Investigation of Feature Quantity in Sound Signal and Feeling Impression Using PCA

Yusuke Kawakami[*], Tetsuo Hattori
Graduate School of Engineering, Kagawa University, 2217-20, Hayashi-Cho
Takamatsu, Kagawa 761-0396, Japan

Hiromichi Kawano
NTT Advanced Technology Corporation, 19-18, Nakamachi
Musashino, Tokyo 180-0006, Japan

Tetsuya Izumi
Micro-Technica Co., ltd., 3-12-2, Higashi-Ikebukuro
Toshima, Tokyo 170-0013, Japan
E-mail: s11d621@stmail.eng.kagawa-u.ac.jp, hattori@eng.kagawa-u.ac.jp,
hiromichi.kawano@ntt-at.co.jp, t-izumi@microtechnica.co.jp
www.kagawa-u.ac.jp

Abstract

This paper investigates the relationship between feature quantity of sound signal and feeling impression using PCA. As the feature quantity, we use Fluctuation value and sum of squared errors (Residual) which is calculated by regression analysis of sound signal, in the same way as our previous paper. In order to investigate the feeling impression and effect from sound signal, we have used a questionnaire survey method. As a result, we have found that the feeling response of examinees can be classified into three groups by a clustering analysis. And also we have obtained the results of PCA for the feeling effects depending on each group of examinees and four kinds of frequency zone of sound signal. we also discuss the analysis results on the Kansei (or feeling) effect.

Keywords: Signal processing, Fluctuation, Intercept, Sum of squared errors, Feeling impression, PCA

1. Introduction

Recently, 1/f fluctuation in various fields of signal has been actively researched, and it brings about an effect of such healing as a human being psychologically feels at ease, if there is a 1/f relation between the power spectrum of the signal and the frequency f [1-7]. However, we focused that the power spectrum have same fluctuation but the distribution are different. And we doubted the strong influence of the emotional impression factors other than fluctuation value.[8]

Therefore, in the previous research, we have defined three kinds of parameters such as fluctuation value (or Fluctuation), intercept (or Intercept), and sum of squared errors (or Residual) as feature quantity in sound signal obtained from the calculation of the signals' fluctuation degree. And we have investigated the relation between feeling impression and those parameters, by using multiple regression analysis[8]. And we eliminate "Intercept" from the analysis, because this quantity (or parameter) is substantially equal to the volume of sound[8].

Moreover we had considered possibility of the effect of feeling impression from frequency domains. So we divided into three frequency domains (Low Frequency (LF); 0~300Hz, Middle Frequency (MF); 300~1000Hz, High Frequency (HF); 1000~22050Hz) and analyzed each domain[10, 11, 16].

As the results, we have understood that feeling impression have an impact on Residual more than

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Fluctuation, especially high frequency. In the regression analysis, we can be seen the impact of the sound features for the evaluation value of individual sensibility adjective items (for example, bright, fast, etc.). Although, it is difficult to capture the main factors on the relation between feature quantity of sound which presented to examinees, and feeling impression of examinees.

In this paper we analyze the affect of the feeling impression, from the music's Fluctuation and Residual, by use of principle component analysis. At first, we investigate the feeling impression of the music by using questionnaire survey. Then, from result we separate the examinees into the groups using clustering analysis.

After that, we perform the PCA by the feeling impression or feature quantity of sound signal each frequency domains. Furthermore we analyze relationship between feeling impression, and Fluctuation or Residual through the correspondence relationship of principal component axis.

2. Investigation between 3 Parameters Accompanying on the Calculation Fluctuation value (3PACF) and Feeling Impression

2.1. *Fluctuation and 3PACF*

Among fluctuations, the well-known $1/f$ fluctuation means that the power spectrum (PS) of a signal is proportional to the $1/f$ of frequency. Moreover, it is pointed out that there is an effect that a human being feels pleasantness[1-6]. Fig. 1 (a) is shown the conceptual image of PS. Let $Y(f)$ and $\varepsilon(f)$ be the power of PS and its error, respectively. And we define the PS which is shown in Fig. 1(a) as Eq. (1).

$$Y(f) = \frac{k}{f^a} + \varepsilon(f) \qquad (1)$$

Taking the logarithm of both sides,

$$\log Y(f) = \log\left(\frac{k}{f^a} + \varepsilon(f)\right) = \log\left\{\frac{k}{f^a}\left(1+\tilde{\varepsilon}(f)\right)\right\}$$
$$= \log\left(\frac{k}{f^a}\right) + \log(1+\tilde{\varepsilon}(f))$$
$$\log Y(f) = -a\log f + \log k + \log(1+\tilde{\varepsilon}(f)) \qquad (2)$$

$\hat{\varepsilon}(f)$ and $y(f)$ define $\hat{\varepsilon}(f) \cong \log(1+\tilde{\varepsilon}(f))$ and $y(f) \equiv \log Y(f)$ respectively, we derive Eq. (3).

$$y(f) = -a\log f + \log k + \hat{\varepsilon}(f)$$
$$\cong -a\log f + b + \hat{\varepsilon}(f) \qquad (3)$$

Fig. 1 (b) shows the regression line of Eq. 3. The vertical axis and the horizontal axis are logarithm of PS and logarithm of frequency f, respectively. In this paper, we define the absolute-degree of the regression line a "Fluctuation". Then, we define the intercept of the regression line ("Intercept") as b, and we also define the error from the line as e[8]. Furthermore, we define the sum of squared errors ("Residual") as Eq. (4). In Eq. (4), y and Y mean the actual measurement value and the theoretical value, respectively[8].

$$s = \sum_i e_i^2 = \sum_i (y_i - Y_i)^2 \qquad (4)$$

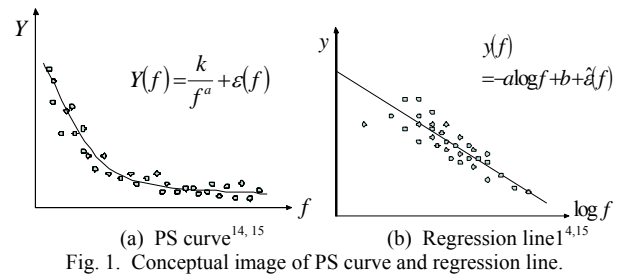(a) PS curve[14, 15]   (b) Regression line1[4,15]
Fig. 1. Conceptual image of PS curve and regression line.

2.2. *Evaluation of feeling impression*

Next, we have used questionnaire survey in order to investigate the relation between 3PACF and feeling impression of music. The examinees are 34 students in the age of early twenties. The list of music used in this survey is shown in Table 1.

These sampling frequency and file format are 44.1 kHz and 16 bit wav, respectively. For every piece of the music, we have taken 20 seconds to play it. The examinees evaluated the 4 items as shown in Table 2, by scoring from one to four. Also they have judged the preference for each of music by scoring from one to ten.

2.3. *Clustering analysis*

Subsequently, we have conducted clustering analysis to divide into examinees groups who was similar feeling impression, by using the results of questionnaire survey. As preprocessing, we convert the evaluation (Item1 ~Item4) and Preference as follows;

- {Item1 ~ Item4} $\geq 3 \rightarrow 1$
- {Item1 ~ Item4} $\leq 2 \rightarrow 0$
- Preference $\geq 6 \rightarrow 1$

- Preference $\leq 5 \rightarrow 0$

Therefore, the data of whole examinees are consist from 34 set of 50 dimensional ((Item1 ~ Item4, and Preference) × 10songs) data. That is, this clustering analysis is performed in the 50-dimensional space. And we adopt Ward method[9] as the analysis.

And then, we perform Wilk's Lambda test as the statistical test[9]. It is a test of the difference between the mean values of the vector comprising a plurality of variables. The null hypothesis H_0 and alternative hypothesis H_1 are as follows;

H_0: Difference of all mean vectors are equal.

H_1: Difference of all mean vectors are not equal.

Whenever each time of clustering has finished, we apply Wilk's Lambda Test repeatedly. In this test, we set significance to 1%. And then, if it will not come into effect significance of 1% on next-time test, the clustering is quit[10, 15, 16].

Table 1. Music list of wave files.[14]

No	Title (.wav)	Genre
1	Another_Sky	Easy Listening
2	Londonderry_Air	Classic
3	Blieve_you	Easy Listening
4	Drafting	Easy Listening
5	Down_by_the_Riverside	Jazz
6	Space_Odessey3_Revelation	Easy Listening
7	TOMORROW	Pops
8	Old_French_Song	Classic
9	Freedom	Pops
10	Red_River_Valley (brass)	Jazz

Table 2. Evaluation items of the questionnaire survey.

Item1	Slow	$1 \Leftrightarrow 4$	Quick
Item2	Heavy	$1 \Leftrightarrow 4$	Light
Item3	Natural	$1 \Leftrightarrow 4$	Artificial
Item4	Negative	$1 \Leftrightarrow 4$	Positive
Preference	Dislike	$1 \Leftrightarrow 10$	Like

Table 3. Fluctuation and Residual

No.	Title (*.wav)	AF		LF		MF		HF	
		Fl.	Re.	Fl.	Re.	Fl.	Re.	Fl.	Re.
1	Another_Sky	1.715	0.414	0.454	0.487	1.713	0.674	1.777	0.394
2	Londonderry_Air	1.627	0.399	1.023	0.489	1.873	0.906	1.706	0.369
3	Blieve_you	2.111	0.466	0.457	0.503	0.527	0.844	2.472	0.409
4	Drafting	1.593	0.431	0.917	0.474	1.296	1.006	1.706	0.404
5	Down_by_the_Riverside	1.724	0.448	0.553	0.502	0.470	0.679	2.115	0.406
6	Space_Odessey3_Revelation	0.990	0.323	1.614	0.195	1.522	0.470	1.004	0.316
7	Tomorrow	2.268	0.555	0.129	0.619	0.721	0.545	2.903	0.463
8	Old_French_Song	1.398	0.433	1.509	0.275	1.633	1.255	1.515	0.399
9	Freedom	2.173	0.589	-0.259	0.535	-0.047	0.575	2.705	0.517
10	Red_River_Valley (brass)	1.520	0.526	0.499	0.653	0.723	0.733	1.658	0.507

Fl.: Fluctuation, Re.: Residual

2.4. *Principal Component Analysis (PCA)*

In this section, we describe the PCA[12, 13] performing space and the set of vectors. However, we decide to eliminate Intercept because it substantially equal to the volume of sound.

First, we define Physical Quantity Space (PQS) that is two-dimensional space which axis is the fluctuation value and Residual. The subject of PCA is a set of 10 pieces of music vectors (Table 3), and also we perform PCA in each frequency domain (AF, LF, MF, and HF). The other hand, we define Feeling Adjective Space (FAS) that is five-dimensional space which axis is the feeling impression of the examinees. The subject of PCA is a set of 10 pieces of music's Feeling Impression Vectors (FIVs).

2.4.1. *Feeling Impression Vector (FIV)*

This subsection, we describe the FIVs.

First, we define the evaluation $S_{(i, k)}$ of examinee k as Eq. (5). i and e_1, …, e_5 are the music number and the evaluation of Item1 ~ Preference, respectively.

$$S_{(i,k)} = (e_1, ..., e_5) \tag{5}$$

Then, we convert the evaluation (Item1 ~ Item4) and Preference as same as Section 2.2. And we define the converting processed vector, as Eq. (6). a_1, …, a_5 are zero or one in Eq. (6). That is;

$$\widetilde{S}_{(i,k)} = (a_1, \cdots, a_5) \tag{6}$$

Hence, the vector S_i^* of the sum of evaluation r people is FIV which is defined by Eq. (7). Z_1, …, Z_5 are the sum of evaluation Item1 ~ Preference of r people, respectively.

$$S_i^* = (Z_1, ..., Z_5) = \sum_{k=1}^{r} \widetilde{S}_{(i,k)} \tag{7}$$

That is, we apply Eq. (5) ~ Eq. (7) to each group, which is divided by using clustering analysis, and we perform PCA of the each group. Subsequent sections, we define u_n (n=1, 2) and v_m (m=1, …, 5) in the principal component axis of set of vectors on PQS and FAS, respectively. Additionally, we define f_i and x_i in the vectors of music number i (i=1, …, 10) on PQS and FAS, respectively. So we can express f_i and x_i on the coordinate axes u_n and v_m respectively as Eq. (8).

$$\left(\langle f_i | u_1 \rangle, \langle f_i | u_2 \rangle\right), \quad \left(\langle x_i | v_1 \rangle, \cdots, \langle x_i | v_5 \rangle\right) \qquad (8)$$

2.5. *Correlation of the principal component axis*

Subsequently, we investigate the correspondence of principal component axes of PQS and principal component axes of FAS. Let C_u and C_v be the coefficient matrix which is calculated by PCA of PQS and the coefficient matrix which is calculated by PCA of FAS, respectively. And we can describe the basis vectors u_n and v_m by using p_n (the basis vectors on PQS) and i_m (the basis vectors on FAS), as shown in Eq. (9) and (10).

$$u_n \equiv C_u p_n = \begin{bmatrix} C_{u11} & C_{u12} \\ C_{u21} & C_{u22} \end{bmatrix} \begin{bmatrix} \delta_{n1} \\ \delta_{n2} \end{bmatrix}, \delta_{nk} = \begin{cases} (n=k) & 1 \\ (n \neq k) & 0 \end{cases} \qquad (9)$$

$$v_m \equiv C_v i_m = \begin{bmatrix} C_{v11} & \cdots & C_{v15} \\ \vdots & \ddots & \vdots \\ C_{v51} & \cdots & C_{v55} \end{bmatrix} \begin{bmatrix} \delta_{m1} \\ \vdots \\ \delta_{m5} \end{bmatrix}, \delta_{mk} = \begin{cases} (m=k) & 1 \\ (m \neq k) & 0 \end{cases} \qquad (10)$$

From Eq. (8) ~ (10), correspondence between u_n and v_m can be judged by the correlation coefficient R between $\langle f_i | u_n \rangle$ and $\langle x_i | v_m \rangle$. R is defined by Eq. (11).

$$R = \frac{\sum \langle f_i | u_n \rangle \langle x_i | v_m \rangle}{\sqrt{\sum \langle f_i | u_n \rangle^2} \sqrt{\sum \langle x_i | v_m \rangle^2}} \qquad (11)$$

3. Results of Feeling Impression and Discussion

3.1. *Clustering analysis*

Fig. 2 shows the result of clustering analysis and its statistical test. As shown in Fig. 2, 34-person examinees are divided 3 groups. The names of groups (G1, G2, and G3) are given in descending order of head-count. Examinees belonging to A, B, and C are 19 person (55.9% of total), 8 person (23.5% of total), and 7 person (20.6% of total), respectively. Table 4 also shows the results of the aggregate of evaluation items that is preprocessed describing in Section 2.3.

3.2. *PCA*

Fig. 3 shows the results of PCA on PQS (Physical Quantity Space). The plotted marks in Fig. 3 indicate endpoints of the vectors from origin. From Fig. 3, we

consider that the music that is used in the investigation of this paper, the weight of Fluctuation and the Residual are same degree. Because the components of the Fluctuation and Residual are contained in u_1 and u_2 approximately equal proportions. The other hand, Fig. 4 shows the results of PCA on FAS (Feeling Adjective Space). In the space, we do not consider principal component v_3, because the cumulative contribution ratio of principal component v_1 and v_2 are about 94.7% in minimum of each groups.

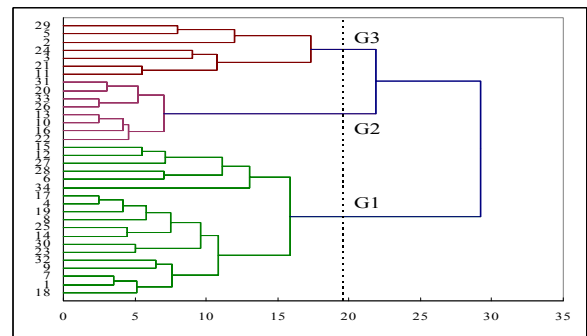From Fig. 4, in group G1, v_2 is Preference, and the

Fig. 2. Dendrogram of clustering result by using questionnaire results of examinees.

Table 4. Results of feeling impression questionnaire

(a) Group G1

Music#	*.wav	Item1 (Quick)	Item2 (Llight)	Item3 (Artificial)	Item4 (Positive)	Preference
1	Another_Sky	3	14	17	15	7
2	Londonderry_Air	1	6	3	8	9
3	Blieve_you	3	5	2	18	10
4	Drafting	0	3	3	0	7
5	Down_by_the_Riverside	18	18	15	19	5
6	Space_Odessey3_Revelation	1	11	6	1	5
7	Tomorrow	12	12	18	19	13
8	Old_French_Song	1	7	7	1	3
9	Freedom	19	15	15	18	8
10	Red_River_Valley (brass)	9	17	15	18	6

(b) Group G2

Music#	*.wav	Item1 (Quick)	Item2 (Llight)	Item3 (Artificial)	Item4 (Positive)	Preference
1	Another_Sky	1	4	5	8	8
2	Londonderry_Air	0	0	0	4	7
3	Blieve_you	0	2	0	8	8
4	Drafting	0	0	2	0	7
5	Down_by_the_Riverside	6	7	6	8	7
6	Space_Odessey3_Revelation	0	2	1	0	8
7	Tomorrow	7	6	8	8	8
8	Old_French_Song	0	0	2	0	8
9	Freedom	8	7	5	8	7
10	Red_River_Valley (brass)	4	8	7	8	8

(c) Group G3

Music#	*.wav	Item1 (Quick)	Item2 (Llight)	Item3 (Artificial)	Item4 (Positive)	Preference
1	Another_Sky	0	5	4	7	7
2	Londonderry_Air	0	1	4	3	6
3	Blieve_you	0	3	4	4	5
4	Drafting	2	2	4	2	6
5	Down_by_the_Riverside	1	4	5	6	6
6	Space_Odessey3_Revelation	1	4	4	2	4
7	Tomorrow	2	1	4	4	7
8	Old_French_Song	5	4	5	3	4
9	Freedom	4	3	5	5	3
10	Red_River_Valley (brass)	5	5	6	6	5

correspondence between v_1 and Item2 (Light) or Item3 (Artificial) are also strong. In group G2 and G3, the correspondence between v_1 and Item4, v_2 and Item1 are strong respectively.

That is, 56% of examinees (G1) prefer brightly and artificial music in which have used this paper. However tendency of music to suit the taste of the remaining of examinees (G2 and G3) are not clear, because there are individual differences. From Fig. 4(a), we consider that examinees of group G1 prefer "Believe_you".

3.3. *Correlation of the principal component axis*

We have calculated the correlation coefficient between principal component axes of PQS (u_n) and FAS (v_m) based on the results of PCA on each space, in each frequency domains (AF, LF, MF, and HF).

Table 5 shows the results of correlation coefficient in each group (G1, G2, and G3). The colored portion of Table 5 indicates that the absolute value of the correlation coefficient is 0.700 or higher.

3.3.1. *Group G1*

From Table 5 (a), the correlation coefficient on AF and HF between u_1 and v_1 are 0.926 and 0.931 respectively, so they have strong positive correlation.

We refer Fig. 3(a) and (d), increase in Fluctuation and Residual are tendency in response to increase of u_1. Also from Fig. 4(a), increase in Item2 (Light) and Item3 (Artificial) are tendency in response to increase of v_1.

Similarly, the correlation coefficient on LF and MF between u_1 and v_1 are 0.774 and 0.704 respectively, so they have positive correlation.

We refer Fig. 3(a) ~ (c), Fluctuation and Residual on LF of all music are lower than AF. And the music which Fluctuation and Residual are small on AF, there are tendency they increase on MF.

Therefore, we consider the music become brightly and artificial impression by increasing Fluctuation and Residual, on AF, MF, and HF.
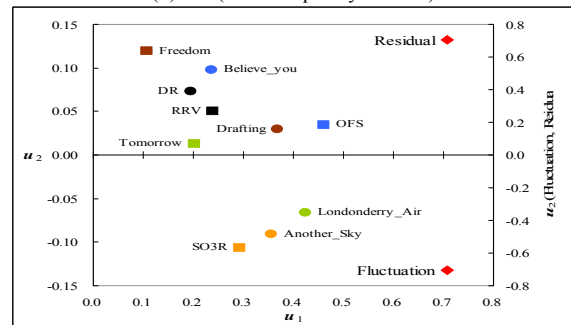
3.3.2. *Group G2*

From Table 5 (b), we understand that G2 have tendency same as G1. And, the correlation coefficient of each domain between u_1 and v_1 are higher than 0.761, so they have positive correlation. Besides, we refer Fig. 4(b),
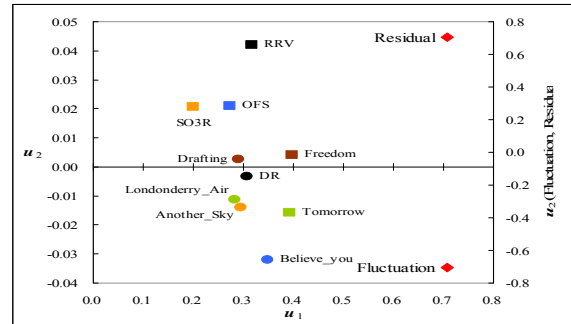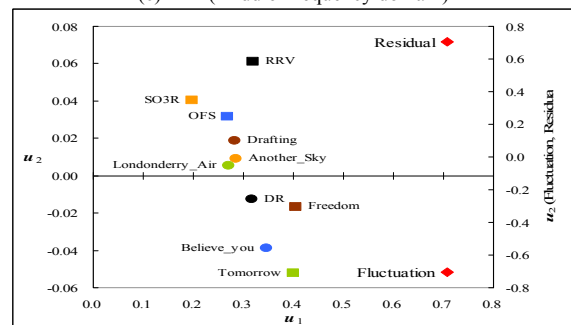

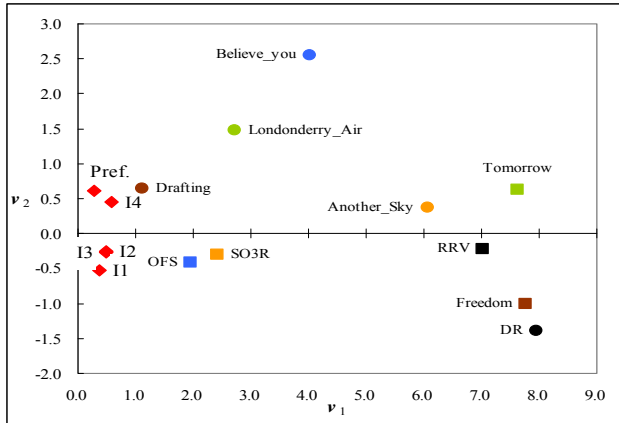(a) AF (All Frequency domain)
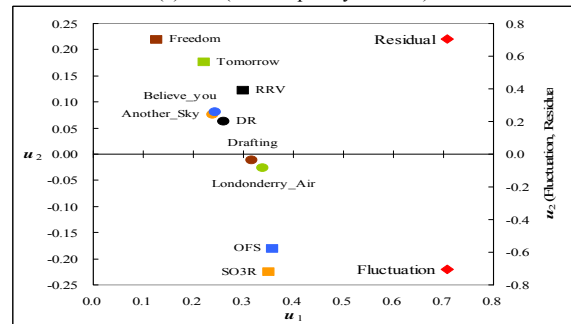
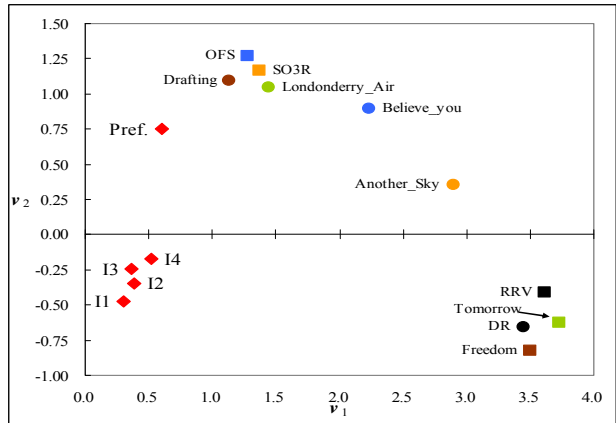(b) LF (Low Frequency domain)

(c) MF (Middle Frequency domain)

(d) HF (High Frequency domain)
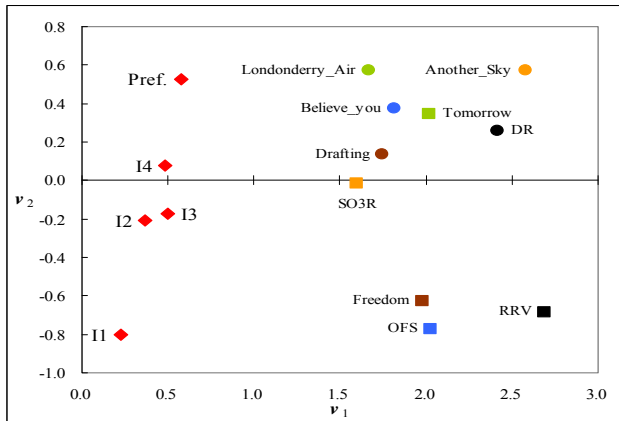
Fig. 3. PCA results on Physical Quantity Space.
DR: Down_by_the_Riverside, SO3R: Space_Odessey3_Reveration,
OFS: Old_French_Song, RRV: Red_River_Valley (brass)

(a) Group G1

(b) Group G2

(c) Group G3

Fig. 4. PCA results on Feeling Adjective Space.
DR: Down_by_the_Riverside, SO3R: Space_Odessey3_Reveration,
OFS: Old_French_Song, RRV: Red_River_Valley (brass),
I1: Item1 (Quick), I2: Item2 (Light), I3: Item3 (Artificial),
I4: Item4 (Positive), Pref.: Preference (Like)

Table 5. Correlation coefficient between principal axes.

(a) Group G1

Principal axis	AF		LF		MF		HF	
	u_1	u_2	u_1	u_2	u_1	u_2	u_1	u_2
v_1	0.926	0.028	0.774	0.547	0.704	0.351	0.931	-0.059
v_2	0.216	-0.579	0.230	0.068	0.288	-0.080	0.203	-0.294

(b) Group G2

Principal axis	AF		LF		MF		HF	
	u_1	u_2	u_1	u_2	u_1	u_2	u_1	u_2
v_1	0.956	0.049	0.827	0.506	0.761	0.341	0.960	-0.015
v_2	0.251	0.000	0.528	-0.660	0.611	-0.351	0.233	0.371

(c) Group G3

Principal axis	AF		LF		MF		HF	
	u_1	u_2	u_1	u_2	u_1	u_2	u_1	u_2
v_1	0.976	0.115	0.945	0.280	0.911	0.226	0.975	0.166
v_2	0.024	-0.784	0.031	0.083	0.075	-0.425	0.016	-0.482

increase in Item4 (Positive) is tendency in response to increase of v_1.

Therefore, we consider the music become positive impression by increasing Fluctuation and Residual.

3.3.3. *Group G3*

From Table 5 (c), we understand that the correlation coefficient of each domain of G3 between u_1 and v_1 are higher than 0.911, so they have strong positive correlation. Especially the correlation coefficient of AF between u_2 and v_2 is -0.784, so they have negative correlation. We refer Fig. 4(c), increase in Item4 (Positive) is tendency in response to increase of v_1. And from Fig 3 (a) ~ (d), increase in Fluctuation and Residual are tendency in response to increase of u_1. Furthermore, decreasing Fluctuation and increasing Residual are tendency in response to decrease of v_2.

Therefore, we consider the music become positive impression by increasing Fluctuation and Residual. Especially, by increasing Fluctuation and Residual on AF, the music becomes fast impression.

4. Conclusion

In this paper, we have investigated the effects between feature quantity of sound signal and feeling impression using PCA. As feature quantity, we have used Fluctuation and Residual. As for the feeling impression questionnaire, we have presented 10 piece of music to examinees and they evaluated 5 items, i.e. quickness, brightness, artificial, positiveness, and preference (like or dislike). Then, we performed clustering analysis based on the evaluation results, the examinees feeling impression could be divided into 3 groups.

Next, we have performed PCA in the Physical Quantity Spaces of the each frequency domain (AF, LF, MF, and HF) and performed PCA in the Feeling Adjective Spaces of each group. Furthermore, we also investigated correlation between the principal component axes.

As the results, we have understood that 56% of examinees feel brightly and artificial impression from the music which both of Fluctuation and Residual were high. And we have also found that they preferred such music. Then, 44% examinees were not seen such correlativity, but they felt positive impression from the music which both of Fluctuation and Residual were high. Moreover, we have found that high frequency feature quantity of sound have the strongest impact to feeling impression.

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