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AN EFFICIENT SYSTEM FOR SUPPORTING BAT SWING OF BEGINEERS IN BASEBALL USING WEARABLE SENSORS

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Recently a support system that improves sports skills using sensor or video camera data is attracting great attention. Since most of these systems are developed for professional athletes, few are available for beginners. In baseball, since hitting skills are generally acquired based on oral pantomimed by baseball experts, it is difficult for beginners to understand the advice based on the skill level of baseball experts. In this paper, we propose a support system through which beginners improve their hitting skills by analyzing the batting stance of baseball players using such wearable sensors as acceleration and angular velocity sensors. In our proposed system, beginners swing based on wearable sensors that compose a triaxial acceleration sensor and an angular velocity sensor to the bat and the body. Next, experts in baseball can analyze the modification of the batting stance of beginners by measuring the sensor values of the swing. In the evaluation result, our proposed system analyzed the differences of batting stance between experts and beginners in baseball and confirmed that we can effectively support the hitting skill of baseball beginners.

Keywords: Baseball, Bat swing, Support system, Wearable sensors

1. Introduction

Due to the recent popularization of sensing technology, the number of systems that analyze the movement of users by sensors in sports is increasing [1, 2]. For example, ForeAthlete [3] has a GPS and heartbeat sensors in addition to the conventional function of watches. Users can greatly improve the training quality by acquiring information on their position, speed, mileage, and heart rate while running. A watch designed for running that is equipped with wearable sensors is expensive because it is used by professional athletes. However, since many types of athlete watches are commercially available, many runners can use them cheaply.

In baseball, which is one of the sports, analysis systems for improving user skills with measured data and videos acquired by sensors and video cameras has recently received much attention [4]. Since a system for motion analysis using sensors was developed for professional athletes at great cost, it is difficult to customize for individual users [5]. Especially in baseball, few systems for beginners have been developed.

In baseball, hitting skills are generally acquired based on direct feedback or pantomimed by baseball players [6]. Therefore, it is difficult for beginners to understand the advice due to the high skill level of baseball experts.

In this paper, we propose a support system with which beginners can improve their hitting skills by analyzing the batting stance of players using multiple sensors, such as acceleration and angular velocity sensors. In our proposed system, beginners measure the values of sensors by wearing a triaxial acceleration sensor and an angular velocity sensor on the bat and body and swinging it. Next, an expert in baseball can analyze the modification of the batting stance in the beginners using their measured data.

Our major contributions are:

- We propose a support system with which beginners can improve their hitting skill by analyzing the batting stance of baseball players using wearable sensors.
- We confirm that we can effectively support the hitting skill of beginners by analyzing the differences of hitting stance between experts and beginners in baseball.

The rest of the paper is organized as follows. We explain the necessity of motion analysis in baseball in Section 2. Related works are explained in Section 3. Our proposed system is described in Section 4. We evaluate our proposed system in Section 5, and conclude our paper in Section 6.

2. Necessity of Motion Analysis in Baseball

2.1. *Motion Analysis in Sports*

With the development of sensing technology, users can acquire biometric information that was difficult to measure. Recently, research on motion analysis using wearable sensors in sports has increased. For example, the conventional athletic watch has the function of measuring each lap while running in addition to its time-telling function. By using such a watch equipped with compact sensors such as a GPS and a heart rate sensor, users can acquire their position, speed, mileage, heart rate, and foot speed while running. Therefore, the quality of training can be greatly improved.

2.2. *Conventional System for Acquiring Technique of Bat Swing in Baseball*

To score points in baseball is necessary to win, users improve the batting skill to increase the score. Also, to swing the bat well, users need to properly move various parts of the body in order. Therefore, it is difficult for the user to recognize the characteristics of the bat swing.

Users may find the modification point of the bat swing using the system that takes a video of bat swing using a mobile device or haves the bat swing with the sensor attached to the grip of the bat. However, it is difficult for the user to solve the modification point oneself and improve the batting technique. Therefore, in order to improve the batting technique of the user, an experienced coach needs to check the user's bat swing, finds the modification point based on his own experience, and tells the direct feedback to the user in pantomime.

In Figure 1, we show the guidance process by advice for learning hitting in baseball. In this process, users can learn a batting stance by repeating the following procedure: (1) practice, (2) feedback from a coach, and (3) advice from the coach. Since the guidance ability depends on the skill of coaches, users may not acquire a batting stance based on their advice.

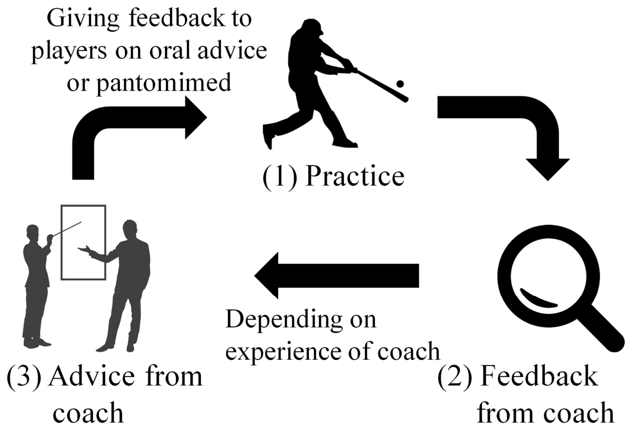

Fig. 1. Basic process for acquiring hitting skill in baseball.

In addition, if the leader has no theoretical foundation for his guidance, users may practice without accepting it.

3. Related Works

3.1. *Motion Analysis Using Videos in Baseball*

In baseball, various motion analysis methods have been proposed to improve the ability of teams and players. For example, the EON Sports Corporation in the United States developed a baseball training system called iCube [7], which uses virtual reality (VR). By combining video of each pitcher with the data accumulated in the ball-tracking systems from baseball stadiums, the pitching motion is reproduced in VR space. By wearing a head-mounted display (HMD), players can acquire such information as pitch speed, the trajectory of pitched balls, and their power. In addition, by freely selecting the pitchers and the types of pitches using accumulated data, players can more effectively prepare for games. The Yokohama DeNA Baystars, a Japanese professional baseball team, introduced iCube during practice in 2017.

Statcast [4] developed by MLB Advanced Media Inc., was introduced by Major League Baseball (MLB) in 2015. Statcast analyzes the movement of players with high-speed and high-precision analysis using high-performance cameras and radar in baseball stadiums and measures such various information as the hitting speed and angle, the pitching release point, and the rotation speed of pitches. Statcast can also manage the physical condition of players and the tactics of teams.

The Houston Astros, an MLB team, analyzed the angles of batted balls with a high possibility of home runs called a barrel zone [8] using the data of ballistic lines obtained from Statcast. Most teams believed that balls should be hit on the ground rather than raising their angles. However, based on this analysis result, Astros suggested that players should raise the launch angle of batted balls rather than hitting them on the ground. This new strategy helped the Astros increase their home runs in the 2017 season and was a leading reason for their championship that year.

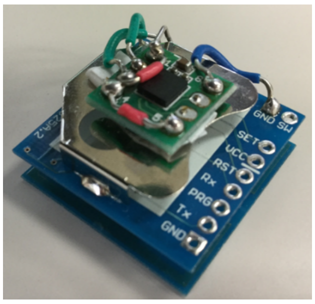

Fig. 2. Appearance of sensor after soldering.

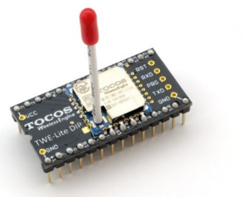

Fig. 3. TWE-Lite DIP.

3.2. *Systems for Motion Analysis Using Sensors*

In baseball, many types of batting systems using sensors have been proposed. Baseball Swing Analyzer [9] can measure the swing speed and the movement of the wrist in cooperation with mobile devices. Also, by displaying on the mobile devices in combination with data and movie in the bat swing, the user can improve its batting form.

In SwingTracker [10], users can check their own batting form using the application on the mobile device. In the mobile device, the maximum speed of the bat swing and the flight distance of the ball are displayed. The user can practice the bat swing based on these information.

We previously proposed a tea ceremony e-learning system using multiple sensors [11]. In this system, users can analyze the movements in the tea ceremony by attaching to their body a GPS, an angular velocity sensor, and a geomagnetic sensor.

However, in leading sports like football and baseball, many companies have already developed a sensor system with a large budget. Also, it is difficult to develop a system especially for professional athletes. We propose a baseball system that supports the coach to instruct the batting techniques to the beginners.

4. Proposed System

4.1. *Outline*

We propose a support system through which beginners can improve their hitting skill by analyzing the batting stance of baseball players using wearable sensors. To measure batting stances of experts and beginners, our proposed system consists of an acceleration sensor, an angular velocity sensor, and a TWE-Lite DIP [12]. The acceleration sensor and the angular velocity sensor are inexpensive and have low-power consumption, and are attached to the body after being soldered by jumper wires. Figure 2 shows an appearance of an acceleration sensor and the angular velocity sensor after being soldered.

To analyze the differences in batting stances between experts and beginners, we measure their hitting stance in practice swings rather than actual swings. Baseball experts and beginners measured their hitting stances by attaching the wearable sensors to their bodies and taking practice swings with a sensor attached to the bat knob.

In the practice swing, without using a ball, users can acquire a batting form, enhance

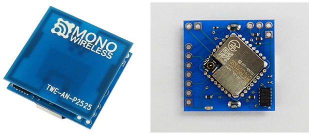

Fig. 4. Acceleration sensor.

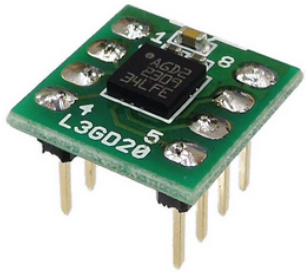

Fig. 5. Angular velocity sensor: L3GD20.

muscle strength, and increase the swing speed. When the user hits the ball to the point called the sweet spot in the bat, the initial speed of hitting ball becomes faster [13]. However, based on the image of practice swing, it is difficult to verify whether the user can actually hit the ball. In this paper, beginners can improve the accuracy of practice swing by teaching the bat swing from the expert in baseball based on the values obtained with wearable sensors.

4.2. *Sensor*

4.2.1. *TWE-Lite DIP*

A TWE-Lite DIP is a wireless microcomputer on which software for an Integrated Circuit (IC) is installed to an ultra-small wireless microcomputer (TWE-Lite) [12]. Figure 3 shows a TWE-Lite DIP, which communicates using the wireless standard in the 2.4-GHz frequency band, its communication speed is 250 kbps.

4.2.2. *Acceleration Sensor*

This system uses an acceleration sensor to analyze the swing speed of users. Figure 4 shows a TWE-Lite 2525A [12], which has a coin battery holder and a triaxial acceleration sensor on a wireless microcomputer TWE-Lite. One side of the acceleration sensor is 25 mm, and the sampling rate is 100 Hz at the maximum. The TWE-Lite 2525A can also be used as a beacon to detect the state of an object, and to wirelessly transmit the acquired information.

4.2.3. *Angular Velocity Sensor*

In this system, an acceleration sensor analyzes the hitting stance of users in terms of the rotation speed of their body. Figure 5 shows the TWE-Lite 2525A [14]. L3GD20 is a compact sensor that can measure the angular velocity with three axes as 16-bit data.

4.3. *Acquiring Scheme for Hitting Skill with Sensors*

In Figure 6, we show our proposed process for acquiring hitting skill using sensors. In this process, users acquire batting stance by repeating the following procedure: (1) practice, (2) data analysis, and (3) proposed improvements from a coach. For hitting, beginners mount their small sensors (an acceleration sensor and an angular velocity sensor) on their body and swing the bat. Next, their batting is analyzed by digitizing the sensor data result of the bat

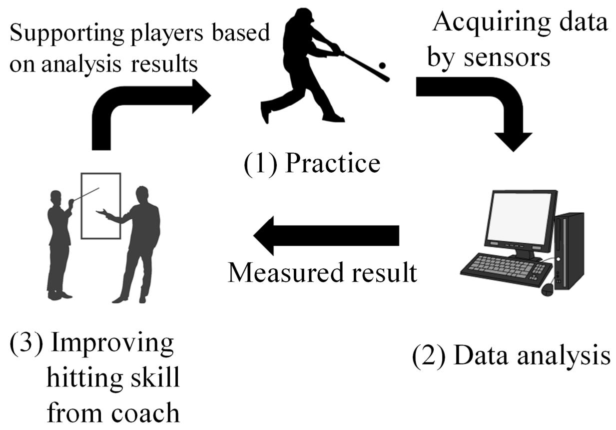

Fig. 6. Proposed process with sensors for acquiring hitting skill in baseball.

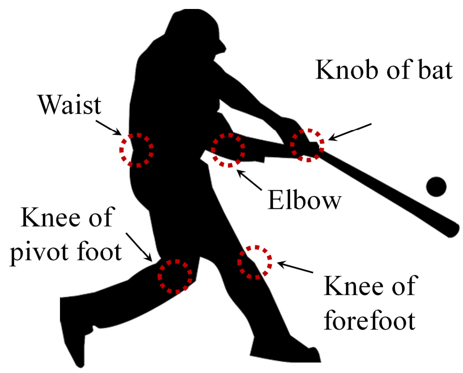

Fig. 7. Position of attached sensors (right-handed batter).

swings with a computer and comparing it to the result of a baseball expert. Based on this analysis result, the coach comments on the improvement and gives feedback. This method does not depend on the skill of the expert who analyzes the value of the hitting stance by sensors to improve the stance of the beginner. A coach can show how to improve hitting skill of beginners by measuring the batting stance with sensors. Therefore, beginners can more readily trust their coach.

4.4. *Position of Wearable Sensors*

Figure 7 shows the position of each sensor. Based on the knowledge of baseball experts, we set the following five fitting positions of the sensor: (1) the knob of the bat, (2) the waist, (3) the knee of the pivot foot, (4) the elbow, and (5) a knee of forefoot. The pivot foot supports the swing's power. The pivot foot of a left-handed batter is the left foot, and that of a right-handed batter is the right foot. Since the swing's power is transferred to the bat by moving the elbow, users can improve their swing speed. The elbow of a left-handed batter

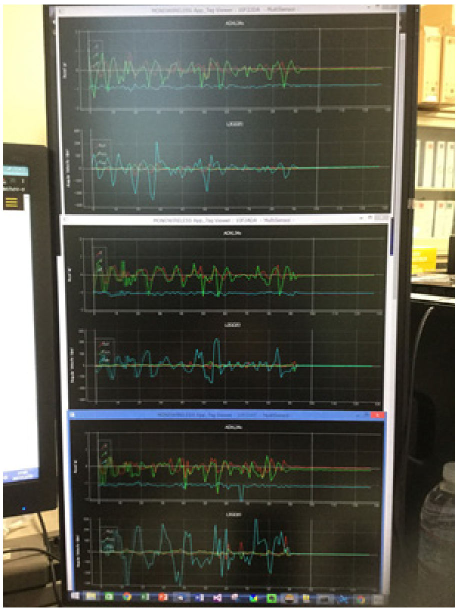

Fig. 8. Graph of real time of acceleration and angular velocity.

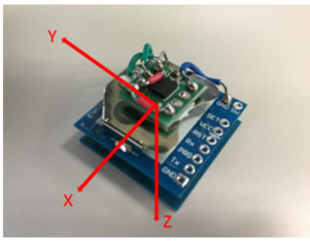

Fig. 9. Coordinate axis of acceleration sensor.

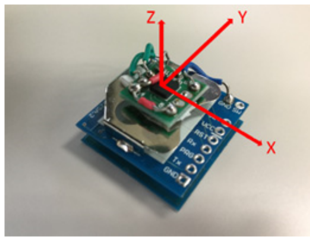

Fig. 10. Coordinate axis of angular velocity sensor.

is the left elbow, and that of a right-handed batter is the right elbow. The forefoot while swinging the bat of a left-handed batter is the right foot, and that of a right-handed batter is the left foot.

4.5. *Procedure of Motion Analysis in Bat Swing*

Based on the process of the proposed system described in Figure 6, we explain the procedure of movement analysis. First, the user attaches the multiple sensors to his body and takes some practice swings using the bat with a sensor. The measured data acquired by the multiple sensors are transmitted to a computer by the TWE-Lite DIP. The computer saves its transmitted data in a CSV format.

Figure 8 shows a graph of acceleration and angular velocity displayed in real time. A coach can improve the batting stance of the beginner by analyzing the measured data and clarifying the differences between the expert and the beginner.

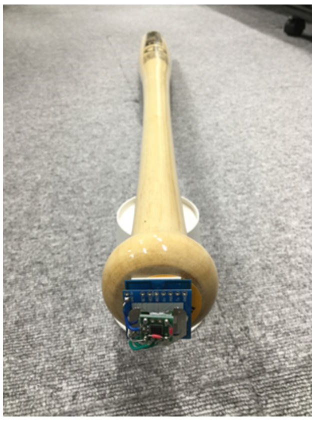

Fig. 11. Wearable sensors attached to bat knob.

5. Evaluation

5.1. *Outline*

In the proposed system using multiple sensors, we evaluated how the hitting skill of beginners changed by comparing the hitting stance with those of experts.

We set the evaluation parameter of our proposal as a change in the swing speed of beginners. There are two advantages when the swing speed increases. The first is that the impact on the ball during hitting becomes stronger and the distance of the batted ball increases. Second, the time at which the pitcher throws the ball to it being hit is shortened, and the time to judge the trajectory and the types of pitches becomes relatively long.

Based on the coaching guide [6], knowledge of baseball experts, to raise their swing speed, beginners must not only quickly swing the bat but also swing it using their entire body. Therefore, the proposed system measures the swing of users with a sensor attached to their body.

5.2. *Evaluation Environment*

Users attached to their bodies multiple sensors, that are composed of an acceleration sensor (TWE-Lite 2525A) and an angular velocity sensor (L3GD20). We set TWE-Lite 2525A as the coordinate axis (Figure 9) and L3GD20 as the coordinate axis (Figure 10).

As shown in Figure 11, we attached multiple sensors at the bat knob. In the experiment, users performed a bat swing with multiple sensors attached to a bat knob, a waist, a knee of pivot foot, an elbow, and a knee of forefoot. In the multiple sensors attached to the waist, the knee of the pivot foot, and the knee of the forefoot, the negative direction of the Y-axis in the acceleration sensor (Figure 9) and the positive direction of the X-axis in the angular velocity sensor (Figure 10) are both identified as the head's direction. Also, in the multiple sensors attached to the elbow, the negative direction of the Y-axis in the acceleration sensor and the positive direction of the X-axis in the angular velocity sensor are both identified as

Table 1. Detailed information of users.

	Carrer in teams	Height	Weight
Expert A	16 years	174 cm	63 kg
Expert B	15 years	170 cm	61 kg
Beginner C	None	178 cm	97 kg
Beginner D	None	176 cm	75 kg

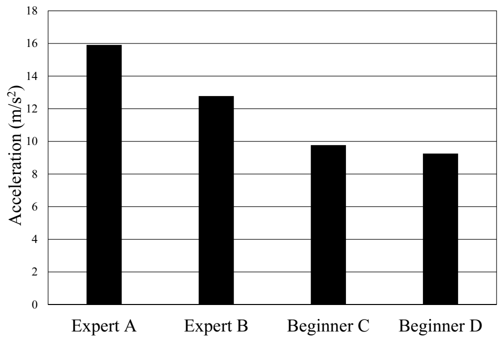

Fig. 12. Average maximum acceleration values of Y-axis of bat knob.

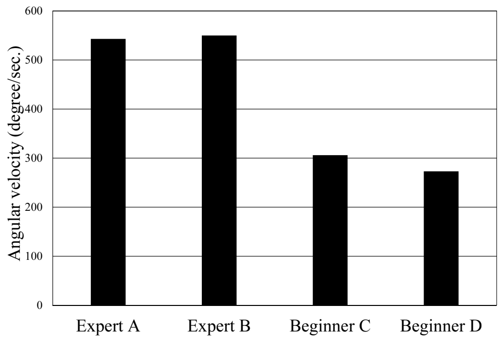

Fig. 13. Average maximum angular velocity values of X-axis at waist.

the direction of the fingertips.

Table 1 shows detailed information of the users, who were composed of two experts (A, B) and two beginners (C, D).

5.3. *Experiment 1: Before Teaching Batting Stance*

We explain the details of Experiment 1. First, the four users attached multiple sensors to their waist and the knee of their pivot foot and swung ten times using a bat to which multiple sensors were attached to the knob. Next, the four users attached multiple sensors to their elbows and the knees of their forefeet and swung ten times with the same bat.

The evaluation results are shown in Figures 12, 13, 14, 15, and 16. The horizontal axis is the users. The vertical axis in Figures 12, 15, 16 is the average maximum acceleration values, and that in Figures 13 and 14 is the average maximum angular velocity values.

5.3.1. *Acceleration at Knob*

Figure 12 shows the average of the maximum acceleration values of the Y-axis at the knob of each user. The swing speed of beginners C and D is slower than experts A and B. The acceleration values of the Y-axis represent a movement where the bat is parallel to the ground while it is being swung. Also, the acceleration values of the knob are represented by an axis composed of a straight line between the pitcher and the catcher around the point where the user hits the ball with her bat. When the acceleration values of the Y-axis at the knob increase, the swing speed also increases.

5.3.2. *Angular Velocity at Waist*

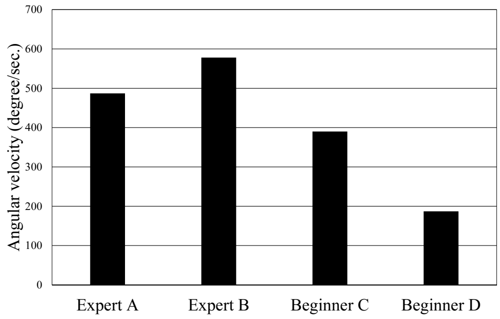

Fig. 14. Average maximum angular velocity values of X-axis in knee of pivot foot.

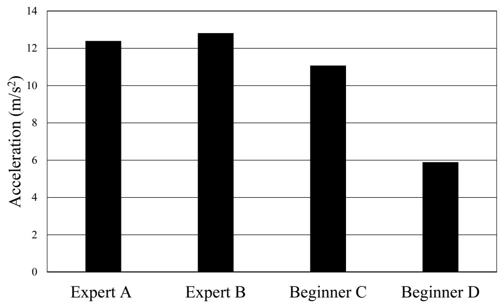

Fig. 15. Average maximum acceleration values of Z-axis in back elbow.

Figure 13 shows the average of the maximum velocity values of the X-axis of the waist of each user. In Figure 13, the rotation speed of the waist in beginners C and D is lower than that of experts A and B. When the waist's rotation speed is slow, the power of the lower body is inadequately transmitted to the bat and the swing speed can not be raised. Therefore, beginners C and D need to swing the bat based on their waist rotation.

5.3.3. *Angular Velocity in Knee of Pivot Foot*

Figure 14 shows the average of the maximum velocity values of the X-axis in the knee of the pivot foot of each user. The rotation speed of the knee of the pivot foot in beginners C and D is lower than that of experts A and B.

For beginners C and D, the difference in the rotation speed in the knee of their pivot foot is large. Therefore, they need to swing the bat based on the rotation of the knee of their pivot foot.

5.3.4. *Acceleration in Elbow*

Figure 15 shows the average of the maximum acceleration values of the Z-axis in the elbow of each user. In Figure 15, its acceleration values of beginner D are slower than those of experts A and B, and beginner C.

When the acceleration of the elbow is low, its movement in beginner D was small, and he swung without keeping his upper arm close to his body. If users swing without keeping their upper arm close, the power of the swing is inadequately transmitted to the bat and the swing speed can not be raised. Therefore, beginner D needs to swing by keeping his upper arm close.

5.3.5. *Acceleration in Knee of Forefoot*

Figure 16 shows the average of the maximum acceleration values of the X-axis in the knee of forefoot of each user. The acceleration values of the knee of the forefoot of beginners C and D are slower than those of experts A and B.

If no foot step is taken during the swing, the acceleration of the knee of the forefoot becomes low. Beginners C and D need to swing after this step.

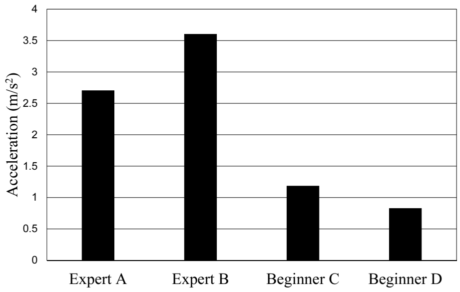

Fig. 16. Average of maximum acceleration values of X-axis in knee of forefoot.

Table 2. Measurement results before and after modification of batting stance for beginners C and D (top: beginner C, bottom: beginner D).

Points	Before (m/s^2)	After (dps)	Variation (%)
Y-axis of acceleration of knob	9.77 9.25	11.74 13.88	+20.16 +50.05
X-axis of angular velocity of waist	306.0 273.0	464.6 376.5	+51.83 +37.91
X-axis of angular velocity in knee of pivot foot	390.0 187.0	490.6 575.9	+25.79 +207.97
Z-axis of acceleration of elbow	11.06 5.88	5.36 8.86	–51.54 +50.68
X-axis of acceleration in knee of forefoot	1.18 0.83	2.11 1.55	+78.81 +86.75

5.4. ***Experiment 2: After Teaching Batting Stance***

We explain the details of Experiment 2. First, based on the results of Experiment 1, beginners C and D received feedback from a coach about modifying their hitting stance and swung for 30 minutes. Then, beginners C and D conducted the same experiment as Experiment 1.

5.4.1. *Comparison Before and After Modification of Hitting Stance*

Table 2 shows the measurement results of beginners C and D before and after modifying their batting stances, respectively. In Table 2, both beginners C and D improved the acceleration Y-axis of the bat knob and increased their swing speed. Both beginners C and D began to swing using their whole body.

5.4.2. *Comparison of Experiments 1 and 2*

Figures 17, 18, 19, 20, and 21 show the comparison results of Experiments 1 and 2 based on the attached points of the multiple sensors and the reference axis. Because we evaluated experiment 2 on beginners C and D, there are no results for experts A and B in experiment 2.

In Figures 17, 18, 19, 20, and 21, the measured values for beginners C and D increased

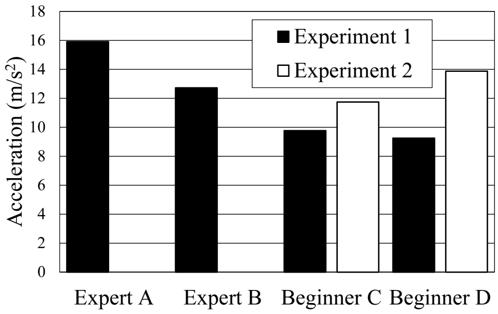

Fig. 17. Comparison of Acceleration Y-axis of knob.

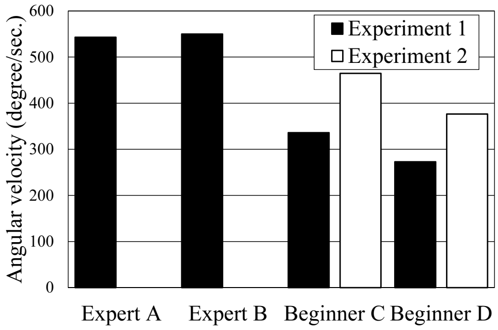

Fig. 18. Comparison of Y-axis of angular velocity of waist.

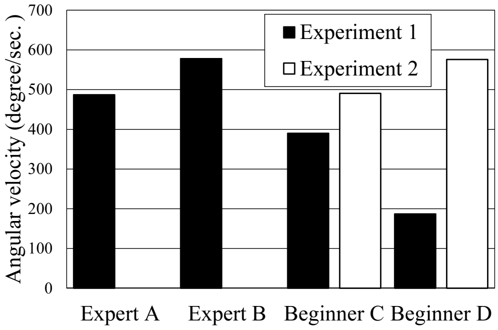

Fig. 19. Comparison on X-axis of angular velocity in knee of pivot foot.

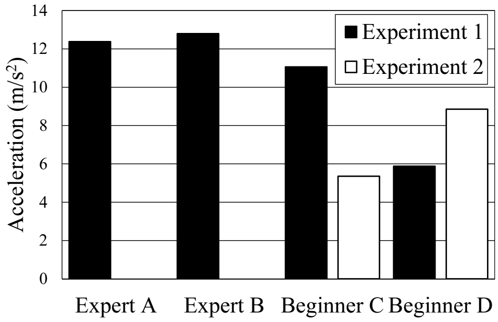

Fig. 20. Comparison on Z-axis of acceleration of elbow.

and approached the values of experts A and B. Since the waist and the knee of the pivot foot of the beginners rotated sufficiently like the experts, we can infer that the movement of the steps in the swing was performed correctly.

In Figure 20, the measured value of beginner D on the Z-axis of the acceleration in the elbow increased and approached that of experts A and B. In addition, the measured value of Experiment 2 in beginner C was lower than that of Experiment 1. Therefore, beginner C can increase swing speed by improving the movement of his elbow.

6. Conclusion

We proposed a support system with which beginners can improve their hitting skill by analyzing the batting stance of baseball players using wearable sensors: an acceleration sensor, an angular velocity sensor, and a TWE-Lite DIP. In our evaluation result, we confirmed that we can effectively support the baseball hitting skill of beginners by analyzing the differences of hitting stance between baseball experts and beginners.

In the future, we will conduct a detailed analysis based on the difference of batting stance between experts and beginners by increasing the number of users. Also, we will automate the process of acquiring the measured data to improve the batting stance of beginners.

Acknowledgements

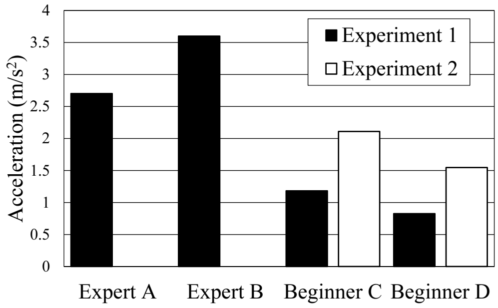

Fig. 21. Comparison on X-axis of acceleration in knee of forefoot.

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