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Sound quality improvement of operation sounds emitted by MFPs

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ABSTRACT

Multifunctional peripherals (MFPs) integrating multiple functions including copying, printing, scanning, and faxing functions in one unit are now widely used in offices. In MFPs there are many sound sources which generate steady sounds such as noises emitted by motors and fans, and transient sounds such as collision noises between parts. It is difficult to identify sound sources for sound quality improvement, because of the variety of sounds when in operation. In this study, we proposed a method to efficiently improve the sound quality of the operation sounds emitted by MFPs. First we performed a subjective sound quality evaluation of the operation sounds using the SD method. Then, we derived an equation (*PSI*) representing pleasantness, based on the subjective sound quality evaluation and the psychoacoustic parameters. We also examined the influence of each sound on a pleasantness scale of the operation sounds. In the examination we performed a sensitivity analysis by calculating the contribution of each sound to the pleasantness by using the *PSI*. Finally, we took steps to modify the sounds that were high in contribution to the improvement in sound quality. Consequently, we efficiently achieved an improvement in sound quality to the operation sound emitted by the MFP.

Keywords: Sound quality, Multifunctional peripheral, Psychoacoustic parameter

1. INTRODUCTION

These days, multifunctional peripherals (MFPs) integrating multiple functions including copying, printing, scanning, and faxing functions in one unit are now widely used in offices. In addition, the number of parts of MFPs has increased compared to a single purpose machine. Additionally, there is a great demand for MFPs to achieve high-speed and small-size, and also to produce images and documents in high-resolution. As a result, operation sound becomes a problem due to the further increase in the number of parts, the complicating of the mechanism, and the speeding up driving parts. Furthermore, quietness of offices has progressed due to the improvement of noise reduction technologies in buildings. Therefore, the operation sounds from the office equipment in offices have become easier to hear than before. Consequently, a pleasant sound emitted by the MFP is desirable.

There are many kinds of sound sources in MFPs. Some examples are: motors, gears, papers, clutches, and other sound sources. Moreover, the sound includes steady sounds and transient sounds. These are the features of MFPs. One of the steady sounds is noise from the motor, and one of the transient sounds is the collision sound between parts. The sound quality emitted by products has become very important in addition to the reduction of sound pressure (1, 2). However, the sound quality improvement of the operation sound emitted by the MFP is difficult, because the sound includes many sound sources and is non-steady (3, 4). Therefore, it is difficult to identify sound sources for an improvement in sound quality. If the part of the sound that makes a high contribution to the sound quality is identified, the sound quality improvement can be made efficiently.

In this study, we proposed a method to efficiently improve the sound quality of the operation sounds emitted by MFPs. First we performed a subjective sound quality evaluation of the operation sounds using the SD method. Then, we derived an equation representing pleasantness, based on the subjective sound quality evaluation and the psychoacoustic parameters. We also examined the influence of each sound on a pleasantness scale of the operation sounds. In the examination we performed a sensitivity analysis by calculating the contribution of each sound to the pleasantness by using the equation we derived. Finally, we took steps to modify the sounds that were high in contribution to the sound quality improvement of the operation sound.

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2. ACOUSTIC CHARACTERISTICS OF OPERATION SOUNDS EMITTED BY MFPS

2.1 Configuration of MFP

Figure 1 (a) shows the MFP which is a Toshiba Tec product, whose configuration is only the main body. Figure 1 (b) shows the main body of the MFP and an optional finisher. The finisher is attached to the main body, and has functions such as stapling, sorting, punching holes, and folding documents, after printing has been performed by the main body.

(a) Main body (b) Main body and finisher

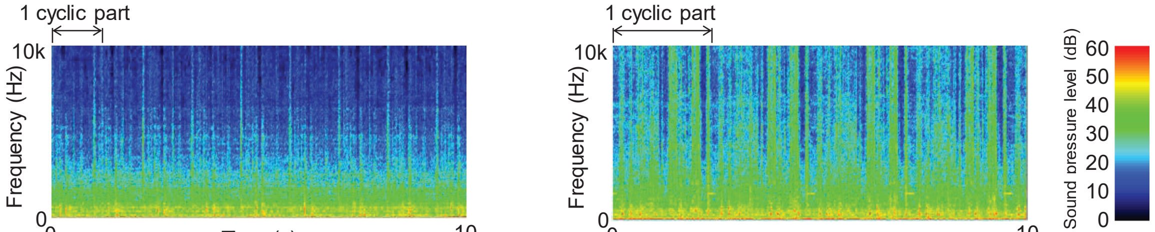
Figure 1 – Appearance of MFP

2.2 Frequency Characteristics of Operation Sounds Emitted by MFPs

First, we measured the characteristics of the sounds emitted by the MFPs during consecutive page printing in color mode. Figure 2 (a) and (b) show color maps of the frequency characteristics of sounds emitted by the MFPs, whose configurations are the main body alone and the main body with the finisher attached, respectively. Figure 3 shows a comparison of each frequency characteristic.

In the Figures the printing speed of the MFP is 50 Pages Per Minute (PPM) in consecutive color printing mode, and the operation mode of the finisher is two sheets two staples mode whose sound is loudest. A microphone is placed at 1 m in front of the machine's front surface. The microphone's position is supposed to represent the position of a bystander.

As shown in Figure 2 and 3, many kinds of transient sounds and steady sounds are included. Moreover, when the finisher is attached, the number of transient sounds and steady sounds increases, and the peak frequency sound is louder. As a result, the sound pressure level of the configuration is larger than that of the main body alone. In Figure 2, the cyclic period is continuously repeated during consecutive page printing. From these characteristics, in this study, we have focused on the operation sound emitted by the MFP whose configuration is the main body with the finisher attached.



(a) Main body (b) Main body and finisher

Figure 2 – Color maps of frequency characteristics of operation sounds emitted by MFPs

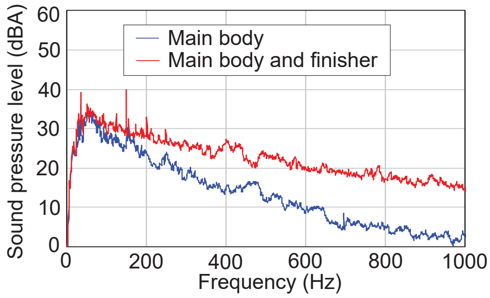


Figure 3 – Comparison of frequency characteristics of operation sounds emitted by MFPs

3. SUBJECTIVE SOUND QUALITY EVALUATION

3.1 Sound Quality Evaluation Using Semantic Differential (SD) Method

We performed a subjective sound quality evaluation of the operation sounds emitted by the MFPs whose configurations were the main body with the finisher attached. We prepared five evaluation sounds which were recorded operation sounds. The printing speeds of the MFPs were from 47.5 to 60 PPM in consecutive color printing, and the operation mode of the finisher was two sheets two staples mode. The microphone for recording sound was placed in the same way as previously mentioned in 2.2.

28 Japanese subjects aged between 22 and 55 participated in the sound quality evaluation using the SD method. The subject sat on a chair and listened to the evaluation sounds from a speaker in the meeting room, then answered the impression of evaluation sound on a scale of one to seven using the form as shown in Figure 4. After that, we performed a factor analysis using the data of the SD method.

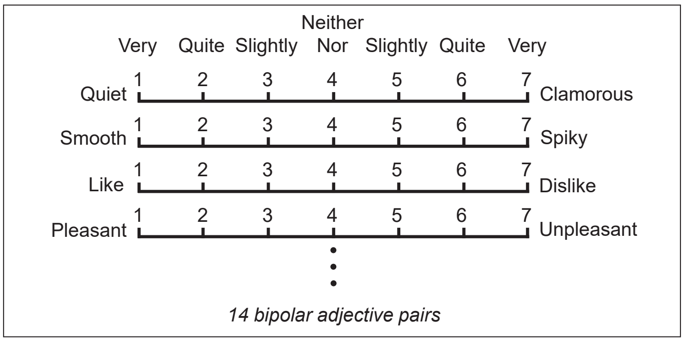


Figure 4 – Questionnaire form for SD method

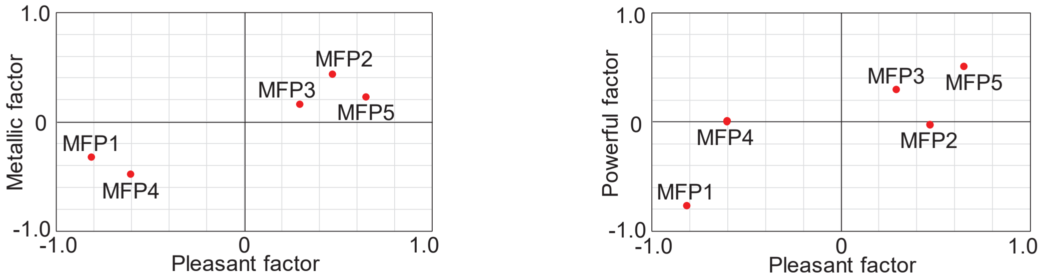
3.2 Result of Sound Quality Evaluation

Table 1 shows the result of the factor analysis. A pleasant factor such as “Pleasant - Unpleasant”, a metallic factor such as “Metallic - Moist” and a powerful factor such as “Powerful - Weak” are classified.

Figure 5 (a) and (b) show the scatter diagrams of the factor scores. In Figure 5 (a), the plotted data on the horizontal axis represents the factor score of a pleasant factor which indicates that operation sound is more pleasant in the upper direction. The plotted data on the vertical axis represents the factor score of a metallic factor which indicates that operation sound is more metallic in the lower direction. In Figure 5 (b), the plotted data on the horizontal axis represents the factor score of a pleasant factor which is the same as Figure 5 (a). The plotted data on the vertical axis represents that of a powerful factor which indicates that operation sound is more powerful in the lower direction. In these Figures, the five operation sounds emitted by the MFPs are defined as MFP1- MFP5, respectively.

Table 1 – Result of factor analysis of operation sounds emitted by MFPs

Adjective pairs	Pleasant factor	Metallic factor	Powerful factor
Pleasant – Unpleasant	-0.82	-0.30	-0.23
Like – Dislike	-0.79	-0.34	-0.09
Beautiful – Dirty	-0.76	-0.32	-0.27
Cheap – Luxurious	0.70	0.41	0.01
Quiet – Clamorous	-0.68	-0.37	-0.37
Restless – Calm	0.66	0.39	0.37
Cracked – Smooth	0.63	0.49	0.17
Round – Square	-0.57	-0.53	-0.17
Metallic – Moist	0.35	0.78	0.16
Gruff – Delicate	0.50	0.74	0.20
Hard – Soft	0.51	0.61	0.39
Powerful – Weak	0.37	0.30	0.77
Contribution ratio	0.36	0.22	0.11
Cumulative contribution ratio	0.36	0.58	0.69



(a) Metallic factor vs. Pleasant factor (b) Powerful factor vs. Pleasant factor

Figure 5 – Scatter diagrams of factor scores

Figure 5 (a) indicates that when an auditory impression of the sound is metallic, the sound is felt unpleasant. Figure 5 (b) indicates that when an auditory impression of the sound is powerful, the sound is felt unpleasant. In order to identify the sound that was deteriorating sound quality, we asked the subjects which sound felt metallic and powerful. The comment of the subjects was that the impulsive sounds in evaluation sound were metallic and powerful, and the motor sounds were metallic.

Therefore, it may be stated that the impulsive sounds and the motor sounds affect an impression of the operation sounds emitted by the MFPs whose configurations are the main body with the finisher attached.

4. DERIVING EQUATION REPRESENTING PLEASANTNESS

4.1 Significance of Deriving Equation Representing Pleasantness

We derived an equation representing pleasantness using psychoacoustic parameters. The significance of derivation is as follows:

It is possible to:

(a) Quantify the sound quality without performing the subjective sound quality evaluation.
(b) Clarify the target value of the sound quality by representing it quantitatively.
(c) Easily identify the part of the sound that makes a high contribution to the sound quality, and predict the effect of the improvement in sound quality, before making a prototype with steps to improve sound quality.

Therefore, the sound quality improvement can be made efficiently, so the duration and the cost of product development can be reduced.

4.2 Deriving Equation Representing Pleasantness Using Multiple Regression Analysis

In order to derive the equation, we performed a multiple regression analysis based on the pleasantness factor score obtained by the factor analysis as previously mentioned in 3.2, and on the psychoacoustic parameters as shown in Table 2. In performing a multiple regression analysis, the objective variable is the pleasantness of the sound, and the explanatory variable is the psychoacoustic parameters. We defined the objective variable of a multiple regression analysis as Pleasant Sound Index (*PSI*). The equation obtained by a multiple regression analysis is as follows:

$$PSI = -0.358 * Loudness - 1.364 * Sharpness - 2.026 * Roughness + 8.036 \quad (1)$$

Table 2 – Psychoacoustic parameters of each MFP

	Loudness (sone)	Sharpness (acum)	Roughness (asper)
MFP1	13.6	1.456	0.929
MFP2	11.8	1.182	0.870
MFP3	12.4	1.491	0.650
MFP4	13.1	1.599	0.912
MFP5	11.0	1.501	0.657

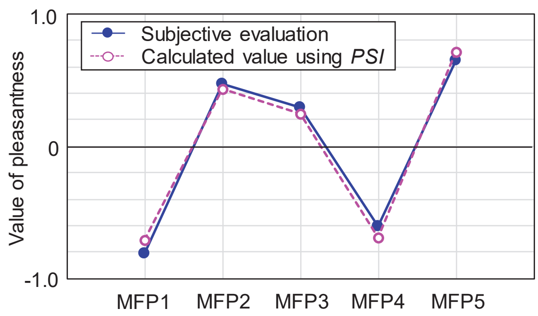


Figure 6 – Difference in value of pleasantness between subjective evaluation and calculated *PSI*

Figure 6 shows the values of the pleasantness factor score obtained by the subjective evaluation and calculated *PSI*. Figure 6 indicates that the calculated values using *PSI* concur with the factor score obtained by the subjective evaluation. The correlation coefficient between the values of the pleasantness by calculating *PSI* and the subjective evaluation is 0.992. From this result, it may be stated that the precision of the equation (*PSI*) we derived is high, and it is possible to use *PSI* to evaluate the pleasantness of operation sounds emitted by MFPs. Additionally, by quantifying the sound quality using the *PSI*, it is possible to clarify the target value of the sound quality.

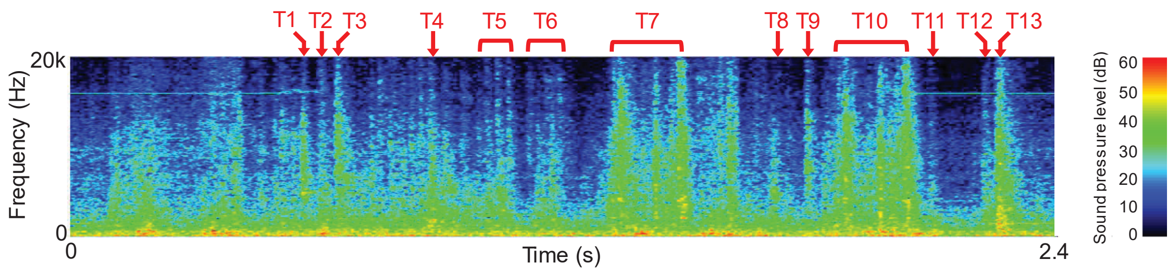
5. IDENTIFYING SOUND THAT MAKES HIGH CONTRIBUTION TO SOUND QUALITY

5.1 Influence of Each Sound on Impression of Operation Sound

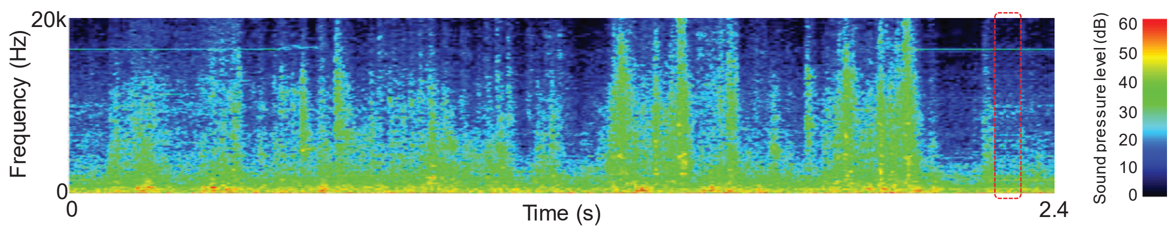
If the part of the sound which makes a high contribution to the sound quality is identified, the sound quality improvement can be made efficiently (5). Therefore, we examined an influence of each sound on an impression of the operation sound emitted by the MFP4. In order to obtain the value of the influence, we performed the sensitivity analysis by calculating the contribution of each sound to the sound quality improvement of the operation sounds, using the *PSI* we derived. In performing the sensitivity analysis, we prepared sounds which were edited sounds that consisted of only part of original sound was changed, and then we calculated the pleasantness of each edited sound using *PSI*.

Figure 7 and 8 show how the evaluation sounds were edited from the original sound using acoustic simulation (6).

1. The transient sound 13 (T13) was edited by replacing it with the steady part as shown in Figure 7 which shows one cyclic part of the operation sound.
2. The peak sounds of the frequency characteristic (363 Hz and 1494 Hz) were cut off with a notch filter as shown in Figure 8.

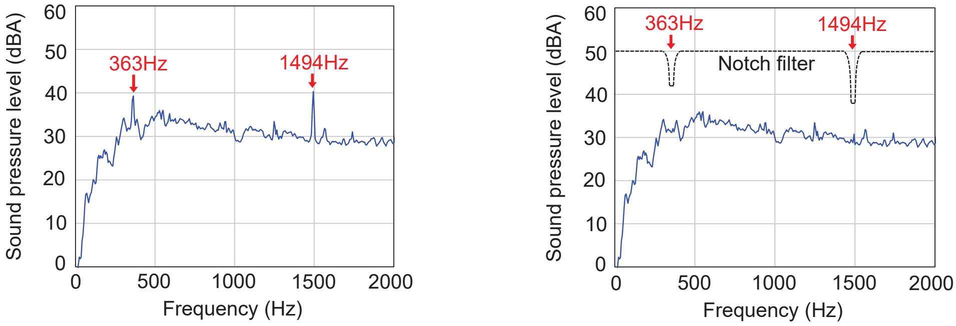


(a) Original sound



(b) Edited sound with T13 removed

Figure 7 – Original sound and edited sound with one transient sound removed



(a) Original steady sound (b) Edited steady sound

Figure 8 – Original steady sound and edited steady sound with peak frequency sounds cut off

We prepared 14 edited sounds, which consisted 13 transient sounds and one steady sound whose sound sources were in the finisher, because in this study we have focused on the operation sound emitted by the finisher. We defined transient sound 1-13 as T1-T13, respectively.

5.2 Result of Sensitivity Analysis

Figure 9 shows the result of the sensitivity analysis by calculating the contribution of each sound to the improvement in pleasantness. In Figure 9 the bar graph data of the calculated improvement value of pleasantness is shown on the left vertical axis, which indicates that the improvement effect of removing transient sound and cutting off peak frequency sound is larger in the upper direction. In this calculation, the *PSI* of the original sound was subtracted from each calculated *PSI* of edited sound which had each transient sound removed and the peak frequency sound cut off. The plotted data of the calculated reduction value of sound pressure level is shown on the right vertical axis, which indicates that the reduction effect of removing transient sound and cutting off peak frequency sound is larger in the upper direction. In this calculation, each sound pressure level of the edited sound was subtracted from that of the original sound.

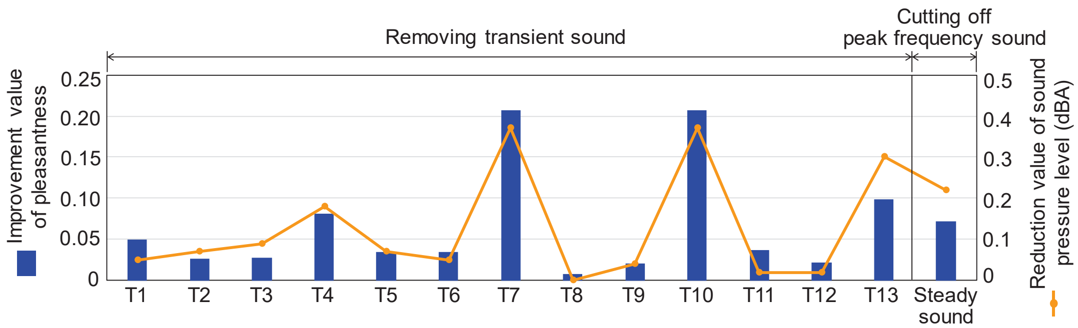


Figure 9 – Sensitivity analysis by calculating contribution of each sound to sound quality improvement

6. SOUND QUALITY IMPROVEMENT OF OPERATION SOUND EMITTED BY MFP

6.1 Taking Steps to Improve Sound Quality

We modified the MFP4 and made a prototype that took steps to improve the sound quality. We accomplished this by using the following policy.

We did not allow:

(1) Major design changes. In other words, we aimed to achieve the sound quality improvement by taking simple steps.

(2) A significant cost increase.

(3) Specification changes to the MFP. The reason behind this is that loudness of the operation sound can be reduced by slowing down driving parts. However, printing speed will also be slowed down, and as a result, specifications need to be changed.

We took steps to modify the top nine sounds that are high in contribution to the improvement in sound quality as shown in Table 3.

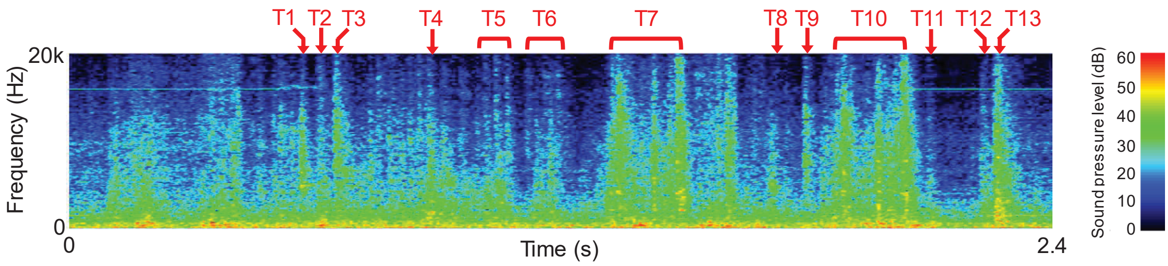
Table 3 – Steps to improve sound quality of operation sound emitted by MFP4

Sounds which taken steps	Causes of sounds	Steps	Effects
T1, T4, T5, T6, T11, T13	Backlash between parts	Reducing gap between parts	- Reducing loudness of sound - Reducing reverberation
T13	Collision between parts	Reducing impact force through installation of shock absorbing material	- Reducing loudness of sound - Reducing reverberation
T4	Shock due to rapid speed fluctuations in operation of part	Smoothing operation of part through smoothing motor control acceleration and deceleration	- Reducing impulsive sound - Reducing reverberation
Steady sound	Vibration caused by drive pulse	Replacing stepping motor with DC motor	- Reducing loudness of peak frequency sound
Main target sounds: T7, T10 This step is effective for all sounds	Sound leakage from the gap	Reducing opening of parts	- Improving sound insulation

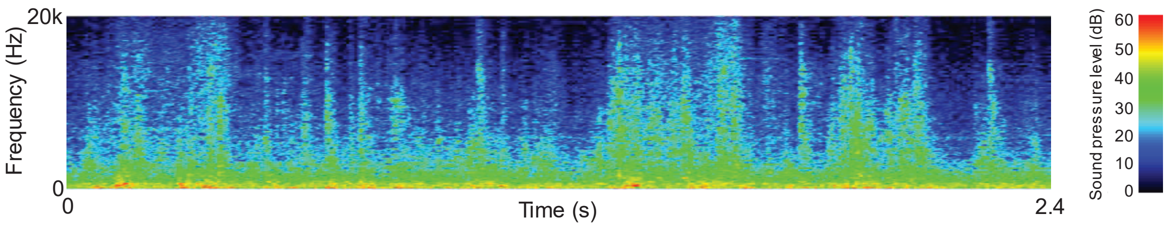
6.2 Result of Sound Quality Improvement

Figure 10 and 11 show the frequency characteristics of the original operation sound emitted by the MFP4 and that of the modified MFP4 for which we have taken steps to improve the pleasantness. Figure 12 shows the values of pleasantness and the sound pressure levels of the operation sounds. In Figure 12, the bar graph data of the calculated value of pleasantness using *PSI* is shown on the left vertical axis, which indicates that the operation sound is more pleasant in the upper direction. The plotted data of the sound pressure level is shown on the right vertical axis.

These figures show that the pleasantness of the operation sound emitted by the modified MFP4 significantly improved compared to the original MFP4 by taking simple steps. However, the value of the pleasantness of the modified MFP4 is lower than that of the MFP5, even though the sound pressure level of the modified MFP4 is lower than that of the MFP5.



(a) Before improvement



(b) After improvement

Figure 10 – Color maps of frequency characteristics of operation sound

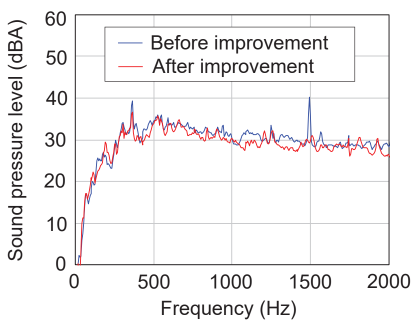


Figure 11 – Comparison of frequency characteristics between original sound and after improvement

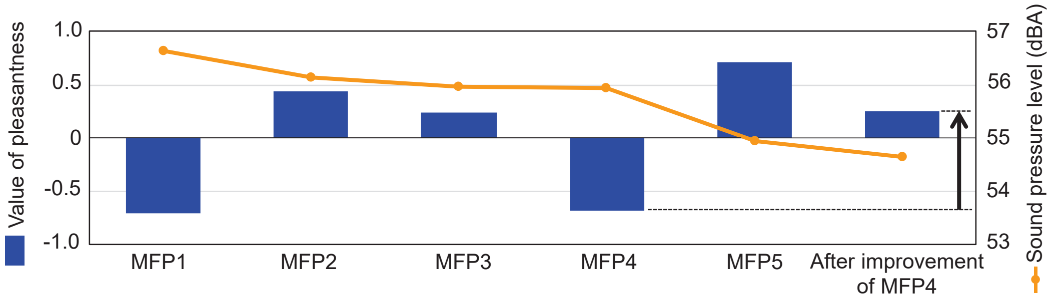


Figure 12 – Comparison of operation sounds emitted by MFPs, including improvement effect of MFP4

As a result of further investigation into the MFPs, it was found that the sound insulation of the MFP5 was higher in value with the cost increase. The sound insulation effect of the MFP5 was found to be 34% higher in sound power than that of the MFP4. Therefore, further improvement in the pleasantness of the modified MFP4 can be expected just by improving the sound insulation. Furthermore, we have clarified the steps to improve the sound quality of the transient sound emitted by the main body. As a result, further improvement in the pleasantness of the modified MFP4 can be expected by taking steps to the main body. Consequently, it may be stated that the sound quality improvement can be made efficiently using the method we carried out.

7. CONCLUSIONS

In this study, we proposed a method to efficiently improve the sound quality of the operation sounds emitted by MFPs. It is difficult to identify the sound which leads to the improvement. In the method, in order to quantify the pleasantness of operation sound emitted by MFPs, we derived the equation (*PSI*) representing the pleasantness. It has been confirmed that the correlation coefficient between the calculated value of the pleasantness using *PSI* and the pleasant factor score obtained by the subjective evaluation is high. Therefore, it may be stated that the precision of the *PSI* which represents the pleasantness is high. Then, we examined the influence of each sound on the pleasantness scale of the operation sounds. In the examination we performed the sensitivity analysis by calculating the contribution of each sound to the pleasantness by using the *PSI*. After that, in order to modify the MFP, we made a prototype that took simple steps to improve the sound quality. As a result, the sound quality of the operation sound emitted by the modified MFP was improved.

By using the *PSI*, it is possible to quantify the sound quality without performing the subjective sound quality evaluation, and to clarify the target value of sound quality as well. Moreover, we can easily identify the part of the sound that makes a high contribution to sound quality. We also can predict the effect of the improvement in sound quality before making a prototype with steps to improve sound quality. Therefore, we can efficiently achieve the improvement in sound quality to the operation sounds emitted by the MFP using the method we carried out, which will lead to a reduction in the duration and the cost of development of MFPs.

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