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PERFORMANCE EVALUATION PROCEDURE OF ACOUSTIC CAMERA FOR SOUND SOURCE LOCALIZATION

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ABSTRACT

Recently, due to the market expansion of the acoustic camera based on the microphone array for sound source localization, it has become a representative acoustic measurement instrument, such as the sound level meter. In order to enlarge the field of application and increase the reliability of performance, the need for a standardized evaluation method is being raised. In this study, a test procedure is proposed to objectively compare the basic specifications of an acoustic camera, developed to simultaneously determine the location and intensity of the sound source. Performance indexes of acoustic cameras can be broadly divided into performance as a sound pressure measurement device, as a microphone array, and as an imaging device. Performance as a sound pressure measurement device is to determine the measurable range and quantification accuracy of the signal level. The characteristics as an array are to be evaluated for the performance of spatial filtering and resolution of localization. The performance indexes as imaging devices are to determine the accuracy as localization devices, including consistency with an optical image. Here, the detailed evaluation procedure and configuration of measurement system are proposed, and a practical example is presented as a demonstration.

1 INTRODUCTION

Acoustic camera, the device to present both of the location and intensity of acoustic source on the optical images, is one of the representative instruments of sound measurement. In the past, it has been mainly used for research purpose or R&D process based on intuitive convenience. However recently, its application is expanding to fields such as diagnosis and abnormality detection, and attempts are being made to utilize it in the field of legal metrology for regulation. As the application field expands, the need for a standardized evaluation method that can objectively evaluate and compare performance has begun to be discussed. In this study, the evaluation parameters and its measurement method are discussed for evaluation parameters for determining the specification of acoustic camera.

2 PREPERATION FOR MEASUREMENT

2.1 Normative references

Currently, no international standards for acoustic cameras have been proposed, but methods and procedures can be referenced in the standards for acoustic measurement instruments that are applicable for part of the functions of acoustic cameras. The most representative instrument is the sound level meter, and it is possible to refer to its specifications [1-3] and calibration methods [4]. In addition, the selection of specifications for the reference artefact to ensure traceability and compare characteristics should also refer to the standard for the standard equipment [5, 6].

2.2 Environmental conditions requirements

The scope for performing the test must be determined in advance because it is necessary to determine the size and environmental conditions of the measurement system. Basically, the measurement environment is configured by checking the frequency range of interest, measurement distance, and self-noise level in advance.

The recommended environmental conditions can utilize the evaluation conditions for sound level meters when considering the general environmental conditions for the calibration equipment used for measurement, as follows

- Temperature: (23.0 ± 3.0) ℃
- Static pressure: (101.325 ± 3.0) kPa
- Relative humidity: (50 ± 20) %

Unless there are special cases, the evaluation is performed within the range that satisfies these conditions.

Except in cases developed for use in a special environment, the evaluation procedure should be conducted in a space that satisfies the free-field conditions satisfying the condition specified in ISO 3745.

2.3 System configuration

The sound source used in the test must be capable of producing enough sound pressure output to measure each item across the entire frequency band to be tested. It must be a sound source whose centre can be easily identified. When configuring a sound source, it is recommended to install an additional monitoring microphone to monitor changes in the sound source. At this time, the monitoring microphone should be located as close to the sound source as possible and should not affect the DUT. It must be assumed to be a plane wave in the range of the wave front reaching the DUT, and it is recommended that the Helmholtz number be 1 or less. It is recommended that the shape of the sound source be axisymmetric when using the reference axis direction as the axis, and can be selected by referring to the information described in IEC 61094-8: Annex A.

The sound source is installed so that the sound source is centred in the reference direction, and is installed at a sufficient distance so that measurements can be made under far-field conditions. When installing the DUT and reference microphone on a stand or turntable, it is recommended to follow the sound level meter installation method presented in IEC 62585. However, if actual usage conditions assume the use of a vertical support, it is also possible to install under those conditions.

In order to evaluate all the performance indexes, it is necessary to obtain raw data from each channel constituting the array. If this is not supported, the parameters that can be evaluated are limited.

3 EVALUATION PARAMETERS FOR SPECIFICATION AND MEASUREMENT METHOD

Performance indexes of acoustic cameras can be broadly divided into performance as a sound pressure measurement device, as a microphone array, and as an imaging device. Here, parameters related to sound cameras are listed and the methods to determine specifications are investigated by considering the characteristics of sound cameras.

3.1 General characteristics – Dimension and composition

The external dimensions of the device under test (DUT) are reported including the maximum dimensions excluding auxiliary equipment and cables to support the device and the DUT must be completely surrounded by a reference box consisting of the reported width, length, and height values. The configuration is reported separately from the minimum components that allow the system to function without other devices and the components required to perform additional functions. The weight of the system is reported separately for the main body, essential parts, and other parts, and other parts may not be included.

3.2 Group 1: Characteristics as a sound pressure measuring instrument

This refers to the characteristics when the entire system output is assumed to be a sound pressure measurement device of one channel. Basically, it is the performance for the set reference axis. Unless otherwise specified, the characteristics for the measurement reference direction are measured, and the same measurement can be performed and reported for other directions.

3.2.1 Sensitivity, frequency response and correction

Sensitivity is the ratio of output voltage to sound pressure and it refers to sensitivity for specific sound field condition. Considering the usage conditions of acoustic cameras, the free-field sensitivity is the most common. The units used are V/Pa and mV/Pa, and the common logarithm is multiplied by 20 and expressed as level (unit: dB re. 1 V/Pa) as follow,

$$M_{DUT} = 20\log_{10}\left(\frac{V_{DUT}}{P}\right) \tag{1}$$

Here, V_{DUT} is the output voltage of DUT exposed to sound pressure P.

Frequency response is the distribution of sensitivity according to frequency normalized to the value of the reference frequency, and is generally defined as the frequency range in the frequency response curve where the deviation of sensitivity is maintained within the allowable deviation presented in the specification. In general, it can be decided by following the allowable deviation in IEC 61094-4 for working standard microphones [5]. However, although acoustic cameras can be used to measure sound pressure, their main purpose is to determine the location of the sound source. Therefore, it can be used even in ranges where the flatness of the frequency response is somewhat poor. From this reason, it is practical to present a range in which sound source tracking is possible for a certain sound pressure level.

Depending on the product, it is generally not possible to obtain the voltage output directly. In this case, since it is impossible to estimate sensitivity directly, a correction value for sound pressure is derived like a sound level meter. The correction value can be derived using the difference between the sound pressure measured with a calibrated reference microphone and the sound pressure output from the DUT, following the substitution method for free-field comparison method presented in IEC 62585 [4].

$$C = 20\log_{10}\left(P_{DUT}\right) - 20\log_{10}(P) \tag{2}$$

3.2.2 Noise floor and dynamic range

Floor noise refers to the noise component measured at the system output stage regardless of external input. In principle, it can be derived from the size of the signal observed in a space where external noise is completely blocked. Dynamic range refers to the range from the lower limit of measurement to the upper limit of measurement, and the upper limit of the dynamic range is determined as the range in which the distortion rate is maintained below a certain level.

In principle, in order to determine the background noise level, the sound pressure under the relevant conditions must be measured with a calibrated reference microphone. However, because a general acoustic camera has a lower level of noise floor than a single-channel reference microphone, there are limitations in directly measuring the sound pressure level corresponding to the noise floor. For this reason, the following two methods can be applied to derive the minimum measurable sound pressure level.

First method is the method using the measured sensitivity (or correction value) and measured output of DUT without specific noise source. At this time, the resultant output with the beamforming filter applied from the entire array is used, and if possible, the signal without steering applied is preferable. In the case of a general delay & sum beamformer, it is the sum of each channel signal in time domain. The sound pressure is converted to frequency by applying a sensitivity or correction value to the measured floor noise signal.

Second approach is the method using the characteristics of geometrical diversions in free-field condition. For the sound source used for measurement, an attenuation curve is derived in advance using the method of ISO 3745: Annex A [8]. First, apply the signal to the sound source at a level (more than 10 dB compared to background noise) that can be sufficiently measured with a reference microphone over the entire target distance. It is recommended that the measurement range be selected so that the sound pressure measured at the closest point and the sound pressure measured at the farthest point from the measurement range are at least 20 dB or more. The closest point is set further than the characteristic length (longest side) of the sound source, and a measurement interval of 100 mm or less is recommended. By using the measured data, the approximated curve for sound propagation can be estimated by

$$L_p\left(r\right) = 20\log_{10}\left(\frac{a}{r - r_0}\right), \tag{3}$$

$$q = 10^{-0.05 L_{pi}}, r_0 = -\left[\frac{\sum_{i=1}^{N} r_i \sum_{i=1}^{N} r_i q_i - \sum_{i=1}^{N} r_i^2 \sum_{i=1}^{N} q_i}{\sum_{i=1}^{N} r_i \sum_{i=1}^{N} q_i - N \sum_{i=1}^{N} r_i\, q_i} \right], a = \frac{\left(\sum_{i=1}^{N} r_i \right)^2 - N \sum_{i=1}^{N} r_i^2}{\sum_{i=1}^{N} r_i \sum_{i=1}^{N} q_i - N \sum_{i=1}^{N} r_i\, q_i}$$

where L_{pi} is the measured sound pressure at the i-th measurement point, r_i.

After obtaining an approximate curve, the sound pressure at the nearest measurement point is lowered to the minimum sound pressure level that can be measured with a reference microphone. Install a DUT instead of a reference microphone and check the maximum distance at which sound pressure is measured. At this time, the sound pressure can be derived based on the approximate curve at the corresponding distance.

3.3 Group 2: Microphone array characteristics

The parameters in this category refer to characteristics that describe improved performance and spatial filtering performance compared to single-channel microphones when an array is configured. Unless otherwise specified, the characteristics of the measurement reference direction or the centre of the screen are measured, and if necessary, the results of steering in the field of view range can be presented as a function of the steering angle.

3.3.1 Array gain

Array gain means the signal-to-noise ratio obtained compared to a single-channel microphone through the equipment under test. In the case of a general D&S beamformer, it is calculated by the following equation,

$$AG = 20 \log_{10} \left(\frac{P_{array}}{P_{mic}} \right) \tag{4}$$

In the case of beamformers that apply algorithms other than D&S, it cannot be evaluated based on the increase rate of the target signal because the output signal is not a simple sum of the input signals. In this case, the array gain must be estimated through the reduction rate of floor noise.

3.3.2 Directional characteristics

General performance indexes can be applied for characterising directional characteristics. As a representative example, spatial filtering performance can be evaluated through the directivity index, which is also related to spatial resolution. Additionally, the maximum sidelobe level and half-power beam width can be derived through the directivity pattern.

3.4 Group 3: Performance as a imaging device

The purpose of parameters in this group is to evaluate the accuracy of the characteristics displayed on the screen or image.

3.4.1 Minimum imaging sound pressure level

This is the minimum sound pressure level at which an image of the sound source can be obtained. If necessary, a standard distance such as 1 m can be set. The basic measurement method is to lower the input voltage of the sound source, find and set the minimum level at which the image is displayed, and measure the sound pressure at this point with a reference microphone. However, as aforementioned, the lower limit of the sound pressure level that can be measured by an acoustic camera is generally lower than that of a single-channel microphone, so a method similar to that applied in Section 3.2.2 can be applied.

3.4.2 Deviation of source localization

It refers to the difference between the location of the sound source displayed in the video and the location of the sound source derived by tracking the sound source and displayed on the screen. The value on the reference axis, centre of image, must be presented, and distribution according to the coordinates of the entire screen can also be presented.

To measure the spatial deviation on the image plane, prepare a spatial reference target that can divide the entire or part of the field of view on the plane into specific spacing. It can be manufactured using checkerboard or mesh made of thin steel wire. The minimum size of the reference target should be sufficiently large to be displayed on the reference target when it has the maximum position estimation error. The grid spacing should be fine enough to evaluate the target resolution.

3.4.3 Distribution of sound pressure measurement deviation

If there is a function to display the sound pressure level measured in the image, it is necessary to know the distribution of sound pressure measurement deviation in the entire measurement area. The distribution of sound pressure measurement deviation is determined by the difference between the sound pressure measured and presented by the DUT and the sound pressure measured using an omnidirectional microphone.

4 TEST EXAMPLES

As a demonstration example, a commercial sound camera for ultrasound range was evaluated by the aforementioned procedure. The measurement was conducted in the anechoic chamber, the lower cut-off frequency of 80 Hz. As a reference microphone, B&K Type 4954-A-011 was employed and B&K LAN-XI Type 3160 is employed as the function generator and data acquisition system. The distance between the source surface and the frontal surface of measurement devices is 1 m. Figure 1 shows the example of the measurement setup for evaluation.

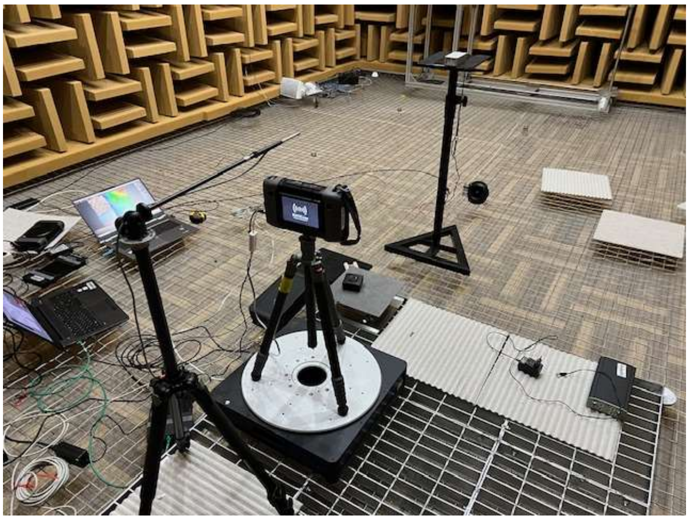

Fig. 1. Example of the measurement setup.

4.1 Example 1: Characteristics as a sound pressure measuring instrument

The correction value for measuring the sound pressure level was obtained by the substitutional comparison method and the result is shown in Fig. 2(a). The correction values less than 3 dB and it satisfying the specification of class 2 sound level meter. For the frequency range higher than 10 kHz, it is observed that the sound pressure level is rather overestimated. However, considering the purpose of detecting sound sources up to the 40 kHz band, it shows adequate performance. Figure 2(b) shows the measured noise floor by using the measured sensitivity (or correction value) and measured output of DUT without specific noise source. It is also observed that the sound source less than 0 dB can be detected for the frequency range up to 40 kHz band.

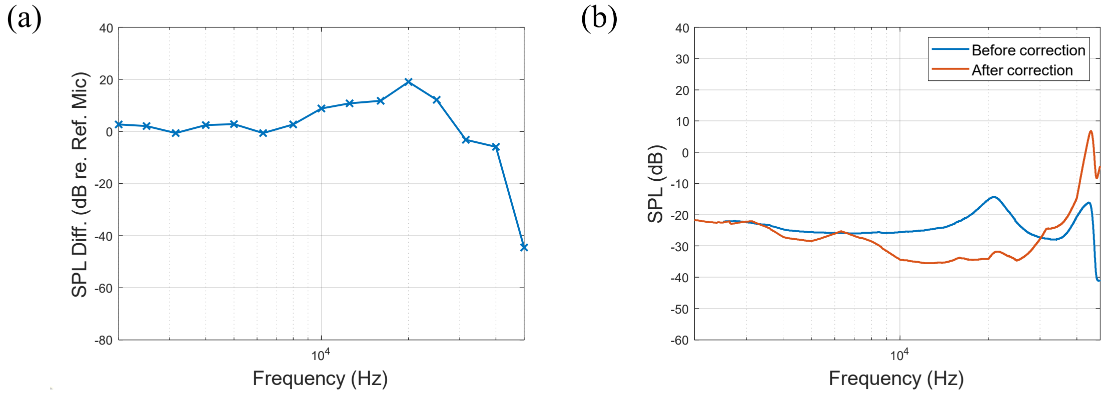

Fig. 2. Example of measurement: (a) Correction value for measuring the sound pressure level, (b) Noise floor.

4.2 Example 2: Performance as a imaging device

To evaluate the deviation of sound source localization, a reference target was installed on the sound source surface as shown in Fig. 3(a). The grid of target was 2.5 cm spacing. Figure 3(b) shows the image captured from the DUT.

Figure 4 shows the result of capturing sound source images displayed according to frequency. To quantitatively check the deviation of the displayed position of sound source, comparison between the positions displayed in each image and the position of grid in Fig. 3(b), as shown in Fig. 5. In Figure 5, it can be observed that the displayed position deviates from the position of the sound source by two grids for a 40 kHz sound source. This corresponds to 5 cm at a distance of 1 m, or less than 3 degrees in angle.

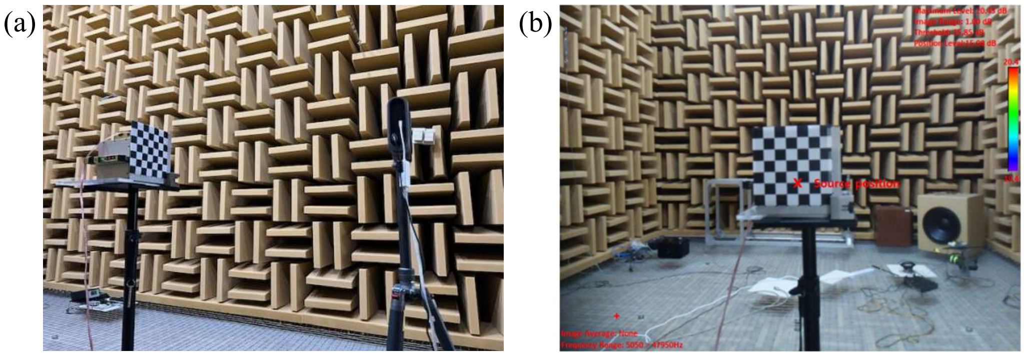

Fig. 3. (a) Measurement setup with the reference target, (b) captured image by DUT without sound.

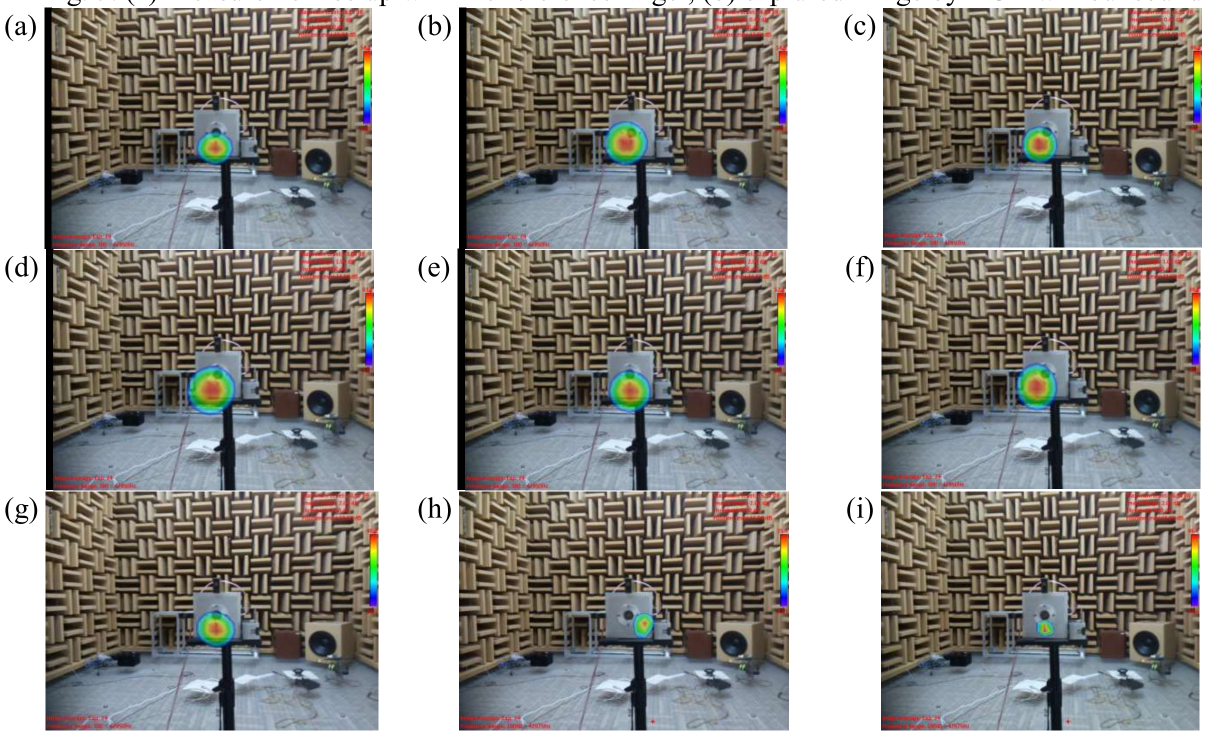

Fig. 4. Capture of the source localization images according to the frequency: (a) 5 kHz, (b) 8 kHz, (c) 10 kHz, (d) 12.5 kHz, (e)16 kHz, (f) 20 kHz, (g) 25 kHz, (h) 31.5 kHz, (i) 40 kHz.

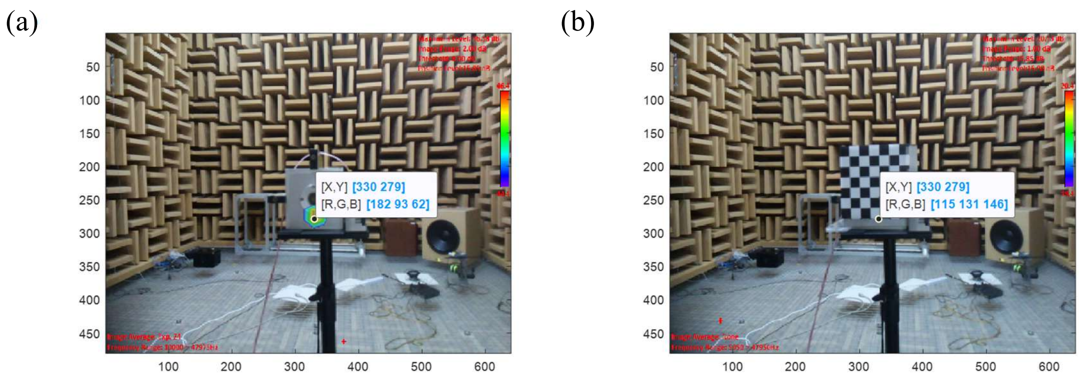

Fig. 5. Example of the process to estimate the deviation by comparing the images: (a) coordinate of the estimated source position, (b) coordinate on the reference target grid.

5 SUMMARY

The parameters for evaluating the performance of sound camera and its measurement procedure are investigated. Performance indexes of acoustic cameras are investigated and it can be broadly divided into performance as a sound pressure measurement device, as a microphone array, and as an imaging device. For these parameters, the method to measurement is proposed and the demonstration is conducted with a commercial sound camera for ultrasound range. In order to evaluate all the performance indexes, it is necessary to obtain raw data from each channel constituting the array. If this is not supported, the parameters that can be evaluated are limited.

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