A study on measures of timbre of electric guitar sounds in terms of power spectrum and auto correlation function

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In order to make appropriate acoustic space for music performance, the relationships between the property of sound fields and the music sound should be considered. However, the study of music sound and acoustic space for modern music like popular and rock music was not done. In this study, timbre of electric guitar sounds was investigated with the final goal of creating acoustic space suitable for popular music or rock music. The electric guitar sound signals with and without vibrato effect were analyzed in terms of power spectrum and autocorrelation function (ACF). Power spectra of non-effected sound signals showed that the signals contained harmonic overtones up to nearly 20th order, and the profile of overtone components were affected by picking point, string and pick-up setting. Then the spectral centroid and flux were calculated and the time trend of them were compared to those of ACF-based factor $W_{\Phi(0)}$. $W_{\Phi(0)}$ increased quickly at the beginning of the sounds and gradually increased or stayed almost constant after that. It was found a high correlation between $W_{\Phi(0)}$ and spectral centroid. Also in $W_{\Phi(0)}$ it was found similar time trend with that of spectral flux at the beginning of the signal. φ_1, another measure of ACF, was calculated for sounds signals with vibrato, the value of φ_1 decreased as vibrato extent increased and gradually approached to 1 in process of time. Also, the greater the power in high order overtones was, the smaller the values of φ_1 of vibrato became. Accordingly, $W_{\Phi(0)}$ was considered to be affected by the high order overtones, and φ_1 by fluctuation of sound signals such as vibrato.

Key words: Timbre, Autocorrelation function, Vibrato, Subjective preference

1. INTRODUCTION

Room acoustic property and music sound signals are investigated separately in most of room acoustics studies, however, as Ando et al. [1] indicated, it is assumed to be necessary to consider the combination of both of them to improve the quality of acoustic spaces. Also while a lot of studies have been done on concert halls for classical music, acoustic spaces for popular or rock music, such as live music clubs, are seldom discussed though such contemporary music is much popular for modern people than classical music. Here, as the first step for the final goal of finding the acoustic characteristic suitable for the performance of popular and rock music, timber of instruments used in those music genres must be examined. Accordingly, in this study, we selected electric guitar as a representative instrument of popular and rock music and investigated the timbre. Electric guitar sound consists of the sound from the instrument itself (so-called as *clean tone*) and additional effect created by various kinds of effecter. Therefore, first, the timbre of clean tones are analyzed in terms of the harmonic overtone components of sound signals obtained by FFT and the autocorrelation function (ACF). Second, the timbre of the electric guitar sound with vibrato effect is analyzed.

2. ANALYSIS OF NON-EFFECTED ELECTRIC GUITAR SOUND

Non-effected electric guitar sounds (*clean tones*) were analyzed by power spectrum and ACF. The timbre is assumed to be influenced by picking point, picked string and pick-up. (A pick-up is a device that is attached on the surface of guitars and converts vibration of strings into electric signals.) Table 1 shows conditions of sounds signals for analysis. The scale of guitar sounds was fixed at 262 Hz (C4). An electric guitar (Gibson, *Les Paul Jr. special*) was connected with an amplifier (Marshall, *MG 10 CD*), and electric signals were taken out from the monitor output of the amplifier. Power spectrum was calculated using FFT. Following the previous study (Hanada et. al [2]), two factors of $W_{\Phi(0)}$ and φ_1 are obtained from running normalized ACF (n-ACF) with 500 ms of integration time and 100 ms of running step. Also, to illustrate the characteristics of $W_{\Phi(0)}$ in comparison with spectral measures, the spectral centroid and spectral flux, which are supposed to be related

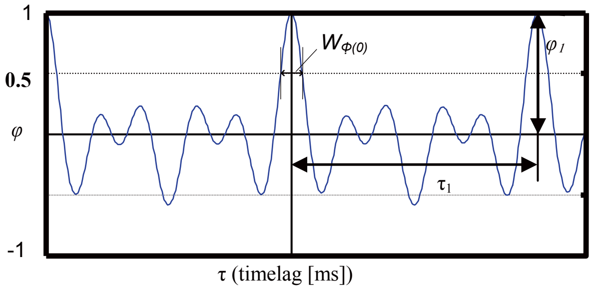

Figure 1. ACF factors

Table 1. Sound signal settings for analysis

Factor	Condition	
Picking point (P.P.)	Picked at every 3 mm interval from bridge	
String	3rd string 5th fret 5th string 15th fret	(3s5f)† (5s15f)†
Pick-up	Front, Rear, F+R	

†Both have the same note of C4 (262Hz)

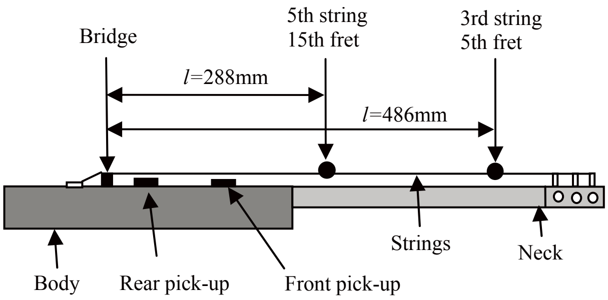

Figure 2. Structure of electric guitar

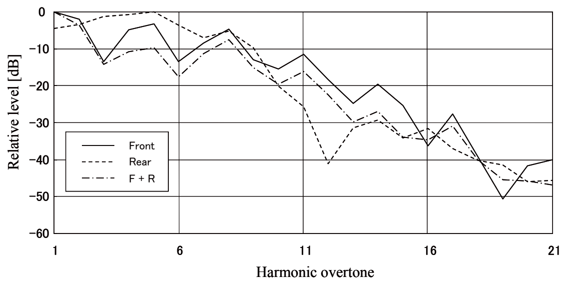

Figure 3. Power spectrum of electric guitar sounds

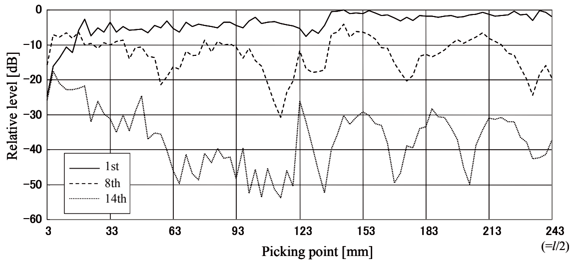

Figure 4. Relative level of overtones at each P.P.

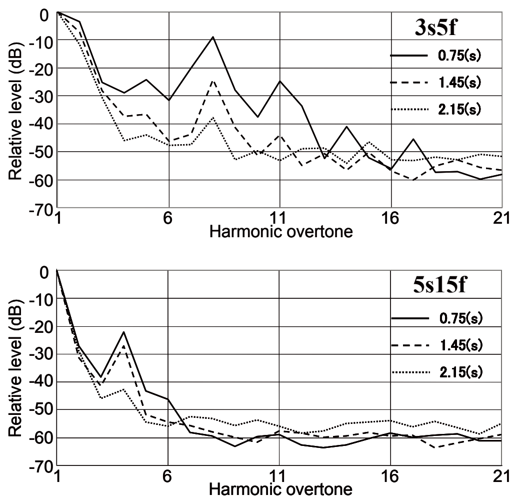

Figure 5. Time variation of power spectrum (pick-up: F+R)

with timbre or time variation of sound signals respectively, were calculated for each of the guitar sound signals.

(1) Power spectrum

The harmonic overtone components of clean tones were analyzed by FFT. Figure 3 shows the energetic averaged relative levels over values obtained from picking points from 117 mm to 171 mm, which are used in usual performance, with each of the lines representing different condition of pick-up. As seen in the graph, the guitar sound signals contained harmonic overtones up to nearly 20th order. The overtone components were varied by the setting of the pick-up possibly because two pick-ups sense different mode of string vibration correspondent to their location and picked-up signals could interfere each other.

Next, variations of overtone components caused by the picking point were examined. Here the string and pick-up condition were fixed at 3s5f and F+R respectively. Figure 4 shows relative levels of 1st, 8th, 14th overtones according to the picking points. The point of picking is considered to affect the profile of the modal excitation of string vibration and this was seen in the graph.

Figure 5 shows the comparison between the sound signals of different strings (3s5f and 5s15f). It was seen that, compared to 5s15f, the signal of 3s5f contained greater power in high order overtones and those overtones decayed slower. This seemed due to the length of the strings.

Next, spectral centroid and flux, which are used to represent timbre or time variation respectively, were calculated. Figure 6 shows the variation of spectral centroid with time. Generally, it was seen that the values of spectral centroid quickly decreased at early time period, as is considered to be the attack of the sound, and then stayed almost constant at a frequency between the 1st and 2nd order harmonic overtone. The spectral centroid of the sound of 5s15f varied little throughout the time. This is possibly due to the rapid decay of high order overtones because of the short length of the string. Figure 7 shows the variation of spectral flux with time. The spectral flux indicated similar time variation as the spectral centroid in general but different vertical order in the curves of different sounds and there was little correlation between them. Also time decay was observed for the 5s15f sound, which exemplified the feature of the spectral flux of detecting onset.

(2) The factors obtained from ACF

Next, two factors obtained from ACF were calculated for the different conditions of picking point, strings and pick-up. Since the values of these factors are assumed to change as time goes, $W_{\Phi(0)}$ and φ_1 were calculated at every running step of ACF. The result is shown in Figure 8. It was seen that $W_{\Phi(0)}$ increased consistently while φ_1 was rather constant at nearly 1. $W_{\Phi(0)}$ varied by the setting. Considering the result from FFT analysis, it was suggested that $W_{\Phi(0)}$ was affected by the power of high order harmonic overtones. Accordingly, $W_{\Phi(0)}$ of the signal of 5s15f, which has less power in overtones than that of 3s5f, showed the greatest value and the others also showed different pattern in the increasing process.

Figure 9 shows the scatterplot of $W_{\Phi(0)}$ vs. (inverse of) spectral centroid. It was seen that the $W_{\Phi(0)}$ was inversely proportional to the spectral centroid and there was a strong correlation (r=0.95). Also the $W_{\Phi(0)}$ showed a increase at early time period for the sounds such as 3s5f 117mm F+R or 5s15f 117mm F+R similarly to the spectral flux. These indicates that ACF-based $W_{\Phi(0)}$ could be a measure as effective as spectrum-based measures for both timbre discrimination and onset detection.

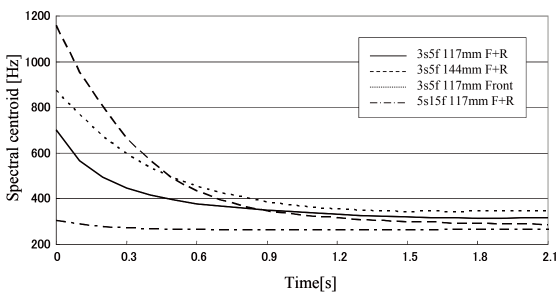

Figure 6. Spectral centroid of clean-tones

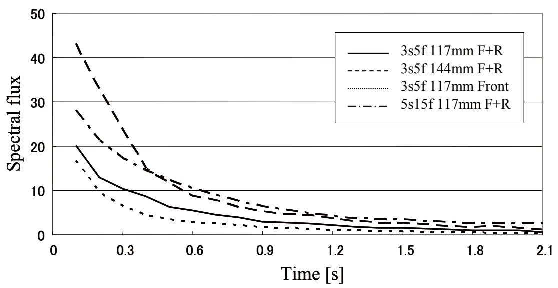

Figure 7. Spectral flux of clean-tones

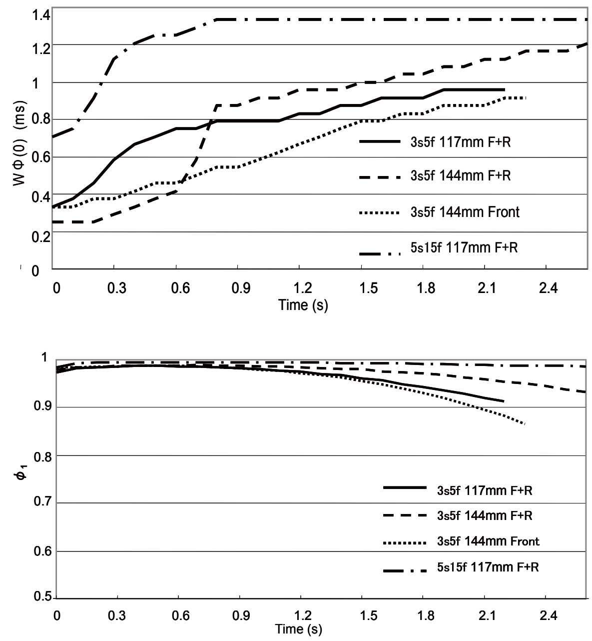

Figure 8. Examples of analysis by ACF

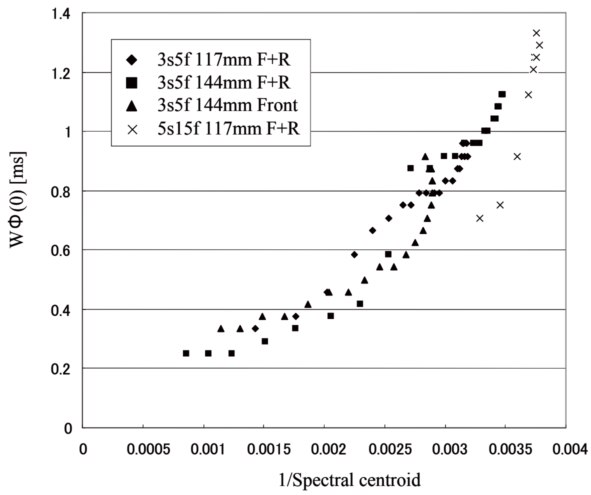

Figure 9. Scatterplot between $W_{\Phi(0)}$ and spectral centroid

3. ANALYSIS OF ELECTRIC GUITAR SOUND WITH VIBRATO EFFECT

The sound signals were processed by a vibrato effecter (electro-harmonix "*The clone theory*") and the running n-ACF was calculated. Here vibrato was controlled by two parameters of vibrato extent [cent] and vibrato rate [Hz]. Figure 10 shows the changes of $W_{\Phi(0)}$ and φ_1 along with vibrato extent. The condition was 168 mm of picking point, 3s5f, 6 Hz of vibrato rate and F+R of pick-up. It was found that φ_1 decreased as vibrato extent increased and gradually approached to 1 in process of time, while $W_{\Phi(0)}$ was not affected by vibrato.

Next, sound signals of different conditions were processed by the same vibrato effect (vibrato extent: 40 cent, vibrato rate: 6 Hz). The partial results on the difference of the picking point and the string are shown in Figure 11. In contrast to the result that the φ_1 of the clean tones were rather constant at nearly 1 regardless of the conditions, φ_1 were obviously changed with the vibrato effect and the change was affected by the condition. It was observed that, in general, the smaller the $W_{\Phi(0)}$ of the clean tones were, the smaller the φ_1 of the signals with vibrato became. It was considered that higher overtones were affected more by the fluctuation of frequency caused by the vibrato effect. Consequently it was suggested that φ_1 could represent the fluctuation of signals.

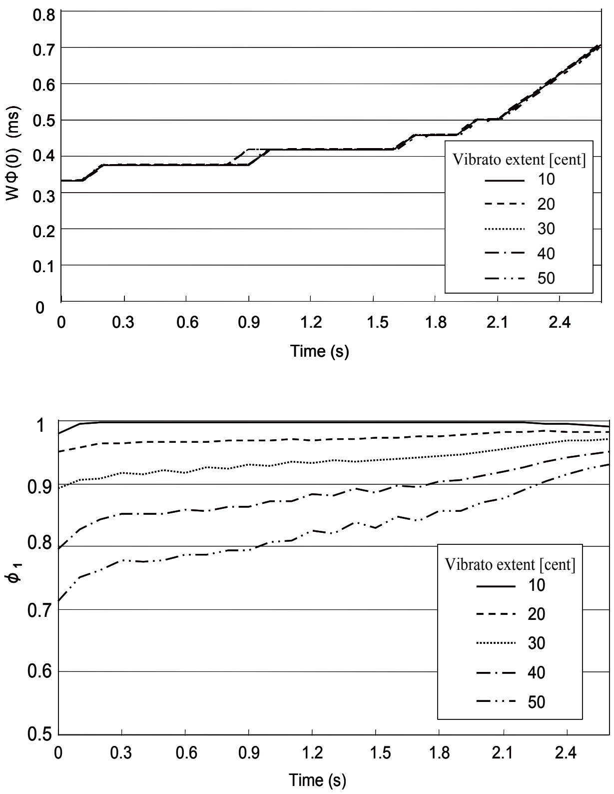

Figure 10. The results of analysis by ACF

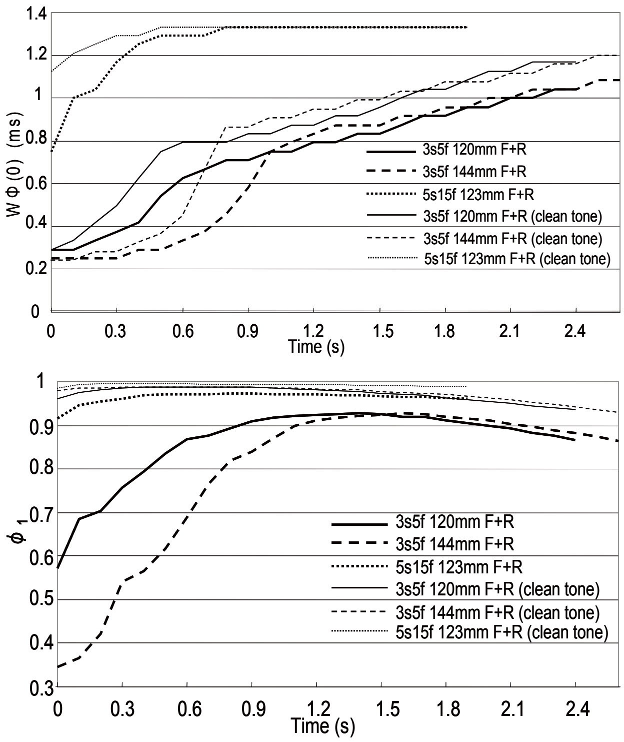

Figure 11. The results of analysis by ACF

4. COMMENTS

In this study, sound signals of an electric guitar, with or without vibrato effect, were analyzed. The result is that the overtone profile of clean tones varied according to the different conditions of electric guitar. The $W_{\Phi(0)}$ showed correspondence with both the profile of overtone components, as inversely proportional with spectral centroid, and onset of the sound signals. φ_1 showed correspondence with fluctuation of frequency of guitar sound signals. In further studies, timbre variations caused by other kinds of effecter or variation due to different instruments or amplifiers should be examined

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