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Classification of Noise Sources in a Printer and Its Application to the Development of Sound Quality Evaluation

Young-Joon Lee[1] and Sang-Kwon Lee[1,#]

1 Department of Mechanical Engineering, Inha University, 253, Younghyun-dong, Nam-gu, Incheon, South Korea, 402-751
Corresponding Author / E-mail: sangkwon@inha.ac.kr, TEL: +82-32-860-7305, FAX: +82-32-868-1716

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A printer noise is an annoying noise source in the office. Previous work for noise reduction in printers has shown that, because of the effects of many different types of noise sources, it is difficult to evaluate printer noise objectively by using only the A-weighted sound pressure level. In this paper, the characteristics of such sound were first investigated in a systematic approach, and a new objective evaluation method is proposed for printer noise. This method is called the total sound quality index, and was developed by the systematic combination of nine major sound indexes based on path analysis. These nine major sounds that radiate from a printer were selected through a basic investigation and evaluated by the members of a focus group, including a customer and a printer engineer. The nine major sound quality indexes were developed by using sound metrics, which are psychoacoustic parameters, and by the multiple regression method, which is used for the modeling of the correlation between objective and subjective evaluation. The newly developed total printer sound quality index can be applied to the objective evaluation of the six sample printers based on the customer preferences.

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NOMENCLATURE

S(f) = Short time Fourier transform
h(t) = Time window function
CWTm,n = Continuous wavelet transform
Y_i = Sound index
β_i = weight coefficient of sound index
$Freq_{m,n}$= Frequency component at *m*-time, *n*-frequency

1. Introduction

Printer noise consists of the sounds of various components such as motors, fans and solenoid actuators. All of the components operate at the same time when the printer starts to work. Because of these concomitant sounds, a printer operator can hear several of the operation sounds radiating from printer components. Since most printers are used in quiet offices or homes, the sound quality of a printer becomes important to obtain competitive power in the printer market. The sound quality is not precisely evaluated by using only the traditional method based on A-weighted sound pressure level,[1] since sounds can have almost infinite variation in spectral and temporal characteristics and many of these differences can be separately perceived, such as the degree of tonality and impulsivity. Therefore, recently, sound quality indexes have been developed for the precise evaluation of sound quality based on psychoacoustic parameters.[2,3] These indexes have been independently developed for the evaluation of the quality of a single sound, such as an impulsive sound and a tonal sound. In this paper, the characteristics of the sound quality for tonal components and impulsive components are investigated and the total sound quality index for a printer is developed based on the classification and systematic combination of tonal sounds and impulsive sounds. Six printer models were used for this research. The major sounds in these printers were selected through a basic investigation evaluated by professional printer engineers at the Samsung Electronics Company in Korea, and the nine major sounds that contribute to the character of total printer sound were classified. At first, the sound quality indexes for nine major sounds were developed by multiple regression for modeling of the correlation between subjective evaluation and sound metrics, which are the parameters designating

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the psychoacoustic characteristics of sound. The total sound quality index of the printer was finally developed by combining the sound indexes for these nine sounds according to the results of a contribution ratio that was obtained by path analysis of these sounds. This total sound quality index for a printer is useful for the objective evaluation of printer noise based on customer preference.

2. Sound recording and subjective evaluation for printer sounds

2.1 Recording of printer sound

The test printers used for the research were the middle class produced by worldwide printer companies. For the recording of printer sound, the test printer was installed in a full anechoic chamber of which the cut-off frequency was 100Hz. The sound was measured by using a binaural head made by the Head Acoustic Company, as shown in Fig. 1(a). The binaural head was located at 1m from the test printer and at a 1.2 m height from the floor. The microphone used for this research was 1/2 inch in size and was built into the binaural head. Binaural signals are used for the subjective evaluation. Sound metrics of both ear signals are averaged. The measured analogue data were converted to digital data with a sampling frequency of 44.1 kHz. The digital data were replayed by using a playback system made by Head Acoustic Company. For the recording of the tonal sounds synchronized to the rotational components, the frequency components of the tonal sounds should be classified. In order to obtain the frequency information for the rotating speed of the rotational components, a tachometer, an accelerometer and a microphone are installed around the rotating components, as shown in Fig. 1(b), (c) and (d), which generate the sources of tonal sounds. Fig. 2 shows the time history for the sounds radiated from the six sample printer models and the time duration for the impulsive sound for the six sample printer models was determined.

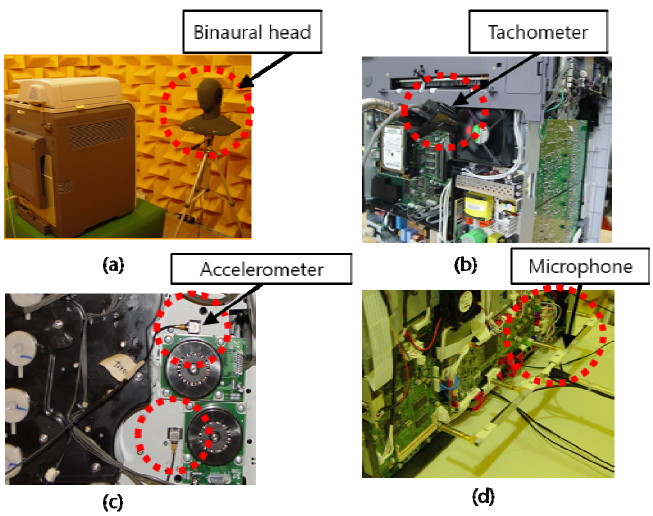


Fig. 1 Experimental set up for printer sound quality test (a) HMS III Artificial Heal for sound measurement (b) tachometer for SMPS fan speed (c) accelerometer for the dev motor (above) and fuser motor (below) speed (d) microphone for a main motor speed

2.2 Classification of major sounds in a printer

Printer sound is classified by using a short time Fourier transform (STFT) of the print sound signal $s(t)$:

$$S_t(f) = \int_{-\infty}^{\infty} h^*(\tau - t) s(\tau) e^{-j2\pi f \tau} d\tau \qquad (1)$$

where $h(t)$ is a window function.

The squared magnitude of the STFT yields a spectrogram as an estimate of the time-varying spectral energy density of the signal:

$$S(t, f) = |S_t(f)|^2 = \left| \int_{-\infty}^{\infty} h^*(\tau - t) s(\tau) e^{-j2\pi f \tau} d\tau \right|^2 \qquad (2)$$

or, if we express the spectrogram in terms of the Fourier transforms of the window $H(f)$ and the signal $S(f)$:

$$S(t, f) = \left| \int_{-\infty}^{\infty} H^*(\lambda - f) S(\lambda) e^{-j2\pi\lambda t} d\lambda \right|^2 \qquad (3)$$

This spectrogram $S(t, f)$ is a joint distribution in the time-frequency domain. Thus the time resolution is indicated by the duration of $h(t)$, whilst frequency resolution is determined by the bandwidth of $H(f)$.

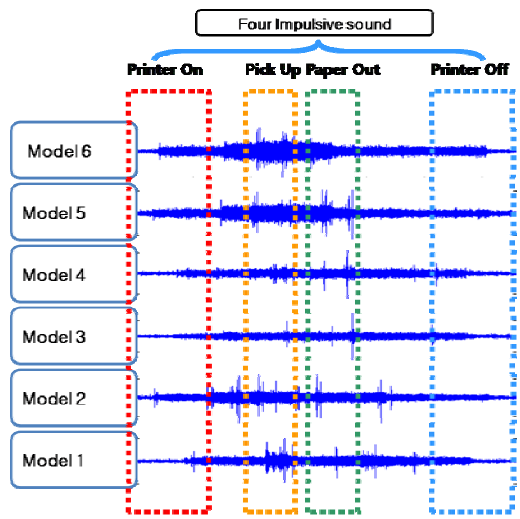


Fig. 2 Four major impulsive sounds are selected for sound quality analysis of six different printer models

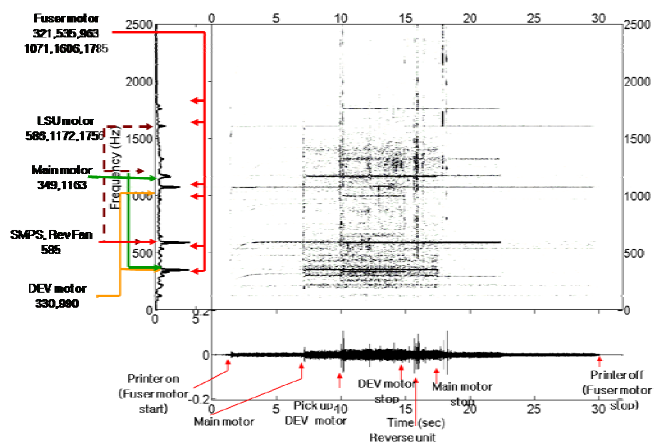


Fig. 3 Time frequency analysis for the sound of the printer model 5 based on short time frequency method

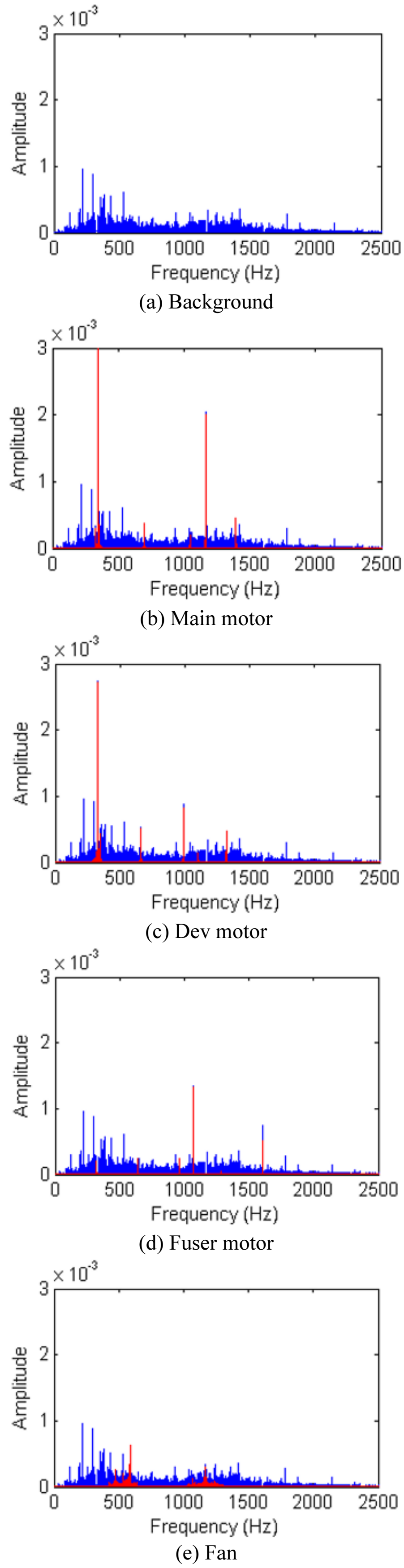
Because the duration of the function $h(t)$ and the bandwidth of its Fourier transform $H(f)$ are inversely related, the spectrogram is incapable of yielding high resolution jointly in the time-frequency plane - a trade off must be endured between the two. This is the major drawback of the spectrogram and of other so-called “short-time” spectral analysis methods. In this study, the duration of a function $h(t)$ is done over a long period of time to increase the frequency resolution for the analysis of tonal sounds. Fig. 3 shows the results of the time-frequency analysis for a sound signal measured at 1m distance from the printer model 5. STFT is used for the time-frequency analysis. There are many tonal components generated by the rotating components such as main motor, fuser motor, dev motor and LSU motor and fan. The frequencies of these tonal components were the fundamental frequency of the rotating machine and its harmonic frequencies. The fundamental frequency of each motor is obtained by multiplying the frequency of the rotating speed of the motor by the number of teeth of the meshing gear engaged with the motor. For the fan, the fundamental frequency is obtained by multiplying the frequency of the rotating speed of the fan by the number of blades in the fan.

The frequency of the rotating speed of the rotational component is measured using different types of sensors such as a tachometer, an accelerometer and a microphone. They are installed around the rotating components, as discussed in the previous section. For example, for the printer model 5, the fundamental frequency and its harmonics of the tonal sounds caused by the rotating motors and fan are as listed in Table 1. These tonal sounds were obtained by filtering the printer sound using a Vold –Kaman order filter based on the measured rotating speed of the rotating components.

These tonal sounds were saved for the jury test of tonal sounds. Fig. 4(a) shows the spectrum of background sound, which does not include the tonal components. Fig. 4(b)-(d) and (e) shows the spectrum of the tonal sounds caused by the main motor, dev motor(Development motor), fuser motor and SMPS (switched mode power supply) fan, respectively in the printer model 5. These are the spectrum of each tonal sound with background sound. Impulsive components of the printer sound are classified by analyzing the time signal, as shown at the bottom of Fig. 3. There are many impulsive sounds in the time signal. The impulsive sounds take place when the printer is working. Four impulsive sounds were selected as major impulsive sounds, which contribute to the sound quality of a printer.

Table 1 Result of the classification of noise sources to each printer

Component	RPS	Tooth	Frequency (Hz)
Dev Motor	36.6	9	330(36.6×9)
			990(36.6×27)
Main Motor	38.7	9	348.9(38.7×9)
			1163(38.7×30)
Fuser Motor	35.7	9	321.3(35.7×9)
			535(35.7×15)
			963(35.7×27)
			1071(35.7×30)
			1606(35.7×45)
			1785(35.7×50)
SMPS Fan	117	5	585(117×5)



(a) Background
(b) Main motor
(c) Dev motor
(d) Fuser motor
(e) Fan

Fig. 4 Spectrum of the background sound without tonal components and spectrum of the tonal sound with fundamental frequency and its harmonics. The tonal sounds in a printer model 5 caused by the rotational components of a printer

The time duration for the impulsive sound for the six sample printer models wasdetermined as shown in Fig. 2 and the time data was recorded for subjective evaluation. Therefore, it was concluded that four tonal sounds, and four impulsive sounds and background sounds should be selected as the nine major sounds that contribute to total printer sound quality.

2.3 Subjective evaluation

For the subjective evaluation of the recorded sounds, 33 individuals, who are general customers of printers, participated. There were 18 males and 15 females. They subjectively evaluated the recorded sounds, such as the nine major sounds in the laboratory. The subjective rating was evaluated from point 4 to point 9, a guideline given by the Samsung Electronics Company in Korea.

Table 2 illustrates the subjective rates and their relationship to the production guide of the printer. A rating method was used for this subjective evaluation;[4,5] see Table 3 for the subjective evaluations of the six sample printers. The subjective rating in Table 3 is the mean value of the subjective ratings evaluated by 33 persons. According to these results, the subjective ratings of the nine major sounds for each printer model are different from each other when the six sample printers work under the same operating conditions. For example, the subjective ratings of printer model 1 are low on the eight conditions except for the condition of "printer off" compared with those values for the other models. The reason for this is the different structure of each printer model. In order to analyze this subjective evaluation in one graphic, the polar diagram is employed.

Fig. 5 shows the polar diagram for the subjective results. According to this diagram, the subjective ratings of printer model 5 and printer model 6 are high in the tonal sounds but low in the impulsive sounds. However, the subjective ratings of printer model 2 and printer model3 are high in impulsive sounds but low in tonal sounds. These results are interesting for the decision of the development direction of printer sound quality.

Table 2 Grade for subjective evaluation of printer sound quality

Subjective rates	Production guide of printers
9	Very excellent
8.5	Excellent
8	Good
7.5	Acceptable for mass production
7	Marginal
6.5	Not good
6	Bad
5.5	Unacceptable to mass production
5	Very bad
4	Fail (Impossible to develop)

Table 3 Averaged subjective rating for nine major sounds of six

	Back-ground	Main motor	Fuser motor	Fan	Dev motor	Printer On	Pick up	Paper out	Printer Off
Model 1	5.71	5.01	5.65	5.69	6.00	5.83	4.63	5.59	8.54
Model 2	8.39	6.20	6.40	7.01	6.32	4.84	7.51	7.59	5.28
Model 3	6.79	7.20	6.58	6.24	6.34	6.26	7.92	7.78	6.08
Model 4	4.72	5.01	4.76	4.66	6.45	6.64	6.36	6.88	5.19
Model 5	7.11	6.90	7.36	7.18	7.05	7.76	6.37	5.66	7.65
Model 6	6.84	7.24	6.51	7.15	6.55	7.46	6.00	4.63	7.59

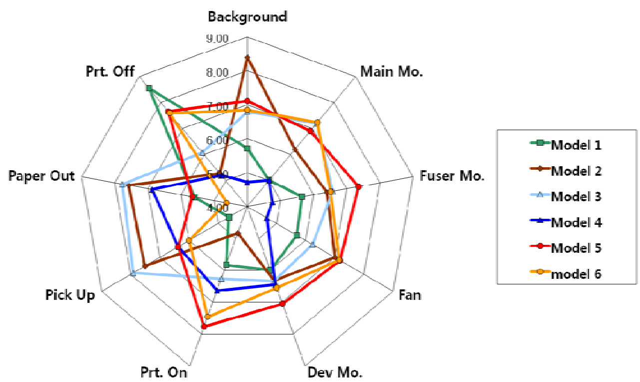


Fig. 5 Polar diagram presenting the subjective evaluation for nine major sounds of six sampled printer model

3. Path analysis of printer noise

To identify the contribution of the nine major sounds that affect printer sound quality, a basic survey was performed with thirty-three individuals who listened to the sounds of the six sample printers. The basic survey was performed by giving a high point to the sound that was highly correlated to total printer sound quality.

Table 4 Basic survey results for classification of nine major sounds contributing to the total printer sound (Motor and fan sound includes background sound)

1st	2nd	3rd	Sound Description	Contribution (%)
All sound	Stationary Sound 25.6%	Tonal Sound 91.8%	Main motor	24.5
			Fuser motor sound	30.9
			Fan motor sound	26.3
			Dev motor sound	18.3
		Background sound 8.2%	Tonal component sounds are removed	100
	Non-stationary Sound 74.4%	Impulsive sound 100%	Printer on sound	20.8
			Paper pick-up sound	35.7
			Paper out sound	25.4
			Printer off sound	18.1

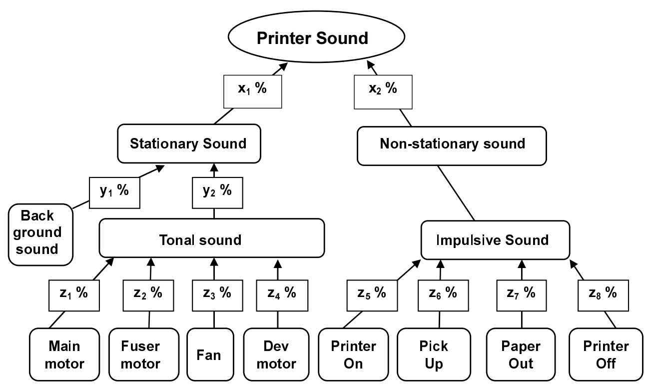


Fig. 6 Path analysis for determination of the contribution ratio of the tonal sounds and impulsive sounds to the printer sound quality

The results are listed in Table 4. The nine major sounds classified by time-frequency analysis can be classified as stationary signals and non-stationary signals. The tonal sounds and the background sound are stationary signals. The impulsive sounds are non-stationary signals. The percentage rate for stationary sounds and non-stationary sounds was asked. The most important sound was given a rating of 100%, and the percentages of the other sounds were given our relatively by comparing the most important sound with the other sounds. According to the results listed in the second column of Table 4, it can be inferred that the contribution of the non-stationary sounds is more important than that of the stationary sounds in the view of total printer sound quality. The sub-sounds for stationary sounds are classified as tonal sounds caused by rotating components and background sound without tonal components. The contributions are rated subjectively in the third column of Table 4. Contribution ratios to printer sound quality of the sound radiating from the four rotational components are given in the fifth column of Table 4. Contribution ratios of four impulsive sounds, which are non-stationary signals, to printer sound quality are also listed in the fifth column of Table 4. The contribution ratios of these sounds, x_i, y_i and z_i, are presented in the path of each stage, as shown in Fig. 6. In z_i, i is an integer from 1 to 8. According to the results of the path analysis listed in Table 4, x_1, x_2, y_1 and y_2 are 25.6, 74.4, 91.8 and 8.2, respectively. These contribution ratios were used to develop a total printer sound quality index for objective evaluation based on a combination of the sound quality indexes of the nine major sounds.

4. Sound metrics

Sound metrics are used for the psychoacoustic parameters designating the objective characteristics of the sound. The sound metrics for the nine major sounds of the six printer models were calculated for the input data of multiple regression models. According to psychoacoustic theory,[2] there are four major sound metrics: loudness, sharpness, roughness, and fluctuation strength. These metrics have been confirmed by psychoacoustic scientists. Many other sound metrics have been developed for application to industrial engineering, such as articulation index (AI), tonality, etc.,[6] depending on their application. These metrics are used for sound index development as input data in the multiple regression model and in the ANN (Artificial neural network) method.[7,8] In this paper, four major sound metrics (loudness, sharpness, roughness and fluctuation strength), articulation index and tonality were calculated and high frequency energy contribution (HFEC), which is a new sound metric designed for this study, was calculated for the consideration of the impulsive sound quality. Among these metrics, loudness, AI and HFEC are highly correlated with subjective evaluation for the nine major sounds. The sound metrics chosen for each major sound are summarized in Table 5. Finally, loudness and AI are chosen for the input of a multiple regression model as the tonal sound and loudness and HFEC is used for the impulsive sound because the correlation of these metrics with subjective rating is high. These criteria were used for the previous work.[9,10] Sound metrics selected in this study are discussed in detail in the following subsidiary section. In Table 5, the minus sign means negative correlation with subjective ratio.

Table 5 Correlations between overall attributes and components of printers

Nine major sounds		Zwicker' Loudness	AI	HFEC
Tonal sounds	Background	-98.86	95.54	-78.79
	Main motor	-83.73	87.63	-42.68
	Fuser motor	-96.88	92.04	-33.26
	Fan	-94.23	95.77	-47.95
	Dev motor	-94.42	87.28	-63.51
Impulsive sounds	Printer On	-74.28	53.49	-87.02
	Pick up	-92.65	96.92	-92.69
	Paper Out	-77.38	72.57	-90.72
	Printer Off	-98.80	95.79	-94.41

4.1 Loudness

Loudness represents the auditory perception character related to the magnitude of sounds.[2] Of the many models[12,13] for calculating the loudness, in this paper, the Zwicker model[13] is used to calculate the loudness for the interior sounds. Loudness is measured in phones or sones, with one sone being the loudness for a pure tone sound with amplitude of 40dB at 1kHz. According to Table 5, it is known that loudness deeply affects the sound quality for both tonal sounds and impulsive sounds according to the idea of Zwicker loudness. From these results, we found that the subjective rating is proportional to 1/loudness.

4.2 Articulation index (AI)

The articulation index is a quantitative measure of the intelligibility of speech: the percentage of speech items correctly perceived and recorded. An articulation index of 100% means that all speech can be understood; 0%, that no speech can be understood. The articulation index is calculated from the 1/3 octave band levels between 200Hz and 6300Hz center frequencies. Each of the 1/3 octave dB(A) levels are weighted according to specific criteria.[14] When a printer is driven, the correlation between articulation index and the subjective rating for the nine major sounds is calculated and the result is plotted in Table 5. From these results, we found that the subjective rating for tonal sound quality is proportional to the articulation index. For impulsive sound quality, some of the correlations between AI and the subjective rating do not exceed 0.7, as listed in Table 5. Therefore, AI is not used for input data of the impulsive sound index model.

4.3 HFEC (High Frequency Energy Contribution)

Continuous wavelet transform (CWT) has been used for analysis of the impulsive noise.[15] CWT is employed in the calculation of a sound metric for impulsive noise.[16] The sound metric based on CWT is developed with the following process. First, we applied A-Weighting to the impulsive signal and obtained an M by N wavelet coefficients matrix by using continuous wavelet transform. Second, the threshold was set at a high level to extract the impulsive parts that are related to the impulsive sounds. Third, in order to obtain the frequency-weighting for the impulsive parts, we multiplied the frequency values by the power of the extracted wavelet coefficients. Fourth, the equation for the sound metric was obtained by dividing the power of the extracted coefficients by the power of the coefficients of the original CWT. Finally, we normalized the magnitude of the coefficients by dividing the calculated value by the maximum frequency. The outcome value is dimensionless. This metric, HFEC (High Frequency Energy Contribution), can be expressed by the following equation:

$$HFEC = \frac{1}{Freq_{\max}} \sum_{m}^{M} \sum_{n}^{M} \frac{\overline{CWT}^{2}_{m,n} \cdot Freq_{m,n}}{CWT^{2}_{m,n}} \quad (4)$$

where $CWT_{m,n}$ is the wavelet coefficient, $\overline{CWT}_{m,n}$ is the wavelet coefficient above the threshold, and $Freq_{m,n}$ is the frequency weight at the impulsive time.[17] Because the impulsive noise contains the high frequency components, the frequency weighting is given.

The original CWT coefficients for an impulsive signal are plotted as shown in Fig. 7 after A-weighting. The processed version is shown in Fig. 8. When a printer is driven, the correlation between articulation index and the subjective rating for the nine major sounds is calculated and the result is listed in Table 5. From these results, we found that the subjective rating for impulsive sound quality is proportional to 1/HFEC. For tonal sound quality, most of correlations between HFEC and the subjective rating do not exceed

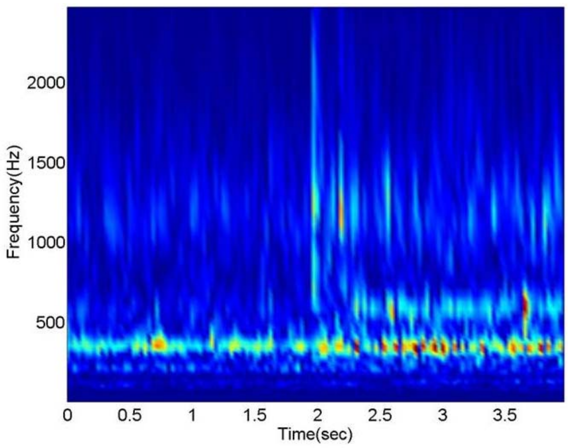


Fig. 7 Wavelet transform for the impulsive noise

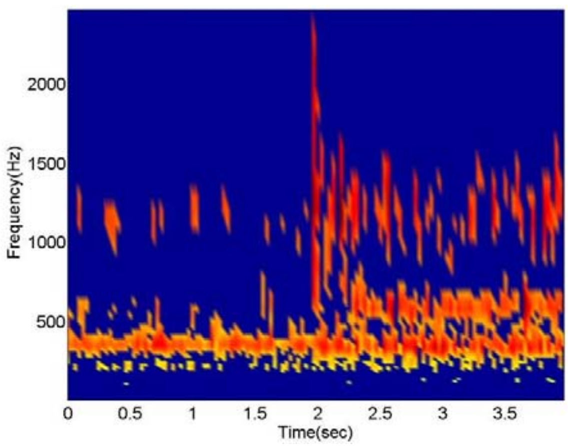


Fig. 8 Wavelet coefficients with frequency

0.7, as listed in Table 5. Therefore, HFEC is not used for input data of the tonal sound index model.

5. Sound quality index for nine major sounds

Sound quality index means the modeling of the correlation between sound metrics and the subject evaluation of the recorded sounds. There are two modeling technologies in the field of sound quality analysis. One is a multiple regression methods,[18] the other is an ANN (artificial neural network model).[10,11,19] ANN is a useful tool for the presentation of a non-linear model but demands a great amount of data for training of the model. Therefore, in this study, the multiple regression method is used since the number of printer sounds is only six. The mathematical expression of multiple regressions is given by

$$Y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_i x_i + \varepsilon \quad (5)$$

where Y_i is the sound index for the nine major sounds, $i = 1, 2, 3, \cdots, n$, β_i is the weighting coefficient to be determined throughout multiple regression and x_i represents the related sound metrics (Table. 6). Fig. 9 shows the correlation between subject evaluation and sound quality index output for the nine major sounds. The vertical axis is the index output and the horizontal axis is the subjective rating for the nine major sounds. The sound quality index for each sound is developed by using multiple regressions. The correlation between index output and subjective evaluation is over 0.7. Therefore, this can be used for the sound quality index for the nine sounds of the printer. Table 6 shows the weighing coefficient β_i and the sound metric x_i used for the sound quality index development for the nine sounds.

6. Total printer sound quality index

From the path analysis of printer sound quality discussed in section 3, it is known that the printer sound is related to the tonal sound, impulsive sound and background sound. The contribution of these sounds is obtained by path analysis. Fig. 10 shows the results of the path analysis for the nine major sounds. By combining the nine major sounds, the total printer sound quality index is developed. For the contribution of tonal sound, the mathematical expression is given by Eq. (6),

Table 6 Weight coefficient for sound quality indexes for nine major sounds and associated sound metrics

Component	β_0	β_1	β_2	x_1	x_2
Background	9.633703	-1.77964	5.044827	Loudness	AI
Main motor	2.464434	-1.2701	9.267429	Loudness	AI
Fuser motor	23.21574	-3.02278	-0.49544	Loudness	AI
Fan	-3.48917	-1.00947	12.85649	Loudness	AI
Dev motor	8.740992	-2.15511	7.976195	Loudness	AI
Printer On	16.84526	-0.00771	-40.2605	Loudness	HFEC
Pick up	13.9027	-0.70118	-9.39263	Loudness	HFEC
Paper Out	13.63504	-0.51708	-25.5688	Loudness	HFEC
Printer Off	11.79604	-2.6837	19.07678	Loudness	HFEC

$$\text{Tonal sound} = 0.245 \times \text{main motor index} + 0.309 \times \text{fuser motor index} + 0.263 \times \text{fan index} + 0.183 \times \text{dev motor} \quad (6)$$

For the contribution of impulsive sound, the mathematical expression is given by Eq. (7),

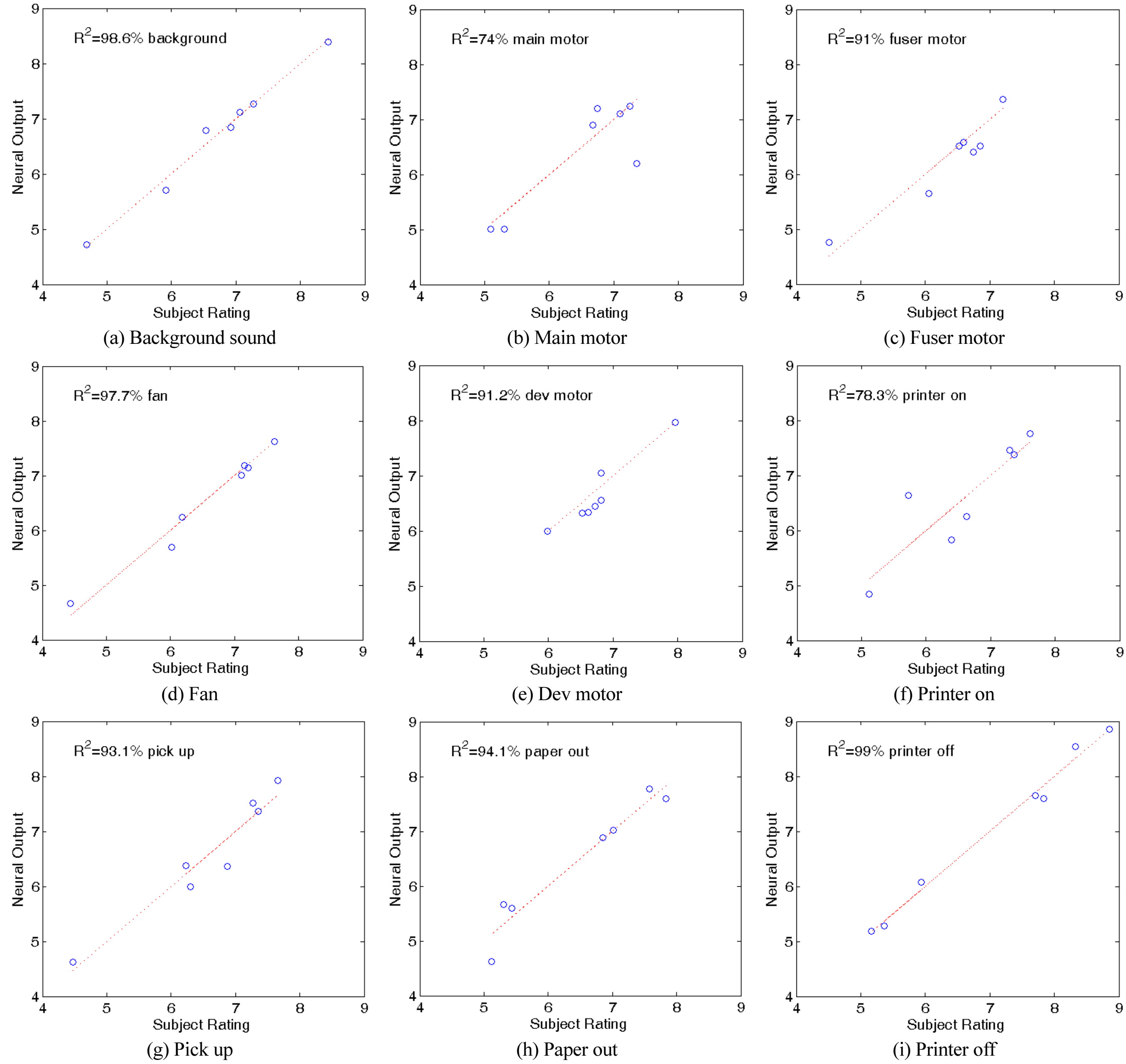
$$\text{Impulsive sound} = 0.208 \times \text{printer on index} + 0.357 \times \text{pick up index} + 0.254 \times \text{paper out index} + 0.181 \times \text{printer off index} \quad (7)$$

Finally, the printer sound quality index is calculated by using Eq. (8),

$$\text{Printer sound quality index} = 0.256 \times (0.082 \times \text{background sound} + 0.918 \times \text{tonal sound}) + 0.744 \times \text{impulsive sound} \quad (8)$$

For the validation of this index, the total printer sound quality for a printer is objectively evaluated by using Eq. (8). The subject rating test for total sound quality of the six printers was performed by the same thirty-three people who participated in the subjective test for the nine major sounds. The validation results are shown in Fig. 11(a). The correlation between index output and subject rating is 95.5%. This is very well correlated. One of the six sample printers was modified for the improvement of the printer sound quality. Model 6 was modified by applying a sound cover to the back of the printer and a laminated plate to the side case of the printer.

Fig. 12 shows the polar diagram presenting the subjective rating of the nine major sounds for the six sample printers and the modified printer. The sound quality of the modified printer is improved between model 6 and model 7, as shown in Fig. 11(b).



(a) Background sound (b) Main motor (c) Fuser motor

(d) Fan (e) Dev motor (f) Printer on

(g) Pick up (h) Paper out (i) Printer off

Fig. 9 Correlation between subjective rating and sound quality index output for nine major sounds in a printer

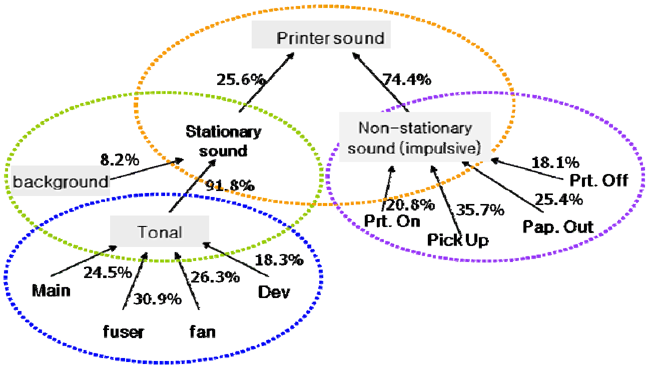
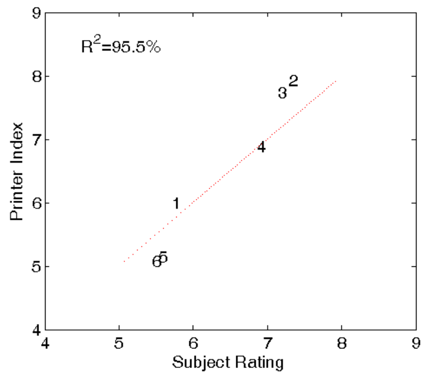
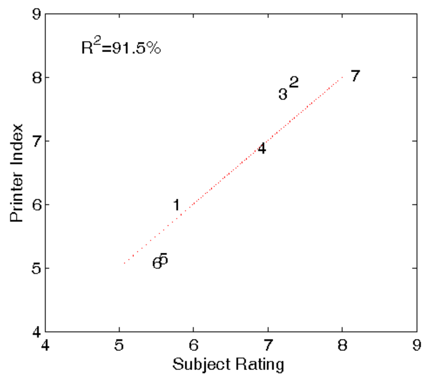


Fig. 10 Contribution percentage of the nine major sounds to printer sound quality, which is obtained by path analysis



(a) 6 sample models



(b) 7 sample models

Fig. 11 Comparison between printer sound quality index and subjective rating. Number in the graph means the printer model number

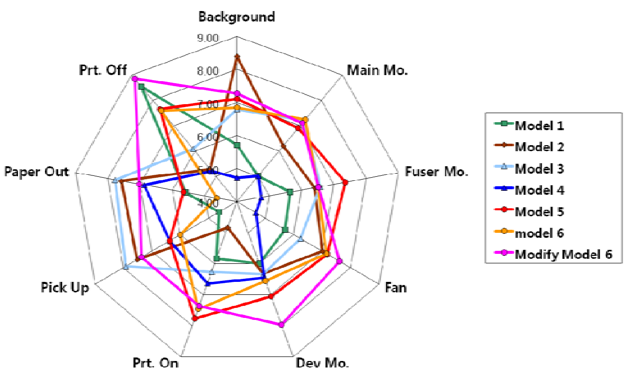


Fig. 12 Polar diagram presenting the subjective evaluation for nine major sounds of six sample printer models and one modified version

However, the correlation between index output and subject rating changed from 95.5% to 91.5%. For the robustness of this correlation, more printer samples are needed.

7. Conclusions

The path analysis for printer sound quality was investigated by using recorded printer sounds. Thirty-three participants, including customers and engineers, took part in the subjective test. Through this investigation, it was concluded that the dominant sounds for printer sound quality are stationary sound and non-stationary sound. The stationary sound includes four tonal sounds and background sound. Non-stationary sound includes four impulsive sounds in transient conditions such as “printer on”, “paper pick up”, “paper off” and “printer off”. Contribution ratios of the nine major sounds to total printer sound quality were obtained by path analysis. A printer sound quality index for middle class printers was developed based on the path analysis. For the development of this index, the nine major sounds, which have a high correlation with total printer sound quality for middle class printers, were recorded in an anechoic chamber. A subjective evaluation of the nine major sounds was made by the test participants. This subjective evaluation was used for the development of a sound quality index of the nine major sounds. These sound quality indexes were developed based on the multiple regression method by modeling the correlation between subjective evaluation and sound metrics for the nine major sounds. Finally, a total printer sound quality index was developed by the systematic combination of the nine major sound quality indexes according to their contribution to printer sound quality. The contribution ratio was calculated by path analysis of the data obtained throughout the basic investigation. This total printer sound quality index was found to very well correlate with the subjective evaluation. This evaluation was applied to the improvement of printer sound quality. Most of printers made by the same company have dev motor, fuser motor, etc. and the engines of the printers are similar. Therefore, for the one same company, this path analysis is useful for the sound quality analysis.

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