# ELECTRIC KOTO BY VIBRATING BODY

*Naoya Takahashi*
Waseda University
School of Science and Engineering

*Mitsuharu Matsumoto*
Waseda University
School of Science and Engineering

*Shuji Hashimoto*
Waseda University
School of Science and Engineering

**ABSTRACT**

In these years, a Japanese string instrument called KOTO and high-volume instruments such as the electric bass and drams are often played together. In that case, the volume of the KOTO sound must be increased to a satisfactory level for balancing. However, when amplifying the volume of the KOTO sound, there are some problems such as the feedback, the cross-talk with other back ground sounds and the degradation of sound quality. The pickup device attached on the specific musical instrument is often employed to obtain only the sound without other instrumental sounds. The obtained timbre is, however, different from the one we hear at the usual listening position. In this paper, we propose an electric KOTO with built-in speaker to make the body resonance. By employing the real KOTO body as a physical sound filter, it is possible to amplify the sound volume without changing the timbre. We achieved 10dB amplification of the sound pressure level without the feedback, the cross-talk of other sounds, and the degradation of the sound quality.

## 1. INTRODUCTION

In these years, the style of concert becomes diverse and the KOTO, which is the Japanese string instrument, and high-volume instruments such as the electric bass the drums are often played together. In that case, the volume of the KOTO sound must be increased to a satisfactory level for balancing. A microphone is often used to record the KOTO sound in concert. The obtained timbre is, however, different from the one we hear at the usual listening position because the microphone is set near the KOTO where the sound volume is maximum. Moreover, we can not amplify KOTO sound exclusively because of the cross-talk with other background sounds. The feedback is also a big problem.

The pickup device attached on the specific musical instrument is often employed to obtain only the objective sound. However, the obtained timbre is different from the original sound because the frequency characteristics of the sound path are different.

Our aim is to amplify the KOTO sound while keeping the timbre. This paper proposes a method to amplify the KOTO sound by vibrating the body. When we utilize the real body as a filter, it is possible to amplify the sound volume without timber degradation. It is reported that in the case of guitar when we listen to the music with the speaker implanted in the instrumental body, we can feel high realistic sensation [1].

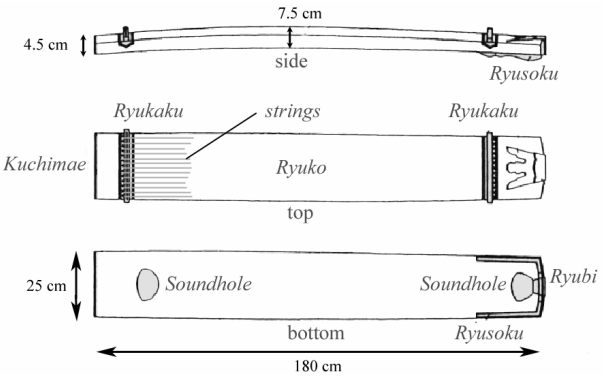


**Figure 1**. Structure of KOTO.

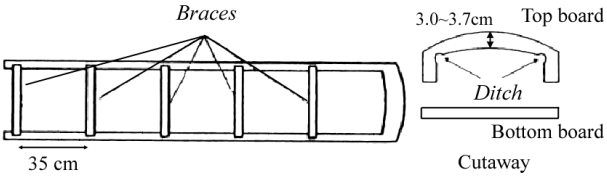


**Figure 2**. Inside structure of KOTO.

## 2. STRUCTURE OF KOTO

KOTO is a Japanese traditional instrument. Figure 1 shows the structure of KOTO. KOTO is 180cm approximately long, 25cm width, 7.5cm thickness at the center of body, and 4.5cm thickness at both ends. There are two sound holes at the bottom of KOTO. Four braces are set on backside at 35cm intervals. The top board is made of one Paulownia plate. It has a face sheet and a side plate as shown in Figure 2. The plate corresponding to the face sheet has 3.7cm thickness in the middle, and 3.0cm thickness in both ends. It is extremely thicker than the other string instruments. As shown in Figure 2, the top board has two ditches at the inside corner. The thickness of the bottom board is 1.1cm. It is thinner than the top board. Therefore, the radiant energy at the bottom side is higher than that at the top side in high-frequency [2].

The KOTO has 13 strings made of polyester. Each string produces one tone. The KOTO has a plate, KOTOJI whose height is 5~6cm, to sustain each strings. KOTOJI has two functions; *i.e.* a bridge in the violin and a fret in a guitar. The feature of KOTOJI is movability. Players can adjust the length of strings from the bridge, RYUKAKU to KOTOJI by moving KOTOJI to tune the strings (Figure 3). The strings are picked by using ivory picks called TSUME, which means nail in English.

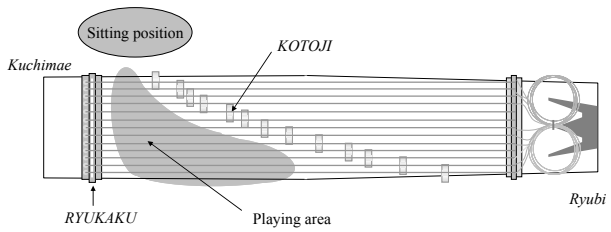


**Figure 3**. Setting position and playing area

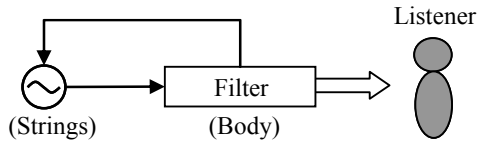


**Figure 4**. Modeling of sound produce system of the KOTO.

Three TSUME are used when we pick the strings. They are attached on the forefinger, middle finger, and thumb of the right hand.

## 3. PROPOSAL METHOD

In this section, firstly we describe the modeling of the sound produce system of KOTO. Then, after discussing the problem of the conventional methods, we explain the proposal method.

### 3.1. Modeling of sound produce system of the KOTO

Figure 4 shows the basic scheme of the sound produce system of KOTO. When a player picks the string, the vibration of the string become an oscillator and vibrates the body through the KOTOJI and the bridge. Body resonates and behaves like a sound filter.

The timbre of KOTO is generated due to the resonance of the body. In other words, the body behaves as a sound filter. As shown in Figure 4, there is also a feedback loop to return the vibration of the body to the strings from the body. The arrow from the filter to the listener represents an acoustic signal. Note that filter in Figure 4 has some volume relatively large. Hence, the vibration of the body differs depending on the position. In other words, the timber is different depending on the listening position and sound characteristics change continuously to the listening position.

### 3.2. The problem of the conventional methods

Figure 5 shows the basic scheme of the amplification utilizing a microphone. In Figure 5, we consider the amplifying path in addition to the sound produce system in Figure 4. The feedback occurs by inputting the output of the speaker to the microphone. Cross-talk of the other back ground sounds occurs by mixing other instrument sounds into the amplifying path. And the timbre is changed depending on the position of the microphone. The microphone is always set under the sound hole to obtain the high gain. Therefore, the timbre is different from the one we hear at the usual listening position [1].

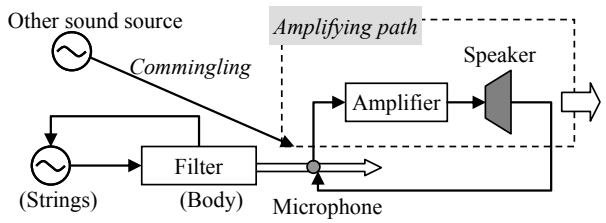


**Figure 5.** Basic scheme of the amplification utilizing a microphone.

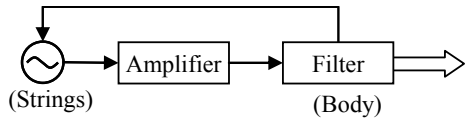


**Figure 6.** Basic scheme of proposal method.

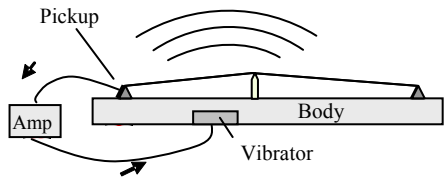


**Figure 7**. The system architecture

### 3.3. Proposal method

Figure 6 shows the basic scheme of the proposal method. The proposal method amplifies the KOTO sound by amplifying the signal based on the vibration of the strings, propagating the signal to the body, and vibrating the body. Figure 7 shows the system architecture. An electric KOTO consists of three kinds of parts; KOTO, the pickup device, and the vibrator. The pickup is for capturing the vibration of strings, and the vibrator is for vibrating the body. As utilizing the real body as a sound filter, the electric KOTO can amplify the sound without changing the timbre. There may exist a phase problem due to the two parallel signal paths (through the body and through the amplifier). We, however, ignore the problem because the amplified signal is mach lager than body path signal. The problem of cross-talk with other back ground sounds is also resolved by utilizing the pickup device. Because it can pick up not the vibration of the air but the vibration of strings through the bridge. The electric KOTO can reproduce acoustic field around the instrument.

## 4. DEVELOPMENT OF ELECTRIC KOTO

To realize the proposal method, we develop the electric KOTO as shown in Figure 8. The piezoelectric device is used as a pickup device. For a vibrator, we utilize a speaker because it can convert electric signal into the physical vibration with the minimal distortion. Five piezoelectric devices are attached at the bottom of bridge as shown in Figure 9 to sense the vibration of all strings [3]. The rubber is attached on back face of the

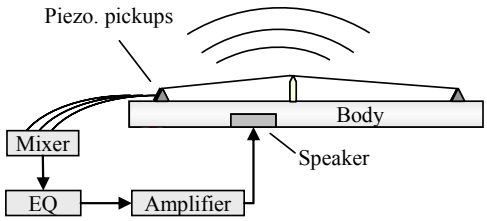


**Figure 8**. The structure of the electric KOTO

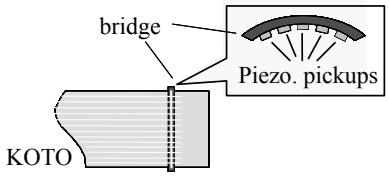


**Figure 9**. Position of the piezoelectric device

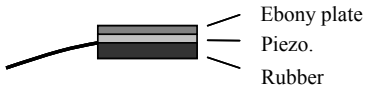


**Figure 10**. The structure of the piezoelectric pickup

| Instrument | Sound pressure[dB] |
|---|---|
| KOTO | 65～80 |
| Electric KOTO | 75～90 |
| Drums | 80～110 |

**Table 1.** Comparison of the sound pressure

| | |
|---|---|
| $SN_m$ | 9.9 [dB] |
| $SN_p$ | 22.5 [dB] |

**Table 2.** Comparison of SNR

piezoelectric device to control the feedback as Figure 10. Signals from these pickups are combined with the mixer for balancing. After the signals pass the equalizer, it is inputted into the amplifier. The signal is definitely played by a speaker. The equalizer is utilized to suppress the feedback. The position of the speaker is determined at the center of KOTO because when we set the speaker at any position of backside KOTO, the difference of timbre is not perceived aurally in the preliminary experiments.

## 5. ASSESSMENT EXPERIMENT

We conducted the experiments from three view points. One is for evaluating the amplification of sound volume. The second is for evaluating the improvement of cross-talk of other back ground sounds. The third is for evaluating the timbre degradation.

### 5.1. Sound volume

We compare the sound pressure of KOTO, the electric KOTO, and drums. We play a general piece and measure the fluctuation band of the sound pressure in front of KOTO utilizing sound-level meter (characteristic A). The distance between KOTO and the sound-level meter is 1.5m. Table 1 show that the sound pressure of the electric KOTO is increased by about 10 dB. Although the sound pressure of electric KOTO is not as large as that of drums, it is large enough to concert with drums acoustically.

### 5.2. Cross-talk of other back ground sounds

We measure the Signal to Noise ratio (SNR) to estimate the amounts of the cross-talk of the other back ground sounds. The recorded accompaniment sound
produced by drums, electric bass, and electric guitar, is outputted from the speaker placed at 2m backside from KOTO. KOTO part is performed by human player. Then we record it with a microphone and a piezoelectric pickup. $A_{Nm}$ and $A_{Np}$ represent the amplitude of signal from microphone and piezoelectric pickup, respectively. $A_{Sm}$ and $A_{Sp}$ represents the amplitude of signal from microphone and piezoelectric pickup when we play KOTO, respectively. SNR can be described as follows;

$$SN_m = 20\log\frac{A_{Sm}}{A_{Nm}} \quad (1)$$

$$SN_p = 20\log\frac{A_{Sp}}{A_{Np}} \quad (2)$$

$SN_m$ and $SN_p$ represent SNR of a microphone and a piezoelectric pickup respectively. $A_{Nm}$ and $A_{Np}$ are set to the average value of the envelope of the background sounds. To get $A_{Sm}$ and $A_{Sp}$, we picked the strings many times and obtained the maximal amplitude of the sound. We then set $A_{Sm}$ and $A_{Sp}$ to the average of the maximal amplitudes. Table 2 shows experimental result. The SNR of the piezoelectric pickup is improved by 12dB. These results show that piezoelectric pickup can be utilized for solving the problem of cross-talk of other back ground sounds.

### 5.3. Timbre

It is known that the sound frequency spectrum is closely related with the timbre, although the relation between tiny difference of the timbre and the physical parameter is not sufficiently clarified [4]. We compare the timbre by utilizing spectrum and spectrogram. When the spectrogram distribution of electric KOTO corresponds with that of KOTO excepting the amplitude difference, we consider that we can amplify the KOTO sound while keeping the timbre.

We compare the spectrum and spectrogram of the electric KOTO with those of KOTO and that of the piezoelectric pickup. The sounds of KOTO and electric KOTO were recorded by a microphone set in 30cm front of KOTO. The piezoelectric pickup to obtain the signal for comparison was attached on the back side of KOTO. The equalizer shown in Figure 8 was omitted to clarify the function of body as a sound filter.

### 5.4. Spectrum

Figure 11 shows the spectrum of KOTO, the piezoelectric pickup, and the electric KOTO. The spectrums were calculated from the signal in case that we played the 9$^{th}$ strings (A, 442Hz). The spectrum was

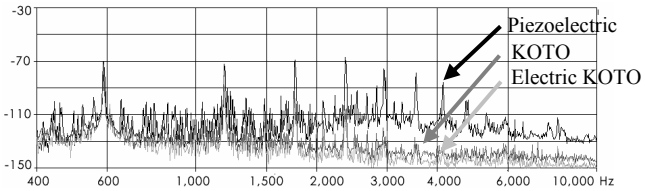


**Figure 11**. The comparison of spectrum

| | |
|---|---|
| Window size | 65,536 |
| Overlap | 75% |
| Window | Blackman |

**Table 3.** Parameter of FFT (spectrum)

calculated for 1 second based on the time when the amplitude of the waveform was maximal. Table 3 shows the parameters of FFT. The sound amplitudes were normalized to make the frequency components equal. We evaluated the timbre by investigating the power ratio of harmonics on the fundamental pitch. If the ratios are similar to KOTO, we consider that the timbre of electric KOTO is similar to KOTO. As shown in Figure 11, the frequency components of the piezoelectric pickup are similar to those of KOTO when we pay attention to the frequency components less than 2 kHz. However, when we pay attention to the frequency components above 2 kHz, the power is 20dB higher than those of KOTO. It may cause the impression like a "dry" or "crisp" sound. Meanwhile, the frequency components of the electric KOTO are very similar to those of KOTO.

### 5.5. Spectrogram

Figures 12, 13 and 14 show the spectrogram of the KOTO, piezoelectric pickup, and the electric KOTO (F# 370Hz), respectively. The spectrogram is calculated for 1 second based on the time after the player picks the string. Table 4 shows the parameter of FFT. These figures show that the spectrogram of the piezoelectric pickup is different from that of KOTO. The power and length of harmonic overtones are different in 2 kHz~5 kHz. Meanwhile, in case of electric KOTO, the decay of harmonic overtone is similar to that of KOTO.

## 6. CONCLUSION

We proposed and developed an electric KOTO by vibrating the body. The proposed electric KOTO could amplify the sound volume by 10 dB. By utilizing piezoelectric pickup, the proposed method could also solve the problem of the cross-talk of other background sounds. We also confirmed that the spectrum and spectrogram of the electric KOTO are similar to those of KOTO. For the future works, we will investigate the acoustic field reproducibility, minimize the system size, and amplify the sound volume more.

## 7. ACKNOWLEDGMENT

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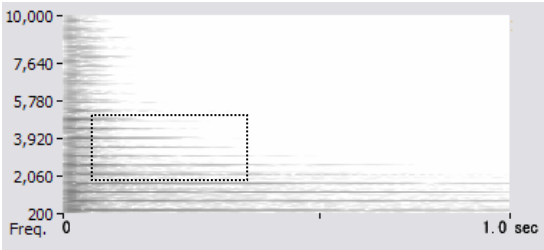


**Figure 12**. Spectrogram of the KOTO

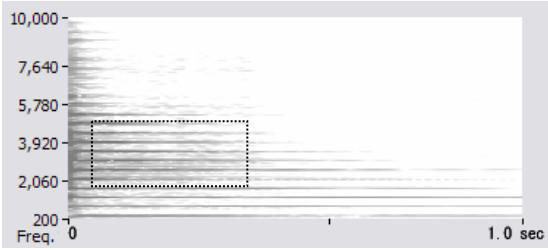


**Figure 13**. Spectrogram of the piezoelectric pickup

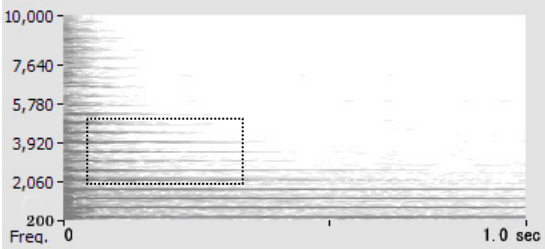


**Figure 14**. Spectrogram of the electric KOTO

| | |
|---|---|
| Window size | 4,096 |
| Overlap | 75% |
| Window | Blackman |

**Table 4.** Parameter of FFT (spectrogram)

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