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# Design of Home Appliance Operation Sounds Based on the Metaphorical Nature of Sound

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## ABSTRACT

Digitized products allow users to operate intuitively using visual *Metaphor* on a screen with a GUI, such as images and icons. Multimodal interaction, traditionally focused on visual information, is increasingly incorporating auditory elements like vibration and sound. This shift is driven by the growing prevalence of screenless devices and voice-activated operations. Unlike visual information, auditory information can be received in any direction. Therefore, *Sound Interaction* will continue to increase in various products used in daily life. However, the monotonous electronic sounds used in numerous products often have similar tones and no meaning. Therefore, users often cannot properly recognize the meaning or status of multiple products when using them, which leads to confusion in determining which function is activated in a product. We adapted the *Metaphor* technique, commonly used in graphical user interfaces (GUI), for auditory information. By employing a variety of real-world sounds in our design, we aim to provide intuitive auditory cues that enhance user interaction with home appliances. The purpose of this research is to see how the concept of "*Sound Metaphoricity"* can be utilized in the design of sound for home appliance operation with respect to human-object interaction. After selecting home appliances and organizing the main functions of the current products, abstract images associated with the product function names and outlines were extracted, and sensitivity evaluation experiments using sound and analysis were conducted. As a result, we were able to clarify the factorial characteristics of the sound that acts as a *Metaphor* in the design of operation sound.

**Keywords:** Sound design, User experience, Interaction design, Metaphor

## INTRODUCTION

With the development of artificial intelligence (AI) and ICT, home appliances used in our daily lives have become increasingly Internet of Things-oriented, and the concept of interaction between people and objects has shifted from "objects to be controlled" to "relationship formation." In the interaction between people and objects, the forms of information expression can be divided into verbal and non-verbal. In addition, each type of information has its own meaning and can be divided into three categories, such as "understanding the state of the system," "understanding what the user should do," and "understanding the use results" (Miyahara et al., 2017). This information can be perceived through various sensory organs–mainly the visual, auditory, and tactile–depending on the type of object. In human interactions with objects, information representations can be divided into verbal and nonverbal cases. In addition, each type of information has its own meaning and can be divided into three categories, such as "understanding the state of the system," "understanding what the user should do," and "understanding the use results" (Miyahara, 2017). This information can be perceived through various sensory organs–mainly the visual, auditory, and tactile–depending on the type of object. Traditionally, this has been achieved through the sense of sight; however, comprehending the meaning of an action or situation in places that the user or person cannot see is difficult. In contrast, compared to vision, hearing has no spatial constraints; therefore, information can be received even if the recipient is some distance away from the object or faces a completely different direction (Shoji, 2016; Morimoto et al., 1998). Therefore, as home appliances become smarter and visual information becomes increasingly unavailable (Nishiyama, 2020), designing home appliances with a focus on interaction not only by visual information but also by auditory information is necessary. Currently, home appliances emit various types of sounds, such as "use sound," which indicates that the device has been operated by the user, "operation sound," which indicates that the device is working, and "function sound," which informs the user about the operating contents and status of the device (Namba et al., 1995; Namba, 2000); however, no unified design index has been defined for any of these sounds. Therefore, it has been suggested that some of the sounds used in reality may not fulfill the role of "conveying a message" and may convey incorrect information (Wake et al., 2003). In interface design that appeal to the sense of sight, the use of *Metaphor* that apply object and concept that exist in the real world to the design has enabled more reliable information transfer, such as increasing familiarity with new devices and facilitating the learning of device operations (Hosoya, 1995; Kusumi et al., Hosoya, 1995; Kusumi et al., 2002). In this research, we focus on the symbolic nature of sound (Akedo, 2013) and define "*Sound Metaphoricity*" as the ability of a sound to evoke a specific event in the listener and induce an emotion, and we will then discuss the possibility of utilizing the Metaphorical nature of sound in the interaction design of auditory information.

## LITERATURE REVIEW ON SOUND DESIGN AND METAPHOR

A literature review was conducted to understand sound design methods that utilize the sensory aspects of sound, and also to understand how *Metaphor* have been utilized in the past when examining the Metaphorical nature of sound, respectively.

### Sound Design Methods That Utilize the Sensory Aspects of Sound

Yamauchi and Nomura (2016) examined the process of materializing the "EV-like sound," a sound that is unknown and for which different people form different images. In their research, they attempted to understand the impression of "EV-like sound" by imagining a non-acoustic event (image or situation) that they perceive as "EV-like," administering a questionnaire survey asking about the impression they receive from the event, and collecting and analyzing the responses. The subjective evaluation experiment using adjective pairs used in this research can be widely adapted to the design of unknown sounds in general, because it is possible to interpret the results in terms of timbre factors. Other research have attempted to make soundscape design more systematic by confirming the correlation between impression evaluation words comprising adjectives and the perception of environmental sounds by people in their daily lives (kawai et al., 2004). Kondo (2020) examined the process of embodying sounds from abstract concepts using factors obtained through subjective evaluation experiments using the SD method and factor analysis as sound evaluation indices. From these results, it is evident that the method of verbalizing and embodying abstract concepts using adjectives is useful for sound design.

### The Role of Metaphor in Interfaces

*Metaphor* are considered useful for improving the harmony between people and objects (Fujimoto and Chen, 1994). *Metaphor* in interfaces play an important role in two aspects: "to support users' cognitive processes by designing tasks, tools, and operations in devices and systems" and "to provide in manuals and education (Kusumi, 2002)." By utilizing *Metaphor* when designing an interface, the constraints that the interface imposes on the user as concerns expression and communication methods can be better aligned with those that the user already knows (Kinoe and Anzai, 1987). Previously, when personal computers were first becoming popular, applying the deskwork *Metaphor* to users who were proficient in the deskwork domain but novices in the computer domain facilitated the use of the knowledge they already possessed and enabled them to learn to operate efficiently. The results of the literature review indicate that the application of the deskwork *Metaphor* to users who are proficient in the deskwork domain but novices in the computer domain facilitates the use of the knowledge they already have and enables them to learn to operate efficiently.

From these literature reviews, it was assumed that applying *Metaphor* to the operating sounds of home appliances would make it easier to operate them using sound cues, even if the functions were cumbersome. This research aims to use motion sound as a cue for the user to determine the optimal function by referring to the sound design methods used in previous research and utilizing other sounds in the real world in the design of motion sounds for home appliances.

## RESEARCH METHOD

In this research, we assumed the design of home appliances that are given artificial sounds during operation. First, home appliances were selected for the experiment, from which current products of the target home appliances were surveyed to extract the main functions and abstract images for each function. Next, based on the extracted functions and words, we selected several sounds to be used in the experiment and conducted a subjective evaluation experiment using the sounds. Finally, we conducted sensitivity evaluation experiments and analysis using the sounds, and discussed the possibility of utilizing the metaphorical nature of sound in the interaction design of auditory information.

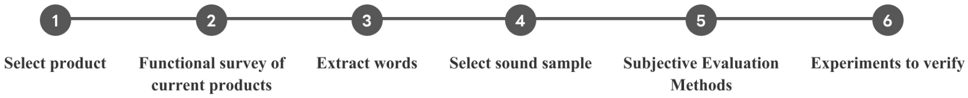


**Figure 1:** Research flow.

## RESEARCH ANALYSIS AND RESULT

### Selection of Appliances to be Used in the Experiment

In this research, we conducted an experiment on the interactions between the sounds emitted by home appliances and users. Therefore, we investigated a series of usage scenarios for four types of home appliances that emit "use sound," "operation sound," and "function sound" on a daily basis: a microwave oven, washing machine, air conditioner, and circulator. In this research, the "circulator," which does not limit the scenes in which interaction occurs, is the subject of the experiment to verify the type of sound that can appropriately utilize *Metaphoricity* and induce the optimal interaction.

### Survey the Current Products of the Target Home Appliance and Extract the Main Functions

From the top 30 circulator models in the sales ranking (Kakaku.com, 2023), we investigated the main functions, focusing on the operation panel part. We focused on "air blowing mode," which has a variety of functions, and excluded from the survey those functions such as "power," "swing," and "timer," which are simple switching functions and only produce a sound signal. As a result of the survey, the top five main functions were identified as "continuous," "rhythm," "clothes dryer," "forced agitation," and "sleep" (Table 1).

**Table 1.** Survey results of the main features of existing circulators (N = 30).

| Function Name | Number |
|---|---|
| Rhythm | 15 |
| Clothes Dryer | 11 |
| Sleep Mode | 6 |
| Forced Stirring | 4 |
| Warm Air | 2 |
| Circulation, Auto Airflow, Baby Mode, High Power Mode, Turbo Direct, Fan, Heater | 1 |

## Extract Words That Represent Images and Situations Evoked by the Function

Because this survey examines the utilization of the Metaphorical nature of sound, deriving a specific sound that has a structural connection to one of its main function names is necessary. Therefore, to obtain the words recalled from the main functions, a questionnaire survey was administered to imagine the non-acoustic events felt from each of the extracted main function names and to ask about the impressions received from them, referring to previous research. From the questionnaire, words representing the images and situations summarized in Table 2 were obtained for each function.

**Table 2.** Words representing images and situations extracted from function names (N = 10).

| Function name | Overview of Functions | Image/Situation |
|---|---|---|
| Consecutive | Operates at the air volume set using the air volume button | Constant, Monotonic, Automatic, Mechanical |
| Rhythm | Reproduce a wind that is close to nature by changing the strength. It sends out natural wind by changing the air volume at a certain rhythm. | Comfortable, Nature, Wave, Regular |
| Clothes Dryer | The strength of the wind is adjusted depending on the direction, so that the speed of the wind hitting the laundry remains almost constant. Dry clothes evenly even when drying indoors The clothes drying mode automatically operates with the air volume and angle suitable for drying programmed. The machine automatically swings its head up, down, left and right, allowing air to blow directly onto the laundry from various angles, allowing it to dry quickly. | Sun, Hot Air, Dry, Drying |
| Forced Stirring | Stir the air in the room to reduce temperature differences. Stirring means stirring. | Strong Wind, Typhoon, Mixing, Turning |
| Sleep Mode | The wind is light in the front range, becomes strong in the upward direction, and gradually changes in strength in between. Direct wind from the front is gentle, and when facing upward, it can be applied to a wall to create indirect wind or create convection of the air in the room. The wind is gradually reduced over time. | Quiet, Wind chimes, Quiet sounds at night, Owl |

### Select Sounds to be Used in the Experiment Based on the Extracted Functions and Words

A table of images and situations (Table 2) extracted from the names of the air-blowing functions was used to select the sounds for later experiments. To examine the influence of the *Metaphor*ic nature of sound, the sounds used in this research are based on objects and concepts that exist in the real world, and are expected to have a structural connection with the circulator, such as "natural sound" and "environmental sound" categories. To ensure objectivity in the selection of sound samples, we asked five students to view Table 2 and thereafter select a sound sample from among the multiple "natural sound" and "environmental sound" samples that were considered to have strong associations with each word. Consequently, 16 sounds were selected, as shown in Table 3. The length of all sounds was set to 10 s, the volume level was standardized to 50 dB, and mp3-standard sound samples were prepared for use in the experiment.

**Table 3.** 16 selected sounds.

| | | | |
|---|---|---|---|
| Draft | Strong wind | Wind chime | Stormy rain |
| Stream | Sugarcane field | Bamboo forest | Rice field |
| Bird (lark) | Frog | Cicada | Noise |
| Bell cricket | Owl | Howler | Bonfire |

### Subjective Evaluation Experiment Using Selected Sounds

Aiming to acquire factors that can be used as indicators when designing a sound that can evoke each function of a circulator, a subjective sound evaluation experiment was conducted on 30 male and female in their early 20s. In parallel with the subjective evaluation, the degree of conformity between the audible sound and functional image was also evaluated. Research participants were asked to listen to 15 pairs of adjectives, selected with reference to previous research (Kondo and Yamanaka, 1998; Inoue and Kobayashi, 1985; Kuwata, Hochin and Nomiya, 2010), in the experimental environment shown in Figure 2, in a room that was sufficiently quiet compared to the sound sample. The following procedures were used in the experiment:

1) Research participant listen to some sound.
2) Research participant responded to their impression of the sound on a 5-point scale from −2 to 2 on the evaluation sheet.
3) Research participant checks any matches with a specific functional image on the sheet related to the congruency verification.
4) The above procedure is repeated a total of 16 times with different samples and in random playback order.

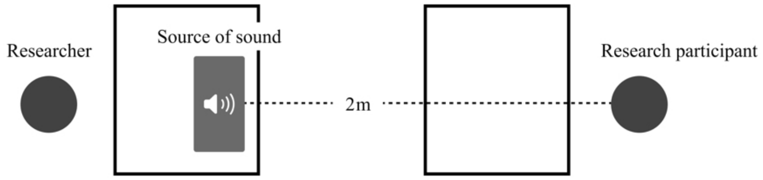


**Figure 2:** Experiment environment.

Using all the data from the sensibility evaluation sheets obtained through the experiment, the maximum likelihood method was applied to extract the three factors, and factor analysis was performed by applying varimax rotation to the three factors. The factor-loadings matrix is shown in Table 4. Focusing on factor loadings with absolute values of 0.4 or higher, the following interpretations were made:

1) Factor 1: Clarity (Contribution ratio: approx. 44.6%).
2) Factor 2: Power (Contribution ratio: approx. 18.0%).
3) Factor 3: Sharpness (Contribution rate: 3.7%).

The contribution rate of Factor 1 was approximately 44.6%, which is considered an important factor accounting for approximately half of the total, indicating that characteristics related to cleanliness and transparency have an important influence on the operating noise of air-conditioning appliances.

**Table 4.** Factor analysis of 15 pairs of adjectives.

| Adjective Pairs | Factor 1 | Factor 2 | Factor 3 |
|---|---|---|---|
| Nervous - Calm | 0.987 | −0.054 | −0.037 |
| Dirty - Clean | 0.943 | −0.065 | 0.092 |
| Muddy - Crisp | 0.887 | 0.092 | 0.157 |
| Hard - Soft | 0.834 | 0.026 | −0.149 |
| Dry - Moist | 0.769 | 0.214 | −0.002 |
| Dull - Vivid | 0.721 | 0.353 | 0.204 |
| Dark - Bright | 0.650 | 0.493 | 0.124 |
| Blurred - Clear | 0.498 | 0.442 | 0.257 |
| Static - Dynamic | −0.212 | 0.863 | 0.023 |
| Insane - Lively | 0.336 | 0.577 | 0.192 |
| Lackluster - Powerful | −0.369 | 0.534 | 0.285 |
| Mild - Bald | −0.751 | 0.515 | 0.149 |
| Delicate - Bold | −0.835 | 0.485 | −0.068 |
| Cold - Warm | 0.104 | 0.453 | 0.018 |
| Blunt - Sharp | 0.028 | 0.090 | 0.479 |
| **Contribution** (%) | 44.635 | 18.018 | 3.700 |
| **Cumulative contribution** (%) | 44.635 | 62.653 | 66.353 |

Based on the results of the above factor analysis, a further cluster analysis using Ward's method was conducted, and the 16 sound samples were classified into three groups as shown in Figure 3. This indicated that specific function names and their images could be explained by the two factors obtained from the subjective evaluation.

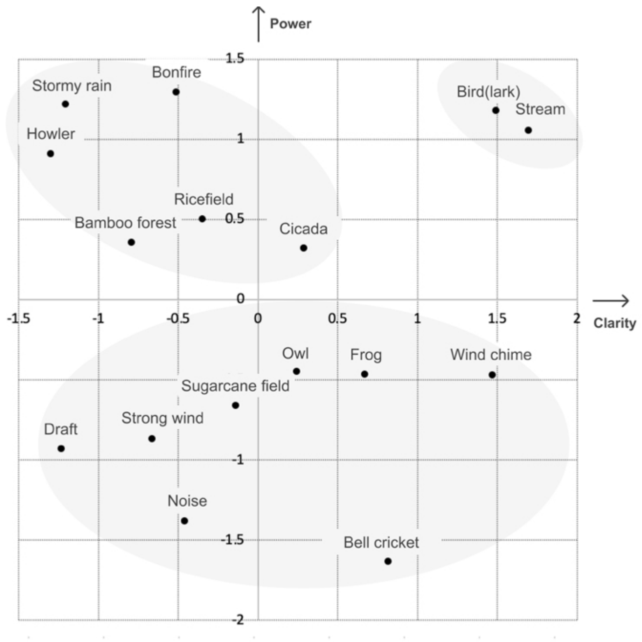


**Figure 3:** MAP based on analysis results.

## Experiments to Verify the Usefulness of Sound Metaphoricity

An experiment was conducted to verify the validity of the factors obtained from the subjective sound evaluation experiment and analysis as well as to verify the influence of the *Metaphor*ic nature of sound. This time, we focused on the "sleep" function among the circulator functions and performed the verification. For validation, we used 8 sound samples–2 of each of 4 types for each factor feature–from the sound samples used in the sensitivity evaluation experiment (Table 5). Two sounds with high intelligibility factor and low intensity factor (i.e., factorial features with high "good night" function congruency) will be designated as Group A, and the other 6 sound samples as Group B.

**Table 5.** Types of sounds used in verification.

| Sound Sample | | Clarity Factor | Impressive Factor |
|---|---|---|---|
| Bird (lark) | Stream | High | High |
| Bell cricket | Wind chime | High | Low |
| Stormy rain | Howler | Low | High |
| Draft | Strong wind | Low | Low |

The experiment was conducted on 7 students using the following procedure.

1) Explain to research participants the purpose of this research and the classification of circulator functions.
2) Have research participants listen to one sound and rate it on a 5-point scale from −2 to 2 as to whether it is appropriate as a sound to be given to the "good night" function.
3) The above procedure was repeated a total of eight times.

A 2 sample T-test with no correspondence was conducted on the data obtained from the experiment (Table 6). The results show that there is a statistically significant difference between the means of Group A and Group B, since $p<0.05$, suggesting that the mean of Group A is larger than that of Group B. This indicates that the interpretation of the factors obtained in the sensitivity evaluation experiment is valid, and that Group A is more appropriate as the operating sound for the "good night" function.

**Table 6.** Results of T-test.

| | Variable 1 | Variable 2 |
|---|---|---|
| Mean | 2.571429 | 1.571429 |
| Variance | 0.369048 | 0.59127 |
| Observations | 7 | 7 |
| Pooled Variance | 0.480159 | |
| Hypothesized Mean Difference | 0 | |
| Degree of freedom | 12 | |
| t | 2.699862 | |
| P(T<=t) One-side | 0.009657 | |
| t Critical One-side | 1.782288 | |
| P(T<=t) Two-side | 0.019314 | |
| t Critical Two-side | 2.178813 | |

## CONCLUSION

In this research, we examined the possibility of utilizing the Metaphorical nature of sound in the design of operating sounds for home appliances that target circulators. First, after organizing the main functions of existing circulators, images for each function were extracted using words, and subjective evaluation and verification experiments were conducted using sounds that evoke objects and concepts that exist in the real world. From the analysis of the experimental results, two factors, "clarity" and "power," were obtained. Additionally, a parallel research was conducted on the correspondence between words representing images and situations extracted from the names and outlines of each function. Consequently, among the main functions, "rhythm" exhibited no correlation or common relationship among the selected samples, while "drying clothes" was a sample sound that was "not powerful and not clear" and "forced agitation" had "powerful and unclear" sample sounds, and “good night” had “not powerful and slightly clear” sample sounds in common. This indicates that a particular function name and its image may be explained by a factor obtained through factor analysis using the results of the subjective evaluation of the sound. Furthermore, from an experiment to verify the validity of the obtained factors, the T-test based on the results of the verification experiment significantly revealed that the factor characteristic of the sound appropriate for the “good night” function was “less powerful and slightly clear,” indicating that the interpretation of the factors was also valid. Therefore, it was assumed that by clarifying the type of sound that acts as a *Metaphor* for a product, based on the relationship between the associative image of the product and the factorial characteristics of the sound, it would be possible to design an auditory information interaction appropriate for the product and its function. However, because personal experiences and preferences significantly influence the establishment of *Metaphor*, we should consider conducting evaluation experiments using a wider range of adjective pairs that consider these factors. In addition, the validity of the factors obtained should be verified for all functions in addition to the “good night” function. We predict that future experiments with larger sample sizes, focusing on home appliances in addition to circulators, and exploring the Metaphorical nature of sound in more detail will provide a method for designing sounds for a wider variety of products.

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