STICK TRACK:
a System Generating Musical Score for Drums Indicating the Hitting Hand

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Abstract  
On playing drums, it is important to master the correct stroking order. Drummers are required to learn the drum rudiment to play drums efficiently. Generally, musical scores for drums do not have the annotation that indicates which hand drummers use to stroke each drum, left or right. Although drum teachers handwrite such annotation on the musical score, there is not the system that generates the musical score indicating the hitting hand on playing drums automatically. In this research, we proposed a musical score generating system that indicates the hitting hand to stroke each drum. Our proposed STICK TRACK recognizes the hitting hand on the basis of the data of a gyro sensor that are embedded in the drum sticks and MIDI message from an electronic drum. We constructed the prototype system and evaluated its effectiveness.

Keywords: Drum, Musical score, Learning support, Motion recognition

1 Introduction  
On playing drums, it is important to master the correct stroking order. For example, when the drummer plays the phrase like Figure 1 red square, there are cases that he/she strokes floor tom with a right hand not to cross his/her hands. In this way, there are the stroking orders to play efficiently. Therefore, drummers should learn the information that indicates which hand they use to stroke each drum referred to as “hitting hand” in this paper) on each phrase. As the previous method to learn the hitting hand, there is the learning method to learn a phrase repeatedly by watching the professional performance. However, in this method, it takes much time to learn the hitting hand because the stroking motion of playing drums is so fast. Also, drum teachers handwrite annotation like the hitting hand on the musical score. As another method, they use the application generating musical score like DAW (Digital Audio Workstation) to indicate the hitting hand. On the other hand, there is not the system that generates the musical score indicating the hitting hand on playing drums automatically.

Therefore, in this research, we construct STICK TRACK for generating the musical score that indicates the hitting hand for drum performance. STICK TRACK recognizes the hitting hand on the basis of the data of a gyro sensor that is embedded in the drum sticks and MIDI message from an electronic drum. STICK TRACK generates musical score that indicates the hitting hand automatically using recognition data. Additionally, the system records information about the hitting hand by using MIDI message.

The remainder of this paper is organized as follows. Section 2 explains the related work. Section 3 describes the design of STICK TRACK, and Section 4 explains the implementation of a prototype system. Section 5 describes the evaluative experiment. Finally, Section 6 gives conclusions and outlines future work.
2 Related Work

On playing the drums, there have been proposed a variety of learning support systems. YAMAHA Song Beats [1] and Roland V-drums Friend Jam [2] are the applications for learning the drums. A user can learn the drums with watching the electronic musical score and the video of professional drummers. However, it is difficult for the user to understand the hitting hand because the stroking motion of playing drums is so fast. Additionally, these applications cannot indicate the hitting hand. Thus, there is not the system that generates the musical score indicating the hitting hand on playing drums automatically.

There are the systems to recognize the motion of players and indicate the performance information on the musical score. Antoniadis et al. [3] developed the system that generates a piano score indicating the gesture information of a pianist, such as fingering and hand position by using the camera and acceleration sensors. However, the indicating information on the score is too complex for the learner to understand that information correctly. Weyde et al. [4] also proposed the learning method for the violinists by using the camera. While they use the system [5] that indicates violinists the motion of their arms as the wave data visually, this system does not assume to generate the musical score.

Sawa et al. [6] proposed the real-time fingering detection system for contrabass by integrating camera image and musical rules. Takegawa et al. [7] also developed the system that detects fingering for piano by camera and color makers and adds fingering information to the musical score. While these systems are not assumed applying drum performance, we consider that generating the musical score that indicates performance information by recognition motion can be applied to play drums. In this research, we aim to develop the system for drums that generates musical score indicating the hitting hand by recognition of stroking motion in real-time.

Also, there is a variety of the methods to recognize the performance information on drum performance. AeroDrums [8] translates the stroking information into MIDI message by using the camera. This application is not assumed to recognize the hitting hand and generate musical score indicating it. Bouenard et al. [9] also analyzed the stroking gestures on percussion performance by motion capture. However, the recognition using the camera and motion capture is inconvenient for drummers to set up the devices and calibrate the motion. It is difficult to use this application on actual performance like a live show because the lighting prevents this application from recognizing the motion correctly. While the DAW applications like Logic Pro X [10] that translates the sound source of the drums into MIDI message also have been developed, the generated musical score cannot indicate the hitting hand. Van Rooyen et al. [11] proposed the system that recognizes the hitting point of drum head by audio data. Although using audio data useful to recognize the timing of stroking, it is difficult to specify the hitting hand on actual performance.

3 Design

We designed STICK TRACK from the following policies:

(1) Usage in actual performance: We assume that this system will be used for not only practicing but also actual performance, such as live show. In general, although the stroking motion on drums is recognized by the camera, this method cannot apply in actual performance due to the lighting. Our system applies the gyro sensor to recognize the stroking motion correctly in such environment.

(2) Real-time recording performance information: The proposed system records the performance information to review them in practicing and actual performance in real-time. We aim that the proposed system is used as the learning support for confirming the characteristics of the hitting hand and the mistaken point after a performance.

3.1 System structure

Figure 2 shows a system structure of the proposed system. This system consists of two drumsticks equipped with a gyro sensor, an electronic drum, a PC, and a MIDI sound generator. The sensor data are sent to the PC by Bluetooth communication. While a drummer plays an electronic drum with the proposed drumsticks, the system generates the musical score indicating the hitting hand. The proposed system recognizes the timing and the instrument that a drummer stroked by gyro data and MIDI message from an electronic drum. Using two information, the system recognizes the hitting hand and the instrument that the drummer stroked. Finally, the system generates the musical score indicating the hitting hand.

3.2 Recognition method of the hitting hand

Figure 3 shows the flow of recognition the hitting hand. The system recognizes whether the drummer stroked the drum by MIDI message at first. Secondly, the proposed system recognizes two stroking patterns. One of them is the stroking that the drummer...
strokes a drum with only one hand (referred to as Single Hand Stroking in this paper) as shown in the left of Figure 4, and the other is the stroking that he/she strokes drums with both hands (referred to as Double Hand Stroking in this paper) at the same time as shown in the right of Figure 4. The system recognizes which pattern he/she stroked the drum with Single Hand Stroking or Double Hand Stroking. On each stroking pattern, the methods to recognize the hitting hand are different. The system recognizes the hitting hand in accordance with each method. Finally, after recognition the hitting hand on each method, the system records information of the hitting hand and generates the musical score.

3.2.1 Recognition of stroking patterns

The proposed system recognizes Single Hand Stroking and Double Hand Stroking on the basis of time interval that the system receives MIDI messages. Figure 5 shows the timing that two MIDI messages (MidiOut₁, MidiOut₂) were sent. The proposed system sets a threshold value to recognize the stroking pattern. For example, a threshold value is set 25ms. If time interval (Δt₁₂) between MidiOut₁ and MidiOut₂ is shorter than 25ms, the system recognizes the stroking as Double Hand Stroking. After recognizing stroking pattern, the proposed system starts to recognize the hitting hand. Recognition methods on each pattern are shown as follows.

3.2.2 Recognition of Single Hand Stroking

The system recognizes the time when the drummer stroked drums by 1-dimensional gyro data. The left of Figure 6 shows the waves of gyro data when the drummer strokes the drum with each hand. Positive values arise when he/she brings his/her arm down to stroke. As shown in Figure 6 red line, when the value is “0” after the gyro data reaches a maximum value, it is considered that the drumstick hit a drumhead. Therefore, in this moment, MIDI messages are sent to PC. In this system, to prevent false recognition when the drummer does not stroke, a threshold value is set to prevent false recognition. The system recognizes the hitting hand by a time interval between the time when the gyro data went down a threshold value and the time when MIDI message was sent. The left of Figure 6 shows the waves of gyro data when the drummer actually stroked snare drum with a left hand and floor tom with a right hand. Compared the time receiving MidiOut₂ with the time when each gyro data went down a threshold value, the time interval on hitting with a right hand (Δt₂₂) is shorter than the time interval on hitting with a left hand (Δt₁₂). Therefore, it is recognized that MidiOut₂ was sent by stroking with a right hand.
However, in this method, the system cannot recognize correctly in the case that the drummer strokes the drums with both hands at the same time. The details on the recognition method for Double Hand Stroking are as follows.

### 3.2.3 Recognition of Double Hand Stroking

On Double Hand Stroking, both MIDI messages are sent at the same time. The gyro data of each hand also goes down a threshold value at the same time. Therefore, as shown in the right of Figure 6, on Double Hand Stroking, the time interval between each hand has no much difference ($\Delta t_L \approx \Delta t_R$). Thus, it is difficult to recognize the hitting hand on Double Hand Stroking by the method of Single Hand Stroking. Then, to recognize the hitting hand the proposed system uses the rules that are defined by the features of drum performance, the layout of drum set and the characteristics of playing a variety of phrases. We define the following 3 rules on Double Hand Stroking to recognize the hitting hand.

**Rule1:** Each hand does not cross if each instrument is set up at the same height.

In this paper, we assume using a general drum set as shown in Figure 7. In this case, the combinations that each instrument is set up at the same height are snare-floor tom, hi tomlow tom, and crash-ride. In general, the drummer does not stroke these instruments with his/her hands crossed. Therefore, when the drummer strokes these combinations, the system recognizes that he/she strokes an instrument on the left side with a left hand and he/she does on the right side with a right hand. For example, in the case of stroking snare and floor tom at the same time, it is recognized that he/she strokes snare with a left hand and floor tom with a right hand.

**Rule2:** Each hand and instrument are at the same side if each instrument is set up at the different height.

On Double Hand Stroking, if both instruments are set up on different height, the drummer does not cross his/her hands to stroke each instrument. However, in the case that horizontal position of each instrument has not much difference, it is not adapted this rule. Additionally, because hihat is stroked to keep the beat and he/she cross their hand frequently, it is also not adapted this rule.

**Rule3:** Each hand crosses on playing 8 beat pattern using hi-hat.

In general, when the drummer strokes hi-hat and plays 8-beat pattern, each hand crosses. Therefore, the drummer who is right-handed strokes hi-hat with a right hand and does snare with a left hand. In this paper, although the system does not recognize the beat pattern, we assume that the drummer strokes hi-hat and snare at the same time on playing 8 beat pattern. Additionally, on playing 16 beat pattern, the system can recognize the hitting hand by the method of Single Hand Stroking because the drummer does not stroke hi-hat and snare at the same time.

### 3.3 Recording information of the hitting hand

The system records information about the hitting hand by using MIDI message. This method is based on the reason that recording performance information as MIDI format has a possibility adapted in a variety of DAW applications. Information about the hitting hand is included as the value of panpot inside MIDI message as follows.

- **Left hand** The value of panpot: 0
- **Right hand** The value of panpot: 127
- **Both hands** The value of panpot: 64

For example, when the drummer strokes the drum with left hand, the value of panpot is adjusted “0”. Also, when the drummer should stroke a drum with a left hand, they can listen drum sound from left side by recording the value of panpot. Therefore, the adjustment panpot also helps him/her indicate the hitting hand as an auditory feedback.
4 Implementation

We implemented a prototype. As shown in Figure 8, a prototype consists of two drum sticks, PC and MIDI sound generator. A drum stick is attached a gyro sensor Wireless Technology WAA-010. We attached a gyro sensor to not drummer’s wrist but drum stick because gyro data changes largely. Also, a gyro sensor is attached to the middle of the drum stick, so as not to hit drums. We used Roland SD-20 as a MIDI sound generator. We connected an electronic drum and PC by using Roland UM-1 as a USB-MIDI interface. An electronic drum is YAMAHA DTXPLORER. We implemented a prototype system on OS X v10.10 using Xcode 8.0.

Figure 9 shows a screenshot of the application for the prototype. A user can confirm the gyro data and set MIDI input and output device, and a threshold of gyro on the application. The center of Figure 9 shows the musical score that is generated on the basis of gyro data and MIDI message. The musical score indicates the stroking information on each drum and the colors of note on each sequence in the center of Figure 9 indicate the hitting hand. The red note describes that drummer stroke with a right hand, the yellow note describes left hand. The blue note describes using a bass drum.

Figure 8 A prototype of the proposed system

Figure 9 Screenshot of our application

5 Evaluation

We conducted two evaluative experiments to investigate the effectiveness of the proposed system. As one experiment, we investigated the recognition accuracy of the proposed system. The other is the investigation of the effectiveness on the performance when the learner uses the proposed system.

5.1 Recognition accuracy

Experimental method

We investigated the recognition ratio of the proposed system. In this evaluation, we used 3 phrases shown in Figure 10 as trial phrases. Tempos are 90 and 120bpm (beats per minute). The subjects studied each phrase with each tempo for 10 times. Trial phrases were composed of two measures. As shown in Figure 10, on Phrase A subjects play 8 beat pattern, on Phrase B they play 16 beat pattern, and on Phrase C they play a fill (a short musical passage). The subjects play each trial phrase in accordance with indicating of the hitting hand on the musical score shown in Figure 10. Four male and one female university students took part in this evaluation. All subjects have more than two years of drum experience. All of them were right handed. In this evaluation, a threshold value of gyro to start recognition was set 3000 dps (degree per second). Also, a threshold value of time interval to recognize the stroking pattern was set 25ms. Before investigating the recognition ratio, the subjects practiced the trial phrases for 10 minutes with the proposed drum sticks.

Results and discussion

Table 2 shows the recognition ratio of each subject stroking each phrase. The recognition ratio shown in Table 2 is calculated on
the basis of false recognition. False recognition describes that the system did not recognize the hitting hand correctly. As shown in Table 2, the recognition ratio was more than 95% in all patterns. On Double Hand Stroking, there was not false recognition. On the other hand, there were false recognition when subjects played Phrase B and Phrase C. Figure 11 shows false recognition when Subject II played phrase B with 120bpm. Actually, in Figure 11 white square, Subject II stroked hihat with a left hand. However, the proposed system recognized that the hitting hand was a right hand falsely. As shown in the bottom half of Figure 11, gyro data in this moment was lower than a threshold value. Therefore, the proposed system did not start to recognize the stroking. As a result, this false recognition arose because the system could not compare time interval between each hand. To prevent these false recognition, it is necessary to adjust a threshold value that enables to recognize weak stroking.

5.2 Effectiveness on the performance

Experimental method

We investigated the effectiveness on the performance in case that the learner uses the musical score indicating the hitting hand. In this evaluation, we compare the performance quality between the usage of the proposed score and the conventional score. While the proposed score includes the indication of the hitting hand, the conventional score does not include it. The subjects play a trial phrase shown in Figure 12. Tempo is 120bpm. Three male university students took part in this evaluation. All subjects have one to three years of drum experience.

Firstly, the subjects learn the phrase with the conventional score shown in the upper half of Figure 12 for five minutes. During this learning, each subject learns the phrase in their own way of the hitting hand. After learning, we recorded their performance with DAW application and the camera.

Nextly, the subjects learn the same phrase with the proposed score shown in the bottom of Figure 12 for five minutes. The proposed score indicates two ways of hitting hand. These scores are generated on the basis of the stroking order that four professional drummers set. All professional drummers have experienced drums more than 15 years. The subject can choose the way of the hitting hand from them and learn the phrase, if the hitting hand in the learning with a conventional score is different from the proposed score. After this learning, we also recorded the performance of subjects. We compare the performance quality between the proposed score and the conventional score.

Results and discussion

Figure 13 shows the stroking order when each subject actually played the phrase with a conventional score. The stroking orders of Subject II and Subject III are different from the proposed score. Two subjects chose the proposed score as shown in Figure 13. Also, Subject I learned the proposed score A.

Firstly, we discuss the effectiveness of stroking timing. In conventional learning, Subject II could not stroke crash cymbal with the correct timing. He had a tendency that he stroked the point shown in the green square of Figure 13 later. He could not move his right hand from floor tom to crash cymbal with keeping tempo, because he stroked the drums with a right hand in a row. In a case of using the proposed score A, he could keep tempo because they use each hand alternately. As these results, the sub-
jects could prevent the failures on their performance by using the musical score indicating the hitting hand.

Nextly, we describe the effectiveness of stroking strength. In conventional learning, Subject III had a tendency that he stroked the point shown in the red square of Figure 13 weakly. This factor is considered that he stroked the drums with a right hand in a row and second stroking was weak. On the other hand, when the subject learns the phrase with the proposed score B again, he could stroke them in the same strength.

However, subjects sometimes dropped the drum sticks and stroked a false instrument with the proposed scores. This reason arose because they played with the hitting hand that they had not used on usual performance. Thus, while the proposed system could improve their performance quality, the subjects are required to get used to the hitting hand. On the usage of the proposed system, we need to collect a variety ways of the hitting hand on each phrase by professional drummers. What the learners find the hitting way that they prefer from them is considered as the efficient usage of the proposed system. Therefore, we need to make the library that a variety ways of the hitting hand are recorded by using the proposed system.

6 Conclusions

In this research, we constructed STICK TRACK for generating musical score that indicates the hitting hand for drum performance and described the construction of a prototype system. STICK TRACK recognizes the hitting hand on the basis of the data of a gyro sensor that are embedded in the drum sticks and MIDI message from an electronic drum. A prototype system generates a musical score that indicates the hitting hand. The results of an experiment demonstrated that our system enabled generating the musical score effectively. Also, the proposed score could indicate the learner the correct stroking order and improve their performance.

For future work, to improve the objectivity of the effectiveness, we plan to evaluate the system with more complex phrases and with more subjects. We also need to investigate the usability of the soft application in the proposed system. Additionally, we plan to implement the plug-in software that is applied in a variety of DAW applications. Furthermore, the drummers of a variety of genre use our system and it is required to extract the characteristics of the hitting hand between genre.

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