Analysis/Synthesis of Stringed Instrument Using Formant Structure

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Summary
In this paper, timbre of stringed instrument is analyzed and the timbre sound is synthesized. Timbre is familiar and looks well known, but it has been unknown even now what an essential factor is. And it is the most important factor for human to distinguish sounds with the same duration, loudness and pitch. The formant structure model for keeping the same timbre is proposed in this paper. The structure proves to be useful for characterizing timbre of an electric bass guitar and an electric guitar. Spectrums of sounds on one string have similar formant structure as far as plucked instruments are concerned. The envelopes are represented by approximate curves of the fundamental and harmonic frequencies among local envelopes. And the relation among strings is expressed by parallel shifting on *x*-axis in log_2 scale. In addition, the tolerance of amplitudes relating with the formant structure model is investigated through some experiments. Moreover, using the formant structure model, an electric bass guitar sound is synthesized and the timbre is evaluated subjectively, and has been got the average score 4.5 by five-grade evaluation, that is, excellent in its quality. In addition, we could arrange the sounds of an electric bass guitar with various atmospheres. The proposed method is so flexible and the tolerance is very high. We have also got similar results about acoustic and electric guitars. In future work, we will expand into general stringed instruments.
Key words:
Timbre of stringed instruments, Electric bass guitar and electric guitar, Formant structure, Tolerance of amplitude, Atmosphere of timbre

1. Introduction

In this paper, the timbre of musical instrument, especially electric bass guitar and electric guitars, is analyzed by using features and synthesized as the original sound. In generally, sounds are classified into three categories: a pure tone, a musical tone and an unpitched sound by vibration condition. A pure tone is non harmonic sound. A musical tone has harmonic overtones, plain pitch, distinct loudness and clear timbre. An unpitched sound has unclear pitch, distinct loudness and clear timbre. Sounds that musical instruments generate are musical tones or unpitched sounds. Musical tones are generated by stringed and wind instruments. And unpitched sounds are generated by percussion instruments. Loudness is amplitude of vibration and a pitch is decided from a frequency of vibration. These two factors need contrast objects so that these are called relative features. On the other hand, timbre is decided by sounding method, materials and structure of instrument.
Therefore, the timbre is constant and be called absolute features[1]. However, there is no decisive factor for timbre and it has been ambiguous factor against loudness and pitch. In general, timbre is defined as follows: "The factor to distinguish instrument's sounds with same loudness and same pitch is timbre". Surely, trumpet, piano and guitar sounds must be distinguished without enough musical knowledge. Differences of timbres are useful for human to distinguish instruments and the timbre is one of important factors for analyzing sounds. However, it is a difficult task to comprehend their differences without some distinct features by computer. To extract features of timbres is very effective for applications, for example, musical transcription, musical information retrieval and so on. Some previous works have dealt with some timbre models[2][3]. Other researches also made use of physical model[4][5] with mathematic formula based on instrument's physical structure. There are many kinds of features used for analyzing spectrum features. Using these features, the envelope models and timbre spaces[6] have been proposed. In many researches, the combination of spectrum and temporal features[7][8] was made use. Other work compares that which features are influence for timbre[9]-[11]. As described above, previous works have analyzed the frequency spectrum and expressed the timbre by various features. However, we think that it is hard to grasp intuitionally these representations and propose the more simplified model.
In this paper, we analyze and synthesize the timbre of electric bass guitar and guitar sounds by the proposed the formant structure model. And we refer to the timbre structure of stringed musical instruments. Traditionally, it is said that a timbre is decide by spectrum amplitudes. But, it has been found that the spectrum has flexible tolerance through some experiments. Horner et al. described tolerances within 50% by keeping SC(Spectrum Centroid)[12][13]. In addition, a stringed instrument has inharmonicity. However, some experiments elucidated that the influence of inharmonicity was small on human perception. It is easy to think that the only sound's pitch

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changes with shifting a spectrum on x-axis in log_2 scale. When the spectrum is shifted to some extent, the timbre of sound becomes different from the original. Actually, two spectrums of different sounds over an octave are dissimilar in amplitude ratio. In the proposed method, it is supposed that spectrums on one string have the some formant structure model so that stringed instruments may have musical scale over an octave on one string. That structure can decide a timbre and easily express its features without a complex combination of features as previous works. The proposed model is consists of the basis formant and the atmosphere mode.

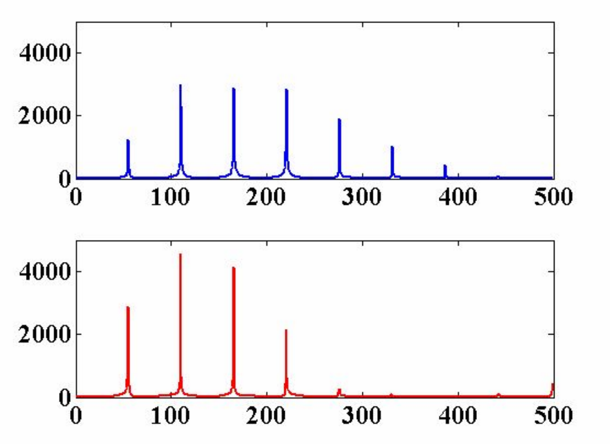
This paper is organized as follows. In Section 2, we analyze the spectrum of guitars and temporal feature is investigated, moreover and describe about the tolerance of the formant structure model. Experimental results are shown in Section 3. Finally, Section 4 concludes this paper.

2. The proposed model

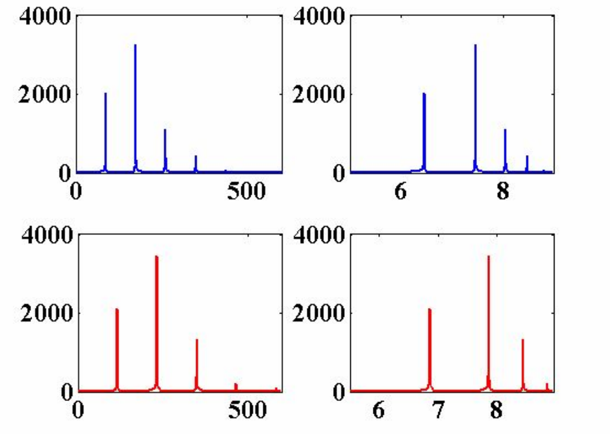
Here, the basic idea of the proposed model is explained. A normal electric bass guitar and electric guitar (hereafter represented as bass and guitar) have four and six strings, respectively. In normal tuning, each string has 400 or 500 cent musical intervals, respectively. For example, the open fret sounds on each string of bass are G2(98.0Hz), D2(73.42Hz), A1(55.0Hz) and E1(41.20Hz). In this paper, spectrum is got by STFT(Short-Time Fourier transition). We use 169 bass sounds and 234 guitar sounds in RWC MDB-I-2001-W04[14] as sound sources. RWC music database has been built up with six kinds of databases: "Popular Music", "Royalty-Free Music", "Classical Music", "Jazz Music", "Music Genre" and "Musical Instrument Sound". "Musical Instrument Sound" database has fifty kinds of instruments: piano, electric bass guitar, violin, saxophone and so on.

2.1 Frequency spectrum

Bass generates same pitch sounds on different strings. For example, sounds on the open fret of third string and fifth fret of fourth string are A1. In Fig.1(a) spectrums of these two sounds didn't match. While spectrum of sounds on the same fret of different strings are so similar as shown in Fig.1(b). Therefore, this paper supposes that spectrum of stringed instrument are influenced from fret position in other word length of string and its diameter change pitch. To observe the transition of spectrums on the same string, each harmonic amplitude of from the open to the twelfth fret sounds is plotted in Fig.2. Squares, circles and triangles are amplitudes of three different electric bass guitars and the numbers are fret number, for example, '0' and '1' mean the open fret and the first fret, respectively. Fig.2(a) shows fundamental amplitudes of thirteen sounds on the fourth string of three kinds of bass. As a fret number becomes bigger, the amplitude value becomes bigger in the similar trend regardless of three different electric bass guitars. Also harmonic amplitudes have similar transition as shown in Fig.2(b)-(f). But, this aspect is limited the fundamental frequency and from the first to the fifth harmonic. And it is suggested that four strings can match roughly by shifting on the x-axis in the log_2 scale. Therefore, the spectrum of an electric bass guitar has similar transition on each string and we propose the formant structure model based on frequencies of the open fret sound. Then the spectrum made from this structure is called "basic formant ". In addition, it is supposed that the rest of spectrum influences the impression of individual instruments, which is called "atmosphere formant". The structure is the important factor for the timbre and has each harmonic amplitude are estimated by six approximate curves.

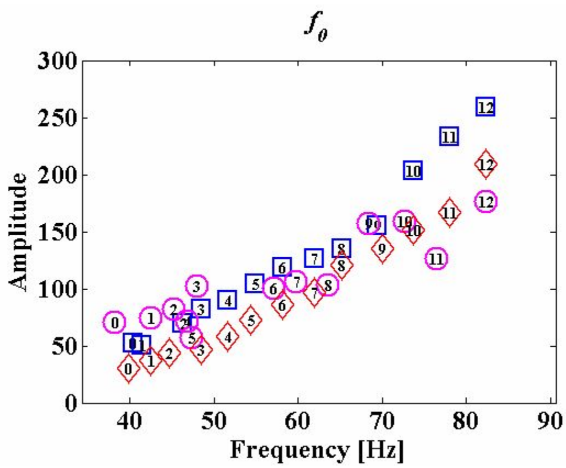


(a) The spectrum of sound A1,

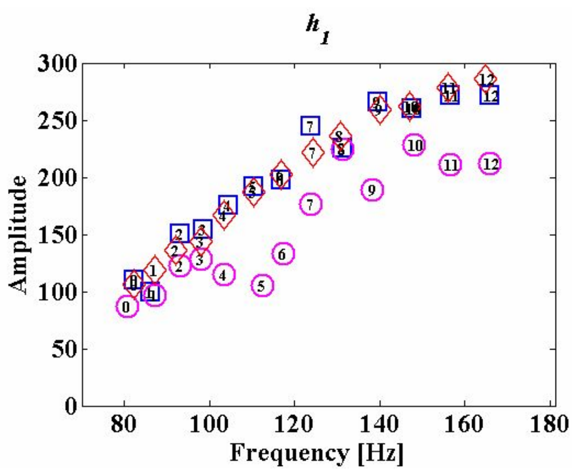


(b) The spectrum on the same fret of different strings,

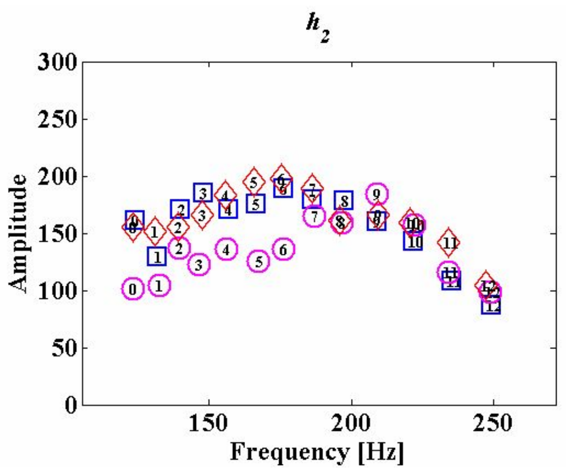
Fig.1 The spectrum of a stringed instrument.



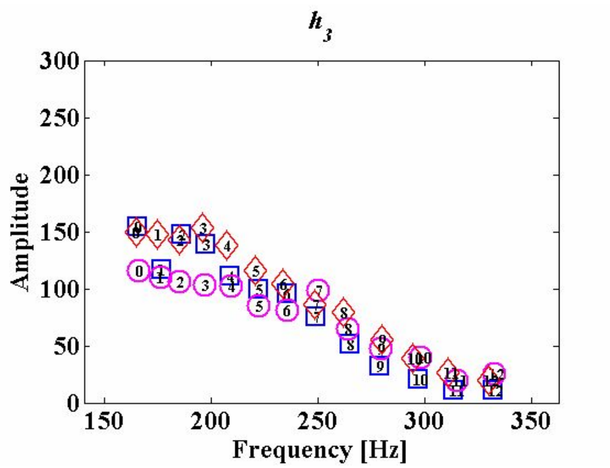
(a) The fundamental frequency,



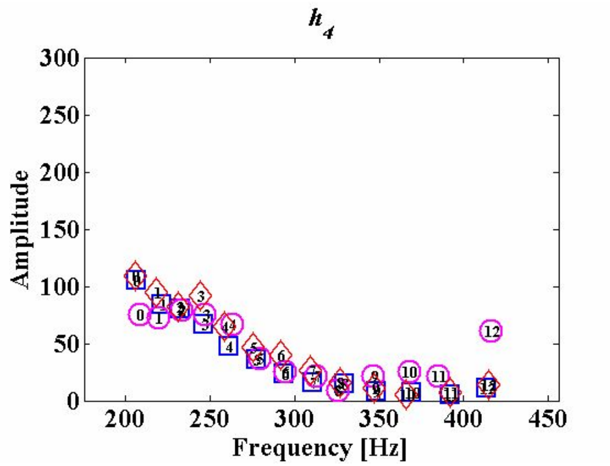
(b) The first harmonics,



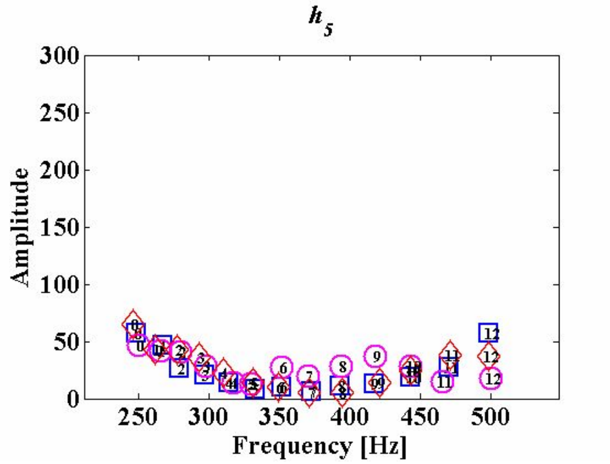
(c) The second harmonics



(d) The third harmonics,



(e) The fourth harmonics,



(f) The fifth harmonics,

Fig.2 Amplitudes of harmonics.

2.2 Temporal feature

This section describes about temporal features of a stringed instrument and analyzes the relation of between transition of energy and timbre. A stringed instrument such as bass and guitar generates sound by plucking a string. The energy increases up to the max at an instant and after that decreases steadily. Fig.4 shows the sound signal wave. So it is supposed that energy transition is classified into two stages: Attack and Release, regardless of pluck strength and the energy decrease at roughly constant ratio. Here we make an experiment to clear whether or not the decreasing ratio influences a timbre. In experiment, decreases of the synthesized sounds are variant and energy of basic and atmosphere formant has energy as same as the origin. As a result, the timbre of synthesized sounds didn't change aurally so much. Moreover, sounds without decrease are perceived as timbre of bass or guitar. Therefore, energy transition isn't so important, but formant structure of timbre.

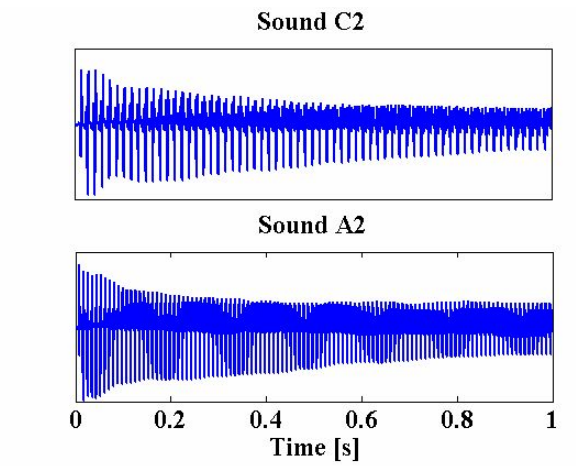
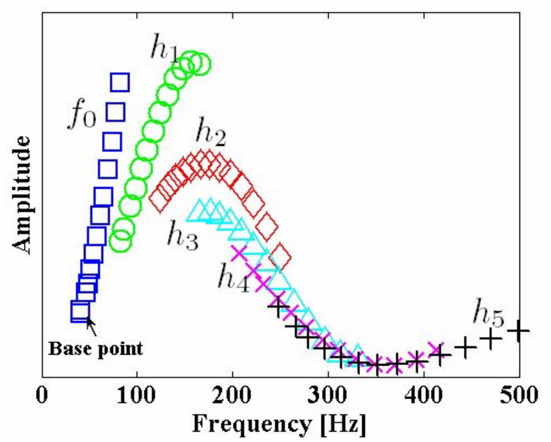


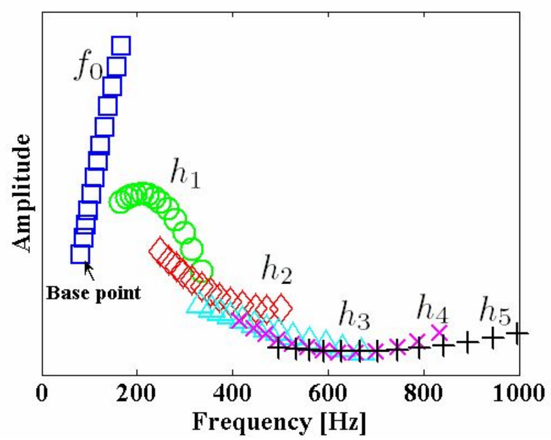
Fig.3 Signal wave of bass sound.

2.3 Formant structure model

As described above, the formant structure model has basic formant and atmosphere formant. Basic formant has six approximate curves and their curves can be shifted based on the pitch on the open fret of each string. And the energy of model is decreasing at constant ratio. Fig.4 indicates basic formant of bass and guitar. However the tolerance exists in our model. The flexibility of a timbre against amplitudes of the formant structure model is analyzed in this section. A timbre may be greatly influenced by changing amplitude value. When each amplitude of the formant structure model becomes α times, it is experimented how much the timbre changes. As a result, influences of changing amplitude were little and the formant structure had wide tolerance. Section 3 makes sure it. The formant structure model mentioned above is proposed and characterizes the timbre of bass. Using this structure it will be able to recognize and segment the electric bass guitar sound in audio signals. And a timbre of bass sound could be synthesized naturally and is arranged for various atmospheres.



(a) Electric bass guitar,

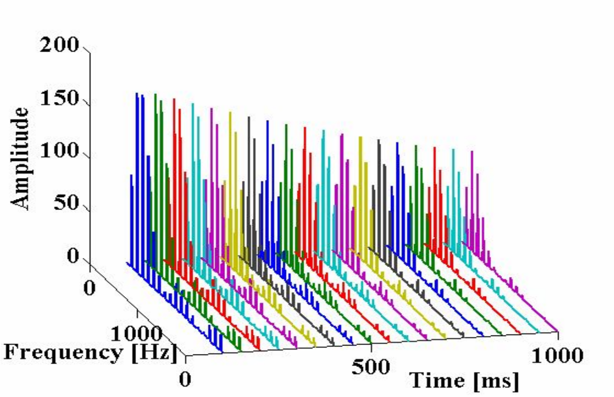


(b) Electric guitar,

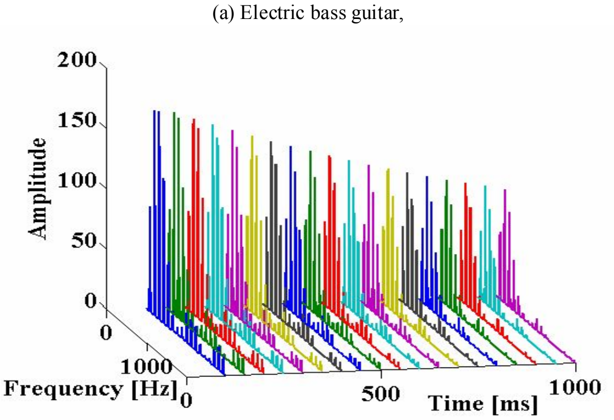
Fig.4 The basic formant structure.

3. Experimental Consideration

In this section, bass and guitar sounds are synthesized from the spectrum based on the proposed formant structure model. To substitute a pitch of sound, the fundamental and the harmonic amplitudes are estimated according to the approximate curve of the formant structure model. The frequency spectrum of a synthesized sound by our model is shown in Fig.5. There is much tolerance and flexibility when deciding the values. And the original atmosphere spectrums are used in this experiment. We confirmed that these spectrums make a timbre sound of bass and guitar with various atmospheres as shown in Fig.6 which shows sound signals on the same fret and string. These sounds' spectrum amplitudes have the similar formant structure model and three definitely different atmosphere spectrums. Their formants are estimated by six approximate curves and atmosphere spectrums are extracted from each original sound. Indeed these sounds have a timbre of the just bass or guitar, but impress with a different atmosphere. In addition, sounds are synthesized with the same pitch and different string. This experiment was put into from the first to the fifth amplitude. Experiments resulted in that as higher pitch, sound was unnatural at attack time. In other words, the timbre was felt with a little alteration, because the sound didn't have Attack time. We think that Attack is influence from phase of spectrum. There experiments were evaluated by seven persons' five-grade marking. Almost all the marks were four and five. Throughout experiments, synthesized sounds based on the formant structure model realized a timbre of bass and guitar sounds with high performance. The timbre of synthesized sounds based on our model wasn't changed such a little that the sounds could be distinguished by human ears. Moreover compared with previous works which used many features and analyzed instrument's structure minutely, our model is not only simple but also flexible and synthesizes sounds naturally.

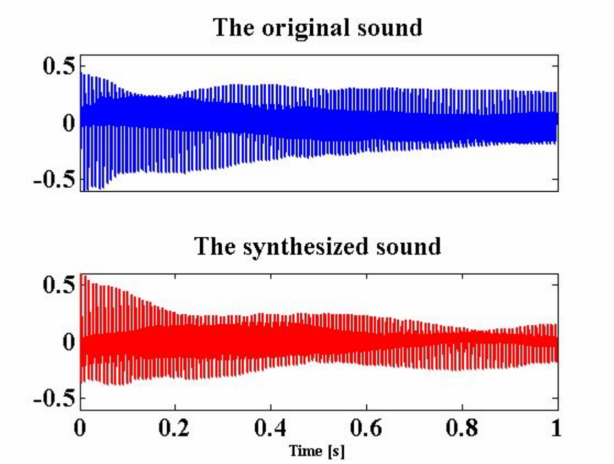


(a) Electric bass guitar,

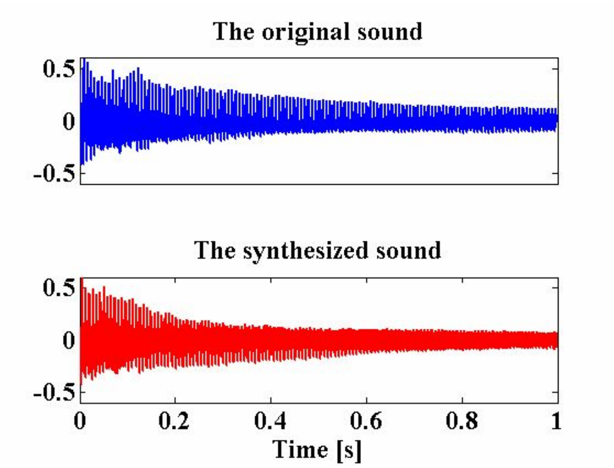


(b) Electric guitar,

Fig.5 Spectrum based on the formant structure.



(a) Electric bass guitar,



(b) Electric guitar,

Fig.6 The synthesized sound.

4. Conclusion

In this paper, a timbre of an electric bass guitar and an electric guitar has been analyzed and the formant structure model has been proposed. The formant structure model made use of physical characteristic of stringed instrument's sounds on the same string. This structure constructed the base timbre of electric bass guitars and electric guitars. And we made it definite that the spectrum except the basic formant structure model represented atmosphere of a individual instrument. Approximate curves of our model represent features of stringed instrument simpler than previous works. Further, using spectrum based on the proposed formant structure model, sounds of an electric bass guitar and an electric guitar were synthesized successfully. It was also found that amplitudes of the formant structure model had a tolerance of about 3 times. In addition, we have got similar results about acoustic and electric guitars. Then, this formant structure model should be improved to other stringed instruments. However, atmosphere spectrums need to be analyzed in more precisely. So we should synthesize the timbre at high quality and with natural sound. And we also need to improve a method to synthesize with less noise.

In near future, we will expand this model into every stringed instrument and generalize this method and adapt it to general instruments. We want to develop the timbre model of musical instruments and find the answer of "what is timbre in essence?".

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