Sound power estimation with an acoustic camera in comparison with sound power determination using sound pressure and sound intensity method

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Abstract. Sound Power Level (SWL) is a measure to be used to describe a sound source regardless its surrounding and environment. In general, there are two different standardized methods to determine the Sound Power Level of a sound source, which are by using sound pressure and sound intensity. Other than that, there is a possibility to estimate Sound Power Level using an acoustic beamforming array or more popularly known as acoustic camera. This estimation is considered more time-efficient compared to the two methods and can be done when there are other sound sources during the measurement. However, this measurement is not yet standard compliant and therefore cannot be used for standardized reporting or legislative purposes.

The paper highlights the possibility to estimate Sound Power Level of a Reference Sound Source using an acoustic beamforming array, when another sound source is present at the time of measurement. Besides comparing to the Reference Sound Source’s calibration chart, the measurement is compared with two ISO-compliant measurements which are ISO 3746 (Survey grade, sound pressure method) and ISO 9614-2 (survey grade, sound intensity method).

1. Introduction

Sound Power determines how much sound energy is produced by a sound source over time. When expressed in decibel, it is called Sound Power Level (SWL).

To do the measurement precisely, the sound source must be placed in an acoustically treated environment. This, however, is not always practical. To overcome this issue, different methods have been proposed so that SWL can be determined in less restricted conditions by measuring sound pressure or sound intensity while indeed reducing the measurement’s accuracy.

Determination of SWL from its sound pressure and sound intensity is possible because of the transport of sound energy in medium causes changes in the medium’s pressure. This change of pressure due to sound energy is called sound pressure. By sensing the changes of pressure in a medium, the sound power can be determined. Similarly, sound intensity can be calculated by having one extra information in addition to the pressure, either one more pressure or velocity with a known distance to the other pressure information. When expressed in decibel (dB), sound pressure is called sound pressure level (SPL) and sound intensity is called sound intensity level (SIL).
2. Experimental Methods
Determination of Sound Power Level by Sound Intensity, Sound Pressure, and Estimation by Acoustic Beamforming Array

2.1 Determination of Sound Power by Sound Intensity Measurement
To determine sound power from either sound intensity and sound pressure, the relationship between the two should be known. Sound power \( W \) is the surface integral of sound intensity \( I \) over the enveloping surface, mathematically written as:

\[
W = \int I \, dS \tag{1}
\]

The surface enclosing the sound source could be defined as any shape of surface, as long as it is enclosing the sound source. Usually a box shape is chosen for sound intensity measurement because of its practicality.

In an intensity-based measurement, two sensors are used, either two pressure microphones (p-p probe) or a pressure microphone and a velocity microphone (p-u probe). Intensity itself is the product of pressure and velocity. This makes it straightforward why it is possible to calculate intensity using p-u probe. If p-p probe is used, some mathematical operations have to be done to be able to obtain the intensity.

Using an intensity probe, it is possible to measure the sound intensity which only going on the same axis as the probe. This causes sound power measurement using sound intensity to be less restricted on the environment and background noise than by sound pressure.

2.2 Determination of Sound Power by Sound Pressure Measurement
The most ideal way to determine SWL by sound pressure is in a free-field – a condition where there is no other object than the sound source. In such condition, the relationship between SWL and SPL for a dot-like sound source is:

\[
SWL = SPL + 20 \log(r) + 10.7 \, dB \tag{2}
\]

Where \( r \) is the distance between the sound source to the receiver.

However, free-field condition rarely happens. In a room, a sound receiver receives both direct sound and reflected sound from the sound source. The relationship between SWL and SPL in a room is:

\[
SWL = SPL - 10 \log \left( \frac{Q}{4\pi r^2} + \frac{4}{A'} \right) \, dB \tag{3}
\]

Where \( Q \) is the directivity factor, and

\[
A' = \frac{\bar{a}S}{1 - \bar{a}} \tag{4}
\]

Where \( \bar{a} \) is mean absorption coefficient and \( S \) is the total surface in a room.

2.3 Estimation by Acoustic Beamforming Array
Acoustic beamforming array or Acoustic Camera is a device constructed by a number of microphones. The main function of an acoustic beamforming array is sound localization and directive listening. Using acoustic beamforming array, it is possible to estimate the sound pressure level coming from a certain direction. One of the beamforming technique that is widely used is delay-and-sum technique. In an acoustic camera which has a lot of microphones, the sound from a source will reach each microphone at different time depending on the position of the sound source relative to each microphone. By knowing the sound velocity in air and the relative distance between each microphone to all other microphones,
the signals can be delayed, summed, and averaged so that the microphone array forms a beam pointing to a certain direction. From this sound pressure level coming from a beam, the sound power level can be obtained using the same formula in (2).

The directivity of the beam can be expressed by beampatterns. Thinner beampattern means the beam is more directive. In general, the lower the frequency, the wider the beampattern are. To reach lower frequency, an array should have a bigger size.

3. Results and Discussion

Measurement results in accordance with ISO 3746, ISO 9614-2, and Estimation Using Acoustic Camera. To have an idea of how accurate the sound power level estimation is using acoustic camera, a known sound source should be measured. In this case, a reference sound source (RSS) is used. Besides comparing with the RSS’ calibration certificate, the estimation is also compared with sound power determination by pressure and intensity, which complies with ISO 3746 [1] and ISO 9614-2 [2] respectively. Both standards are survey grade method.

All measurements were conducted in a hemi-anechoic chamber in Adhiwijogo Acoustics Laboratory in Institut Teknologi Bandung, Indonesia. The cut off frequency of this chamber is 100Hz.

The background noise was measured 4 times in 4 different positions. The averaged measurement result can be seen in table 1.

![Background Noise](image)

**Figure 1.** Averaged background noise

There were two conditions in which the measurements are conducted. First, there were only one sound source in the room which is the RSS. For the other measurement, there were two sound sources which are the RSS and a dodecahedral speaker which emitted pink noise. The sound sources used are presented in Table 1.

| Sound sources used in the measurements |
|--------------------------------------|
| **Brand**                     | **Type**        |
| Reference Sound Source           | Norsonic        |
| Dodecahedral speaker             | Norsonic        |
| Power amplifier with built-in signal generator | Norsonic | Nor276 |

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3.1 Measurement in accordance with ISO 3746

A hemispherical surface for the measurement was chosen with 20 measurement points. The measurement devices used are presented in Table 2.

Table 2. Measurement devices for sound pressure

| Measurement                                | Brand   | Type   |
|--------------------------------------------|---------|--------|
| Handheld Sound Analyzer                    | Norsonic| Nor150 |
| Microphone                                 | Norsonic| Nor1225|
| Pre-amplifier                              | Norsonic| Nor1209|
| Sound Calibrator                           | Norsonic| Nor1251|
| Windscreen                                 | Norsonic| Nor1451|
| Measurement and calculation software       | Norsonic| Nor850 |

The result is presented on Figure 2.

Figure 2. Measurement result in accordance to ISO 3746

Table 3. Measurement devices for sound intensity

| Measurement                                | Brand   | Type   |
|--------------------------------------------|---------|--------|
| Handheld Sound Analyzer                    | Norsonic| Nor150 |
| Sound Calibrator                           | Norsonic| Nor1251|
| Intensity probe                            | Norsonic| Nor1290|
| Phase Calibration Coupler                  | Norsonic| Nor1294|
3.2 Measurement in accordance with ISO 9614-2

A box surface with 1 m x 1 m x 1 m size was chosen for the measurement in accordance with ISO 9614-2. Only one direction of scanning, which is horizontal was chosen, and therefore could be considered as survey grade measurement. The result is presented in figure 3.

![Figure 3. Measurement result in accordance to ISO 9614-2](image)

3.3 Sound Power Estimation using Acoustic Camera

The acoustic camera used in this measurement is from Norsonic, Nor848A. The acoustic camera has 128 microphones with array diameter of 0.4 meter.

Previous work in [4] shows that there is no significant difference in which beam to be used in the estimation. Simply, no matter where the RSS on the screen is, it should produce similar result. Another findings from the previous work is that the measurement in the distance of 3-5 m from the RSS produces better result compared to 1-2 m. It’s also been suggested that the closer the disturbing sound source to the measured sound source, the less accurate the results are. However, this previous work did the measurement in an anechoic chamber and uses different type of microphone array, which might have a different beampattern as well, and therefore draw a different conclusion with the array used in this measurement.

Taking into account the previous work and the size of the hemi-anechoic chamber. Three measurement positions were chosen, which are in 0°, 45°, and 90° angle relative to the RSS. The snapshot of this recording can be seen on Figure 4, Figure 5, and Figure 6.

![Figure 4. Measurement from 90 degree angle](image)
![Figure 5. Measurement from 45 degree angle](image)
![Figure 6. Measurement from 0 degree angle](image)
The averaged SWL estimation from the three position is presented in Figure 7.

![Figure 7 Estimated SWL from the Acoustic Camera](image)

To compare the results, the errors are calculated according to this formula:

$$\text{Error} = \frac{|\text{SWL measured} - \text{calibration certificate}|}{\text{calibration certificate}} \times 100\%$$  \hspace{1cm} (5)

The errors are presented in Figure 8.

![Figure 8. Comparison of Errors of each measurement](image)

### 4. Discussion and Further Work

From these measurement, the total sound power estimation using acoustic camera is comparable to ISO3746 and ISO9614-2 compliant measurement, if expressed in dBA. This is because the high errors in the measurement using acoustic camera are in the lower frequency, which are heavily weighted in A-weighting.

However, if we have a look at each frequency band, determination of SWL by sound intensity measurement produces less error in the lower frequency and higher consistency when another sound source is present.

In the future, more setups and configurations can be explored to get a more accurate estimation using acoustic camera. Other than that, measurements in a common room which normally are more reverberant could also be explored.
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6. References

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