STUDY ON EVALUATION METHOD OF THE TONAL NOISE COMPONENTS FOR SMALL FAN

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SUMMARY

The small fan noise which includes multiple pure tones becomes annoying components in the field of information technology devices. These pure tones are caused by the temporal variation of flow, the mechanical vibration, the electromagnetic force fluctuation of motor and so on. It has been confirmed that they contribute not only to the overall of A-weighted sound pressure level but also to auditory annoying components. In the past some metrics had been proposed for the pure tone, however the one which evaluates multiple pure tones for small fan has not been developed. In this study, we propose the evaluation method and the evaluation indexes of multiple pure tones for small fan and examine usefulness of them by using sensory test.

INTRODUCTION

In recent years, the information technology devices such as personal computers, projectors, and so on have become the necessities of modern life. The amount of heat generated due to high integration of electronic components is increasing along with the high performance or miniaturization of these devices. As a result, the small fans are required so as to exhaust the big amount of heat because they are very efficient and low-cost. Although the exhaust heat is easy by using them, the fan noise will be problem. Especially, although the overall of A-weighted sound pressure level itself is low, the tonal component of the noise is unpleasant.

In the standards, such as the ISO 7779[6], ECMA-74[8] and ANSI S1.13[9], the judgment methods of the certain prominent discrete tone in information technology devices are presented as Tone-to-Noise Ratio (TNR) and Prominence Ratio (PR). On the other hand, the psychoacoustic approach to detect the tonal feeling has been developed and the metrics such as Tonality[2] has been used for the evaluation of the tonal feeling. In this study, the sound quality evaluation for small fan is done by using the metrics based on TNR and PR.

NOISE CHARACTERISTICS OF SMALL FAN

Fan noise generation mechanism

The noise generated from fan includes the aerodynamic noise that temporal fluctuation of flow is sound source, the mechanical noise that mechanical vibration is sound source, the electromagnetic noise that electromagnetic force fluctuation of motor is sound source and the like. The aerodynamic noise is dominant in the operating state of a normal fan, and it can be classified into the rotational noise and the turbulent flow noise from its sound source characteristics.

The rotational noise is caused by periodic pressure fluctuations accompanying the passage of the impeller and the axial flow fan has the discrete components at the blade passing frequency which is the product of the number of rotor blades Z_r and rotational speed n and its harmonics. It becomes very annoying sound because it has high contribution to the overall of A-weighted sound pressure level. This noise is caused by two types of unsteady flow[1]. One is called the potential interference noise caused by the pressure distribution around the impeller and the other is called wake interference noise induced by the separated flow from the trailing edge of the impeller. In case of the small axial fan, the unsteady flow interfere the obstacles and large noise is generated, when the obstacles such as stators and spokes are located just behind the impeller.

On the other hand, the turbulent noise is caused by the random turbulent flow generated by the fan. The noise source consists of the pressure fluctuations induced by the turbulent boundary layer on the surface of the impeller, the fluctuation of lift caused by the vortex shedding from the trailing edge of the impeller and so on. It has broadband frequency components, though the energy is smaller than the rotational noise energy and the contribution to the overall of A-weighted sound pressure level is secondary. In fan noise, the noise with high tonal components is more annoying even if the overall of A-weighted sound pressure level is the same.

Tonal components of centrifugal fan

The rotational noise from centrifugal fans is caused by the interference between the periodic flow from the impeller blade and the tongue of the fan casing[1]. The frequency of tonal components f_r are shown as the following formula,

$$f_r = i \cdot Z_r \cdot n \ \text{[Hz]} \quad (1)$$

where,

i : number of frequency components
Z_r : number of rotor blades
n : rotational speed [rps]

Tonal components of axial fan

The rotational noise from axial fans is caused by the interference between the periodic flow from the impeller and the stator or the spoke which supports the motor. In general, the number of the blades and the spokes should be the prime number so as not to occur the interference of the blades and the spokes at the same time, so the frequency components are more complicated matter than that of centrifugal fan. The frequency of tonal components are shown as the following formula,

$$f_r = \frac{j \cdot Z_r \cdot n}{j \cdot Z_r + k \cdot Z_s} \ \text{[Hz]} \quad (2)$$

where,

j,k : integer index (…-2, -1, 0, 1, 2…)

Z_r, Z_s : Number of rotor blades and spokes

n : rotational speed [rps]

On both cases, the shape of the wake is not exact sinusoidal, so the harmonics components are appeared at the same time in FFT spectrum. In addition, these components are influenced by the frequency response function of the fan system. The typical noise spectrum of the small axial fan is shown in Figure 1.

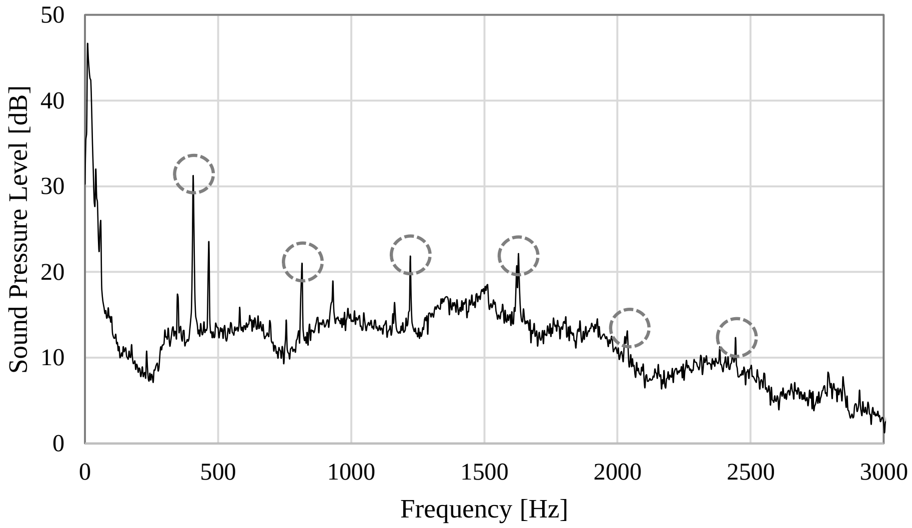

Figure 1: Typical noise spectrum of small axial fan

EVALUATION METHODS OF TONAL COMPONENTS

Tonality

Tonality, T is widely known as the metrics that indicate the tonal feeling of the sound. This metrics is provided by Terhardt or Aures[2]. It is calculated as the product of the various weighted functions to the tonal components such as the influence of masking by other tones, the ratio of tonal components and noise, the influence of hearing threshold and is applicable to the evaluation of subjective tonality for the object sound.

$$T = c \cdot w_T^{0.29} \cdot w_{Gr}^{0.79} \text{ [tu]} \quad (3)$$

where,

c : constant that makes tonality 1 with 1 kHz/60 dB of pure tone.

w_T : weighting function for tonal components

w_{Gr} : weighting function for tone and noise

Tone-to-Noise Ratio (TNR) and Prominence Ratio (PR)

DIN 45681 "*Acoustics - Determination of tonal components of noise and determination of a tone adjustment for the assessment of noise immissions*"[10] defines how to determine the tonal component to the noise. However the method of this standard shows only about the excess of level and does not include the psychoacoustic consideration.

In general, the audible threshold or the prominence of a tonal component is decided by the relationships between the tonal component level and the surrounding band noise level which is masking the tonal component. The frequency bandwidth is so called the critical band that is centered at the frequency of the tone. In the standards such as the ISO 7779[6], ECMA-74[8] and ANSI S1.13[9], the judgment methods of the certain prominent discrete tone in information technology devices are presented as the Tone-to-Noise Ratio (TNR) and the Prominence Ratio (PR).

TNR is defined as the decibel value of the ratio of the power of tonal component and other noise component in the critical band. In the ECMA-74, when TNR exceeds by 8 dB at 1 kHz or higher, the tonal component is regarded as the prominent discrete tone. In case that multiple peaks exist in the same critical band or the noise levels adjacent to the critical band is considerable, TNR vales tends to show bigger or smaller.

PR is defined as the decibel value of the ratio of the critical band power including the tonal component and the average of the adjacent critical band power on both sides. In the ECMA-74, when PR exceeds by 9 dB at 1 kHz or higher, the tonal component is regarded as the prominent discrete tone. Figure 2 is the schematic view of calculating TNR and PR.

$$\Delta L_T = 10 \log_{10}\left(\frac{W_t}{W_n}\right) \ \text{[dB]} \tag{4}$$

$$\Delta L_P = 10 \log_{10}\left[\frac{W_M}{(W_L + W_U)/2}\right] \ \text{[dB]} \tag{5}$$

where,

ΔL_T : Tone-to-noise ratio [dB] (according to ECMA-74)
W_t : Power of tone [Pa^2]
W_n : Power of other components in critical band [Pa^2]
ΔL_P : Prominence ratio [dB] (according to ECMA-74)
W_M : Power of middle critical band [Pa^2]
W_L : Power of lower critical band [Pa^2]
W_U : Power of upper critical band [Pa^2]

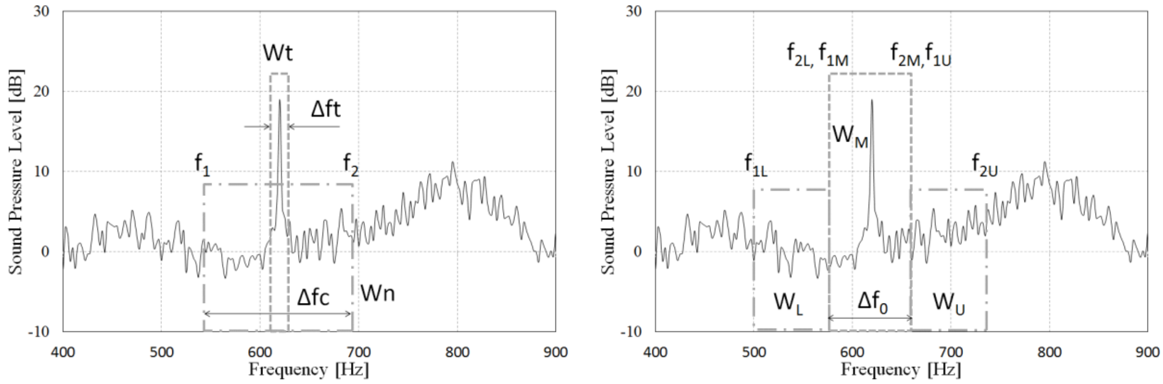

Figure 2: Schematic view of TNR and PR calculation
(Left: TNR, Right: PR)

Total TNR (T-TNR) and Total PR (T-PR)

In fan noise evaluation, it is important to quantify the tonal components for the product quality control, the identification of noise source and the noise reduction. In Tonality, the method of calculation is a little bit complicated and it is difficult to identify which tonal components have high contribution. On the other hand, TNR and PR are the indicators for the prominent discrete tone of one tonal component and don't consider relationship between the multiple tonal components.

In this study, the new evaluation parameters called T-TNR and T-PR are presented. The individual levels (TNRs or PRs) are calculated for a plurality of tonal components in noise by calculation methods of TNR or PR, and the sum thereof is defined as an evaluation index T-TNR or T-PR.

$$\langle L_T \rangle = 10\log_{10}\left(\sum_{i=1}^{n} 10^{\frac{\Delta L_{Ti}}{10}}\right) \text{ [dB]} \quad (6)$$

$$\langle L_P \rangle = 10\log_{10}\left(\sum_{i=1}^{n} 10^{\frac{\Delta L_{Pi}}{10}}\right) \text{ [dB]} \quad (7)$$

where,

$\langle L_T \rangle$: Total tone-to-noise ratio [dB]

ΔL_{Ti} : Tone-to-noise ratio for i-th peak component [dB]

$\langle L_P \rangle$: Total prominence ratio [dB]

ΔL_{Pi} : Prominence ratio for i-th peak component [dB]

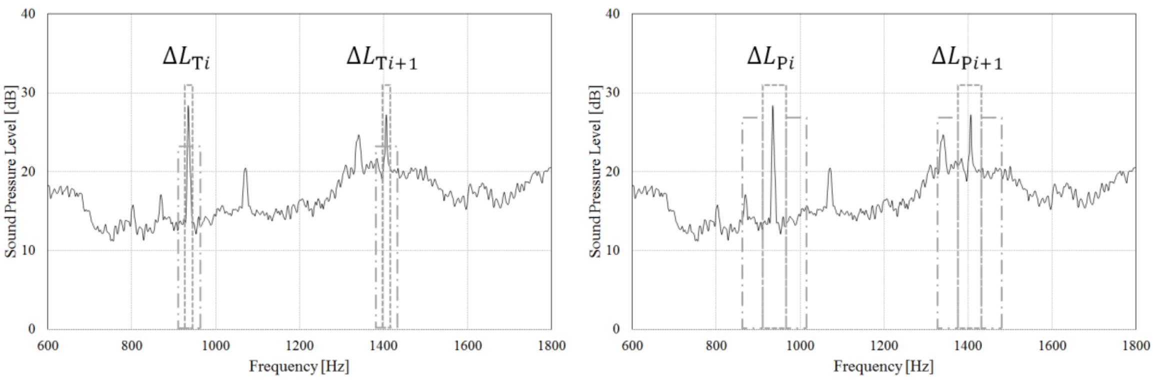

Figure 3: Schematic view of T-TNR and T-PR calculation
(Left: T-TNR, Right: T-PR)

About the threshold level for prominent discrete tone

TNR and PR can be easily calculated from the result of frequency analysis, but these values are invalid below the lower threshold of hearing (LTH)[7]. Therefore, it is necessary to exclude them from the calculation when their values are less than LTH. Details about this are shown in ECMA-74.

On the other hand, it is considered that it is also effective to find the threshold level for prominent discrete tone in T-TNR and T-PR just as the threshold levels of prominent discrete tone in TNR and PR have been found. In this study, we also examine these.

EFFECTIVENESS OF T-TNR AND T-PR FOR FAN NOISE

Study on T-TNR and T-PR

In the study by Yamaguchi et al. (2014)[3], the effectiveness of T-TNR and T-PR for the subjective annoyance was verified by using real noise samples of axial fans and centrifugal fans generally widely used for cooling IT devises. The test sounds were adjusted to suit the test conditions based on the real noise samples. In addition, sensory test was carried out based on the Scheffe's paired comparison method (Ura's version)[4].

In their study, it was concluded that T-TNR and T-PR were highly correlated with the subjective annoyance and it was effective to use these parameters to evaluate fan noise having high tonal components. Furthermore, it also said that even though the OASPL (overall sound pressure level) or Loudness which was the measure of the subjective loudness stayed constant, these parameters could be the annoyance index.

However, it was not possible to obtain the threshold levels of harsh feeling since the sensory test was the evaluation by paired comparison method.

SENSORY TEST

About test sound

As already stated, the aerodynamic noise is dominant in the operating state of a normal fan and it can be classified into the rotational noise (tonal component) and the turbulent flow noise (broadband components) from its sound source characteristics.

In this study, we use the synthesized sound (pseudo fan noise) with white noise as broadband components and sine wave as tonal components for sensory test because the convenience of creating a test sound is high.

Paired comparison method

The paired comparison method is the methodology for estimating the intensity of each stimulus by presenting two different stimuli in pairs, being made to judge the magnitude relation of paired stimulus, and being performed this procedure for all combinations. The Scheffe's paired comparison method (Ura's version) used in this experiment is the method that single jury compares all pairs that are considered the sequence only once, and has the advantage that scores can be calculated by a small number of juries[5].

The synthesized sounds of white noise and sine wave which are changed the balance are used in this study. White noise is simulating broadband components and sine wave is simulating tonal component, because the aerodynamic noise emitted by a fan is classified as broadband and tonal components.

Table 1 shows the summary of test sound adjustment methods by each jury.

Table 1: Noise source patterns

	Methods for coordination
Pattern 1	Adjust the proportion of tonal components and noise components and adjust that the loudness of all test sounds becomes equal.
Pattern 2	Adjust each tonal components and adjust that the loudness of all test tones becomes equal.
Pattern 3	Adjust the proportion of tonal components and noise components so that loudness decreases with increasing tone property.

In the test sound pattern 1, peak components equal in size are set at equal intervals at 600, 1200, 1800, 2400 and 3000 Hz, and all the peak components are changed by 1 time to 5 times for each test sound . Test sounds whose peak component is 1 time are defined as "test sound 1", test sounds 2 to 5 are prepared. The loudness of all the test sound is substantially equal.

In the test sound pattern 2, peak components are set at 4 positions of 720, 1440, 2880 and 5760 Hz so that they are separated by 2 or more on the Bark scale, and the sound that is set equal of all peak components is defined as "test sound 1". Next, the first peak component is changed from 2 times to 5 times, and the remaining peak components are adjusted so that the loudness of all the test sounds are equal, and test sound 2 to 5 are prepared.

In the test sound pattern 3, the peak component is changed similarly to the test sound pattern 1, and the whole sound volume is adjusted so as to lower the loudness as the peak component became high, and a test sound is created.

To obtain sensory relative distance between test sounds for each test sound pattern, the sensory test by the Scheffe's paired comparison method (Ura's version) is carried out. In our test, the adjective-pairs "Annoying – Not annoying" is used as evaluation axis. Two randomly selected sounds from each test sound pattern are listened in order, the second sound (comparison sound) to the first sound (reference sound) is evaluated in five stages. Also all combinations are presented in order to investigate the effect of sounds presentation order. The correlation analysis is performed the subjective rank order (mean value of subjects) by the paired comparison method and sound quality evaluation index.

The juries are 20 college students who have the normal hearing and are selected at random.

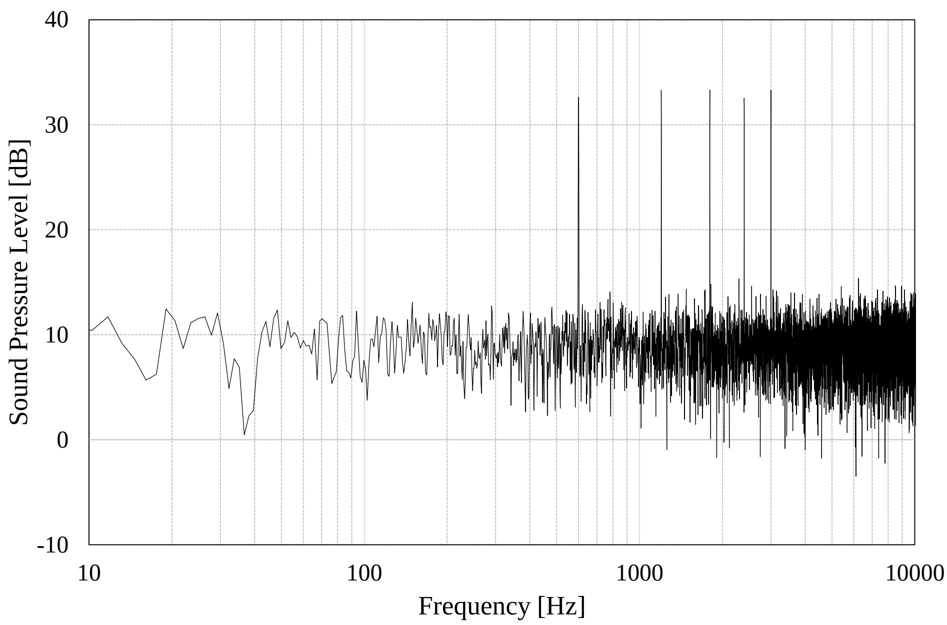

Figure 4: Test sound 1 of pattern 1

Method of adjustment

The method of adjustment is a process in which a jury (i.e., an experimenter) freely changes a stimulus to obtain PSE (point of subjective equality) and the like. In this sensory test, we selected the method that juries adjust the stimulus[5].

The sensory test with the method of adjustment is carried out to find the threshold levels for the tonal component of single frequency, that is, the threshold levels of TNR and PR or the threshold levels of T-TNR and T-PR. As with paired comparison method, white noise is simulating broadband components and sine wave is simulating tonal component. The sound that is synthesized the tonal components (720, 1440, 2880, 5760 Hz) used in the test sound pattern 2 of the pair comparison method and the white noise is used as the test sound.

The each jury adjusts the white noise level or tonal component levels with control knob displayed on the personal computer screen and decides his or her threshold level about subjective annoyance. Although the defined time limit for judging one sound is not set, each jury is given instructions so as not to spend too much time for one sound before the test. In addition, in order to eliminate series errors, the initial gain of the presentation sound is adjusted so as to be ascending series and descending series.

First, only white noise is played as test sound and the allowable annoying range is estimated by adjusting volume. The adjustment value of white noise level obtained here is applied to all synthetic sounds. That is the average value of ascending series and descent series.

Next, the sound of only single frequency is played as test sound and the allowable annoying range of each frequency is estimated by adjusting volume. The average value of ascending series and descent series of each frequency is applied to the initial value of the synthetic sound.

The synthetic sound based on these results is created and played as test sound, the threshold levels of annoying is detected by freely adjusting volume. In case of the synthetic sound, adjustment of volume is done only for the target one frequency or four frequencies. When the four tone frequencies are adjusted at the same time, their adjustment gains are unified all.

The juries are 10 college students who have the normal hearing and are selected at random.

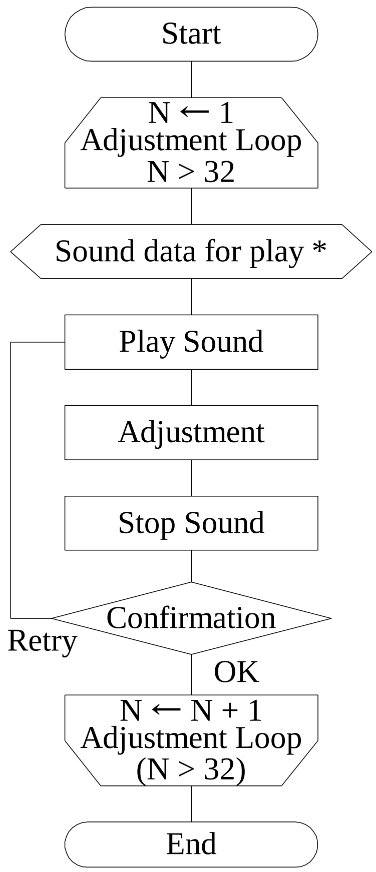

Figure 5: Jury test for method of adjustment

Table 2: Noise source patterns

N	Noise source	Series	N	Noise source	Series
1	White Noise	Ascending	17	White Noise + Sine Wave 2880Hz	Ascending
2	White Noise	Descending	18	White Noise + Sine Wave 2880Hz	Descending
3	Sine Wave 720Hz	Ascending	19	White Noise + Sine Wave 57600Hz	Ascending
4	Sine Wave 720Hz	Descending	20	White Noise + Sine Wave 57600Hz	Descending
5	Sine Wave 1440Hz	Ascending	21	White Noise + Sine Waves (720/1440/2880/5760Hz)	Ascending
6	Sine Wave 1440Hz	Descending	22	White Noise + Sine Waves (720/1440/2880/5760Hz)	Descending
7	Sine Wave 2880Hz	Ascending	23	White Noise + Sine Wave 720Hz	Descending
8	Sine Wave 2880Hz	Descending	24	White Noise + Sine Wave 720Hz	Ascending
9	Sine Wave 5760Hz	Ascending	25	White Noise + Sine Wave 1440Hz	Descending
10	Sine Wave 5760Hz	Descending	26	White Noise + Sine Wave 1440Hz	Ascending
11	White Noise + Sine Waves (720/1440/2880/5760Hz)	Ascending	27	White Noise + Sine Wave 2880Hz	Descending
12	White Noise + Sine Waves (720/1440/2880/5760Hz)	Descending	28	White Noise + Sine Wave 2880Hz	Ascending
13	White Noise + Sine Wave 720Hz	Ascending	29	White Noise + Sine Wave 57600Hz	Descending
14	White Noise + Sine Wave 720Hz	Descending	30	White Noise + Sine Wave 57600Hz	Ascending
15	White Noise + Sine Wave 1440Hz	Ascending	31	White Noise + Sine Waves (720/1440/2880/5760Hz)	Descending
16	White Noise + Sine Wave 1440Hz	Descending	32	White Noise + Sine Waves (720/1440/2880/5760Hz)	Ascending

RESULTS AND DISCUSSIONS

Paired comparison method

The results for each noise source patterns are shown below. It is found that the subjective annoyance and T-TNR or T-PR have very high correlation (Figure 6). From this, it is considered these evaluation indexes (T-TNR and T-PR) are effectively when fan noise having tonal components is evaluated.

It is found that there is high correlation also in the subjective annoyance and Tonality except for the noise source pattern 2 (Figure 7). In the noise source pattern 2, it is considered that Tonality is calculated almost constant value (slightly decreasing trend at increasing of the subjective annoyance) since the influence of frequency masking is small and the loudness is set almost constant. Therefore, it is considered that it became a negative correlation with the subjective annoyance.

Also, T-TNR and T-PR have the sufficient standard deviations comparison with the subjective annoyance (Table 4) and they are effective as the sound quality evaluation index. On the other hand, it is considered that it is difficult to evaluate the subjective annoyance by using Tonality because the standard deviation is not sufficient comparison with the subjective annoyance.

In the noise source pattern 3, it is found that the correlations of the subjective annoyance and T-TNR or T-PR are very high. However, it is necessary to consider how much change range is effective since the change range of loudness is very small.

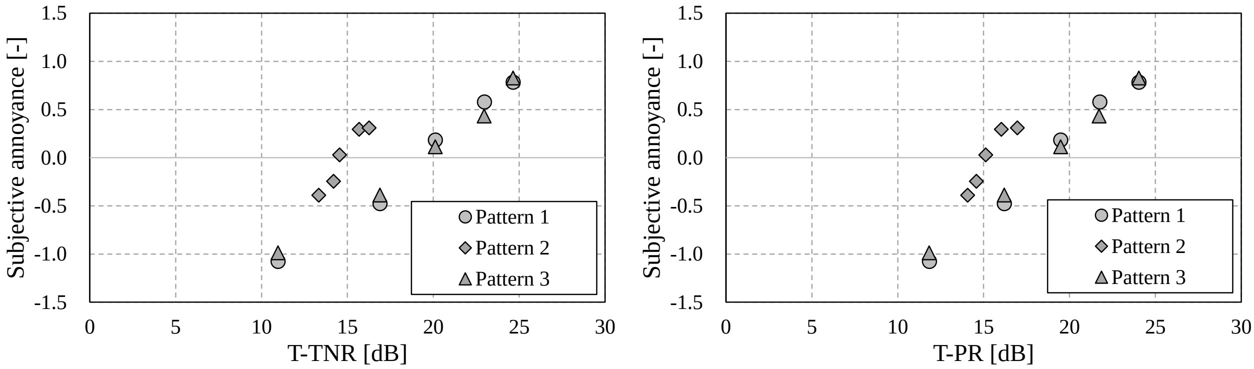

Figure 6: Relationships between T-TNR or T-PR and subjective annoyance

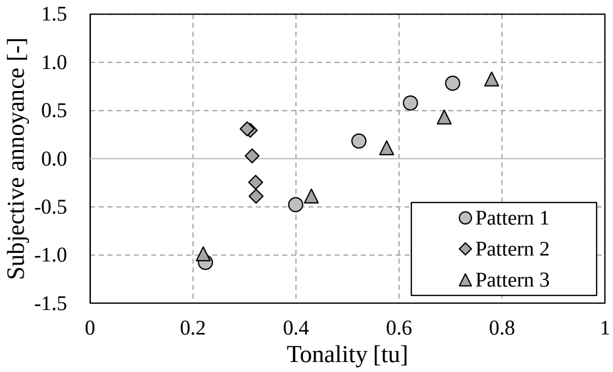

Figure 7: Relationships between tonality and subjective annoyance

Table 3: Results of noise source Pattern 1

Sound No.	T-TNR [dB]	T-PR [dB]	Tonality [tu]	Subjective annoyance [-]
1	11.0	11.8	0.224	-1.08
2	16.9	16.2	0.399	-0.48
3	20.1	19.5	0.522	0.19
4	23.0	21.8	0.622	0.58
5	24.6	24.0	0.704	0.79
Standard Deviation	5.431	4.792	0.189	0.769
Correlation Coefficient	0.993	0.995	0.995	

Table 4: Results of noise source Pattern 2

Sound No.	T-TNR [dB]	T-PR [dB]	Tonality [tu]	Subjective annoyance [-]
1	13.3	14.1	0.322	-0.39
2	14.2	14.6	0.321	-0.25
3	14.5	15.1	0.315	0.03
4	15.7	16.0	0.311	0.30
5	16.3	17.0	0.305	0.31
Standard Deviation	1.174	1.154	0.007	0.315
Correlation Coefficient	0.966	0.949	-0.952	

Table 5: Results of noise source Pattern 3

Sound No.	T-TNR [dB]	T-PR [dB]	Tonality [tu]	Subjective annoyance [-]
1	11.0	11.8	0.220	-0.99
2	16.9	16.2	0.430	-0.39
3	20.1	19.5	0.576	0.11
4	23.0	21.7	0.688	0.43
5	24.6	24.0	0.780	0.83
Standard Deviation	5.429	4.790	0.221	0.708
Correlation Coefficient	0.992	0.999	0.998	

Method of adjustment

The threshold of annoyance at each frequency is determined by means of method of adjustment. In addition, the threshold levels for T-TNR and T-PR are obtained from the synthesized sounds white noise is simulating broadband components and sine wave is simulating tonal component.

The threshold of annoyance at each frequency is determined by using the composite sounds of white noise and single frequency tone as shown in Table 2. The threshold of annoyance at each frequency and the reference curve of "Prominent Discrete Tone" (ECMA-74) are compared in Figure 8 and the threshold levels of annoyance at each frequency is shown in Table 6.

It is found from Figure 8 that the threshold levels are higher (the response is dull) than the criterion for the discrete tones less than 2 kHz and are lower (the response is high) than the criterion for the discrete tones higher than 2 kHz.

It is found from Table 6 that as the frequency of tonal component increases, the standard deviation of threshold decreases. It is thought that this is affected the critical bandwidth differs from frequency to frequency and the white noise where the broadband components are uniformly distributed. On the other hand, it can also be considered that the permissible range of each individual is large at low frequencies and it is small at high frequencies.

The threshold levels for T-TNR and T-PR ($\langle L_{\mathrm{T}} \rangle_0$ and $\langle L_{\mathrm{P}} \rangle_0$) are shown on Table 7. It is defined that the thresholds of annoyance in T-TNR or T-PR can be calculated by the sum of TNR or PR. The threshold of annoyance in T-TNR or T-PR did not coincide with the sum of TNR and PR of each frequency. It is considered that the total value of TNR or PR of each frequency did not match the thresholds of T-TNR or T-PR since the adjustment values of four frequencies of synthesized sound for obtaining T-TNR or T-PR are unified. The standard deviations of $\langle L_{\mathrm{T}} \rangle_0$ and $\langle L_{\mathrm{P}} \rangle_0$ are almost the same.

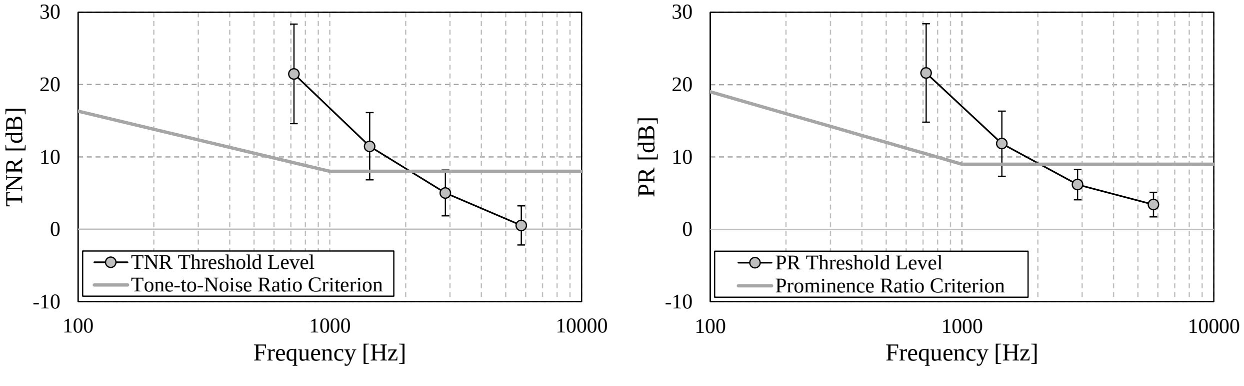

Figure 8: Average threshold levels of annoyance in TNR and PR

Table 6: Threshold levels at each frequency

Frequency [Hz]	TNR [dB]	Standard Deviation [dB]	Frequency [Hz]	PR [dB]	Standard Deviation [dB]
720	21.5	6.9	720	21.6	6.8
1440	11.5	4.7	1440	11.8	4.5
2880	5.0	3.2	2880	6.2	2.1
5760	0.5	2.7	5760	3.4	1.7

Table 7: Threshold levels for T-TNR and T-PR

	Threshold Level [dB]	Standard Deviation [dB]
$\langle L_{\mathrm{T}} \rangle_0$	17.8	6.3
$\langle L_{\mathrm{P}} \rangle_0$	18.2	6.0

CONCLUSION

It has be confirmed that T-TNR and T-PR proposed in this study are effective as evaluation index of noise with multiple tonal components from the results of both previous study (the real noise samples) and this study (the synthetic sound samples). In addition, these are considered to be useful also in that they are obtained by relatively simple calculations based on the calculation method of existing standard (ECMA-74).

The annoyance threshold levels of TNR and PR for single tonal component and the annoyance threshold levels of T-TNR and T-PR for multiple tonal components are able to determine by method of adjustment. However, there is a high possibility that these values can not be directly applied as threshold values since the test sounds are the synthetic sound. Therefore, we would like to examine the method etc. of giving the gain adjustment value of each frequency and conduct additional test. Eventually, we would like to verify the effectiveness of these thresholds for the noise generated from the actual small fan and apply to product evaluation of small fan.

Furthermore, it is thought T-TNR and T-PR will be effective for not only small fan noise but also other noise which consists of tonal components and broadband components, we want to also apply them to evaluation of various products in the future.

REFERENCES

[1] Shoji Suzuki, Masaharu Nishimura, Shinya Kijimoto and Gaku Minorikawa, *Mechanical Acoustical Engineering*, Corona publishing, **1993**

[2] Ernst Terhardt, Gerhard Stoll and Manfred Seewann, *Algorithm for extraction of pitch salience from complex tonal signals*, J. Acoust. Soc. Am **1982**

[3] Takao Yamaguchi, Gaku Minorikawa, Masayuki Kihara, *Study on evaluation method of the pure tone for small fan*, Proceedings of Internoise2014 (**2014**)

[4] Union of Japanese Scientists and Engineers, Research Committee of Sensory Evaluation, *Sensory Evaluation Handbook*, JUSE Press, **1973**

[5] Seiichiro Namba and Sonoko Kuwano, *Psychological measuring method for sound evaluation,* Corona publishing, **1998**

[6] ISO 7779 3rd edition, *Acoustics – Measurement of airborne noise emitted by information technology and telecommunications equipment*, International Organization for Standardization, **2010**

[7] ISO 28961 1st edition, *Acoustics – Statistical distribution of hearing thresholds of otologically normal persons in the age range from 18 years to 25 years under free-field listening conditions*, International Organization for Standardization, **2012**

[8] ECMA-74 12th edition, *Measurement of Airborne Noise emitted by Information Technology and Telecommunications Equipment*, Ecma International, **2012**

[9] ANSI S1.13 5th Edition, *American National Standard Measurement of Sound Pressure Levels in Air*, American National Standards Institute, **2005**

[10] DIN 45681, *Acoustics - Determination of tonal components of noise and determination of a tone adjustment for the assessment of noise immissions*, DIN (Deutsches Institut für Normung), **2005**