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DISCUSSIONS OF SOUND CHARACTERISTICS OF VIBRAPHONE BY DIFFERENT PLAYING TECHNIQUES

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In musical performance, different playing techniques applied to percussion instruments can produce rigorous effects on sound characteristics. This work aims to discuss the topic about playing different percussion skills on the vibraphone and measure the sound spectrum to study the sound effects of vibraphone due to different kinds of plays. The playing techniques include dyad (dual notes), triad (triple notes), broken chord (arpeggio), grace note (appoggiatura), and rolling note. The radiated percussion sound of vibraphone bar is recorded and analyzed by fast Fourier transform (FFT) spectrum analyzer. The time domain response and sound spectrum are, respectively, presented to show the continuity and timbre effects for different plays. Results show the temporal response and spectral contents by different playing techniques are quite different from just single note stroke. The beating phenomenon in time domain can be specifically interpreted by the frequency spectrum contents. This work presents the quantified approach in studying percussion instrument sound.

1. Introduction

The vibraphone that consists of different sizes of metal bars is one of commonly used percussion instruments. It is interesting to quantify the sound quality of a percussion instrument[1]. The most important index is the pitch for each note. The fundamental natural frequency of a vibraphone bar indicates the pitch of a note which frequency is generally standardized. For pitch evaluation, the first modal frequency of the vibraphone bar in comparison to the absolute frequency of the note must be within 6 cents difference, i.e. about 0.3472%.

The other quality index is the timbre or tone color. Percussion instruments are some kinds of solid structures. Each structure has its modal properties such as natural frequencies, modal damping ratios and mode shapes[2,3]. The first natural frequency of the instrument structure is so called the fundamental frequency that should be corresponding to the standard frequency of the note. For example, the standard frequency for A4 is 440 Hz. The natural frequencies for higher modes of the instrument can also reveal their modal effect on sound pressure response. The higher mode responses are known as timbre that contains those overtone frequencies and makes the instrument with its own style of sound characteristics. The frequency ratios for the overtones over the fundamental frequency can be calculated to show their effects either harmonics or partials. If the frequency ratios are integer values, the overtones are harmonics. Otherwise, the overtones are partials. The harmonic overtones are known for good sound quality and comfort listening for an instrument[4,5].

The percussion sound generally has the exponential decay effect and decay rapidly or slowly dependent on the material or the structural geometry[6]. The decay rate can be used to characterize the percussion instrument for its continuity evaluation. The smaller value of the decay rate indicates the better continuity of the sound. The optimum decay rate for an instrument is not clear. However, the continuity reflects the residual effect of percussion sound.

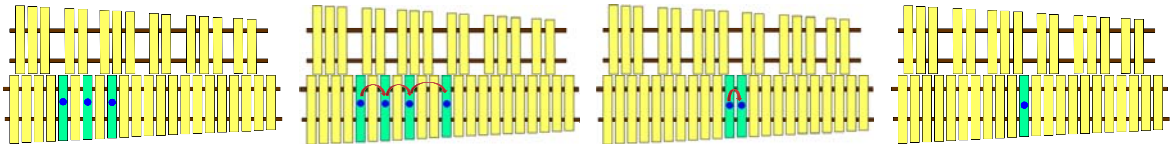
This work aims to discuss the sound characteristics of vibraphone[7] produced by different playing methods. The percussion sound is measured and analyzed by Fast Fourier transform (FFT) analyzer. The sound pressure response in time domain is presented for showing the continuity effect by using the definition of decay rate. The auto power spectral density (PSD) function or simply called auto spectrum for the measured sound is also obtained to visualize the frequency contents for tone color or timbre evaluation.

2. Playing Techniques for Vibraphone

Figure 1 is the picture of the vibraphone studied in this work. For typical percussion instrument performance, different playing methods can be applied to produce different sound effects. This section will briefly introduce the playing methods studied in this work. Besides of single stroke, Figure 2 shows five types of playing methods described as follows:

- **Dyad.** A dyad is a set of two notes or pitches that are played simultaneously[8].
- **Triad.** A triad is a three-note chord[9]. Three strokes are played on the three notes simultaneously. The major triad contains a major third and perfect fifth interval such as C major containing C-E-G.
- **Broken chord.** The broken chord is also termed the arpeggio[10] that is to play notes in a chord one after the other, rather than stroke simultaneously. The player has to play the sounds of a chord individually to differentiate the notes. An arpeggio in the key of C major going up one octave is the notes such as (C4, E4, G4, and C5).
- **Grace note.** The grace note is defined as consisting of two single strokes played by alternating hands[11]. The first stroke is a quieter grace note followed by a louder primary stroke on the opposite hand. The temporal distance between the grace note and the primary note is short in this study and the combination of the grace note and primary note play is called appoggiatura.
- **Roll.** The open roll is to play with double strokes alternating between two hands, i.e. rolling the strokes with two hands on a note to produce a sustained, continuous sound[12].

Figure 1. Picture of Vibraphone.



(a) Dyad/Triad (b) Broken chord (c) Grace note (d) Roll

Figure 2. Different playing techniques for vibraphone.

3. Sound measurement and engineering interpretations

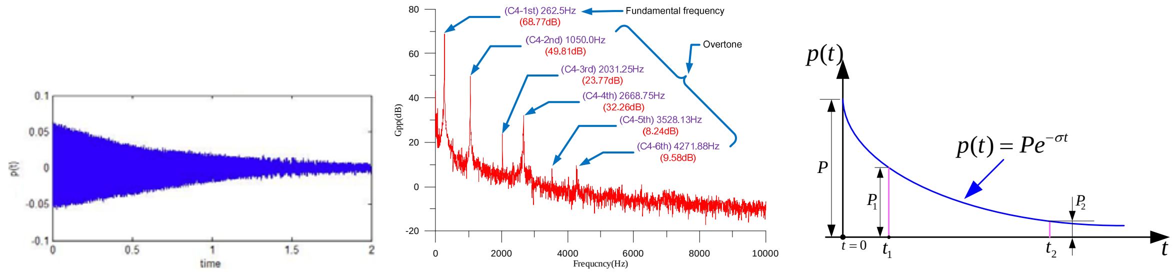
The vibraphone can be played by different playing methods. The sound pressure response in time domain is recorded and processed by the FFT analyzer to obtain its frequency spectrum in terms of auto spectrum. The fundamental frequency as well as overtone frequencies of a note for the vibraphone bar is studied. The sound pressure amplitudes corresponding to those resonant frequencies are monitored to characterize the percussion sound effects due to different playing methods.

Figure 3(a) is the typical time domain response of sound pressure revealed the exponential decay phenomenon, and Figure 3(b) is its frequency domain plots shown several peaks that are structural resonant frequencies. To quantify the sound quality of a vibraphone bar, we use three sound quality indices as follows.

- **Pitch.** Each note has its standard frequency. The standard frequency for the C4 note is 261.63 Hz. As shown in Figure 3(b), the fundamental frequency is 262.5 Hz. There is only 0.9 Hz difference. This indicates the pitch of the C4 note is quite accurate.
- **Timbre or tone color.** Other than the fundamental frequency that is the tone or note of the music sound, the other significant peak frequencies are called overtones that make the sound hear differently for different instruments. The overtones compose of the tone color or timbre of percussion sound of vibraphone bar. For the studied vibraphone, each note of vibraphone bar contains a fourth harmonics overtone, i.e. the second modal frequency (1050 Hz) is just the ratio of four to the fundamental frequency (262.5 Hz). The harmonic that is the whole number multiply of the fundamental frequency is believed to have a good sound quality for an instrument.
- **Continuity.** As shown in Figure 3(a), the exponential decay effect can be observed. The continuity of the percussion is defined by the exponential decay rate as shown in Figure 3(c). The decay rate σ can be determined as follows:

$$\sigma = \frac{\ln P_2 - \ln P_1}{t_2 - t_1}. \tag{1}$$

where P_i is the amplitude at time t_i as shown in Figure 3(c).



(a) time domain (b) frequency domain (c) exponential decay

Figure 3. Typical sound pressure of C4 note of vibraphone bar.

4. Results and discussions

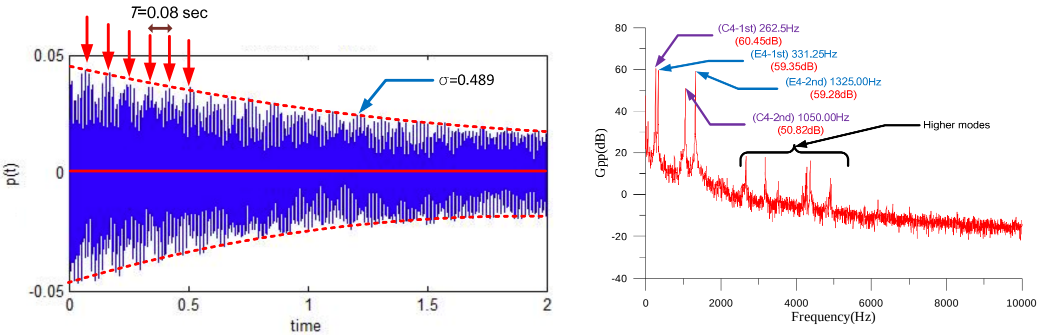
This section will discuss the percussion sound characteristics of the vibraphone played by different techniques illustrated in Section 2. The sound pressure characteristics of the single stroke of each note for the vibraphone bar are studied and not shown in this paper for brevity. The pitches of notes for the vibraphone bars are generally very good and fulfilled with standard frequencies. The special timbre properties of the vibraphone is that each vibraphone bar almost has the fourth harmonics and some may also have the second, third, fifth, or ninth harmonics. The harmonics make the vibraphone bar producing a comfortable listening effect. The continuity of the percussion sound for the vibraphone bar lasts quite long. The decay rates for all notes of the vibraphone bars are ranged between 0.4 and 1.4.

4.1 Percussion sound effects for Dyad and Triad plays

Figures 4(a) and 4(b) show the time and frequency domain response of the percussion sound produced by the dyad play on C4 and E4 notes of vibraphone bars. Other than the similar exponential effect which decay rate is σ =0.489 for the dyad play smaller than σ =1.204 for C4 and σ =0.819 for E4 by the single stroke play, the dyad play increases the continuity of the percussion sound. For the timbre of dyad play, the first two modes of both C4 and E4 notes of vibraphone bars are dominantly excited and produce the beating phenomenon in time response. The beating period as shown in Figure 4(a) can be identified about 0.8 sec that produces the beating frequency 12.5 Hz. The beating effect can be postulated from the frequency difference between E4 and C4 notes, i.e. 331.25(E4) − 262.50(C4)=68.75 Hz. Other relations are (262.50 − 68.75x4)= − 12.50 Hz and (331.25 − 68.75x5)= − 12.50 Hz. The dyad play produces a good partial effect on beating phenomenon.

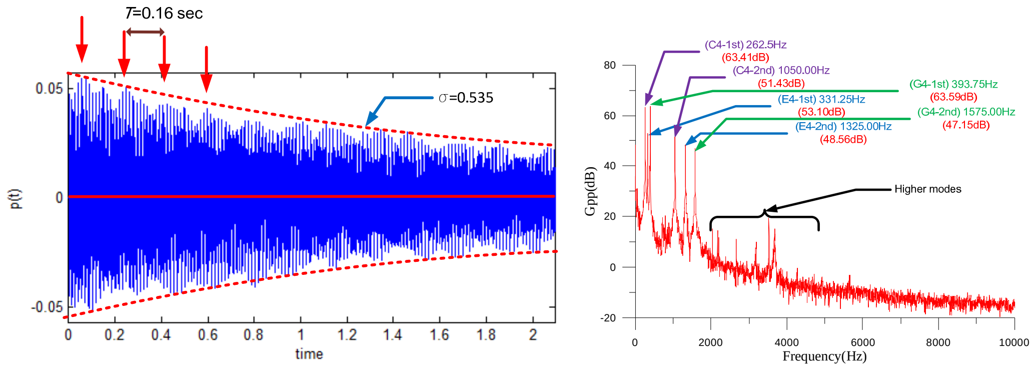
Figure 5 is similar to Figure 4 but for the triad play on C4, E4 and G4 notes of vibraphone bars. The decay rate for the Triad play is σ =0.535. The beating phenomenon can also be observed as shown in Figure 5(a). The beating period is about 0.16 sec and results in the beating frequency 6.25 Hz. The beating effect can be explained by the following calculations from frequency spectrum:

$$\begin{aligned} &331.25(\mathrm{E4}) - 262.50(\mathrm{C4}) = 68.75\ \mathrm{Hz} \\ &393.75(\mathrm{G4}) - 331.25(\mathrm{E4}) = 62.50\ \mathrm{Hz} \\ &393.75(\mathrm{G4}) - 262.50(\mathrm{C4}) = 131.25\ \mathrm{Hz} \\ &68.75 - 62.50 = 6.25\ \mathrm{Hz} \\ &131.25 - 62.50 \times 2 = 6.25\ \mathrm{Hz} \\ &131.25 - 68.75 \times 2 = -6.25\ \mathrm{Hz} \end{aligned} \quad . \tag{2}$$



(a) time domain (b) frequency domain

Figure 4. Typical sound pressure for Dyad play on C4 and E4 notes of vibraphone bars.

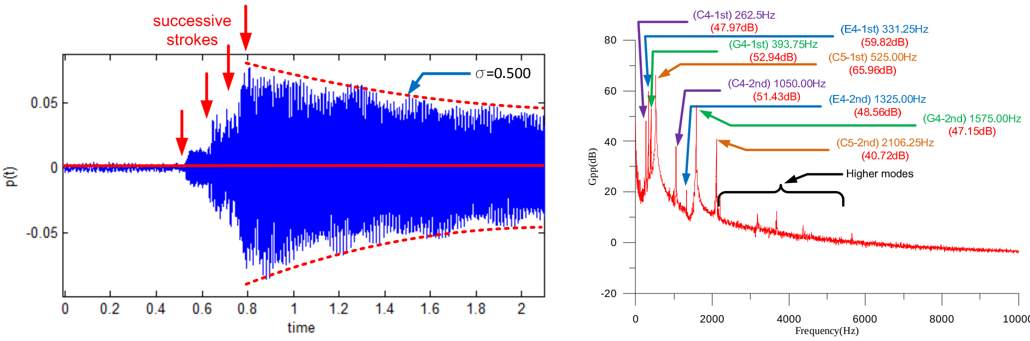


(a) time domain (b) frequency domain

Figure 5. Typical sound pressure for Triad play on C4, E4 and G4 notes of vibraphone bars.

4.2 Percussion sound effects for broken chord play

Figure 6 shows the sound pressure response produced by the broken chord play on C4, E4, G4, and C5 individually and successively. The sound amplitude in the time domain gradually increases while the individual stroke successively plays on the notes. The decay rate is about σ =0.5 smaller than the values for the single stroke on each note. The spectral amplitude of the first mode for each note is higher than that of the second mode. The first modal amplitude of C4 note is the smallest and roughly increases up to the C5 note which modal amplitude is the largest one.

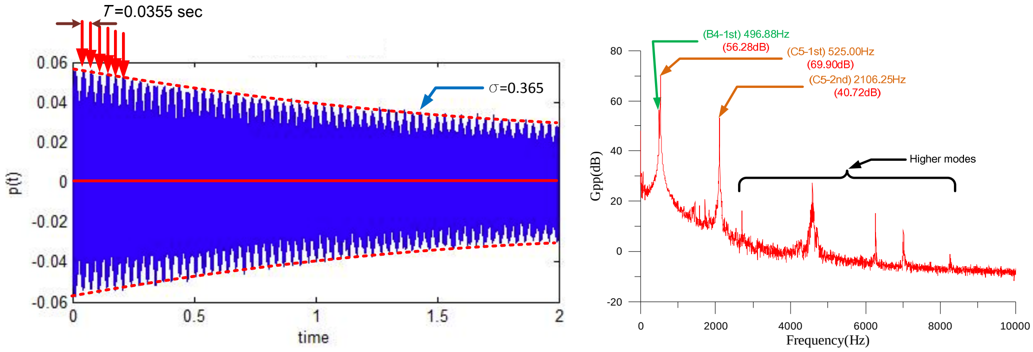


(a) time domain (b) frequency domain

Figure 6. Typical sound pressure for broken chord play on C4, E4, G4 and C5 notes of vibraphone bars.

4.3 Percussion sound effects for grace note play

The grace note play is to have the first quieter stroke on B4 note followed by the louder primary stroke on C5 note. As shown in Figure 7(a), a strong beating phenomenon can be observed with the beating period about $T_b = 0.0355$ sec and the beating frequency $f_b = 28.17$ Hz. Figure 7(b) shows the auto spectrum for the grace note play. The grace note is B4 that produces only the first modal or fundamental frequency response. The primary note C5 reveals all resonant frequencies just like the single stroke play on C5. Since the composition of both the first modal response from B4 and C4, the beating frequency can be identified as the difference between the first modal frequencies of B4 (grace note) and C5 (primary note), i.e. 525.00(C5)－496.88(B4)=28.12 Hz that is close to 28.17 Hz obtained from the time domain response. As discussed, the grace note play produces the strong beating effect and increases the continuity of percussion sound for the decay rate σ =0.365 smaller than other plays in this study.

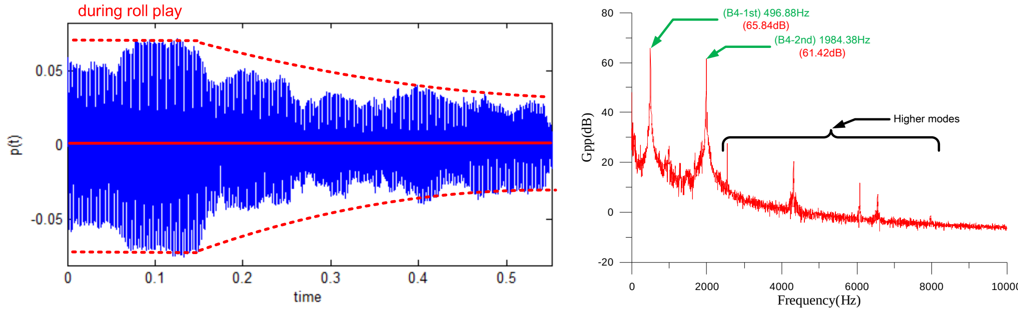


(a) time domain (b) frequency domain

Figure 7. Typical sound pressure for grace note play on B4 and C5 notes of vibraphone bars.

4.4 Percussion sound effects for roll play

Figure 8 shows the sound pressure response produced by the roll play on B4 note stroke alternatively and rapidly by two hands. The major difference of the roll play from the single stroke play is that the second modal frequency (B4-2nd) 1984.38 Hz is strongly excited only about 4.4 dB lower than the first mode as shown in Figure 8(b). For single stroke play, the second modal amplitude is normally less than the first mode for over 10 dB.



(a) time domain (b) frequency domain

Figure 8. Typical sound pressure for roll play on B4 note of vibraphone bars.

5. Conclusions

The percussion sound characteristics of vibraphone bars by different playing techniques are discussed. The time and frequency domain response for the sound pressure produced by the dyad, triad, broken chord, grace note and roll plays of vibraphone bars are examined. The continuity of percussion sound and the timbre, i.e. the frequency contents, are presented to show the sound effects due to different kinds of plays. The beating phenomenon in the time domain can be observed and characterized by the beating frequency that is related to the difference among the fundamental frequencies of the notes. The spectral contents by different playing methods may compose different modal amplitudes due to different excitation patterns. This work introduces the engineering method to interpret the percussion sound of vibraphone bars by different playing techniques and shows the physical explanation and quantification of percussion sound quality. The engineering analysis approach can be adopted for other percussion instruments as well.

REFERENCES

1. Fletcher, N.H., and Rossing, T.D., *Physics of Musical Instruments*, Springer-Verlag, New York, (1991).
2. Chaigne, A., "Recent Advances in Vibration and Radiation of Musical Instruments," *Flow, Turbulence and Combustion*, Vol. 61, No. 1-4, pp.31-41, (1999).
3. Rossing, T. D., Yoo, J., and Morrison, A., "Acoustics of Percussion Instruments: An Update," *Acoust. Sci. & Tech.*, Vol. 25, No:. 6, pp.406-412, (2004).
4. Wang, B. T., and Jian, X. M., "Model Verification and Percussion Sound Characteristics of Metallophone with Chord Sound," *Proceedings of the 17th International Congress on Sound and Vibration*, Cairo, Egypt, Paper No.: 376, (2010)
5. Wang, B. T., "Integration of FEA and EMA Techniques for Percussion Instrument Design Analysis," *2011 International Conference on System Science and Engineering*, Macau, China, pp. 11-16, (2011).
6. Bundesanstalt, P. T., Braunschweig, and Germany, "Practical Tuning of Xylophone Bars and Resonators," *Applied Acoustics*, Vol. 46, pp. 103-127, (1995).
7. http://en.wikipedia.org/wiki/Vibraphone.
8. http://en.wikipedia.org/wiki/Dyad_(music).
9. http://en.wikipedia.org/wiki/Triad_(music).
10. http://en.wikipedia.org/wiki/Arpeggio.
11. http://en.wikipedia.org/wiki/Grace_note.
12. http://en.wikipedia.org/wiki/Drum_roll