

Systematic Design Method of Auditory Interface for Home Appliances

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Abstract: There is a growing interest to introduce auditory interface into home appliances to improve their usability. However two issues hinder the penetration of utilizing sound for home appliances.

(1) High design cost

Information sound design requires both significant expertise and long development time. Information sounds are usually designed by a cut-and-try approach, because no systematic methods are known.

(2) Floods of similar information sounds in residences

Many sounds have been installed in appliances without consistent design rules. Thus, similar sounds like beep are in flood over a home. The residents cannot distinguish these sounds.

In this paper, we propose a systematic design method of auditory interface as below.

(1) Framework of information sounds required for home appliances.

(2) Design rules based on the framework.

Several design rules were supposed on the framework, and brushed up through two experiments with test subjects. One experiment was conducted to find out which of sound parameters was mapped onto an operating function, and the other experiment was conducted to know which of operating functions was awaked by a sound. In these experiments, multivariate analysis was applied to finding out the correlation between sound parameter and operating function. The systematic design method was established through these experiments.

We applied the method to obtain a sound set of an electrical cooking heater and confirmed improvement of usability through an evaluation test.

Key words: *Auditory Interface, Information Sound, Systematic Approach, Design Method, Home Appliances*

1. Introduction

Recently auditory interface is utilized in various home appliances. Deathridge [1] and Gaver [2] pointed out that auditory interface is more effective than visual interface in displaying eventual information. Kramer [3] indicated three features of auditory interface: eye free, rapid detection and alert. For some kinds of home appliances operated in parallel, such as a cooking machine and a washing machine, auditory interface is very important because of these features.

However, the following issues hinder penetration of utilizing sounds for home appliances.

(1) High design cost

Information sound design requires both significant expertise and long development time. Information sounds are usually designed by a cut-and-try approach, because no systematic methods are known.

(2) Floods of similar information sounds in residences.

Many sounds have been installed in appliances without consistent design rules. Thus, similar sounds like beep are in flood over a home. The residents cannot distinguish these sounds.

To solve the above-mentioned issues, a design framework and design rules for information sound have been established.

2. Present Conditions of Utilizing Information Sound

Graver also indicated that the number of sounds should be restricted in practical use because of discernment limitations [2]. It is important to select scenes of using sound carefully so as to reduce the total number of sounds. We surveyed information sounds of 10 categories and 41 home appliances: Cooking heater, Rice cooker, Electric oven range, Refrigerator, Toaster, Dish washing machine, Washing machine, Drying machine, Air conditioner, Oil heater and Water warmer. The information sound for a rice cooker and a washing machine are shown in Table 1, Table 2 for example.

According to the survey, the scenes of using information sounds are categorized into four:

- (1) Feedback for the operation
- (2) Instruction for the next operation
- (3) Report for the machine status
- (4) Alert

Each category of sounds is expressed by repetition pattern of the same frequency monotone sound in many appliances. Thus it is very difficult to understand its meaning by information sound. Moreover, in spite of the same manufacture products, information sounds to the same function is different from each other. The fact exposes that the sounds have not been designed on consistent design rules.

Table 1 Information Sounds for Rice Cookers

| Category | | Rice Cooker | | | | | |
|----------------------------|---|---|--|--|----------------------------|----------------------------|-------------------------------------|
| Product | | A | B | C | D | E | F |
| Feedback for the operation | | menu selection (urgent) "beep" start "be-beep" | *button (pushed) "beep" after that, the machine announces "stop keeping warmth", etc. | *select button "beep" power OFF "beep, beeeep" *cooking "be-beep" | *button (pushed) "beep" | *button (pushed) "beep" | *button (pushed) "beep" |
| | Indication for the next operation | | *timer reservation speech sound: "Set the time, and push the cooking button." | | | | |
| Notifi- cation | Reporting for the status of the machine | *finish "beeeep"x 5 | *finish "beeeep"x 8 *finish keeping warmth speech sound: "Finished cooking, and Start keeping warmth." | *finish "beeeep"x 5 | | | *finish "be-beep, be-beeeep" x 8 |
| | Alerting | | | | | | |

Table 2 Information Sounds for Electrical Washing Machines

| Category | | Washing machine | | | | | | |
|----------------------------|-----------------------------------|------------------------|--|--|---------------------------------|------------------------|--|---|
| Product | | A | B | C | D | E | F | G |
| Feedback for the operation | | button (pushed) "beep" | button (pushed) "beep" | power ON "beep" power OFF "beeeep" | ON/OFF "beep" start "melody" | button (pushed) "beep" | button (pushed) "beep" | power ON "beep" select button "beep" |
| Notification | Indication for the next operation | | | | | | | |
| | Reporting for the machine status | finish "beeeep"x6 | finish "beeeep"x6 | finish "beeeep"x6 | finish "melody" | | finish "beeeep"x6 + switch up | finish "beeeep"x16 |
| Alerting | | | alerting for lid opened "be-be-beep"x5 | Stop washing automatically when the lid being opened | | | alerting for lid opened "be-be-beep"x5 | |

3. Issues and Solutions

These two issues are discussed in this paper.

- (1) High design cost
- (2) Floods of similar information sounds in residences

Lack of design method for auditory interface causes these issues. There are few researches for design method for auditory interface. Wake [4] studied a sound design method with tone and rhythm. However, many sound parameters of other than rhythm and tone are applicable in low cost by the latest evolution of sound devices. Our research aims to establish a systematic design method for information sound with many sound parameters as below.

- (1) Framework of information sounds required for home appliances
- (2) Design rules for sounds on the framework.

Several hypotheses of design rules with many sound parameters were supposed on the framework, and brushed up these hypotheses through two experiments with 40 test subjects. One experiment was conducted to find out which of sound parameters was mapped onto operating function, and the other experiment was conducted to know which of operating functions was awakened by a sound. In these both directions experiments, multivariate analysis was applied to finding out the correlation between sound parameters and functions. The systematic design method was established through these experiments. We applied the method to obtain a sound set for an electrical cooking heater and confirmed improvement of usability through evaluation test. These design processes are shown in Fig .1.

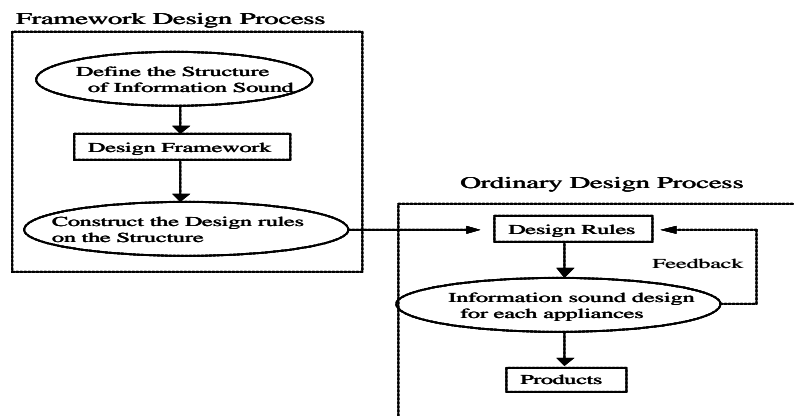


Fig.1 Systematic Design Method of Auditory Interface for Home Appliances

3.1 Framework of the Information sound for Home appliances

We defined a design framework according to the following three viewpoints:

(1) User's position to the machine:

- User and machine are in close or apart when sounding

(2) Depth of interaction with machine (Fig.2):

- First level response: response sound for the machine accepting the operation
- Second level response: response sound for the machine interpreting and performing the operation
- Third level response: response sound for the machine notifying results of the operation

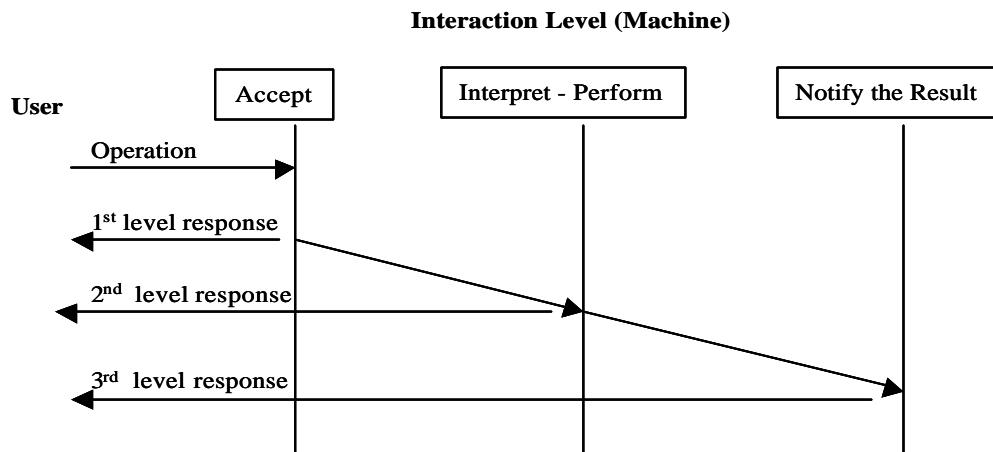


Fig.2 Depth of Interaction between User and Machine

(3) Functional classification of information sound:

- Feedback of the operation
- Notification:
 - Instruction for the next operation
 - Report for the machine status
- Alert

The framework was combined with these three viewpoints (Table 3). Generally, 8 classifications are considered as adequate for discrimination of sounds [5]. The number of functional classifications of the framework is reasonable from this point.

Table 3 Framework of Information Sound Design for Home Appliances

| Functional Classifications | | Depth of interaction | | | User's position to the machine |
|----------------------------|---|-----------------------|-----------------------|-----------------------|--------------------------------|
| | | 1 st level | 2 nd level | 3 rd level | |
| Feedback for the operation | Valid / Invalid | | | | C |
| | Return | | | | C |
| | Cancel | | | | C |
| | Increase/ Decrease (of value, quantity) | | | | C |
| | Item Selection | | | | C |
| Notification | Instruction for the next operation | | | | C/A |
| | Report for the machine status | | | | C/A |
| | Report for the finish | | | | C/A |
| Alert | Alert | | | | C/A |

C: Close, A: Apart, C/A: Close or Apart

3.2 Design Rules for Information Sounds

The design rules for information sound were defined with musical grammar on the framework (Table 4). Sound parameters were assigned to each classification of the framework by the following reasons.

(1) User’s position to the machine

- Sound volume: User’s position settles sound volume.

(2) Depth of the interaction and functional classification for the information sound

- Monotone: Monotone sound is assigned to the first level response. Because the sound is a substitution for the mechanical response and the sound is utilized frequently at every operation. Conciseness is most important for the first level response.

- Chord: Chord is assigned to the feedback of the operation for attaching expression.

Major chord is assigned to “Valid response” and Minor chord is to “Invalid response”.

“Cancel” and “Return” are considered as valid operations so that major chord is assigned to the response for them.

Ascent chord is assigned to “Increase” and Descent chord is assigned to “Decrease” operation.

- Arpeggio: Arpeggio is assigned to the notification. The notification requires discriminatory and redundancy because it is recognized regardless of User’s position.

Ascent chord arpeggio is assigned to the instruction for the next operation.

Descent chord arpeggio is assigned to the report for the machine status.

- Tremolo: Tremolo is assigned to the alert to provide a feeling of tension.

Table 4 Design Rules of Information Sounds

| Functional classifications | | Depth of interaction | | | user’s position to the machine | Characteristics of each information sound | Design rules |
|----------------------------|---|-----------------------|-----------------------|-----------------------|--------------------------------|---|---|
| | | 1 st level | 2 nd level | 3 rd level | | | |
| Feedback for the operation | Valid / Invalid | | | | C | • Short | Valid : Major Chord Invalid : Minor Chord |
| | Return | | | | C | • Short | Major Chord |
| | Cancel | | | | C | • Short | Major Chord |
| | Increase/ Decrease (of value, quantity) | | | | C | • Short | Increase: Ascent chord Decrease: Descent chord |
| | Item Selection | | | | C | • Short | Monotone |
| Notification | Instruction for the next operation | | | | C/A | • Rather long • Large sound | Arpeggio (ascent chord) |
| | Report for the machine status | | | | C/A | • Rather short • Large sound | Arpeggio (undulations) Accelerando |
| | Report for the finish | | | | C/A | • Rather long • Large sound | Arpeggio (descent chord) Melodious |
| Alert | Alert | | | | C/A | • Rather long • Large sound | Tremolo |

3.3 Evaluation of the Design Rules

We evaluated the information sound through two experiments with 40 test subjects.

(1) Experiment-1 was conducted to find out which of sound parameter was mapped onto the function

(2) Experiment-2 was conducted to know which of functions was awaked by each sound.

In the experiments, multivariate analysis was applied to finding out the correlation between 10 sound parameters and 8 functions.

3.3.1 Experiment-1

(1) Test process

In order to evaluate sounds, some operation scenes should be assumed. A cooking heater was chosen because of information sound significance.

- Define test cases for the information sound (Table 5)
- Provide two sets of the information sound (Group -A and Group-B) designed by two composers based on the same design rules independently.
- Experiment which of sounds affords the operating function.

The experiment was performed through the following procedure.

- Subjects marked information sound at the order of desirable for each function. The subjects described the reason why the sound was desirable by sentences.
- Subjects consisted of 20 males and 20 females.

(2) Test Results

- High scored sample number (ex. D1A3, D1B2) of information sound is shown in Table 5.
- Reasons of high scored were analyzed by multivariate analysis (principle component analysis)[6]. Each sound parameter weight for the analysis is defined in Table 6.
- Results of the multivariate analysis are shown in the Table 7.

Table 5 Experiment -1

















| Test Case | Function | Test Samples | High Scored Test Sample |
|-----------|--------------------------------|--|--|
| CASE1 | Valid | Group-A 5-samples D1A1-D1A5 Group-B 5-samples D1B1-D1B5 | (Group-A) D1A3  (Group-B) D1B2  |
| CASE2 | Invalid | Group-A 5-samples D2A1-D2A5 Group-B 5-samples D2B1-D2B5 | (Group-A) D2A5  (Group-B) D2B5  |
| CASE3 | Increase / Decrease | Group-A 5-samples D31A1-D31A5 5-samples D32A1-D32A5 Group-B 5-samples D2B1-D2B5 5-samples D32B1-D32B5 | (Group-A) D31A4  (Group-B) D31B3  |
| CASE4 | Item Selection | Group-A 2-samples D4A1-D2A2 Group-B 2-samples D4B1-D2B2 | (Group-A) D4A1  (Group-B) D4B1  |
| CASE5 | Report of the Status | Group-A 6-samples D5A1-D2A6 Group-B 6-samples D5B1-D2B6 | (Group-A) D5A6  (Group-B) D5B4  |
| CASE6 | Report if the Finish | Group-A 3-samples D6A1-D2A3 Group-B 5-samples D6B1-D2B5 | (Group-A) D6A3  (Group-B) D6B2  |
| CASE7 | Instruction for next Operation | Group-A 3-samples D7A1-D7A3 Group-B 5-samples D7B1-D7B5 | (Group-A) D7A1  (Group-B) D7B4  |
| CASE8 | Alert | Group-A 2-samples D8A1 ~ D2A2 Group-B 5-samples D8B1 ~ D2B5 | (Group-A) D8A1  (Group-B) D8B2  |

Table 6 Sound Parameters for Analysis and Weight Assignment

| Sound parameters | Weight of each parameter |
|---|---|
| Total duration (long / short) | < 0.5[sec] : 0 point , 0.5 ~ 0.625[sec] : 1 point, 0.625[sec] < : 2 points |
| Number of the musical notes (plural / singular) | Plural : 2 points, Singular : 0 point (in a time scale) |
| Chord / Single Sound | Chord : 2 points, Single Sound : 0 point |
| Major / Minor | Major : 2 points, Minor : 0 point, None of the each(ex. Single Sound) : 1 point |
| Pitch (high / low) | < o5 : 0 point, o5 : 1 point, o5 < : 2 points |
| Tempo (fast / slow) | < = 96 : 0 point, = 96 ~ 120 : 1 point, =120 < : 2 points |
| Undulations / Flat | Undulations : 2 points, Flat : 0 point |
| Musical scale (ascent / descent) | Ascent : 2 points, Flat (or single sound) : 1 point, Descent : 0 point |
| Duration(ending) (long / short) | Long(relative) : 2 points, Short : 0 point |
| Trailing note (existent / nonexistent) | Existent : 2 points, Nonexistent : 0 point |

Table 7 Results of the Multivariate Analysis of Experiment-1

| Test Case | Function | Characteristics of the high scored information sounds | |
|-----------|------------------------------------|---|---|
| CASE1 | Valid | Group-A (D1A3, D1A2) | •Chord + High pitch + Long duration(ending) |
| | | Group-B (D1B2, D1B1) | •Trailing note + Single sound |
| CASE 2 | Invalid | Group-A (D2A5) | •Singular notes + Long duration(ending) |
| | | Group-B (D2B5) | •Singular notes + Chord |
| CASE3 | Increase/Decrease | Group-A (D31A4 D32A2/4) | •Ascent/Descent + Fast(tempo) |
| | | Group-B (D31B3 D32B3/4) | •Ascent/Descent + Fast(tempo) |
| CASE4 | Item Selection | Group-A (D4A1) | •(Pitch)Middle level + Singular notes |
| | | Group-B (D4B1) | •Short duration(total) |
| CASE5 | Report of the status | Group-A (D5A6/3) | •Ascent scale(ending) + Long duration(ending) |
| | | Group-B (D5B4) | •Ascent scale(ending) + Fast(tempo) •Leading tone is used at the end of the arpeggio |
| CASE6 | Report of the finish | Group-A (D6A3) | •Ascent scale(ending) + Long duration(ending) |
| | | Group-B (D6B2) | •Ascent scale(ending) + Long duration(ending) •Solved chord on harmony |
| CASE7 | Instruction for the next operation | Group-A (D7A1) | •Ascent scale(ending) + Long duration(ending) |
| | | Group-B (D7B4,D7B5) | •Long duration(total) + Trailing note •Unsolved chord on harmony |
| CASE8 | Alert | Group-A (D8A1) | •Undulations |
| | | Group-B (D8B2/5) | •(Pitch)Middle level + Simple sound |

3.3.2 Experiment -2

A sound set was selected by the highest scored sounds from Group-A and Group-B (Table 8). Experiment -2 was carried out to know which of functions was awaked by a sound.

(1) Test process

Test cases were simplified by the following reason.

- “Item selection” was removed because the sound was too simple for the experiment.
- “Instruction for the next operation ”and “Report for the machine status ” were unified in one case because it was difficult to understand differences between each scenes.
- Only a “increase operation” was examined. Because it was easy to guess effect of “decrease ” by being examined “increase” case.

The experiment was performed through the following procedure.

- Subjects listened to the sounds and chose the most suitable function from the function list.
- Subject answered which of sounds between Group-A and Group-B was more intelligible.
- Subjects consist of 20 males and 20 females.

Table 8 Exeperiment-2

| | Function | Use case | Assigned sounds | |
|-------|----------------------|--|-----------------|---------|
| | | | Group-A | Group-B |
| Case1 | Valid | Indicate the ON status when pushing the ON button. | D1A3 | D1B2 |
| Case2 | Invalid | Indicate that the operation is invalid or wrong. | D2A5 | D2B5 |
| Case3 | Increase | Indicate increasing the value on display (e.g. Temperature) | D31A4 | D31B3 |
| Case4 | Report of the status | Inform that the value got closed to the set value. (Inform you when the temperature got 70 to the set value 90 .) | D5A6 | D5B4 |
| Case5 | Report of the finish | Inform that the value got reached the set value. | D6A3 | D6B2 |
| Case6 | Alert | Alert to the danger or undesirable status. (e.g. water boils over) | D8A1 | D8B2 |

(2) Test Results

The result of Group-A and Group-B are shown in Table 9 and Table 10.

Table 9 Results of Experiment-2 (Group-A)

| Use case- | D1A3 | D2A5 | D31A4 | D5A6 | D6A3 | D8A1 | Total Subjects | Correct | Incorrect | Rate of correct answers [%] |
|-----------|------|------|-------|------|------|------|----------------|---------|-----------|-----------------------------|
| Case1 | 7 | 0 | 30 | 3 | 0 | 0 | 40 | 30 | 10 | 75.0 |
| Case2 | 5 | 1 | 0 | 0 | 34 | 0 | 40 | 34 | 6 | 85.0 |
| Case3 | 25 | 3 | 4 | 4 | 0 | 4 | 40 | 25 | 15 | 62.5 |
| Case4 | 0 | 2 | 0 | 29 | 3 | 6 | 40 | 29 | 11 | 72.5 |
| Case5 | 1 | 0 | 6 | 3 | 1 | 29 | 40 | 29 | 11 | 72.5 |
| Case6 | 2 | 34 | 0 | 1 | 2 | 1 | 40 | 34 | 6 | 85.0 |

Table 10 Results of Experiment-2 (Group-B)

| Use case- | D1B2 | D2B5 | D31B3 | D5B4 | D6B2 | D8B2 | Total Subjects | Correct | Incorrect | Rate of correct answers [%] |
|-----------|------|------|-------|------|------|------|----------------|---------|-----------|-----------------------------|
| Case1 | 0 | 36 | 0 | 4 | 0 | 0 | 40 | 36 | 4 | 90.0 |
| Case2 | 0 | 2 | 2 | 35 | 1 | 0 | 40 | 35 | 5 | 87.5 |
| Case3 | 0 | 0 | 32 | 1 | 0 | 7 | 40 | 32 | 8 | 80.0 |
| Case4 | 5 | 0 | 4 | 0 | 0 | 31 | 40 | 31 | 9 | 77.5 |
| Case5 | 35 | 2 | 1 | 0 | 0 | 2 | 40 | 35 | 5 | 87.5 |
| Case6 | 0 | 0 | 1 | 0 | 39 | 0 | 40 | 39 | 1 | 97.5 |

Correct answers rate were obtained 62.5-97.5% in both Group-A and Group-B. Correlation between the use case and the correct/incorrect answer was not observed. On the other hand, strong correlation was observed between use case and the information sound chosen. Sounds were chosen correctly to each use case independently. Consequently, It was confirmed that sound parameters were mapped appropriately to the operating functions by the experiment-1.

Subjects esteemed that Group-A was more intelligible than Group-B in questionnaire (Table11).







Table 11 Results of Questionnaire in Experiment-2

| Use case | Support Group-A | Support Group-B | Differences | More Intelligible Sound |
|----------|-----------------|-----------------|-------------|-------------------------|
| Case1 | 24 | 16 | 8 | Group-A |
| Case2 | 21 | 19 | 2 | Group-A |
| Case3 | 31 | 9 | 22 | Group-A |
| Case4 | 28 | 12 | 16 | Group-A |
| Case5 | 13 | 27 | 14 | Group-B |
| Case6 | 21 | 19 | 2 | Group-A |

The best sound set was chosen through both directions experiments from the following viewpoints (Table 12).

- Sounds for same categorized functions were chosen from same composer's sounds to give a unified feeling.
- For the first level response sound, intelligible is more important than distinguishable, because they are learnt easily in everyday operations.
- For the second and third level response sound, Distinguishable is more important than intelligible, because they are heard distantly in many cases.

Table 12 Best Information Sound Set through two Experiments

| Function | Information sounds |
|----------------------|--|
| Valid (OK) | D1A3  |
| Invalid (NG) | D2A5  |
| Increase | D31A4  |
| Report of the status | D5B4  |
| Report of the finish | D6B2  |
| Alert | D8B2  |

3.4 Brushing up the Design rules

We brushed up the design rules through the experiments (Table 13).

- Major chord was assigned for “Valid” operation for the purpose of giving a bright image. Furthermore, pregnant sound parameter was added for giving feeling of achievement.
- Minor chord was assigned for “Invalid” operation for giving dark image. Furthermore, Non- pregnant sound parameter was added for not-remaining disagreeable image.
- Unsolved chord on harmony was assigned for “Instruction” and “ Report” because unsolved on harmony expresses continuation feeling.
- Solved chord on harmony was assigned to “Finish” because solved chord expresses accomplishment feeling.

Table 13 Design Rules of Information Sounds for Home Appliances

| Category | Function | Position to the machine | Chord | Duration (Total) | Tempo | Other characteristics |
|----------------------------|------------------------------------|-------------------------|----------|------------------|-------|--|
| Feedback for the operation | Valid | C | Chord | Short | Fast | Major chord, Trailing note |
| | Invalid | | | | | Minor chord, Short duration (ending) |
| | Increase/Decrease | | | | | Ascent/Descent scale (Single sound) |
| | Item Selection | | Monotone | | | Singular note |
| Notification | Instruction for the next operation | C/A | Arpeggio | Long | Slow | Unsolved chord on harmony Large sound |
| | Report for the machine status | | | | | Solved chord on harmony Large sound |
| | Report for the finish | | | | | |
| Alert | Alert | | Tremolo | | Fast | Repetition (unlimited) Large sound |

4. Prototyping Cocking Heater Information Sound with the Design Rules

A set of information sounds for an electrical cooking heater was designed based on the design rules and they were installed into a prototype machine. A usability test was conducted on the prototype (Fig.3).



Fig.3 Electrical Cooking Heater Prototype for Experiment

(1) Test Process

- The task document was handed to subjects. The examiner explained each function of the prototype with the document at every task.
- Subjects operated the cooking heater according to the document and marked score in five stages for “Desirability” and “Intelligibility” of the sound.
- The machine was designed as two sound sets exchangeable so as to compare the design rule based sound set with the conventional beep sound set.
- Subjects consist of 20 males and females each.

(2) Test Results

The results of the experiment are shown in Fig.4 and Fig.5. The design rule based sound set was highly evaluated in both desirability and intelligibility. Only for "Valid" operation, the conventional sound obtained higher evaluation. Beep sound was preferred for simple and frequent operation. This fact supported the validity of the design rules for the first level response. Improvement of the usability was confirmed through the experiment.

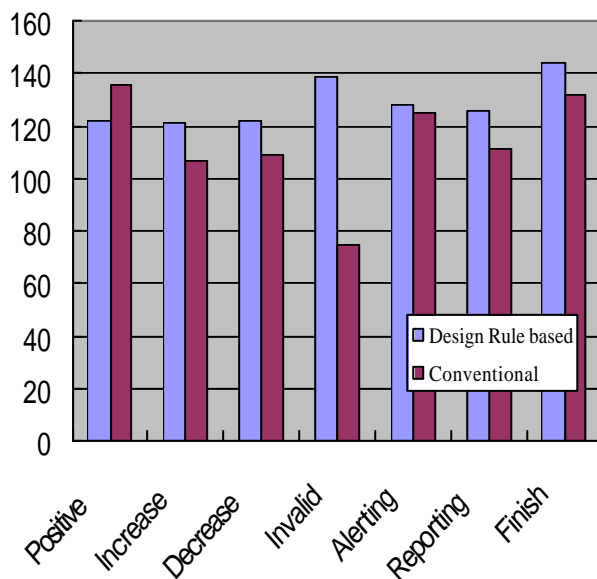


Fig.4 Results of Experiment (Desirability)

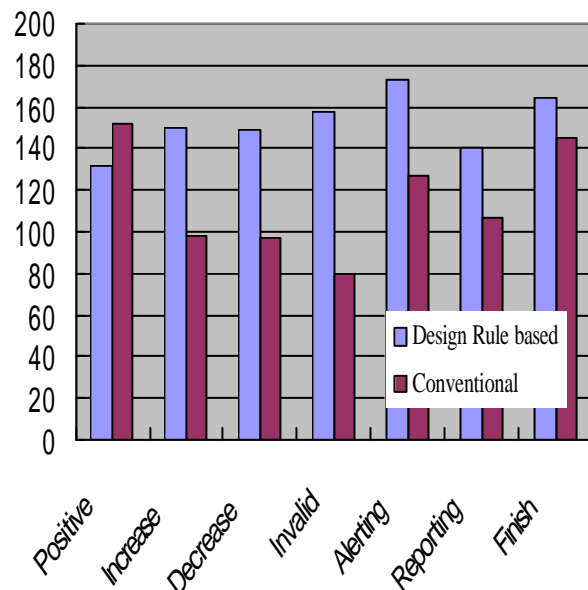


Fig.5 Results of Experiment (Intelligibility)

5. Conclusions

The systematic design method of auditory interface for Home appliances was proposed.

- Framework of information sounds required for home appliances
- Design rules with musical grammar based on the framework.

Several hypotheses of design rules were supposed with musical grammar, and brushed up these hypotheses through two experiments with 40 test subjects. One experiment was conducted to find out which of sound parameters was mapped onto the operating function, and the other experiment was carried out to know which of functions was awaked by a sound. In the experiments, multivariate analysis was applied to finding out the correlation between sound parameters and each function. Consequently, It is confirmed that the mapping between the sound parameter to the operating function chosen by the experiment-1 was highly coordinated. The method was applied to obtain a set of sounds for an electrical cooking heater. Usability test has been conducted by utilizing the prototype. We confirmed that the information sounds on the design rules were excellent in both desirability and intelligibility.

However, a design rule to identify appliances has not been examined yet. For identifying appliances, sound tone by using musical instrument is considered as a hypothesis of design rule. And the method was applied for only one appliance. Improvement of design efficiency has not been estimated yet too. We will evaluate the design efficiency by applying the method to various home appliances. These will be reported in the future.

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