A Gesture Detection with Guitar Pickup and Earphone

Sangwon Suh, Jeong-seob Lee and Woon Seung Yeo
Audio & Interactive Media Lab
Graduate School of Culture Technology, KAIST
335 Gwahangno, Yuseong-gu, Daejeon, Korea
suhsw1210@kaist.ac.kr, jslee85@kaist.ac.kr, woony@kaist.edu

ABSTRACT
We have introduced a new gesture-detection technique that utilizes the interference of earphones on a magnetic pickup. This technique is advantageous because it can be easily applied to almost any type of electric guitar without cracking it, and it can be used as a gesture-based effect control system. This system utilizes a *theoretically audible, but practically inaudible range* (TAPIR) acoustic signal, which can rarely be perceived by most people, to trace the guitar player's hand motion. The frequency band of a TAPIR signal can be played on typical transducers such as headphones and speakers. Therefore, this system is also advantageous in that it can be built using an earphone as a signal transmitter, an electric guitar as a receiver, and a PC as a sound processor. From the transmitter attached on the player's picking hand, the TAPIR signal is transmitted to the magnetic pickup installed on the electric guitar. The player's gestures are captured by analyzing the Doppler shift of the original signal, and the processor converts this Doppler shift value into a delay time. By using this system, players can control the effector by using their own guitar and earphone.

Keywords
TAPIR, Doppler effect, musical interface, novel controller, gesture, sonic interaction design

1. INTRODUCTION
For the electric guitar, which is widely used in modern pop music, an effector (or guitar effect) is no longer optional. Many guitarists already "play" their effectors like a part of instrument. However, it is not easy to control these effectors while playing the guitar, and therefore, many new controllers and interfaces have been devised. One example is a pedal-type effector that helps players to control effects with their foot while using their hands to play the guitar; the player should kneeling beside pedals while he is playing them. Another example is installing an extra controller on their guitars. This method may damage the instrument, and is unrealistic for most of players.

To overcome these problems, we designed a new control system for electric guitars. This system uses off-the-shelf earphones and a PC and entails no physical damage to the guitar to provide gesture detection. The Doppler shift, which is generated by sonic wave from earphones, is captured and analyzed to calculate the distance between hand and guitar. Depending on this distance, the effect value is changed.

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2. RESEARCH BACKGROUND

2.1 TAPIR Signal
A *theoretically audible, but practically inaudible range* (TAPIR) signal is one in the highest bandwidth of human hearing [5, 8]. It is barely perceptible by most people, but it can be transmitted and received by typical transducers such as headphones, microphones, and speakers. The originality of this system is derived from the fact that this system utilizes an electromagnetic pickup instead of an acoustic receiver. The system utilizes the 19 kHz frequency band as a TAPIR signal beacon.

2.2 Doppler Shift
Doppler shift (or Doppler effect) is a phenomenon, which is the change in frequency of a wave for an observer moving relative to its source. Furthermore, this change in frequency is closely related to the velocity of observer's movement. In our system, the wave source is an earphone attached to the hand and the observer is a guitar pickup. Therefore, the observer's position is fixed, but the wave source moves. The velocity of the wave source v_s can be derived from the relationship between observed frequency f and emitted frequency f_0 : see formula (A). c is the velocity of waves in the medium.

$$f = \left(\frac{c}{c + v_s}\right) f_0 \qquad \text{(A)}$$

2.3 Advantages and Disadvantages of Existing Guitar Sound Controllers
A pedal-shaped effector is useful to guitarists when their hands are busy playing the guitar. They can turn effects on or off and change the strength of the effect using their foot. Therefore, many types of effect pedals are widely used even today. However, the player needs to stay beside the effectors to control the effects. This is a negative aspect from the viewpoint of a live performance.

The EBow (or E-Bow) is a handheld electronic device for playing the guitar [4]. This device generates an electromagnetic field that produces a sound reminiscent of using a bow on strings. For example, U2's song "With or Without You" contains the sound of a guitar played using the EBow. This device does not require any physical modification of the guitar. EBow has been loved by many guitarists for its simplicity.

Some other types of controllers are installed on guitars. One example is the "Touch Screen Guitar" [1]. A touchscreen is implemented on the guitar board, and people can play the guitar using a touch sensor on the neck and a touchscreen on the body. Matthew Bellamy, the guitarist of the band Muse, is a famous artist who modifies his guitar with a touchscreen. These modified guitars are suitable for playing specialized sounds and songs. However, most players prefer not to modify their instrument because it is better to not change the shape and characteristics of a conventional guitar.

2.4 Gesture-based Controller

The Theremin is one of the most famous gesture-based electronic musical instruments [6]. When playing this instrument, the player controls the frequency with one hand and the amplitude with the other. Basically, this instrument utilizes a radio frequency signal as its medium. Roland's D Beam Controller is a similar instrument, which utilizes infrared rays as a medium [2]. However, these media cannot be utilized without RF and IR sensors, respectively. To avoid the installation of additional devices on the guitar, we should aim at utilizing the sensor it already has, namely, the magnetic pickup. We chose a TAPIR signal (18 - 22 kHz) as the medium because it is easy to generate using typical earphones and speakers.

3. RESEARCH PURPOSE

This study aims to develop a gesture-based electric guitar sound control system using a magnetic pickup and a TAPIR signal transmitter. The system would not require a complicated installation or unfamiliar control style, because usually the players are conservative to the characteristics of instrument. The playing style or the instrumental tone can be a unique characteristic of musical instruments.

4. SYSTEM DESIGN

4.1 System Overview

The proposed system consists of an earphone as a signal transmitter, a guitar pickup as a receiver, and a PC as the sound processor (Figure 1). An earphone attached to the player's picking hand plays the role of a TAPIR signal transmitter. The player moves his or her hands back and forth to control the effector. Then, the magnetic pickup on the electric guitar senses the TAPIR signal and sends it to the sound processor. The input channel receives the signal from the guitar, and the output channel sends the effected sound to the amplifier. The sound processor performs two functions: (1) it detects the Doppler shift using the TAPIR signal and converts its value to the delay time, and (2) it processes the guitar sound.

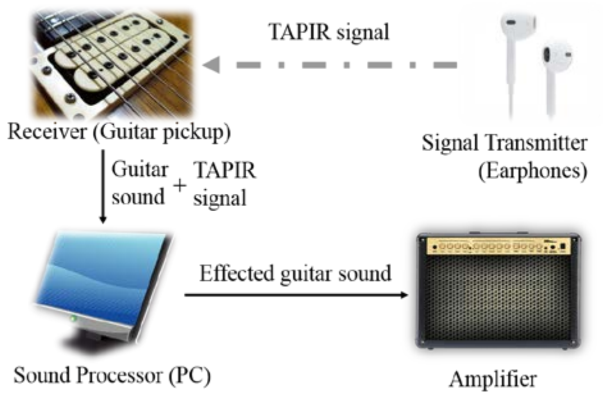

Figure 1. System overview

4.2 Sound Processor

The sound processor is shown in Figure 2. As aforementioned, signal from the guitar is a mixture of guitar –playing sound and received TAPIR signal. Hence, those signals are divided into two ways by means of filters; TAPIR signal filter and another the low pass filter. As the original signal is noisy, TAPIR signal filter (a band-pass filter with 19 kHz center frequency, gained with 5 and slope with 30) filters out all noises other than the TAPIR signal. In the case of the low-pass filter, it eliminates the TAPIR signal before the sound processing.

A filtered signal that only carries a 19 kHz band goes into a Doppler shift analysis module that calculates the Doppler shift and sends the velocity value to the effecter unit; by integrating the acquired velocity over time, we are able to know the displacement of hand whether moved forward or backward. The effector has two inputs; the original guitar sound signal and the gesture data. At this stage, the original guitar sound is modified by the effector, which is controlled by the Doppler shift value.

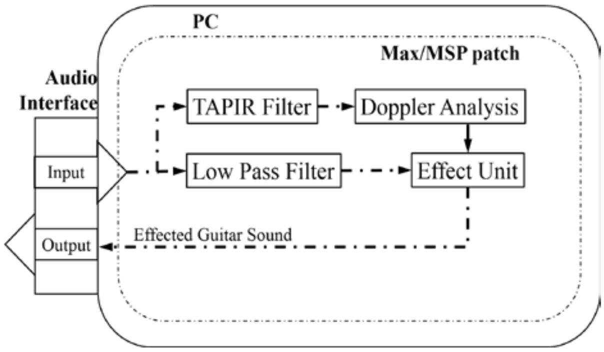

Figure 2. Sound processor

4.3 TAPIR signal transmitter

In this study, an Apple EarPod is selected as the TAPIR signal transmitter; however, we can utilize any earphone, with bandwidth over 19 kHz. When connected to the playback machine, the earphone continuously generates a 19 kHz sinusoidal sound signal. It is attached on the palm of the player's picking hand using a band (Figure 3).

Figure 3. Transmitter and receiver (earphone and pickup)

5. EVALUATION

We performed tests to evaluate the TAPIR signal filter for several scenarios; (1) muting/strumming guitar, (2) with/without TAPIR signal and (3) minimum/maximum distance between pickup and earphone. With combining above 3 criteria, 6 tests are selected for the evaluation. Frequency responses are captured before and after the TAPIR filter for each test.

The efficiency of tracking hand motion was also measured. The system captures the motion of hand by analyzing the Doppler shift of received TAPIR signal. The case that the hand travels away from the body of the guitar was tested, and the hand velocity was recorded every 5 millisecond. Continually, to see whether the system detects the change in motion, the hand traveled back and forth three times.

6. RESULTS

6.1 Effectiveness of TAPIR Filter

The graphs included in figure 4 shows frequency response of input from the guitar pickup for each scenario. Graph (1) of figure 4 serves as references for the muted test. (2) shows the case in which the distance between the earphone and the pickup is the minimum (0 cm). (3) shows the case in which the distance is the maximum (15 cm). After three tests under the muted condition, we strummed the guitar strings and tested another three identical cases including a reference: graph (4) to (6). The effectiveness of TAPIR filter is evaluated by comparing 19 kHz band of the left and right graph.

In all cases except the reference, the peaks at 19 kHz can be observed after filtering the signal, and we can observe the peaks even when the strings are strummed (noisy environment). In the fourth case, a signal is captured at 19 kHz band, which was originally a guitar sound. This implies that a high frequency part of guitar sound can pass through the TAPIR filter and may cause an error. Fortunately, the TAPIR signal was loud enough to distinguish it from the guitar sound.

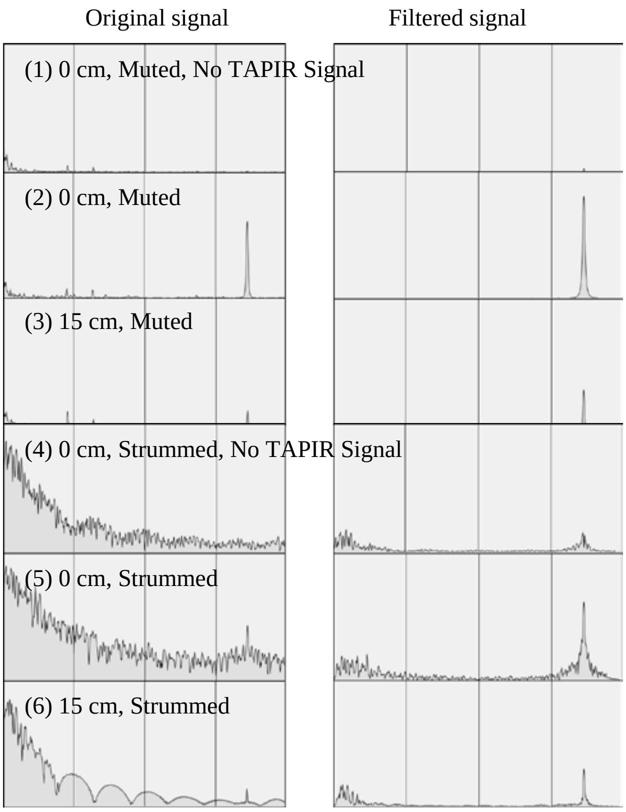

Figure 4. Frequency responses of input from the guitar in multiple situations with frequency range from 0 to 22 kHz.

6.2 Tracking of Hand Motion

Figure 2 shows the result of hand moving away from the guitar. The data were collected every 5 millisecond, but plotted every 50 millisecond; because it is hard to display all. The x-axis represents the time coordinate, and the y-axis represents the velocity of the hand motion. The hand starts moving at 505 millisecond. It reaches the maximum speed at 705 millisecond and decreases to zero at 955. On figure 3, we performed three-time movement of the hand traveling back and forth to see whether the system detects the change in motion. Though fluctuations (circled area) were detected every time between each rounds, the plotted data shows three repeated segments clearly.

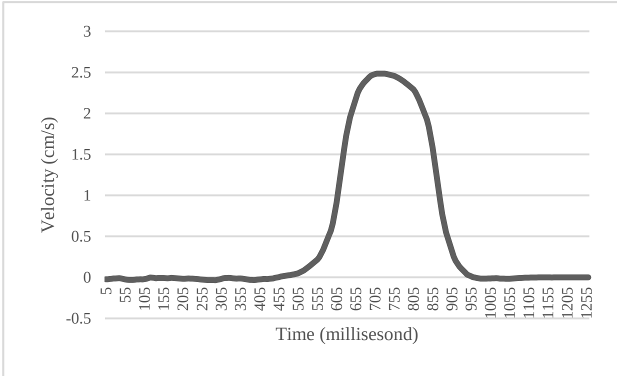

Figure 5. Time versus velocity graph of hand motion

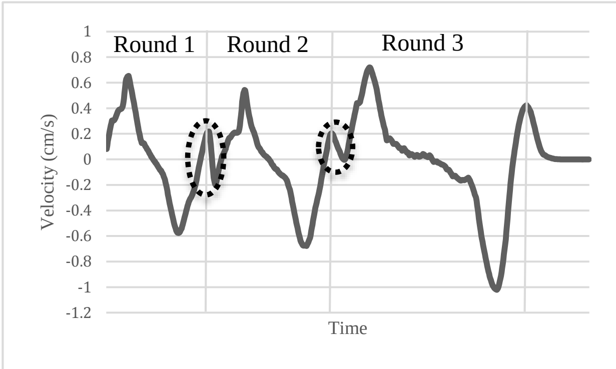

Figure 6. Time versus velocity graph of back and forth movement

7. CONTROL SCENARIO

For an application of this system, we suggested a scenario for controlling a delay effect by gesture input. When a typical playing situation, the system is off; because it will capture the stroking motion as a gesture input. Usually when guitarists sustain their guitars, they do not use their picking arm, therefore the system is able to work properly in this situation.

An integration of velocity data is mapped to a delay time. In other words, according to the distance between hand and guitar pickup, delay time changes. When the player moves the hand to the outside, the delay time decreases (Figure 7).

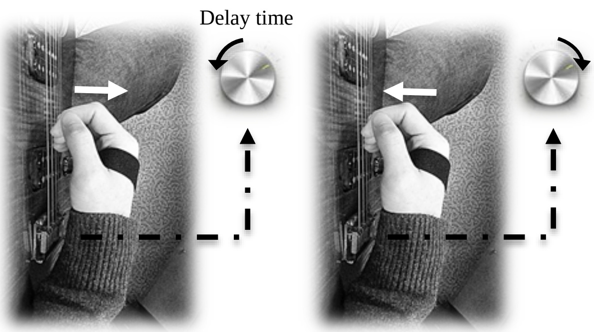

Figure 7 Relation between gesture and delay time

8. CONCLUSION

In this study, we introduce a system that captures a gesture of the guitarist by interference between a typical earphone and a guitar pickup. This system utilizes an installed pickup of a conventional guitar; therefore it does not require a physical modification or an attachment on the body of the guitar. This enables almost any kind of guitar to become a motion capture interface. The earphone attached on the player's hand transmits a TAPIR signal, and a signal processor connected to the guitar analyzes a received signal from the guitar pickup. A movement of the hand generates the Doppler effect of the TAPIR signal. Therefore, we made an algorithm that calculates the current velocity of the hand by analyzing the Doppler shift on received TAPIR signal. The system was tested to evaluate the efficiency of noise filter and the accuracy of the motion-tracking algorithm. Finally, a scenario suggests an application of this system.

When designing this system, we tried to reinterpret and utilize typical devices. Sonicstrument, which was the previous research of this project, reinterpreted stereotypical transducers (like earphones, speakers and microphones) and suggested as a new interface. Continually, a follow-up study suggested a new concept named TAPIR; and the motto of this concept is also reinterpreting and combining conventional devices into a new system. It would be much easier to introduce an interface that utilizes conventional devices.

In this study, we reinterpreted the electric guitar, which is essential in modern pop music history, as a TAPIR interface. Actually, the concept of data communication, which utilizes guitar pickup as a receiver, was already commercialized by TonePrint system of TC Electronic [7]. However, it is totally irrelevant to the live performance, so it is far from musical interface. This research is about developing a gesture-based control system, so the actions that controlling the system can be integrated into live performance. In addition, even though we designed the system that reinterprets the guitar as an interface, it does not require any modification because the system utilizes the unique features of the electric guitar.

To improve the performance of the system, the first plan is to adopt more sound effects, which is able to control by hand gesture, on this system. In addition, we are planning to design a wearable transmitter, which is implemented with earphones in this study, to improve convenience and playability of the player.

9. REFERENCES

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