Effect of the Distribution of Mirror-Image Sources on the Acoustic Response of the Simulated Room

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Abstract

The aim of this study is to find out the most important reflections that may simulate plausibly the acoustic response of rooms. Various distributions of mirror-image sources are presented, and the corresponding acoustical parameters are studied. The results are evaluated subjectively.

Introduction

The mirror-image method has been applied to calculate the impulse response of rooms. The response consists of the direct sound and a large number of successive sound reflections that arrive at different delay times. From point of view of speech, early sound reflections are useful, whereas late ones that arrive at longer delay at the listener are unfavorable as they impair the speech intelligibility. The delay time that separates early and late reflections lies in the range from 50 to 100 ms. By using the pattern of mirror image sources [1] that is constructed for a room of volume V, the mean density of reflections arriving at time t is: $\frac{dN}{dt} = \frac{4\pi c^3 t^2}{V}$. Therefore the number of MIS and hence the number of reflections arriving at the listener in a time range from t_1 to t_2 is: $N = \frac{4\pi c^3}{3V}\left(t_2^3 - t_1^3\right)$, which implies that for a room of dimensions 11 x 7 x 3 (m), 89 mirror-image sources (MIS) have to be calculated and auralized to simulate the response for a time range lying from 0 to 50 ms and 623 MIS for a time range lying from 50 to 100 ms. Figure 1 shows the temporal distribution of the MIS as function of their order of reflection. Such a large number of MIS increases the complexity of the computation process.

The aim of this article is to calculate the impulse response of enclosures using a reduced number of MIS and without changing its acoustic behavior. However, the monaural room response is computed without any reduction for the number of MIS, then the calculation process is repeated after reducing the number of MIS. The responses are compared to each other by means of objective and subjective tests. It is shown that a reasonable configuration of reduced MIS could be obtained and there is no considerable change on the resulted monaural room response.

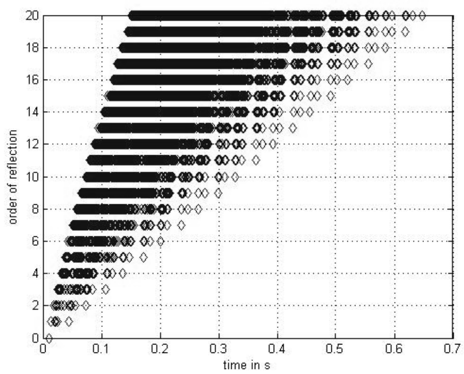

Figure 1: The temporal distribution of the MIS as function of their order of reflection.

Reduction of the number of MIS

In this section three field configurations are presented. The reduction algorithm is applied to those sound reflections that arrive up to 50 or 100 ms.

For the first configuration, the reduction is done according to the order of reflection. The early part of the room response is calculated using a pattern of MIS up to a certain order of reflection.

For the second and third configuration, the reduction is done according to the distance of the MIS with respect to the listener. For the second configuration the reduction is done once over the whole arrival time of the early sound reflections, i.e. the pattern of image sources consists of a certain number of MIS that are nearest to the listener, whereas for the third configuration the overall arrival time is divided into a certain number of time intervals, each of Δt. Within each time interval, a certain number of MIS that are nearest to the listener are included into the MIS-pattern.

Evaluation tests

In this section, the acoustic performance of the room responses that are calculated before and after the reduction of the number of MIS respectively is evaluated by means of objective and subjective tests.

<u>*Objective Tes*ts:</u>

Objective criteria [1] that are derived from the impulse response have been proposed, to measure the acoustic performance of enclosures. A well-known criterion is the reverberation time (RT). Another criterion, such as the definition (D), is based on comparing the energy contained in the early reflections to that contained in all ones. A third criterion [2][3] has been developed to measure the speech intelligibility in enclosures, such as the speech transmission index (STI) or the rapid speech transmission index (RASTI), which depends on the spectral composition of the sound signal and the contributions of the different frequency bands to the quality of the perceived speech.

The three field configurations are realized for a rectangular room of dimensions 11 x 7 x 3 (m) and a uniform absorption coefficient of 0.08. Moreover the room response is calculated without reducing the number of MIS by means of the mirror-image method for order of reflection = 20. Two sets of tests are done. In the first set, the number of the early reflections that arrive at a time up to 50 ms is reduced according to the first, the second and the third configurations respectively. In the second set, the number of the early reflections that arrive at a time up to 100 ms is reduced according to the second and the third configuration respectively.

A new quantity is introduced to measure the distortion between the acoustic behavior of the room without reducing the number of MIS and its behavior after the reduction of the number of the MIS. The distortion measure is defined as $DM = \sum_{i=1}^{1}\left(B_i - A_i\right)^2$, where A and B are vectors containing a set of the acoustic criteria calculated from the impulse response before and after reducing the number of MIS respectively. The distortion measure for each set of tests is shown in tables 1 and 2. Each vector consists of three elements: RT, D, and RASTI. Tables 1 and 2 show that the reduction algorithms affect mainly the definition, and that for a reduction over the first 50 ms only configuration2 shows less DM, whereas for a reduction over the 100 ms configuration 3 would be preferred.

<u>*Subjective test*</u>

No difference is perceived while comparing the monaural response for each set of tests to that obtained without applying any reduction algorithm.

Table 1: Results for the first set of tests. Reduction over the first 50 ms. N is the number of MIS before or after reduction. For configuration no. 3, Δt1 = 30 ms, Δt2 = 20 ms, and N1, N2 are the number of MIS in each time interval respectively.

Configuration		RT	D	RASTI	DM
Without reduction, N = 88		1.2	0.3403	0.299	0
No.1	Order = 2, N=22	1.26	0.2237	0.2925	0.0172
No. 2	N = 44	1.26	0.2916	0.2994	0.006
	N = 22	1.26	0.2387	0.2975	0.0139
	N =17	1.26	0.2189	0.2946	0.0184
	N = 12	1.26	0.1936	0.2908	0.0252
No.3	N1=17 N2= 5	1.26	0.2347	0.2971	0.0148
	N1=12 N2=10	1.26	0.2239	0.294	0.0172

Table 2: Results for the second set of tests. Reduction over the first 100 ms. N is the number of MIS before or after reduction. For configuration no. 3, Δt = 50 ms, and N1, N2 are the number of MIS in each time interval.

Configuration		RT	D	RASTI	DM
No 2	N = 152	1.32	0.4298	0.3063	0.0225
	N =178	1.32	0.4196	0.3051	0.0207
No 3	N1=22 N2=130	1.32	0.2944	0.3057	0.0166
	N1=22 N2=156	1.32	0.2886	0.3053	0.0171

Conclusion

In this article, various algorithms have been presented to reduce the number of early reflections in the room response. The results are evaluated by means of objective and subjective tests.

References

[1] Heinrich Kuttruff, Room acoustics, Elsevier Science publishers, 2000.

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[3] T. Houtgast and H.J.M.Steeneken, "The modulation transfer function in Room Acoustics as a predictor of speech intelligibility", acustica vol. 28, 1973, p66-73.