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Continuous judgment of sound quality of electric home appliances

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ABSTRACT

The sound quality of machinery noises is multi-dimensional and is often examined using semantic differential. In this case the overall impression of sound quality is judged. However, sound quality may vary according to the temporal stream of sounds. In this study, sound quality of electric home appliances was judged using the continuous judgment by line length. Forty-one kinds of the sound of home electric appliances were connected in random sequences with a slight interval between the sounds. The original sounds and their modified sounds were included in the stimulus of 8 min. The experiment was conducted in Technische Universiät München. Ten German participants joined the experiment. They conducted three sessions in which they judged the instantaneous impression of loudness, sharpness and unpleasantness, respectively. The subjective responses were sampled every 100ms. The values of every 100ms of L_{Aeq}, LLz(p), calculated sharpness and comfort index (CI) were measured. As a whole the physical metrics showed good correlation with subjective judgments. On the other hand, when the relation between physical metrics and subjective judgments was examined in a limited portion, different tendency was found. It would be better to examine the sound quality along the temporal stream in detail in order to find the clues to improve the sound quality.

Keywords: Sound Quality, Home Electric Appliance, Continuous Judgment
Transmission I-INCE Classification of Subjects Number(s): 63.7

1. INTRODUCTION

Machinery noises are usually perceived as being unpleasant. However, since they give us various kinds of information such as the approach of vehicles from behind, improvement of sound quality of machinery noise is desired as well as the reduction of the sound level. Many studies have been conducted concerning the sound quality of machinery noise [e.g. 1-3]. Namba and Kuwano with their colleagues have conducted experiments of sound quality of environmental noise [4], helicopter noise [5], air-conditioner noise [6], accelerating noise [7] and rumble noise [8] using semantic differential. As a result of factor analysis in these studies, three factors were usually extracted. They are "powerful" factor, "metallic" factor and "pleasant" factor.

In order to design machines with good sound quality, it is desirable to predict the sound quality using physical metrics. The impression of powerful factor usually shows good correlation with L_{Aeq} [9] and/or loudness level based on ISO 532B (LLz) [10]. Kuwano et al. [11] have proposed LLz(P) in order to apply LLz to temporally varying sounds. LLz(P) is the mean of instantaneous loudness level calculated on energy basis. That is, LLz(P) is the combination of ISO1996 [9] and ISO532. The impression of metallic factor usually shows good correlation with calculated sharpness [12]. The impression of pleasant factor is complex and it is not easy to predict the impression of pleasant factor by a single physical metric. Many physical metrics may contribute to the impression of pleasant factor. Among them it is reported that loudness and sharpness have a large effect on the impression of pleasant factor [13, 14]. In reference to these studies, Kuwano et al. have proposed

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"comfort index (*CI*)" as a metric for the impression of pleasant factor [15]. *CI* is defined by the following equation.

$CI = 1/10\ L_{Aeq} + \text{sharpness}$

L_{Aeq} in dB, sharpness in acum

Also LLz(P) can be used in place of L_{Aeq}. *CI* was found to be a good index of sound quality [16-18]. Examples are shown in Figures 1 and 2.

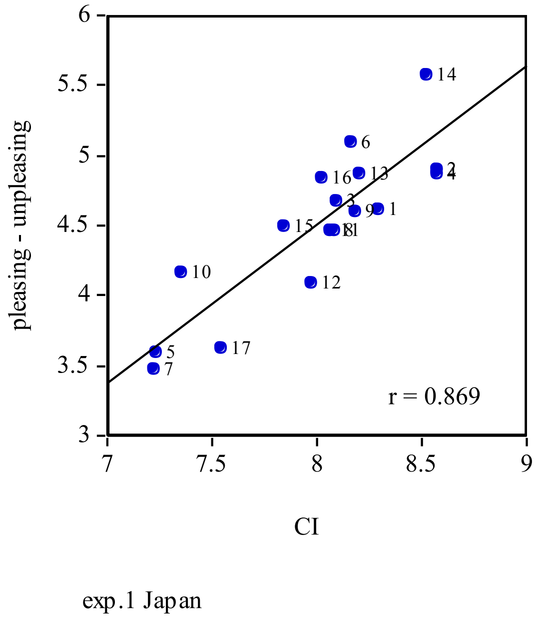

Figure 1Relation between unpleasant impression and *CI* of the sound of copying machines [16, 17].

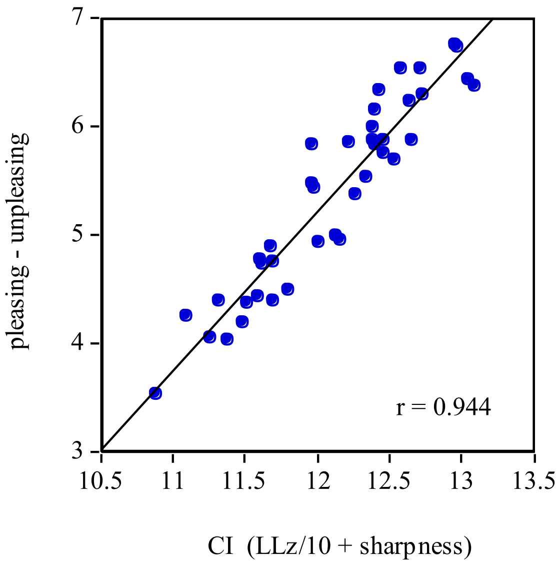

Figure 2 Relation between unpleasant impression and *CI* of the sound of dental drills [18].

When sound quality of machinery noises is judged using semantic differential, only the overall impression of sound quality is judged. However, sound quality may vary according to the temporal stream. In this study the instantaneous impression of sound quality was examined using the method of continuous judgment by line length [5].

2. EXPERIMENT

2.1 Stimulus

The sounds from four kinds of washing machine, two kinds of microwave oven, nine kinds of vacuum cleaner and four kinds of dish washing machine were recorded. They were carefully listened and the portions to be improved were selected in reference to physical analyses of their frequency components and level fluctuation. In total 19 original sounds were selected. These sounds were modified by reducing sound levels, prominent frequency components or eliminating impulsive components. In total 41 sounds including 19 original sounds and 22 their modified sounds were used in the experiment. The duration was from 5 to 32 s. The duration was decided taking the operation of each machine into consideration. These forty-one sounds were successively connected with the interval of 5 ms for continuous judgment. The total duration was about 8 min.

2.2 Procedure

The instantaneous impression of the loudness, sharpness and unpleasantness of the sound was judged using the method of continuous judgment by line length. The participants were asked to judge continuously by matching the length of a line on a monitor using a mouse so that the length of the line corresponds to their impression at each moment. After a short training session, they conducted three sessions. Half of the participants judged in the order of the loudness, sharpness and unpleasantness. The other half judged in the order of sharpness, loudness and unpleasantness. All the participants agreed to participate in the experiment before starting experiment. The experiment was conducted at the Institute of Man-Machine Communication in Technische Universität München.

2.3 Equipment

The sound was reproduced with a computer (DEL Precision 380) and presented to the both ears of the participants in a sound proof room through an audio interface (RME face), a free field equalizer and headphones (Beyer DT-48).

2.4 Participant

Two females and eight males aged between 25 and 47 (average 29.8 years old) with normal hearing ability participated in the experiment. All were German.

3. RESULTS AND DISCUSION

3.1 Relation between physical metrics and subjective judgments

The continuous judgment was sampled every 100 ms. L_{Aeq}, Loudness level (LLz(p))[11], sharpness [12] and comfort index [15] was calculated every 100 ms using a software (OSCOPE; Ono Sokki).

Relationships between L_{Aeq}, loudness level (LLz(P)) and instantaneous loudness judgments, between calculated sharpness and instantaneous sharpness judgments and between comfort index (*CI*) and instantaneous unpleasantness judgments are shown Figures 3-7.

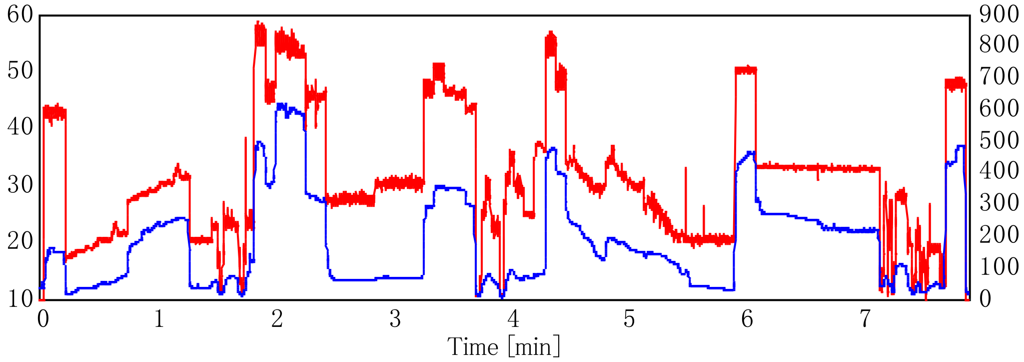

Figure 3 Relation between loudness judgment and L_{Aeq}. Red line indicates L_{Aeq} calculated every 100ms and blue line indicates loudness judgment sampled every 100 ms. Fairly good correlation can be seen between them (r=0.890).

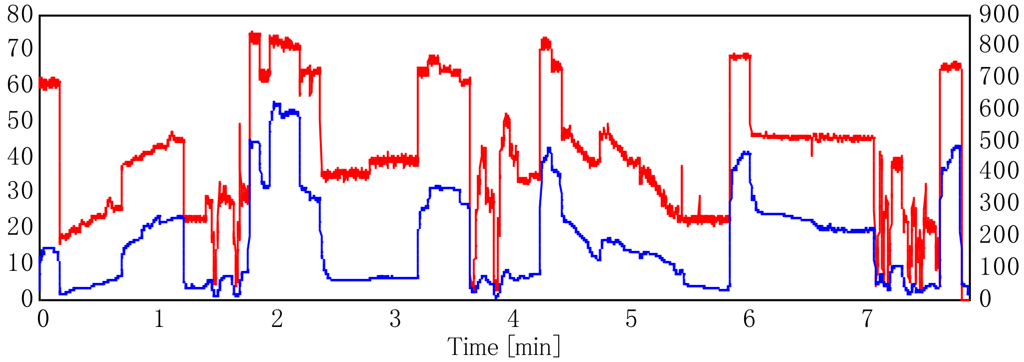

Figure 4 Relation between loudness judgment and *LL*(P). Red line indicates *LL*(P) calculated every 100ms and blue line indicates loudness judgment sampled every 100 ms. Fairly good correlation can be seen between them (r=0.882).

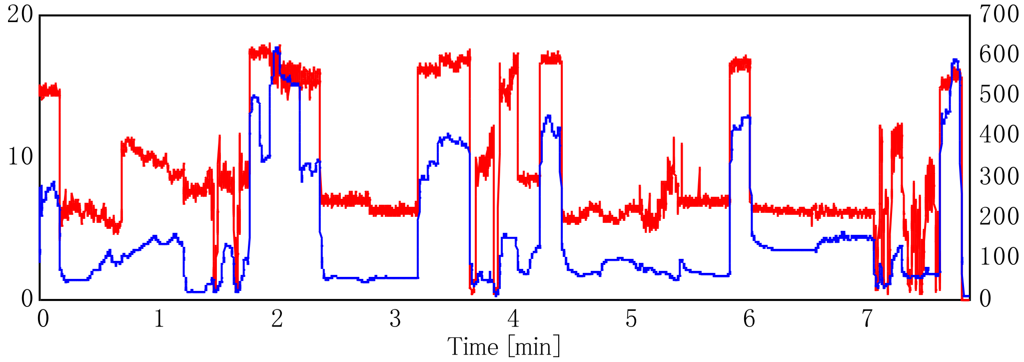

Figure 5 Relation between sharpness judgment and calculated sharpness. Red line indicates sharpness calculated every 100ms and blue line indicates sharpness judgment sampled every 100 ms. Fairly good correlation can be seen between them (r=0.842). Note that the values of sharpness were multiplied 10 times in order to draw clear figure.

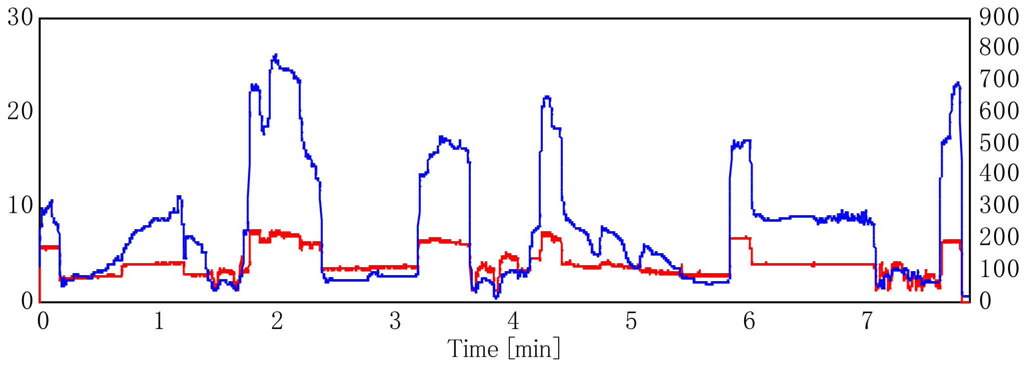

Figure 6 Relation between unpleasantness judgment and *CI* (L_{Aeq}). Red line indicates *CI* (L_{Aeq}) calculated every 100ms and blue line indicates unpleasantness judgment sampled every 100 ms. Fairly good correlation can be seen between them (r=0.891).

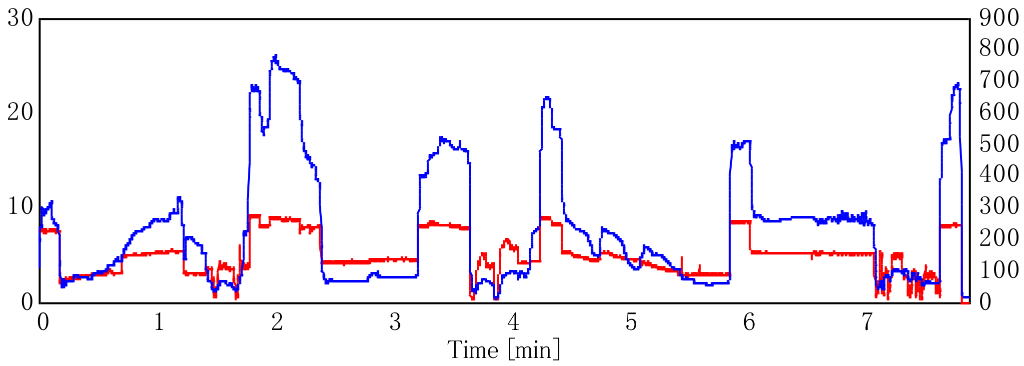

Figure 7 Relation between unpleasantness judgment and *CI* (*LL*). Red line indicates *CI* (*LL*) calculated every 100ms and blue line indicates unpleasantness judgment sampled every 100 ms. Fairly good correlation can be seen between them (r=0.878).

When the relations between physical metrics and subjective judgment of every 100ms were examined for the whole sound (8 mim), fairly good correlation was found as shown in Figures 3-6. That is, instantaneous impression of loudness, sharpness and unpleasantness shows good correlation with L_{Aeq} and loudness level, calculated sharpness and *CI*, respectively.

3.2 Analysis of a portion with a prominent temporal pattern

One of the merits of the continuous judgment is that the results can be examined from various viewpoints after the experiment is over. In the present experiment, various sounds of home electric appliances were included. As an example of the further analysis, the portion where the sound of vacuum cleaner was included was examined. The duration of the portion was 17s and many impulsive components were included in this portion.

The relation between physical metrics and subjective judgment of every 100ms were examined. The results are shown in Figures 8-10. As shown in these figures, it was found that loudness judgment showed fairly good correlation with *LL*(P) in the instantaneous judgment in this portion (Figure 8). Also, unpleasantness judgment showed high correlation with *CI* based on *LL*(P) (Figure10). On the other hand, little correlation was found between sharpness judgment and calculated sharpness (Figure 9). One of the reasons why there was little correlation in the case of sharpness may be due to the poor tracking ability of the participants to the rapid change of the impression of sharpness. This should be carefully examined by the further analysis.

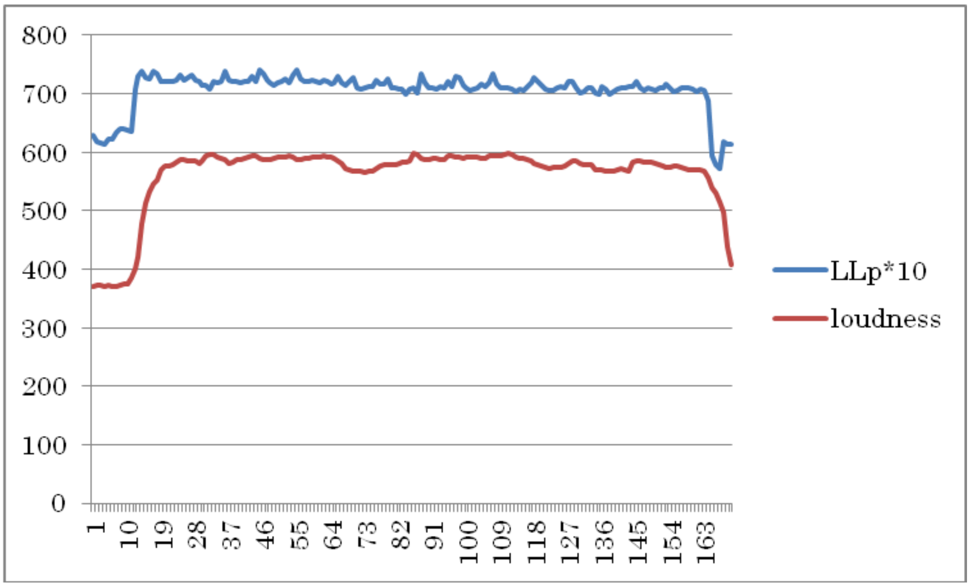

Figure 8 Temporal change of *LL*(P) and loudness judgments of every 100ms in the portion where impulsive sounds were included in the sound from a vacuum cleaner. Fairly good correlation between *LL*(P) and loudness judgment can be seen (r=0.774). Note that the values of *LL*(P) were multiplied 10 times and the numeral of temporal axis indicates by the unit of 100 ms.

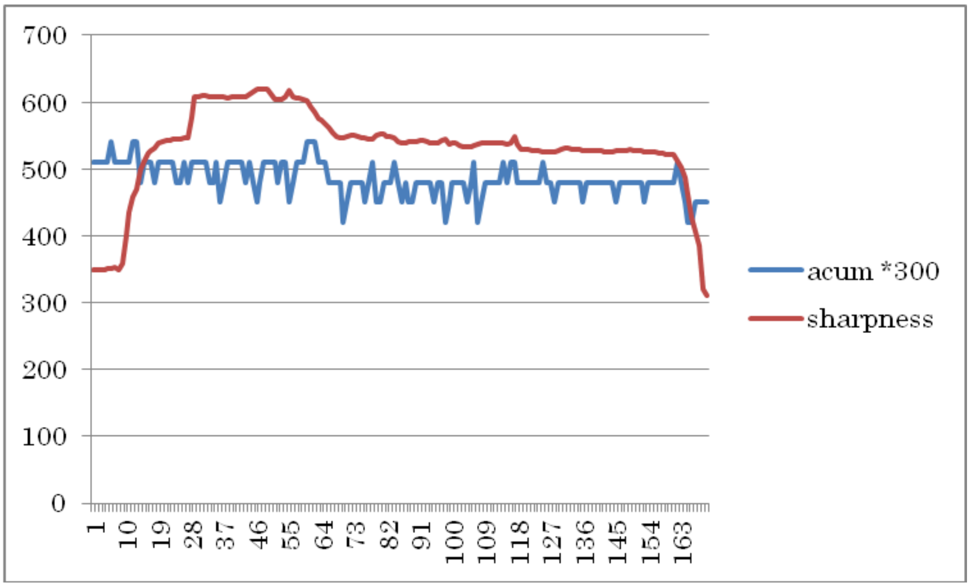

Figure 9 Temporal change of calculated sharpness and sharpness judgments of every 100ms in the portion where impulsive sounds were included in the sound from a vacuum cleaner. Little correlation between calculated sharpness and sharpness judgment is found (r=0.054). Note that the values of calculated sharpness were multiplied 300 times and the numeral of temporal axis indicates by the unit of 100 ms.

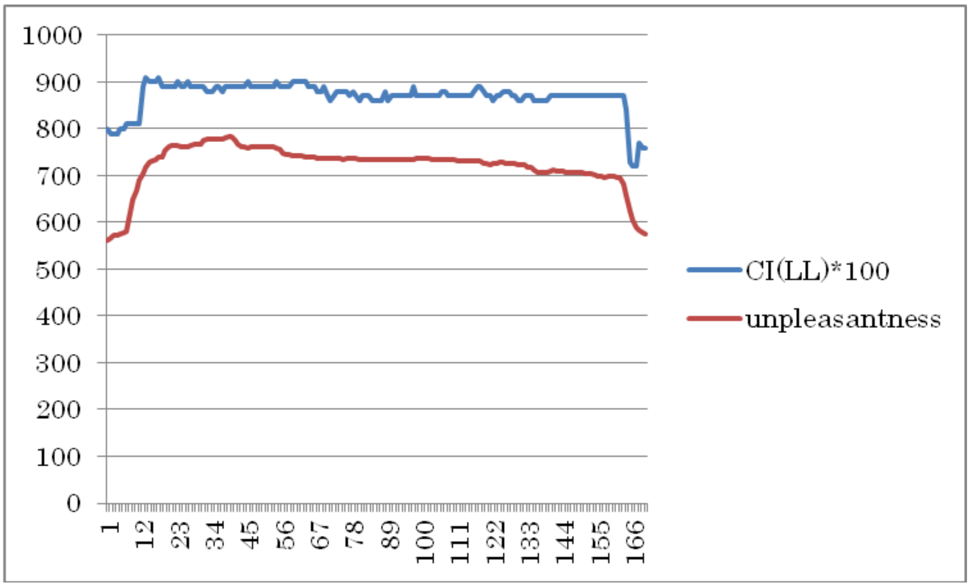

Figure 10 Temporal change of *CI* (*LL*) and unpleasantness judgments of every 100ms in the portion where impulsive sounds were included in the sound from a vacuum cleaner. Good correlation can be seen (r=0.870). Note that the values of *CI* (*LL*(P)) were multiplied 100 times and the numeral of temporal axis indicates by the unit of 100 ms.

4. FINAL REMARKS

The sound quality of electric home appliances was judged using the continuous judgment by line length. The impressions of loudness, sharpness and unpleasantness were judged continuously. The subjective responses were sampled every 100ms. The values of every 100ms of L_{Aeq}, *LL*z(P), calculated sharpness and comfort index (*CI*) were measured. When the sound of 8 m was examined as a whole, the physical metrics showed good correlation with subjective judgments. That is, instantaneous impression of loudness, sharpness and unpleasantness shows good correlation with L_{Aeq} and loudness level, calculated sharpness and *CI*, respectively.

On the other hand, when the relation between physical metrics and subjective judgments was examined in a limited portion, different tendency was found. It would be better to examine the sound quality along the temporal stream in detail in order to find the clues to improve the sound quality.

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