Development of a Synthesis Model Based on KS Algorithm for Metallic Percussion Instrument

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Abstract. This paper describes a basic synthesis model based on the KS algorithm for metallic percussion instrument. Unlike other percussion instruments, Korean metallic percussion instrument called Jing have a precise harmonic structure that is characteristic of stringed instruments. In addition, each harmonic exhibits a frequency gliding phenomenon called softening according to the intensity of the deriving, and irregular non-linearity called hardening for some partials. Therefore, the proposed synthesis model applies KS algorithm for harmonic structure and KS algorithm with time-varying propagation speed for irregular nonlinearity, hardening.

Introduction

The metallic percussion gong renders a single pitch and has a frequency gliding due to the structural characteristics. In 1978, Rossing and Ross studied the vibration mode and the timbre of Chinese and Indonesian percussion instruments, confirming that the Chinese gong has a pitch and a semitone variation depending on its size [1]. Peterson and Rossing researched vibrational modes and spectra of cymbal, tamtam, and gong [2]. Fletcher reported that the shape of the gong is related to the nonlinearity of the hardening or softening [3]. Based on these results, Krueger et al. revealed two sources of the ombak (beating) phenomenon produced by the nonlinear mode coupling [4].

For the Korean metallic percussion instruments, Sung in 1994 analyzed the acoustical and vibrational characteristics of Jing and Kkwaenggwari (Korean folk style gong) and reported that they show the softening phenomenon [5]. Afterwards, Kwon et al. discovered the vibration mode of Jing and the natural frequency through the acoustic analysis using the planar acoustic holography and accelerometer, and observed a rotating energy phenomenon at a specific frequency [6]. Also, researches were conducted on how to construct Korean gong and its acoustic characteristics [7], on sound amplification and duration according to the depth of rim [8], as well as on the detection of eigen frequency from gong sound using ensemble empirical mode decomposition [9]. Likewise, most studies until now have focused on discovering vibration modes and natural frequencies. In this paper, we propose a sound synthesis model for metallic percussion instrument, especially, for Korean percussion instrument. The proposed model is able to express both the exact pitch and nonlinearity as a model combining the conventional KS algorithm and the KS algorithm with time-varying propagation speed.

Korean Gong called Jing

Physical Characteristics

Jing is a traditional Korean metallic percussion instrument having the structure of curved plate, and was used widely from old for the palace music as well as the folk music. The making of Jing relies a great deal on the word of mouth and experience because it is constructed using the traditional quenching method in which an alloy of copper and tin with 72 to 28 ratio is hammered by numerous
craftsmen [10]. Accordingly, Jing is not uniform in size, but it can be measured approximately in comparison to Jing manufactured by the craftsmen (See Figure 1(a)).

![Figure 1. Structure and measurement. The measurements in the figure are indicated with min-max (this study). E.g.: 382-400 (382).](image)

**Acoustical Characteristics**

Although Jing is a percussion instrument, it has a harmonic structure like a stringed instrument. It also has a number of partials, which are characteristic of percussion instruments. In particular, due to the structural characteristic of the curved plate, when the Jing is strongly derived, the harmonics show the frequency gliding called softening. This phenomenon appears most pronounced in the harmonics and also in some partials. The hardening phenomenon also appears. Harding differs from softening in that it appears only in certain partials. The softening can be observed even if the deriving is relatively weak, but the hardening can be observed only when the gong is strongly struck, and the frequency gliding is relatively small compared to the softening.

**Sound Synthesis**

**Proposed Model**

The KS algorithm was proposed by Karplus and Strong [11] to synthesize sounds of plucked string instrument and drum timbre. A number of harmonics should be produced in order to synthesize the realistic sound of a stringed instrument. For this, random noise is applied to the wave table, in which case sounds that are very similar to the guitar can be synthesized. The KS algorithm can be mathematically expressed as

\[
y(n) = \frac{1}{2} \{y(n - N) + y(n - N - 1)\}
\]  

(1)

Smith developed a digital waveguide model by generalizing the KS algorithm [12]. Eq. 2 is obtained by modifying Eq. 1 with a waveguide model.

\[
y(n,k) = \frac{1}{2} \{y(n - N,k) + y(n - N - 1,k)\}
\]  

(2)

This is the case when the wave propagation speed is fixed at 1, and if the propagation speed is not a unit sample, the output at the same observation point is expressed by Eq. 3 [13].

\[
y(n,k) = y(0,k - T \sum_{j=0}^{n-1} c(j)), \quad n > 0
\]  

(3)
Therefore, Eq. 2 can be modified as

$$y(n, k) = \frac{1}{2} \left\{ y(0, k - T \sum_{j=0}^{n-N-1} c(j)) + y(0, k - T \sum_{j=0}^{n-N-2} c(j)) \right\}, \quad n > 0$$

(4)

where $T$ is the sampling time, $N$ is the length of the wavetable, and $c(j)$ is the time-varying propagation speed.

Since the nonlinearity of a percussion instrument such as hardening occurs only at a specific frequency, the final synthesized sound is produced by adding Eq. 2 and band pass filtered Eq. 4. The block diagram of the proposed synthesis model is shown in Figure 2.

**Figure 2. Proposed synthesis model including the conventional KS algorithm and the KS algorithm with time-varying propagation speed.**

### Results

To verify the proposed model, we synthesized the sound with the fundamental frequency of 150Hz and the hardening occurs at 200Hz. In order to make it easy to distinguish visually, the amount of frequency shift is set to 15 Hz.

**Figure 3.** (a) Waveform and spectrum of synthesized sound by conventional KS algorithm, (b) STFT of the sound synthesized by using KS algorithm with time-varying propagation speed. This sound shows the frequency gliding from 200Hz to 185Hz. (c) Waveform and spectrum of synthesized sound by proposed model, and (d) spectrogram of the sound shown in (c).
Figure 3(a) shows the waveform and spectrum of the sound synthesized by the conventional KS algorithm. The sound existing for a long time and the harmonic structure are similar to the characteristics of gong and string instrument, respectively. Figure 3(b) depicts the frequency shifting from 200Hz to 185Hz. In other words, this means that the KS algorithm with time-varying propagation speed can represent the nonlinearity of metallic percussion instruments. Figure 3(c) shows the waveform and spectrum of the synthesized sound using the proposed model, and Figure 3(d) represents the spectrogram of the synthesized sound. The synthesized sound exhibits a nonlinear characteristic at a specific frequency while exhibiting an accurate harmonic structure.

Conclusions

This paper proposes a basic synthesis model for metallic percussion instrument. The proposed model consists of the conventional KS algorithm and the KS algorithm with time-varying propagation speed and can describe the representative characteristics of the gong. However, this model cannot express all of the sophisticated timbre of metallic percussion instruments. Future work in making the model more accurate is required.

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