Measurement of Acoustic Performance of an Auditorium

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Abstract. Objective of this paper is to obtain speech-related acoustic parameters in auditorium. The object of this research is a room that has T-shape geometry with amphitheater seating. Evaluation was carried out by measurement in empty room with two different sound source position. The following impulse response objective parameters were analyzed: Early Decay Time, Reverberation Time and Definition. Convergence of each configurations was analyzed through standard deviation and just noticeable difference (JND). Additionally, noise criteria considered as evaluation since there are active ACs inside the object.

1. Introduction
Currently, most of academic activities are held at enclosed space. Every physical boundary contributes to draw phenomenon of reflection, absorption, diffusion and transmission whenever sound wave interacts with it. The peculiar behavior of sound field might be perceived as pleasant or irritating sound. Acoustic performance can be analyzed from impulse response parameters such as Reverberation Time ($T_{30}$), Early Decay Time (EDT) and Definition ($D_{50}$). Those parameters are dependent to room geometry, position of sound source and receivers, sound level of the source and absorption [1]. In addition, background noise contributes to sound masking hence it needs to be rated as parameters that represent noise quality inside room in noise criteria (NC).

Measurement procedure complies to ISO 3382-1:2009 with previously stated parameters are analyzed. Since parameters potentially have spatial variation across floor plan [3],[4], arrival sound might be perceived differently. The analysis of data variation is through least difference value that human ear could detect. It is expressed in Just Noticeable Difference (JND). According to ISO:3382-1:2009, consideration of JND is only at 500 Hz and 1000 Hz. JND value is presented at Table 1. JND analysis leads to identify impact of sound source position to perceived sound.

| Acoustic Parameter | JND   | Typical Range |
|--------------------|-------|---------------|
| EDT                | rel. 5% | 1.0 s; 3.0 s |
| $D_{50}$           | 5%    | 30%; 70%      |
| $T_{30}$           | 5%    |               |
2. Description of an object 

The object of this research is one of academic facilities which is use for speech purposes. It has unique geometry featured, the floor plan is T-shaped with stage location is in intersection between line of word T. However, room is designed to accommodate clear and comfort view for audience from every section of seating area to the stage. So, seat direction is set into stage and ground floor for seating area is inclined. Illustration of floor plan and view from last row to stage is at Figure 1 and Figure 2, respectively. Contrarily to inclined seating, the distance between floor and ceiling does not have constant distance. Furthermore, air temperature is controlled by ACs that installed at several strategic spot on ceiling.

Total area of this room is about 135.68 m$^2$ and height dimension from lowest floor to ceiling is around 3.16 m. Seating capacity of this room is around 95 persons. Each seating was made of fabric and no surfaces of floor is exposed since it is entirely covered by carpet (Figure 3). Differently, there are some section of wall surfaces is exposed while the rest is already covered by fabric. Location of uncovered part is around stage area.

![Figure 1. Floor plan](image1)

![Figure 2. Inclined seating](image2)

![Figure 3. Material surfaces](image3)

3. Acoustic Parameters

Considering purpose of the object is for speech activity, impulse response parameters are chosen so it may illustrate room performance relate with it. In this research, those parameters are Early Decay Time (EDT), Reverberation Time ($T_{30}$) and Definition ($D_{50}$). Noise Criteria is assessed too since ACs may cause intolerable noise for specific activities inside closed space.

Early Decay Time (EDT) is defined as time necessary for the sound level to decrease by first 10 dB. EDT has chosen because it shows better correlation to geometry shape and strongly influenced by early reflection rather than reverberation time [1]. Reverberation time ($T_{30}$) is required time for room to decrease the energy by 30 dB after source is turned off.

Speech intelligibility is represented by definition $D_{50}$. Theoretically, it defines as ratio of useful energy within first 50 ms to total energy. It is expected that arrival energy within first 50 ms is having large energy. Mathematical expression to calculate $D_{50}$ as follow:

$$D_{50} = \frac{\int_0^{0.05} h^2(t) dt}{\int_0^{\infty} h^2(t) dt}$$  \hspace{1cm} (1)

The satisfaction condition for speech intelligibility and general living environments is depend on energy level of background noise, hence, it needs to be rated. Noise criteria or NC is a single number or rating used to define the maximum allowable background noise in enclosed space. t is also used to establish satisfaction conditions for speech intelligibility and general living environments [5].
4. Measurement method
Acoustic parameters can be carried out through measurement with impulse response technique that comply to ISO 3382-1:2009. Acoustic parameters are taken to analyze decaying sound in audience area. Measurement points are used to represent it. In this research, every section is divided into 3 measurement points that spread symmetrically from rear to front seat. Measurement is conducted while room in unoccupied condition with one active AC (number II). Location of AC is at Figure 4.

The sound source is dodecahedron that located in front area of auditorium. Signal MLS is emitted to source then sensors capture the decaying signal as room impulse response (RIR). Measurement is conducted with two different excitation positions of sound source. Position of sound source and receivers is plot at Figure 4. Also, data is taken about 5 times at each receiver position for every position of source. The purpose of this configuration is to find the measurement accuracy.

5. Experimental Result and Analysis
5.1. Noise Criteria Analysis
According to experiment and calculation, NC has range from 30-33. This paper presents only the highest level of background noise from each section. It is showed by point 1, 4 and 7 with value of NC value is about 33 for all points.

5.2. Acoustic Parameters Analysis
For impulse response parameters, data is presented in two type: (1) standard deviation (STDEV) and (2) Average (Ave.). Both analysis are tabulated on two frequency (500 Hz and 1000 Hz) for all measurement positions. JND is analyzed by two way. First is by comparing deviation in particular measurement point and second to find the least difference between measurement points. Analyzed frequency is only at 500 Hz and 1000 Hz.

The result of repeated measurements of acoustic parameters is presented at Table 2, Table 3, and Table 4 for EDT, $D_{50}$ and $T_{30}$, respectively. Standard deviation for EDT (Table 2) is vary for source position at A. Some point has standard deviation less than JND and the other is
large than 2 JND for both analysis frequencies. It occurs at point 7, 8 and 9. However, source position at B have different pattern to position at A. Standard deviation value for each receivers point is less than 1 JND. Moreover, JND of average value at both frequencies between receiver positions is more than 1 JND.

**Table 2. Standard deviation and average of EDT (s)**

| Receivers position (Sound source position: A) | f (Hz) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-----------------------------------------------|--------|---|---|---|---|---|---|---|---|---|
| 500 (STDEV)                                   | 0.00   | 0.00 | 0.01 | 0.01 | 0.02 | 0.00 | 0.46 | 4.92 | 1.62 |
| 500 (Ave.)                                    | 0.37   | 0.43 | 0.45 | 0.45 | 0.42 | 0.36 | 0.53 | 2.54 | 1.17 |
| 1000 (STDEV)                                  | 0.00   | 0.00 | 0.01 | 0.01 | 0.03 | 0.00 | 0.96 | 4.14 | 0.10 |
| 1000 (Ave.)                                   | 0.39   | 0.51 | 0.57 | 0.35 | 0.50 | 0.58 | 0.89 | 2.27 | 0.50 |

| Receivers position (Sound source position: B) | f (Hz) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-----------------------------------------------|--------|---|---|---|---|---|---|---|---|---|
| 500 (STDEV)                                   | 0.02   | 0.00 | 0.01 | 0.01 | 0.02 | 0.11 | 0.01 | 0.02 | 0.00 |
| 500 (Ave.)                                    | 0.44   | 0.38 | 0.40 | 0.37 | 0.43 | 0.58 | 0.27 | 0.34 | 0.51 |
| 1000 (STDEV)                                  | 0.02   | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.00 |
| 1000 (Ave.)                                   | 0.44   | 0.43 | 0.39 | 0.40 | 0.65 | 0.50 | 0.35 | 0.45 | 0.37 |

$D_{50}$ has quite similar pattern with EDT. Point 7, 8 and 9 has standard deviation larger than 1 JND for source position at A. Contrarily, sound source position at B has no impact to repeated measurement since it has standard deviation less than 1 JND. However, the different between the range of average value (maximum value - minimum value) among receivers point can be divided into more than 3 JND for both frequencies.

**Table 3. Standard deviation and average of $D_{50}$ (%)**

| Receivers position (Sound source position: A) | f (Hz) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-----------------------------------------------|--------|---|---|---|---|---|---|---|---|---|
| 500 (STDEV)                                   | 0.59   | 0.29 | 0.75 | 0.96 | 1.02 | 0.71 | 5.69 | 10.30 | 9.50 |
| 500 (Ave.)                                    | 89.02  | 79.60 | 84.01 | 82.61 | 85.13 | 85.11 | 83.93 | 85.30 | 76.88 |
| 1000 (STDEV)                                  | 0.27   | 0.25 | 1.62 | 0.40 | 1.04 | 0.89 | 10.77 | 11.37 | 3.87 |
| 1000 (Ave.)                                   | 85.42  | 81.28 | 77.55 | 87.72 | 82.16 | 72.50 | 78.20 | 76.48 | 75.73 |

| Receivers position (Sound source position: B) | f (Hz) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-----------------------------------------------|--------|---|---|---|---|---|---|---|---|---|
| 500 (STDEV)                                   | 1.66   | 0.43 | 0.52 | 1.53 | 6.68 | 2.57 | 0.90 | 1.23 | 1.19 |
| 500 (Ave.)                                    | 79.58  | 85.83 | 83.87 | 91.38 | 74.75 | 75.71 | 91.56 | 86.44 | 78.47 |
| 1000 (STDEV)                                  | 1.08   | 0.17 | 0.39 | 0.59 | 3.32 | 3.50 | 0.88 | 0.67 | 0.26 |
| 1000 (Ave.)                                   | 81.35  | 82.96 | 84.04 | 86.62 | 74.96 | 70.14 | 87.55 | 81.73 | 84.21 |

The range of standard deviation of $T_{30}$ (Table 4) is quite different than previous parameters. JND for both configuration (position A & B) has vary value from less than 1 JND to large than 1 JND. By comparing average value at particular point to the others, the difference is also large than 1 JND.
Table 4. Standard deviation and average of $T_{30}$ (s)

| Receivers position (Sound source position: A) | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|---------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| $f$ (Hz) 500 (STDEV)                        | 0.48| 0.10| 0.14| 0.29| 0.83| 0.83| 1.55| 0.26| 1.41|
| $f$ (Hz) 500 (Ave.)                         | 1.10| 1.26| 1.37| 1.28| 1.48| 1.62| 1.90| 1.38| 1.94|
| $f$ (Hz) 1000 (STDEV)                       | 0.01| 0.00| 0.41| 0.66| 1.06| 0.27| 0.19| 0.44| 3.05|
| $f$ (Hz) 1000 (Ave.)                        | 0.43| 0.43| 0.91| 0.93| 1.27| 0.91| 0.74| 0.69| 2.07|
| All (Ave.)                                  | 1.24| 1.29| 1.29| 1.30| 1.44| 1.41| 1.45| 1.23| 1.58|

| Receivers position (Sound source position: B) | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|---------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| $f$ (Hz) 500 (STDEV)                        | 0.58| 0.10| 0.37| 1.03| 0.56| 0.55| 0.79| 0.56| 1.22|
| $f$ (Hz) 500 (Ave.)                         | 2.06| 1.00| 0.85| 1.41| 1.28| 1.60| 1.35| 1.32| 1.22|
| $f$ (Hz) 1000 (STDEV)                       | 0.46| 0.00| 0.04| 0.90| 0.62| 0.72| 0.99| 0.36| 0.52|
| $f$ (Hz) 1000 (Ave.)                        | 1.76| 0.46| 0.49| 0.90| 0.90| 1.54| 1.12| 0.71| 0.52|
| All (Ave.)                                  | 1.75| 1.24| 1.13| 1.34| 1.44| 1.72| 1.36| 1.27| 1.31|

6. Conclusion
The paper presents acoustical performance of T-shaped auditorium by using two position of sound source. The result indicates that the accuracy of EDT and $D_{50}$ measurement depend on sound source position since there are variation of standard deviation value from less to larger than 1 JND. But $T_{30}$ is independent to sound source position since the standard deviation is larger than JND. Comparison of different average value between receivers point to JND value shows that the impression of arrival sound is perceived differently for most audience area.

Energy of background noise reaches the peak at area around noise source (AC). It is shown by three receivers position at point 1, 4 and 7 which is represent maximum background noise for each section. As it is getting further from noise source, background noise level is decaying.

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