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On a relation between feeling Impression and 3PACF of sound signal

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Abstract: This paper presents an experimental investigation correlation between human feeling impression and some physical feature quantity in sound signal. We focus on three kinds of values, that is, fluctuation value, intercept, and sum of squared errors that are obtained when making a regression analysis of sound signal in Fourier domain, as for the feature quantity. In our investigation using a questionnaire survey over 34 persons, we apply multiple regression model to the relation between the feature quantity of signal and human evaluation about Kansei impression for each person. And, after making the construction of the regression equation for each person, we show the strength between the quantity and impression. Moreover, we classify the set of coefficients of the equation into three groups and discuss some tendency of human impression resulting from the quantity.

Keywords: feeling impression, fluctuation value, intercept, signal processing, sum of squared errors

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, in the past research about 1/*f* fluctuation focused attention on the value of fluctuation. And it has not yet led to analyze when signals have the same 1/*f* fluctuations those power spectrum distributions. Therefore, we wonder that feeling impression strongly affects not only value of fluctuation but also other factors.

In this paper, we introduce three kinds of parameters such as fluctuation value, 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 investigate the relation between feeling impression and those parameters. We investigate sensitivity of the feeling impression by those parameters, especially fluctuation value and residual.

2 QUANTITIES ACCOMPANYING CALCULATION OF FLUCTUATION

2.1 3PACF

Fig. 1 shows an example of the regression line. Its horizontal axis shows the logarithm of the frequency and vertical axis shows the logarithm of the PS. Where, this regression line has an absolute-slope of a. In this paper, we call the absolute-degree of the slope "Fluctuation value".

Accompanying when the regression line is computed as shown in Fig. 1, three kinds of parameters are defined, i.e., (1) Fluctuation value as the absolute value of slope a, (2) Intercept b, and (3) Residual of the line. We call the set of these parameters "3PACF" that stands for Three Parameters Accompanying Calculation of Fluctuation [8].

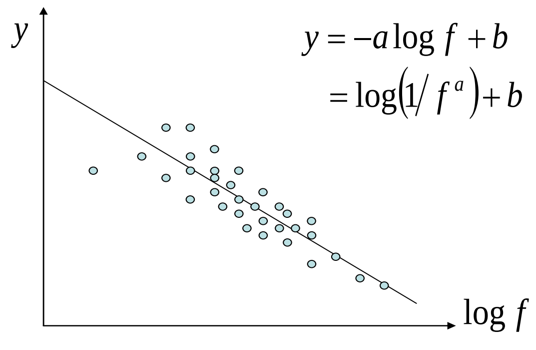


Fig. 1. Example of regression line

The residual of the regression line is defined by Eq. (1) as in the form of a sum of the squared error, where *y* and *Y* show a target variable and an estimated regression value respectively.

$$s = \sum_i e_i^2 = \sum_i (y_i - Y_i)^2 \quad (1)$$

2.2 Correlation between 3PACF

We have investigated as to whether or not there exists correlation between 3PACFs of music. Table 1 shows using music list of wave file. Their sampling rate and quantization bit rate are 44.1 kHz and 16 bit. Fig. 2 (a)-(c) shows the plotted graph between two parameters of 3PACF of music.

Table 1. Music list of wave file

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

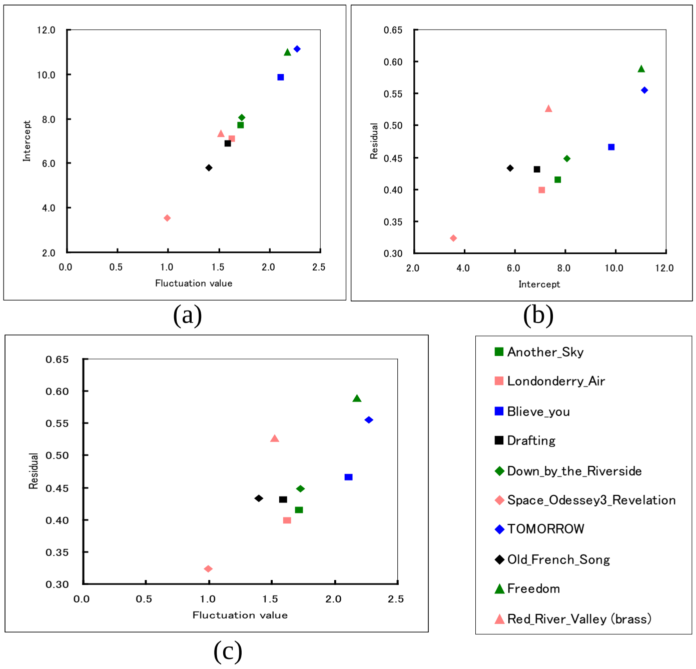


Fig. 2. Correlation of 3PACF (a) Fluctuation value and Intercept (b) Intercept and Residual (c) Fluctuation value and Residual

The correlation coefficient in Fig. 2: (a) 0.99061 between Fluctuation value and Intercept. (b) 0.85238 between Intercept and Residual. (c) 0.78630 between Fluctuation value and Residual. We consider that there exist high correlation between Fluctuation value and Intercept, between Intercept and Residual, or between Fluctuation value and Residual.

3 INVESTIGATION

3.1 Outline

We have used questionnaire survey in order to investigate the relation between 3PACF and feeling impression of music. The examinees are 34 university students in the age of early twenties. We have given some questions about their feeling impressions for 10 pieces of music. The list of music used in this survey is the same as shown in Table 1. For every piece of the music, we have taken 20 seconds to play it. After that, we have asked the students to evaluate the 4 items as shown in Table 2, by scoring from one to four. Also the students have judged the total evaluation for each music by scoring from 1 to 10.

Table 2. Questions in the survey

Item 1	Slow	1 ⇔ 4	Quick
Item 2	Heavy	1 ⇔ 4	Light
Item 3	Natural	1 ⇔ 4	Artificial
Item 4	Negative	1 ⇔ 4	Positive

3.2. Multiple regression analysis

We have conducted multiple regression analysis of the results as shown in Eq. (2) in the four-item score (item1, item2, item3, and item4) and the total evaluation score, where, y is the score of the each examinee, x_1 and x_2 are explanatory variables of "Fluctuation" and "Residual", respectively. And, error ε is independence variable and follows the normal distribution N(0, σ^2). We eliminate the third variable for "Intercept", because this quantity (or parameter) is substantially equal to the volume of sound [8].

$$y = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \varepsilon, \quad \varepsilon \sim N\left(0, \sigma^2\right) \qquad (2)$$

Also, we have noticed that the influence of four kinds of frequency domains, i.e. (i) All-frequency domain (AF; 0~22050Hz), (ii) Low-frequency domain (LF; 0~300Hz), (iii) Middle-frequency domain (MF; 300~1000Hz), (iv) High-frequency domain (HF; 1000~22050Hz). So, we have analyzed the results of questionnaire for each person using Eq. (2), for each item, and for each frequency domain.

Then we will obtain the concrete the coefficients and regression equation for Item1 in AF using the Least Squares Method. However we have set the coefficient α_0 = 0, because the multiple correlation coefficient tends to be higher as a result of analysis at this time, as a whole. In this way, the regression equation for each item of {Item1, Item2, Item3, Item4, Total Evaluation} and for each person will be available. So we will obtain five regression equations from feeling impression data of each examinee, and we carry out this analysis for 34 examinees.

After that, we make a clustering analysis for them, using Ward Method [9]. As the result, those equations are generally classified into three groups. We will get regression coefficient of Fluctuation (α_1) and regression coefficient Residual (α_2). However we have to calculate Normalized Fluctuation Coefficient (NFC) α_1^* and Normalized Residual coefficient (NRC) α_2^* using Eq. (3) and Eq. (4), in order to compare α_1 and α_2.

$$x_n^* = \frac{x_n - \overline{x_n}}{\sigma_n}, \quad \therefore \; x_n = x_n^* \sigma_n + \overline{x_n}, \quad (n = 1, 2) \qquad (3)$$

$$\begin{aligned} y &= \alpha_1 x_1 + \alpha_2 x_2 = \alpha_1\left(x_1^* \sigma_1 + \overline{x_1}\right) + \alpha_2\left(x_2^* \sigma_2 + \overline{x_2}\right) \\ &= (\alpha_1 \sigma_1) x_1^* + (\alpha_2 \sigma_2) x_2^* + \left(\alpha_1 \overline{x_1} + \alpha_2 \overline{x_2}\right) \qquad (4) \\ &= \alpha_1^* x_1^* + \alpha_2^* x_2^* + \alpha_3^* \end{aligned}$$

Where $\overline{x_n}$ is average of explanatory variables of Fluctuation or Residual, and x_n^* is normalized explanatory variables of Fluctuation or Residual. And σ_n is standard deviation.

3.3. Results

3.3.1 AF (All-frequency domain)

Table 3 shows correlation coefficient and average of normalized regression coefficient of AF. The average of normalized regression coefficient is between Normalized Fluctuation Coefficient (NFC) and Normalized Regression Coefficient (NRC).

As shown in Table 3, in Group1, NRC α_2^* is higher than NFC α_1^*. So we consider that the Residual has more affected feeling impression than the Fluctuation. This situation is same in Group2 or Group3. Further more, we have used the Wilks-Lambda Test for statistical tests to the grouping in each evaluation item. Those groupings hold within 1% of significance whole frequency domains, i.e. AF, LF, MF and HF. Fig. 3(a) shows the clustering result for Total Evaluation in AF, as an example of classification.

3.3.2 LF (Low-frequency domain)

Table 4 shows correlation coefficient and average of normalized regression coefficient of LF.

Where, we have to pay attention to Evaluation Item in Table 4. NRC α_2^* is higher than the NFC α_1^* same as AF in Item1 through Item4. Then, Item3 and Total evaluation have weak correlations, and NFC α_1^* is higher than NRC α_2^* in Total Evaluation of Group2 and Group3.

From these results, Item1, Item2 and Item4 have slightly strong correlations, but Item3 and Total Evaluation have very poor correlations. Though Residual is the stronger factor than Fluctuation in this feeling impression evaluation. Fig. 3(b) shows the clustering result for Total Evaluation in LF, as an example of classification.

Table 3. Correlation coefficient and regression coefficient (a)AF, (b)LF, (c)MF, (d)HF

(a)

Evaluation Item	Multiple correlation coefficient	Significance level of regression	Average of Regression Coefficient					
			Group 1		Group 2		Group 3	
			α_1^*	α_2^*	α_1^*	α_2^*	α_1^*	α_2^*
Item 1	0.991	1%	-0.949	1.082	-0.295	0.625	0.132	0.252
Item 2	0.980	1%	-0.941	1.154	-0.404	0.772	0.024	0.408
Item 3	0.980	1%	-0.657	0.968	-0.097	0.528	0.395	0.112
Item 4	0.990	1%	-0.812	1.103	0.199	0.317	0.620	0.014
Total Evaluation	0.949	1%	-0.939	1.925	1.478	-0.186	0.150	0.831

(b)

Evaluation Item	Multiple correlation coefficient	Significance level of regression	Average of Regression Coefficient					
			Group 1		Group 2		Group 3	
			α_1^*	α_2^*	α_1^*	α_2^*	α_1^*	α_2^*
Item 1	0.763	1%	-0.182	0.662	0.403	0.448	-	-
Item 2	0.669	1%	0.099	0.757	0.563	0.520	-	-
Item 3	0.316	1%	0.085	0.788	0.258	0.634	-	-
Item 4	0.829	1%	-0.143	0.862	0.449	0.629	-	-
Total Evaluation	0.021	1%	0.904	1.684	1.177	1.228	0.830	0.317

(c)

Evaluation Item	Multiple correlation coefficient	Significance level of regression	Average of Regression Coefficient					
			Group 1		Group 2		Group 3	
			α_1^*	α_2^*	α_1^*	α_2^*	α_1^*	α_2^*
Item 1	0.831	1%	-0.671	0.887	-0.174	0.670	-	-
Item 2	0.816	1%	-0.293	0.880	0.112	0.629	0.699	0.349
Item 3	0.879	1%	-0.444	0.983	-0.050	0.778	0.303	0.422
Item 4	0.911	1%	-0.556	1.048	-0.218	0.842	0.289	0.583
Total Evaluation	0.613	1%	-0.173	2.070	0.397	1.365	0.841	0.620

(d)

Evaluation Item	Multiple correlation coefficient	Significance level of regression	Average of Regression Coefficient					
			Group 1		Group 2		Group 3	
			α_1^*	α_2^*	α_1^*	α_2^*	α_1^*	α_2^*
Item 1	0.984	1%	-0.361	0.502	0.359	0.143	0.649	-0.031
Item 2	0.973	1%	-0.846	0.840	-0.293	0.503	0.280	0.240
Item 3	0.947	1%	-0.423	0.585	0.046	0.398	0.367	0.178
Item 4	0.984	1%	-0.859	0.841	0.365	0.227	0.709	0.061
Total Evaluation	0.880	1%	-0.620	1.299	0.260	0.661	1.053	0.193

3.3.3 MF (Middle-frequency domain)

Table 5 shows correlation coefficient and average of normalized regression coefficient of MF.

As shown in Table 5, NRC α_2^* is higher than NFC α_1^* in Group1 and Group2. So we thought that the feeling impression of them has much more related NRC. Generally speaking, Residual is the stronger factor than Fluctuation in MF-feeling impression evaluation, too. Fig. 3(c) shows the clustering result for Total Evaluation in MF, as an example of classification.

3.3.4 HF (High-frequency domain)

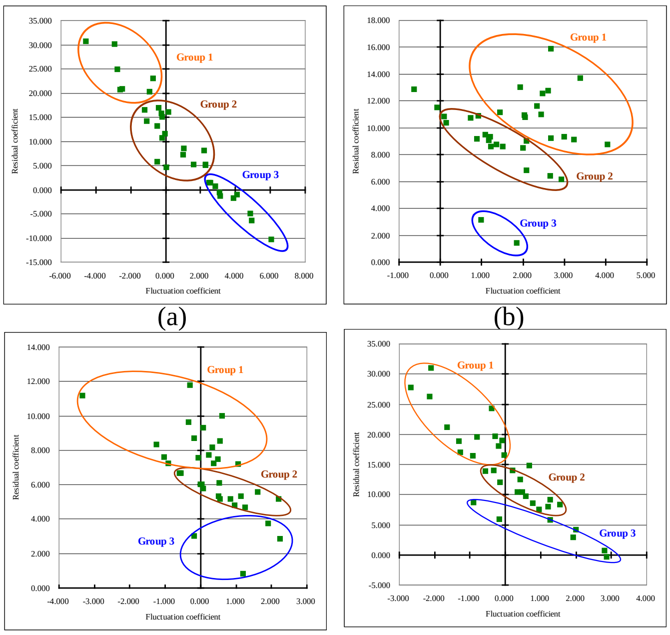
Table 6 shows correlation coefficient and average of normalized regression coefficient of HF.

As shown in Table 6, in Group2 and Group3, NFC α_1^* is higher than NRC α_2^* in Item1 and Item4. In the rest of them, NRC α_2^* is higher than NFC α_1^*. As for the feeling impression of Group2 and Group3 in Item1 and Item4, Fluctuation is stronger factor than Residual. And rest of them, Residual is stronger factor than Fluctuation.Fig. 3(d) shows the clustering result for Total Evaluation in AF, as an example of classification.

3.4. Discussion

In section 3.3, we have found that each item of feeling impressions can be expressed as Eq. (2), and the average of regression coefficient as shown as Table 3 (AF), Table 4 (LF), Table 5 (MF), and Table 6 (HF).

As shown in Table 3 trough Table 6, we can see the tendency that Normalized Residual Coefficient (NRC) α_2^* is higher than Normalized Fluctuation Coefficient (NFC) α_1^* as investigation results, generally. And Group1 has a feature that the NFC is negative value for all items in whole frequency domain. From these results, NRC α_2^* is much higher than NFC α_1^*, so normalized explanatory variable of Residual x_2^* has more affective to feeling impression score y than normalized explanatory variable of Fluctuation x_1^*.



(a) (b) (c) (d)

Fig. 3. Example of Regression analysis of feeling impression (a)AF, (b)LF, (c)MF, (d)HF

4 CONCLUSION

In this paper, we have researched the relationship between 3PACF of frequency domains and feeling impression in sound signal. As a way of research, we have used a questionnaire survey concerning how the relation between 3PACF and the feeling impression of music is. Based on the constructed multiple linear regression equations, we can also consider the statistical tendency as to how the human impression will change if the explanatory variable of Fluctuation (x_1) or Residual (x_2) change. Briefly speaking, the effect of the Residual seems to be stronger than that of Fluctuation. For further study, we need some sensitivity analysis for those parameters.

The questionnaire survey was acquired by limited number of persons or age, music as investigation objects was also limited, though we have understood the feeling impression of music can be some classified using 3PACF of the frequency domains.

For further study, we need some sensitivity analysis for 3PACF or we need to use principal component analysis. Moreover, we have to investigate if we modify 3PACF of the each frequency domains independence, how affect feeling impressions change.

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