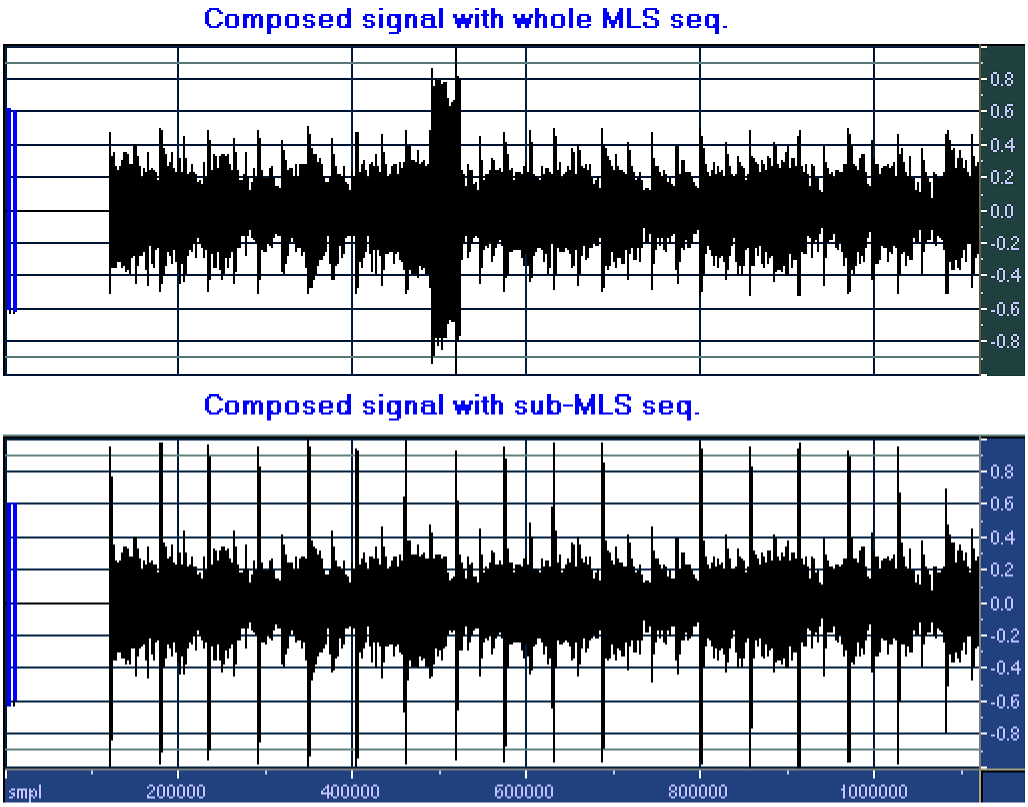

Figure 7. Input signals using MLS sequences. a) Composed Signal corresponding to a MLS sequence superimposed to a music signal track. b) Composed Signal consisting in sub-MLS sequences superimposed to a music signal track

The performance focused essentially on the difference in the depth of the energy decay between the two methods, whole and segmented MLS sequence.

The results show that with this new technique, the SNR can be controlled and the test signals can be significantly attenuated, avoiding negative perception in the audience. This improvement depends on the kind of the disturbances, especially the spectral contents and the band limits of the noise signal.

Other intermediate kinds of audio signals were analyzed. Some results are depicted in Figure 8.

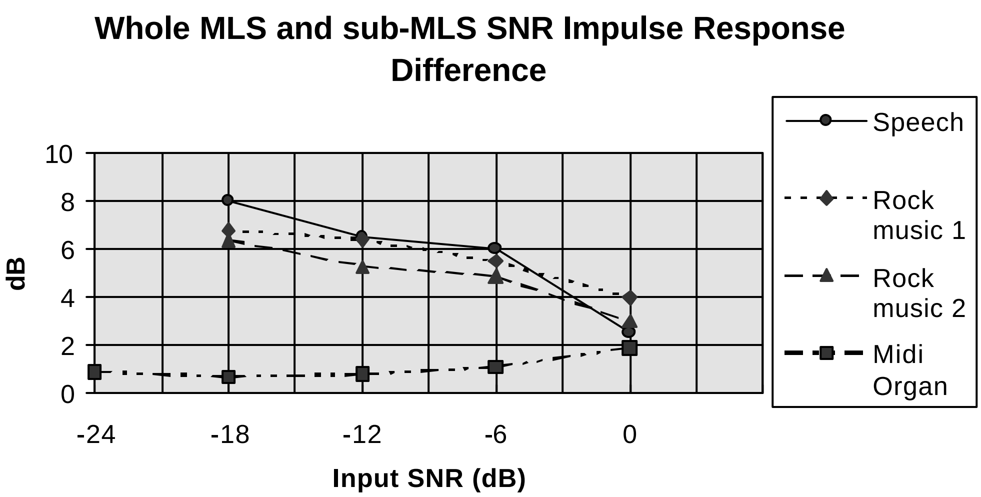

Figure 8. Difference between the whole MLS and sub-MLS.

In general, as the SNR of the composed signal increases a poorer performance is obtained by this method. This tendency is inverted when a synthesized Midi Organ is used as the noise signal. This means that with a careful choice of masking signals, this method will approximately equal the standard MLS method.

The change in overlap of each segment was investigated showing 4000 samples for best results.

At present, a database is being created with a collection of preset acoustical and synthesized sounds in order to help the sound technician to choose the best for his work.

6. CONCLUSIONS AND FUTURE WORK

An alternative MLS based measurement technique was described for situations when constraints with people annoyance is important. This is a very powerful method to be applied in acoustical measurements when the presence of the people in the audience is required.

This method is poorer than the standard MLS for some kind of disturbance signals. However, the SNR difference is not so large, which means that with the average procedure similar results as with the standard MLS method can be achieved, with the associated benefits.

The results of the study showed that this method is very dependent on the type of the disturbance signal.

In future phases of this work, the disturbance spectrum will be analyzed in real time. Some relevant parameters, such as the sub-sequence length will be investigated.

The averaging procedure can always be applied in order to improve the results.

7. REFERENCES

[1] Rife, D. D., Vanderkooy, J., "Transfer-Function Measurement with Maximum-Length Sequences", J. Audio Eng. Soc., Vol. 37, No. 6 (1989).

[2] Vorlander, Michael, Mommertz, E., "Guidelines for the Application of the MLS Technique in Buildings Acoustics and in Outdoor Measurements", Inter-Noise 1997, Budapest - Hungary, August 25-27 (1997).

[3] Borish, J, Angell, James B., "An Efficient Algorithm for Measuring the Impulse Response Using Pseudorandom Noise", J. Audio Eng. Soc., Vol. 31, No. 7 (1983).

[4] Vorlander, Michael, "Aplications of Maximum Length Sequences in Acoustics", I Simpósio Brasileiro de Metrologia em Acústica e Vibrações. Petrópolis, RJ, Brasil, December 04-06, (1996).

[5] Nielsen, Johan L., "Improvement of Signal-To-Noise Ratio in Long-Term MLS Measurements with High Level Nonstationary Disturbances", J. Audio Eng. Soc., Vol. 45, No. 12 (1997).

[6] Paulo, J., Martins, C. R., Bento Coelho, J. L., "Determinação da Resposta Impulsional de espaços fechados utilizando a técnica de sequências de compriment máximo". Proc. TecniAcustica, Spain (in Portuguese) (1999).

[7] Paulo, J., Martins, C. R., Bento Coelho, J. L., " Room Impulse Response Measurement in the Presence of High Noise Levels using Maximum Length Sequences (MLS)". Proc. 7th ICSV, Germany (2000).

[8] Auditory Demonstrations. Philips CD.