HYBRID M SEQUENCES FOR ROOM IMPULSE RESPONSE ESTIMATION IN FREQUENCY DOMAIN

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Abstract
The Maximum Length Sequences (MLS) technique for the measurement of room impulse responses allows achieving large Signal-to-Noise Ratios, SNR. However, in case of high background noise levels, the SNR can be very low, and the measurements will yield unreliable results for sound insulation, reverberation time and amplitude frequency response.

Generally, during the acoustical tests, the noise spectrum amplitude varies with time. This suggests that the analysis may be performed in frequency sub-bands.

In this way, a new MLS based technique referred as Spectral Hybrid Sequences is presented here. When compared with the MLS technique the main feature of this method is the increasing of the SNR.

This new approach consists in exciting the room with a set of MLS sequences (referred in the following as 1 to M sequences) with some time delay between them. At the receiver point, the sequences are filtered by a filter bank, which splits the audio spectrum in multiple sub-bands. The energy within each sub-band is then computed to form a new sequence that corresponds to the lower spectral energy, i.e., the sequence with the highest SNR value. Finally, the cross-correlation is calculated in order to obtain the room impulse response.
A modified MLS measurement method working in the frequency domain, for applications in the room acoustics field is proposed. The new approach, Hybrid Sequence in Frequency Domain, will be detailed described in the full paper version. When compared against the classic MLS technique, the new method has shown a significant increase in the SNR, which is demonstrated by experimental results obtained in real conditions.

1. INTRODUCTION

The Maximum Length Sequences (MLS) technique for the measurement of room impulse responses allows achieving large Signal-to-Noise Ratios, SNR [1]. However, in case of high background noise levels, the SNR can be very low, and the measurements will yield unreliable results for sound insulation, reverberation time and amplitude frequency response [2,3].

In most situations, it possible to model the room under test by a LTI system such as represented in Fig. 1 [4].

![Block diagram representing a Linear Time Invariant System with additive noise.](image)

The LTI system can be described by

\[
\text{Res}(n) = \text{SeqMLS}(n) \ast h(n) + N(n) = y(n) + N(n) , \tag{1}
\]

where \( \ast \) stands for circular convolution operation.

To evaluate the SNR, the following expression is used [5]

\[
\text{SNR} = \frac{\text{MS}(y(n))}{\text{MS}(N(n))} , \tag{2}
\]
where MS stands for Mean Square Value.

Generally, during the acoustical tests, the noise spectrum amplitude varies all the time as is depicted in Fig. 2.

![Noise Spectrum Amplitude](image)

Fig. 2 – Noise spectrum amplitude obtained in two different slots of time.

This suggests that the analysis may be performed in frequency sub-bands [6].

2. METHOD

In this way, a new MLS based technique referred as Spectral Hybrid Sequences is presented here. When compared with the MLS technique the main feature of this method is the increasing of the SNR.

This new approach consists in exciting the room with a set of MLS sequences (referred in the following as 1 to M sequences) with some time delay between them. At the receiver point, the sequences are filtered by a filter bank, which splits the audio spectrum in multiple sub-bands. The energy within each sub-band is then computed to form a new sequence that corresponds to the lower spectral energy, i.e., the sequence with the highest SNR value. Finally the cross-correlation is calculated in order to obtain the room impulse response.

An overview of this method is illustrated in Figs. 3 and 4.
In order to evaluate the performance of the new method by means of the increasing in the SNR, it should keep in mind (1). After filtering the room response of the input sequence by the filter bank with B sub-bands, we can obtain
The MS value of the system response $y(n)$, is constant for the whole set of sequences. As a consequence, from (2) we obtain

$$\text{SNR}_{\text{HybrEspect}} = \frac{\text{MS}(y_1(n)) + \text{MS}(y_2(n)) + \ldots + \text{MS}(y_B(n))}{\text{MS}(N_1(n)) + \text{MS}(N_2(n)) + \ldots + \text{MS}(N_B(n))}$$

$$= \frac{\sum_{k=1}^{B} \text{MS}(y_k(n))}{\sum_{k=1}^{B} \text{MS}(N_k(n))} = \frac{\text{MS}(y(n))}{\sum_{k=1}^{B} \text{MS}(N_k(n))}.$$  \hspace{1cm} (4)

Maximizing (4) corresponds to minimizing the MS value of the noise $N_k(n)$, within each sub-band, or

$$N_k(n) = N_i(n) \bigg|_{\text{min MS}} \quad i \in [1, M].$$ \hspace{1cm} (5)

The using of the new method allows to increase the SNR by

$$\Delta \text{SNR} = \frac{\text{SNR}_{\text{HybrEspect}}}{\text{SNR}_{\text{Class}}} = \frac{\text{MS}(N(n))}{\sum_{k=1}^{B} \text{MS}(N_k(n))} \geq 1,$$ \hspace{1cm} (6)

where $N_k(n)$ is defined by (5), and $\text{SNR}_{\text{HybrEspect}}$ and $\text{SNR}_{\text{Class}}$ are respectively the SNR for the Spectral Hybrid Sequence and for the MLS classic technique.
3. EXPERIMENTAL RESULTS

The experiments were performed by splitting the audio spectrum with different number of sub-bands (wide band, 4 bands and 10 bands) and by using several SNR values. Also different order of sequences and kinds of noise were used for comparison purposes. In Fig. 5 are presented some experimental results concerning the increasing of the SNR when compared against the classical MLS technique.

![SNR's curves for the Spectral Hybrid Sequence and MLS classic technique (wide band)](image)

Fig. 5 – SNR’s curves for the Spectral Hybrid Sequence and MLS classic technique (wide band). The curves corresponds to different types of ambiance noise (i) triangle mark – speech, (ii) circle mark – classic music, (iii) star mark – jazz music, (iv) asterisk mark – rock 1 music, (v) square mark - rock 2 music, (vi) cross mark acoustic rock and (vii) diamond mark– world music.
4. CONCLUSIONS

A modified MLS measurement method working in the frequency domain, for applications in the room acoustics field is proposed. The new approach referred as Spectral Hybrid Sequences will be detailed described in the full paper version. When compared against the classic MLS technique, the new method has shown a significant increase in the SNR, which is demonstrated by experimental results obtained in real conditions.

REFERENCES