BEAM-TRACING PREDICTION OF ROOM-TO-ROOM SOUND TRANSMISSION AND THE ACCURACY OF DIFFUSE-FIELD THEORY

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1 Introduction

The diffuse field prediction of acoustic transmission between two rooms is a significant aspect of building comfort. The sound field of a room is diffuse if the reverberant sound field is the same at every position in the room and reverberant sound waves are incident from all directions with equal intensity and random phase relations and [1].

Most of the existing standards for evaluating transmission loss of a partition wall are based on statistical theory [2]. However, this theory is unacceptable when the reverberant sound field departs from the diffuse field assumptions, like in long or flat rooms [2]. Although the existing diffusion model [2] and Odeon model [3] can accurately predict diffuse field theory in coupled rooms for diffuse and non-diffuse sound fields, they are not deterministic and accurate gemotrical acoustics approach like beam tracing.

In this paper, an extension of the existing beam tracing model for empty, parallelepiped rooms with specularly reflecting surfaces is proposed for predicting room-to-room sound transmission using energy approach (EBTM) which is the first work of room-to-room sound transmission using beam tracing technique. This new model is being used to investigate the accuracy of the classical diffuse-field formula (DFT) (L2=L1-TL+10log(S/A2)) [2] for both diffuse and non-diffuse configurations, which is the objective of this work.

2 Method

Similar to ref.[2, 3], the reference configuration has identical parallelepiped source and receiver room of 5m×5m×5m. All surfaces are specularly-reflected surfaces, local reaction and impedance boundary condition with 0.10 absorption coefficient; separated by a homogenous transmitting surface of 25 m^2 having frequency independent transmission loss (TL) of 20 dB. Source and receivers are kept 0.2 wavelengths away from surfaces and far apart so that the direct sound is ignorable; both receivers are placed near the middle of each room. The source is modelled as an omnidirectional sphere with a sound power level of 100 dB. At each frequency, f- input data for the source, receiver room, source and receivers, beam resolution and surface properties are entered in the model. Then, each beam is generated if it hits the transmitting surface in source room, part of the beam is reflected back and continue to propagate in the source room and checks if it strikes the receiver R1 and the complex-pressure contribution and SPL are calculated in source room; another part of the beam is transmitted into the receiver room and continues to propagate, checks if it encounters the receiver R2; the complex-pressure contribution and SPL are calculated in the receiver room. It is to be noted that no sound transmission from receiver to source room is considered in this model. To get the converged results for beam tracing models for reference configuration, 10580 beams and 50 reflections are required with computation time of 3 hours, 7 minutes and 38.93 seconds in a computer with an Intel i7 processor and 16 GB of memory.

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3 Results

3.1 Energy-based methods

Case 1: reference configuration (diffuse sound field)

The accuracy of DFT is investigatied for reference configuration (diffuse sound field) by EBTM, ODEON results [3] and CATT-Acoustic (CAT-TM) simulation results as shown in Table 1 below.

Table 1: Comparison between DFT and the energy-based methods for the reference configuration (diffuse sound field).

Room	DFT	EBTM	CAT-TM	ODEON
Source	93.8	94.03	93.5	93.25
Receiver	76.02	74.24	76.2	75.11

In source room, the departure of DFT from all 3 methods and difference between each of them are within only 0.5 dB. Therefore, all three energy-based methods are quite accurate in predicting the diffuse field theory in source room.

In receiver room, the departure of DFT from EBTM is 1.78 dB; 0.18 from CAT-TM and 0.91 dB from ODEON. So, EBTM values are 1.5 dB and 0.8 dB lower than CAT-TM and ODEON respectively. Results shows that the energy-based methods shows higher discrepancies in predicting the diffuse field theory in receiver room while compared to the source room.

Case 2: effect of room shape (for uniform absorption)

In case 2, the shapes of both source and receiver rooms are varied while keeping the absorption of the surfaces uniform as case 1.

#1 Between a small cubic office room and large room.

Table 2: Comparison between DFT and EBTM results for a small cubic office office room (source) and large room (receiver).

Room	Dimensions	DF	EBTM	Departure
Source	5m×5m×5m	93.8	94.03	0.23
Receiver	10m×10m×10m	73.8	71.59	2.1

The departure from DFT rises to 2.21 dB from 1.87 dB: 0.5 dB more deviation in receiver room in case 2 for only doubling the length of the receiver room i.e. long room (more non-diffuse sound field) from case 1: cubic room(more diffuse sound field). Results remained unchanged from case 1 for source room as expected since it is unchanged.

#2 Between a large room and small cubic room.

Table 3: Comparison between DFT and EBTM results for a large room (source) and a small cubic office room (receiver)

Room	Dimensions	DFT	EBTM	Departure
Source	10m×10m×10m	91.58	91.15	0.43
Receiver	5m×5m×5m	73.8	71.3	2.5

The departure of EBTM from DFT increases from 0.23 to 0.43 dB in source room; from 2.21 to 2.5 dB for receiver room for only doubling the length of source room for case #2 (more non-diffuse sound field) from case 1 (more diffuse sound field). So, increasing the length of the source room twice results in only 0.4 dB increase of departure in the receiver room from case #1.

#3: Between two large rooms (10m×10m×10m)

Table 4: Comparison between DFT and the EBTM results for two large rooms (10m×10m×10m)

Room	Dimensions	DFT	EBTM	Departure
Source	10m×10m×10m	91.58	91.15	0.43
Receiver	10m×10m×10m	68.93	71.3	2.65

The departure of EBTM from DFT are 0.43 and 2.5 dB for case #3 (more non-diffuse sound fields); 0.23 and and 0.78 dB rise in departure for only doubling the length of the reference (case 1) source and receiver room respectively. For increasing the length of the receiver room twice from case #2, the departure only increases by 0.15 dB.

#4: Between two more larger rooms (25m×25m×25m)

Table 5: Comparison between DFT and EBTM results for two large rooms (25m×25m×25m).

Room	Dimensions	DFT	EBT	Departure
Source	25m×25m×25m	88.16	86.85	1.31
Receive	25m×25m×25m	64.74	60.58	4.16

The departure of EBTM from DFT are 1.31 and 4.16 dB; 1.08 and and 2.29 dB increase for two large rooms of case #4 (more non-diffuse sound fields) for just increasing the length of both source and receiver room of case 1 by five times. Therefore, the departure of reverberant sound field from the diffuse field rises gradually with increasing the size of both source and receiver rooms from case 1 as expected. However, these depatur is considerably higher in receiver room compared to the source room of same size.

Case 3: effect of surface absorption distribution

The absorption distribution is made non-uniform from reference room configuration (case 1) by placing most absorptions in the ceiling while always keeping the same equivalent absorption area in both source and receiver room. Equivalent absorption area for reference configurations, 0.1×150 m^2 i.e. 15m^2 is distributed among the room surfaces keeping same equivalent absorption area as follows; 0.55×25 m^2 (ceiling)+ 0.01×125 m^2 (remaining 5 surfaces except ceiling) = 13.75+1.25=15 $m^{2.}$ The results for the effect of surface absorption distribution are shown for both source and receiver room in table 6.

Table 6: Comparison between DFT and EBTM for the reference configuration (non-uniform absorption)

Room	Dimensions	DFT	EBTM	Departure
Source	5m×5m×5m	93.8	95.45	1.6
Receiver	5m×5m×5m	76.02	79.42	3.4

For reference rooms (case 1) with non-uniform absorption distribution (more non-diffuse sound field), increases the departure from DFT to 1.6 dB and 3.4 dB, which are 1.42 dB and 1.53 dB higher in source and receiver room respectively compared to case 1 with uniform absorption (more diffuse sound field).

4 Conclusion

The results of this paper shows that in energy based methods, diffuse field theory is relatively more accurate for source room while compared to receiver room for reference configuration (i.e. more diffuse sound field); however its accuracy decreases significantly with changes in the shape of the room and distribution of its surface absorption (i.e. more non-diffuse sound field). The departure from diffuse field is particularly more significant with changes in absorption distributions while compared to the room shape while later further increase with changes of width and height of the rooms.

References

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