Airstic Drum: a Drumstick for Integration of Real and Virtual Drums

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Abstract. Drum kits consist of various kinds of percussion instruments. As all percussion instruments are large and heavy, they are inconvenient for drummers to carry and set up. Virtual drums, which include motion sensors and enable drummers to imitate playing drums by stroking a virtual drum, are highly portable. However, drummers, who are used to playing real drums, have difficulty in demonstrating their drum skills with virtual drums because of the lack of feedback from stroking, low sound quality, and so on. Our proposed *Airstic Drum* achieves high portability and performance quality by integrating real and virtual drums. *Airstic Drum* can distinguish the stroking of virtual drums from the stroking of real drums, and it outputs digital sound only when the drummer strokes virtual drums. We have developed a prototype system and evaluated its effectiveness by actual use.

Keywords: Virtual drum, Real drum, Motion recognition

1 Introduction

Drum kits are composed of various kinds of percussion instruments, such as snare drums, bass drums, and cymbals. Since each percussion instrument is large and heavy, it is inconvenient for drummers to carry and set up. This means that drummers usually use drum kits arranged at a venue beforehand such as club or ball room, and sometimes the kits lack some percussion instruments that the drummers want to use.

The electronic drum kit SPD-S [1], which has a flat surface divided into several electronic pads, has high portability, assigns various tones to each pad, and outputs sounds. However, it is difficult for drummers to apply conventional drumming techniques to it, because the layout of the electronic drums is completely different from that of real drums. Recently, virtual drums have been

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developed, such as Wii Music [2], WorldBeat [3], V-beat Air Drum [4], Virtual Xylophone [5], and Lightning [6], which enable drummers to output drum sounds by mimicking the motion of stroking a real drum. Virtual drums do not restrict space for playing because they do not require a real upper drumhead, and generate many percussion sounds using a sound generator. However, since drummers are not stroking a real drum, the drumming motion is harder to control. This prevents the drummers from keeping tempos and playing drum-rolls, rim-shots, and so on. Drummers, who are used to playing real drums, have difficulty in utilizing their drumming techniques with virtual drums. In this way, real and virtual drums have advantages and disadvantages. To solve this problem, we focus on the difference in frequency of using real drums. If we apply less frequently used drums to virtual drums, we achieve high portability and can keep the performance quality.

Therefore, the goal of our study is to construct *Airstic Drum* for integrating real and virtual drums. *Airstic Drum* can distinguish the stroking of virtual drums from the stroking of real drums on the basis of the data of an acceleration sensor and a gyro sensor that are embedded in the drum sticks, and it outputs digital sound only when drummers stroke virtual drums.

The remainder of this paper is organized as follows. Section 2 explains related work. Section 3 describes the design of *Airstic Drum*, and Section 4 explains the implementation of a prototype system. Section 5 describes evaluative experiment, and Section 6 explains the actual use. Finally, Section 7 gives conclusions and outlines future work.

2 Related Work

Some researchers have developed virtual drums, such as Wii Music, WorldBeat, V-beat Air Drum, Virtual Xylophone, and Lightning. For example, in Wii Music, a player uses a controller equipped with motion sensors. It outputs drum noises on the basis of stroking motion, which is recognized using acceleration data. Players can control drum sounds by changing the stroke of the controller. Users can enjoy playing the drum anytime and anywhere, but its performance quality is low because of the lack of feedback from stroking the virtual drum, and the low sound quality of virtual drums. While these electronic instruments are similar to the proposed system in controlling sounds by changing motion, they are not assumed to be used with existing instruments.

T. M. Patola evaluated the difference in performance quality between real drums and virtual drums, and described how virtual drums were difficult for keeping tempos accurately compared with real drums [7]. M. Collicutt et al. investigated the difference in motion between playing real drums and a virtual drum [8]. Trial users used four real percussion instruments and one virtual percussion instrument, and stroked each percussion in single and double strokes. The authors confirmed that when making a single stroke, players tended to raise their hand to a similar height with all the percussion instruments. On the other hand, the lack of tactile feedback made double stroking difficult, which resulted

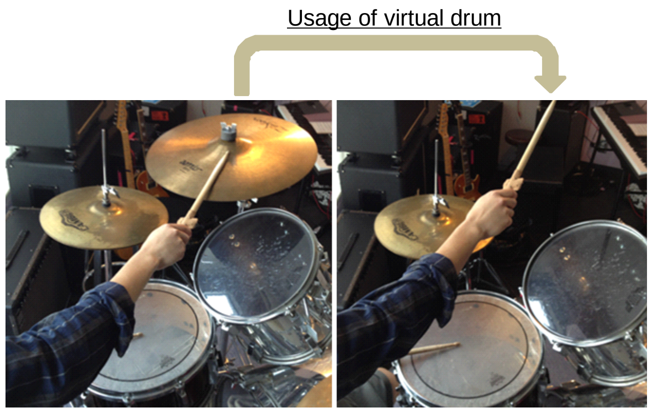

Fig. 1. An example of virtual drums

in low performance quality. The results of these experiments show that the performance with the virtual drums prevents drummers from fully displaying their drum skills. In this research, we use the virtual drum in place of less frequently used real drums to improve the portability and keep the performance quality as much as possible.

3 Design

To solve the problems of the low portability of real drums and the low performance quality of virtual drums, we designed the *Airstic Drum* from the following policies:

(1) The support of real drums: We assume that *Airstic Drum* will be used in the performance in which a drummer uses real drums. It is difficult for the drummer to play the conventional virtual drums and the real drums at the same time, as drummers require high performance quality of the drums in concerts. They value the high performance quality of the real drums over the portability of the virtual drums. However, the frequency of usage of each drum is different. For example, standard drums such as hi-hats, snare drums, and bass drums are used frequently, but percussion instruments that are used as accents in music, such as the cymbal, the cowbell, and the mark tree, are used much less often when playing drums. We achieve high portability and performance quality by swapping less frequently used drums for virtual drums. Furthermore, we propose a recognition method that allows users to play both virtual and real drums at the same manner.

(2) Utilizing accumulated drum skills: Conventional electronic percussion instruments, such as SPD-S, which are composed of multiple drum pads, are extremely portable. When drummers, who is used to real drums, first use the

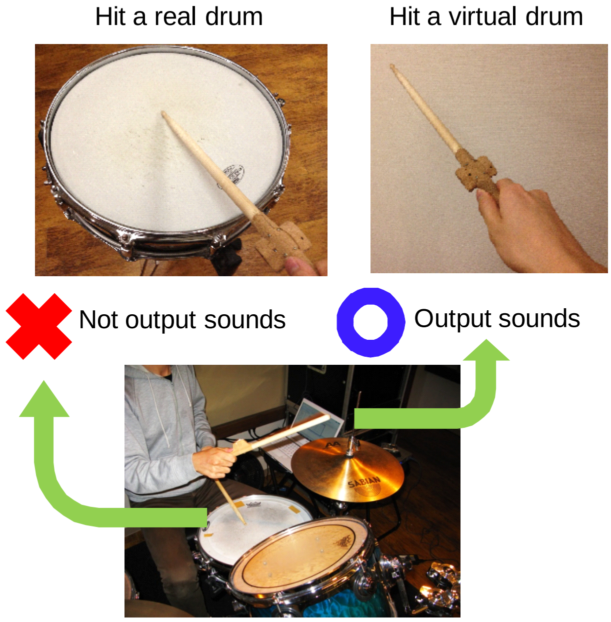

Fig. 2. Control of outputs

electronic percussion instruments, they must practice using them due to the difference in the layout and the size. On the other hand, our proposed system exploits the techniques that drummers have mastered with real drums. For example, as shown in Figure 1, when users play a drum set composed of real drums and a virtual cymbal, the proposed system distinguishes between stroking real drums and stroking virtual drums. When the system recognizes a virtual drum stroke, the system outputs an electronic cymbal sound as shown in Figure 2. If the system detects stroking of a real drum, it does not output any sound. In this way, drummers can use the proposed system without special training.

3.1 System structure

Figure 3 shows a system structure of the *Airstic Drum*. This system consists of the drumsticks equipped with an acceleration sensor, a gyro sensor, a PC, and a MIDI sound generator. The sensor data are sent to the PC by wireless communication. The PC recognizes stroking motion on the basis of the sensor data and sends MIDI messages to the MIDI sound generator to output sounds when the PC recognizes the motion of the virtual drum.

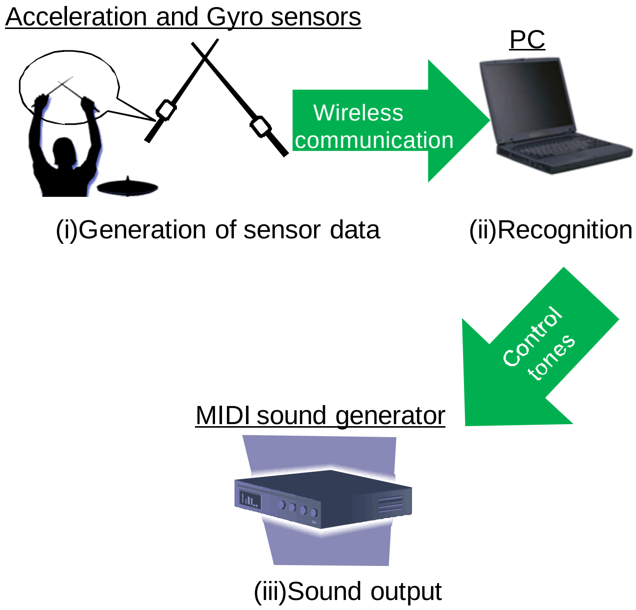

Fig. 3. System structure

3.2 Recognition method for stroking motion

The proposed system recognizes the stroking motion of real and virtual drums. As it is a serious problem if sound is output with some delay after motion, we propose a motion recognition method that has high-speed recognition with enough accuracy. We investigated acceleration and gyro data in stroking a hi-hat, floor tom, and ride cymbal of real drums so as to prevent false recognition of virtual drums in the stroking of real drums. Figure 4 shows waves of acceleration and gyro data in the stroking of a real drum used as a typical part of a drum kit and a virtual drum.

Looking at the wave of the hi-hat, the acceleration data of the real drum are different from those of the virtual drum. Though the vibration (Figure 4 red square (i)) arising from stroking a hi-hat is a particular phenomenon, when the system uses this feature, sound delay arises. It is difficult to use this particular vibration to distinguish between the stroking of the hi-hat and the virtual drum. We should focus on the acceleration data of bringing the arm down when stroking the hi-hat. When the drummer brings his/her arm down to stroke the hi-hat and the stick hits the hi-hat, the acceleration drops rapidly and vibration occurs. On the other hand, when stroking the virtual drum, the drummer brings his/her arm down to stroke the hi-hat and the stick hits the hi-hat, the acceleration does not drop rapidly, since a drummer has to stop the stroking motion by himself/herself. Therefore, the hi-hat's duration (referred to as *Through Time* in this paper) from

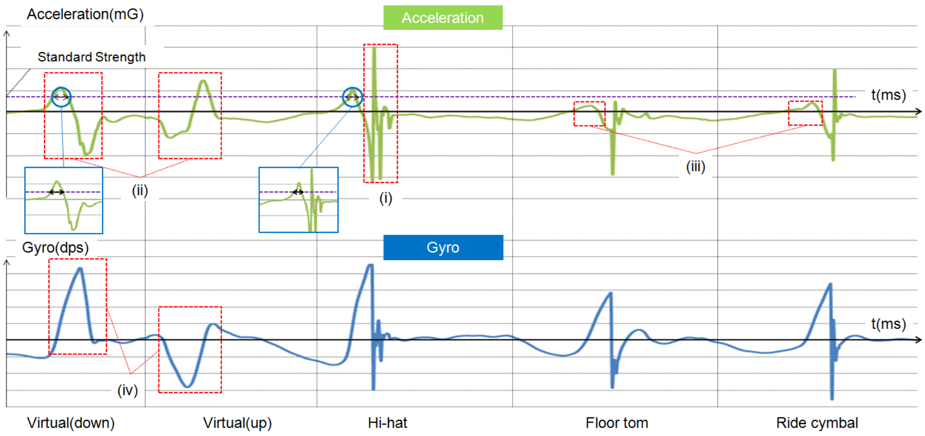

Fig. 4. Acceleration and gyro data of stroking

the time that it goes over a threshold (referred to as *Standard Strength* in this paper) to the time that the acceleration data go down the *Standard Strength* is different from that of the virtual drum, as shown by the blue circles in Figure 4. For example, if *Standard Strength* is 4000mG, *Through Time* is from 5ms to 15ms in stroking the hi-hat and is from 25ms to 40ms in stroking the virtual drum. The proposed system distinguishes the stroking of the hi-hat from that of the virtual drum by using the difference in *Through Time*. Additionally, acceleration sensor data when an user bring down the arm to stroke the virtual drum and the acceleration data when an user brings up the arm are symmetrical, as shown in Figure 4 (ii). If the system uses only the *Through Time*, the system recognizes bringing the arm up as a drum stroke as shown in Figure 4 (ii). To solve this problem, we use the data of the gyro sensor as well. The gyro sensor data of bringing the stick up are typically different from those of bringing the stick down, as shown in Figure 4 (iv).

For stroking the floor tom and the ride cymbal, the acceleration data before the stick hits the drums are fewer than those of stroking the virtual drums, as shown in Figure 4 (iii). This means that these strokes do not influence the recognition of stroking a virtual drum because the acceleration data do not exceed *Standard Strength* before the stick hits the drums. Also, while the vibration arises after the stick hits the drums, this feature does not influence the recognition because *Through Time* of stroking a real drum is shorter than that of virtual drums.

3.3 Deciding of threshold value

The proposed system requires high accuracy and high speed recognition for the stroking of virtual drums. The stroking motion is different for each drummer. The

Table 1. Recognition ratio of each Standard Strength and Through Time

Standard Strength(mG)	Through Time(ms) 10	15	20	25	30	35	40
2000	90.0-54.3*	90.0-55.0	90.0-56.4	90.0-57.9	90.0-58.6	90.0-63.6	90.0-69.3
2500	95.0-60.0	95.0-61.4	95.0-64.3	95.0-69.3	95.0-75.0	95.0-81.4	95.0-87.1
3000	95.0-71.4	95.0-73.6	95.0-77.1	95.0-82.9	95.0-87.9	95.0-95.0	90.0-97.9
3500	100-80.0	100-87.1	100-91.4	100-95.0	100-97.1	95.0-100	65.0-100
4000	100-95.0	100-95.0	100-100	100-100	90.0-100	70.0-100	45.0-100
4500	100-98.6	100-100	100-100	95.0-100	75.0-100	60.0-100	15.0-100
5000	100-100	100-100	100-100	85.0-100	65.0-100	35.0-100	5.0-100
5500	100-100	100-100	90.0-100	75.0-100	55.0-100	20.0-100	0-100
6000	100-100	95.0-100	85.0-100	60.0-100	25.0-100	5.0-100	0-100
6500	90.0-100	80.0-100	65.0-100	45.0-100	15.0-100	0-100	0-100
7000	85.0-100	80.0-100	50.0-100	20.0-100	5.0-100	0-100	0-100

*True positive- True negative

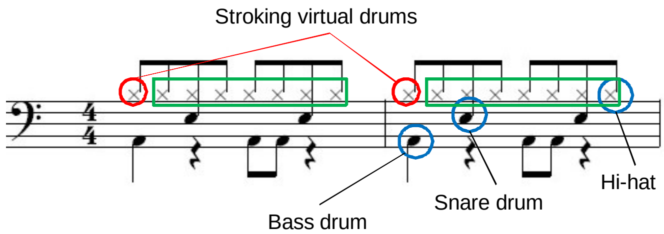

Fig. 5. 8-beat in stroking hi-hats

proposed system measures acceleration and gyro data of each player in advance and sets appropriate *Standard Strength* and *Through Time* for each player. For example, Table 1 shows recognition results from playing a phrase 10 times that involves stroking the virtual drum assigned to the crash cymbal used as part of a typical drum kit at the beginning of an 8-beat pattern, as shown in Figure 5. The recognition ratio shown in Table 1 is calculated on the basis of the true positive, which is the recognition ratio of playing a virtual drum (the left value on each cell in the table) and the true negative, which is the non-recognition ratio of virtual drum in playing real drums (the right value on each cell in the table). The recognition ratio, of *Standard Strength* from 4000mG to 6000mG and *Through Time* from 10ms to 25ms, is 100%. We adopted values at the midpoint of a 100% recognition ratio area as the threshold value of *Standard Strength* and that of *Through Time*. In this case, the *Standard Strength* is 5000mG and the *Through Time* is 15ms.

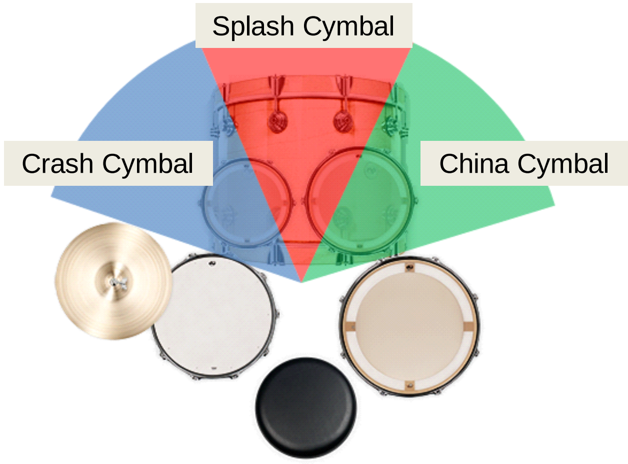

Fig. 6. An example of extension of sounds in detecting stroking position

3.4 Changing sound by stroking direction

Our system allows users to control output sounds of virtual drums by orientation of stroking, as shown in Figure 6. The proposed system calculates the orientation by integrating gyro data. Furthermore, the orientation data help the system improve the recognition ratio the of stroking of real drums and virtual drums. For example, as shown in Figure 6, the proposed system prevents false recognition because the hi-hats of real drum are not set up in the area of the virtual china cymbal.

3.5 Volume control

The proposed system controls the sound volume of virtual drums to enable drummers to play virtual drums well. The sound volume is decided on the basis of the peak value of the acceleration data during the stroking of virtual drums.

3.6 Cut off sounds by being output mistakenly

The system recognizes the output timing of sound by only using the motion of bringing the arm down when stroking. In this recognition, if the sound of virtual drums is output mistakenly when real drums are played, it interrupts the performance. Therefore, we propose a function that cuts off the sound that is output mistakenly at once when the player strokes a real drum. As described in Section 3.2, after the stroking of real drums, the vibration of acceleration data arises as a particular phenomenon. The proposed system uses this feature to cut

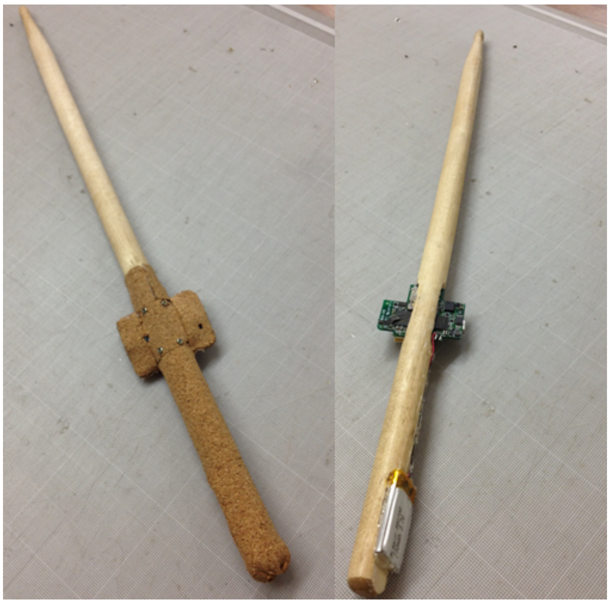

Fig. 7. A prototype of Airstic Drum

the sound that is output mistakenly. To use this function, the proposed system will possibly minimize performance interruption.

4 Implementation

We implemented a prototype *Airstic drum*, as shown on the left in Figure 7. The inside of the prototype drumstick is shown on the right in Figure 7. The drumstick is the wooden type that is used in general drum performances and is attached with Wireless Technology WAA-010, equipped with a 3-dimensional acceleration sensor and a 3-dimensional gyro sensor. The WAA-010 is attached to the middle of the drum stick so as not to touch fingers. Table 2 shows the specifications of WAA-010. We implemented a prototype system on Windows 7 using Microsoft Visual ++.NET 2008. Also, we used Roland SD-20 as a MIDI sound generator. Figure 8 shows a screenshot of the application for prototype. A user can set values of *Standard Strength* and *Through Time*, select the drum sounds, confirm the orientation of a drumstick and waves of acceleration and gyro data in stroking drums, and so on with the this application.

5 Evaluation

We conducted an evaluative experiment to investigate the recognition ratio to confirm the effectiveness of the proposed system.

Table 2. Specification

Communications standards	Bluetooth Ver 2.0
	+ EDR Class 2
Baud rate	2.1Mbps
Communication distance	Up to 10m
Size	39(W)×44(H)×12(D)mm
Weight	20g
Power source	230mAh
	Lithium polymer battery

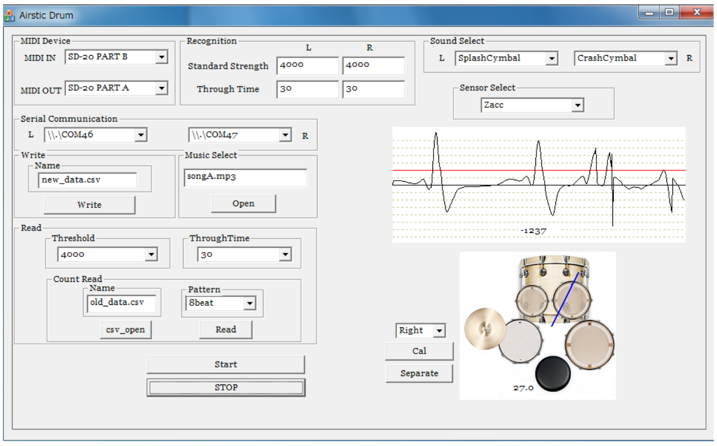

Fig. 8. Screenshot of the proposed application

In this evaluation, we used a phrase shown in Figure 5 as a trial phrase. The phrase uses the virtual drum as a crash cymbal, the hi-hat, the floor tom, and the ride cymbal. The virtual drum is only used at the beginning of each 8-beat pattern. The sound of the virtual drum is a digital sound produced by a MIDI sound generator and other percussion sounds are output from an acoustic drum kit. Testers repeated the phrase 10 times in this evaluation. Tempo is 100bpm (beats per minute). Two male university students took part in this evaluation. Both testers were experienced drummers and were able to play the trial phrase with the acoustic drum kit fully.

Table 3 shows that the proper threshold values should be a 100% recognition rate when each tester strokes each percussion instrument. Also, Table 4 shows the recognition ratio of each tester stroking each percussion instrument using the threshold value adapted for each tester in Table 3. The recognition ratio shown in Table 4 is calculated on the basis of the true positive, which is the recognition ratio of playing a virtual drum (the left value on each cell in the table) and the

Table 3. The threshold value of each tester and each percussion instrument

	Tester A			Tester B		
	HH	FT	RD	HH	FT	RD
Standard Strength(mG)	5000	4500	4500	4500	3500	3500
Through Time(ms)	25	25	25	20	20	15

Table 4. The recognition ratio using the threshold value for each tester [%]

		Threshold of Tester A			Threshold of Tester B		
		HH	FT	RD	HH	FT	RD
Tester A	HH	100-100*	100-100	100-100	100-100	100-100	100-100
	FT	100-100	100-100	100-100	100-90.0	100-99.3	95.0-100
	RD	100-100	100-100	100-100	100-86.4	100-98.8	100-100
Tester B	HH	85.0-100	70.0-100	70.0-100	100-100	100-100	95.0-100
	FT	95.0-100	90.0-100	90.0-100	100-91.4	100-100	100-100
	RD	95.0-100	90.0-100	90.0-100	100-87.1	100-100	100-100

* True positive - True negative
HH:Hi-hat, FT:Floor tom, RD:Ride cymbal

true negative, which is the non-recognition ratio of virtual drum in playing real drums (the right value on each cell in the table).

As shown in Table 4, when Tester A played using the threshold value adapted for him, recognition ratio was 100% in all patterns and all percussion instruments. Also, when each tester played threshold values that were not adapted for themselves, for Tester A a false positive while playing real drums occurred, and for Tester B a false negative while playing virtual drums occurred. These results arose because the threshold value of Tester A's *Standard Strength* is higher than that of Tester B as a whole, and the threshold value of Tester B's *Through Time* is shorter than that of Tester A. Analyzing the performance data of Tester B, the motion of raising and lowering a drumstick was small when he stroked virtual drums. From the difference in the stroking motion among drummers, a different threshold value evidently exists for each drummer. Moreover, when both testers used the threshold value with which Tester B stroked hi-hats, false positives were seen in stroking real drums. Compared with stroking a floor tom or a ride cymbal, when drummers stroke the hi-hats several times in a row, such as an 8-beat pattern, an *up-down stroking* motion, in which drummers stroke both the edge and the top of the hi-hats in one stroke, is used frequently. With this playing style, when drummers perform a phrase in which stroking motion tends to change, the threshold value has a bias. Therefore, it is necessary to investigate the data in all kinds of phrases.

Fig. 9. Actual performance at Illumine Kobe in 2010

6 Actual use

We used the prototype at the Illumine Kobe [9] event on December 12th, 2010, as shown in Figure 9. The drummer is the first author of this paper. At this event, he performed with an electric bass guitarist. He used two drumsticks equipped with sensors, and both sticks output different digital sounds. The performance quality with the proposed system was similar as that with a complete set of real drums. However, in stroking virtual drums, sometimes digital sound was not output due to non-recognition. The lack of sound is a serious problem that decreases performance quality. We need to investigate how to recognize the stroke of virtual drums with higher accuracy.

7 Conclusions

In this research, we constructed *Airstic Drum*, which integrates real and virtual drums. The proposed drumstick enables integration of virtual and real drums by recognizing the stroking motion using the acceleration and the gyro data unlike conventional virtual drums that must be used alone. Because in order not to output digital sounds of virtual drums when stroking real drums, drummers do not have to use particular motion that is different from usual drum playing, so drummers can use their conventional drumming technique. Moreover, the proposed system detects the orientation of stroking to change output sounds of the virtual drum. Also, drummers can control the sound volume of virtual drums by changing the stroking motion. Experimental results showed that the use of a proper threshold for each drummer enables effective integration of real and virtual drums.

For future work, we plan to reproduce the playing style of real drums in virtual drums and to increase the perception of the drummers and audience by visual feedback of stroking.

Acknowledgments

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References

1. SPD-S:
   `http://www.roland.com/products/en/SPD-S/.`
2. Wii Music:
   `http://www.wiimusic.com/launch/.`
3. J. O. Borchers: WorldBeat: Designing a Baton-Based Interface for an Interactive Music Exhibit, *Proc. of the International Conference on Human Factors in Computing Systems (CHI97)*, pp. 131–138 (Mar 1997).
4. Silverlit V-beat AirDrum:
   `http://www.silverlit.com/product\_04.htm.`
5. T. M. Patola, A. Kanerva, J. Laitinen, and T. Takala: Experiments with Virtual Reality Instruments, *Proc. of the International Conference on New Interfaces for Musical Expression (NIME05)*, pp. 11–16 (May 2005).
6. Lightning:
   `http://www.buchla.com/lightning3.html.`
7. T. M. Patola: User Interface Comparison for Virtual Drums, *Proc. of the International Conference on New Interfaces for Musical Expression (NIME05)*, pp. 144–147 (May 2005).
8. M. Collicutt, C. Casciato, and M. M. Wanderley: From Real to Virtual: A Comparison of Input Devices for Percussion Tasks, *Proc. of the International Conference on New Interfaces for Musical Expression (NIME09)*, pp. 1–6 (June 2009).
9. Illumine KOBE 2010:
   `http://cse.eedept.kobe-u.ac.jp/illumineKOBE2010/main.html.`