Journal of Mechanics Engineering and Automation 5 (2015) 190-196
doi: 10.17265/2159-5275/2016.04.004

# Evaluation of Skills in Swing Technique in Classical Japanese Swordsmanship in Iaido Using Sensors

Satoru Okamoto[1] and Satomi Adachi[2]

*1. Interdisciplinary Graduate School of Science and Engineering, Shimane University, Matsue 690-8504, Japan*

*2. Department of Social Informatics, Graduate School of Informatics, Kyoto University, Kyoto 606-8501, Japan*

**Abstract:** In this study, we analyzed the swing motions of more experienced practitioner and new practitioner of iaido players by using tri-axial acceleration sensor and gyro sensor. Iaido is a modern Japanese martial art/sport. In this way, the acceleration and gyro sensor measurement enabled detailed motion information at the installation points to be displayed in a short time, thus making it possible to easily extract the objective problems. Although it was not possible to confirm by the acceleration and angular velocity measurements the detailed motion of the entire body as obtained in the 2D motion analysis with a high-speed camera, it was confirmed that the acceleration and gyro sensor is an evaluation means that can be installed easily and can provide the exercise information in a short time as an objective index.

**Key words:** Skill science, classical Japanese swordsmanship in iaido, acceleration sensor, high-speed video camera, gyro sensor.

## Nomenclature

| | |
|---|---|
| M | Average value |
| S.D | Standard deviation |
| $t$ | Time (s) |
| $\Delta t$ | Elapsed time between Stages I and IV (s) |
| $V$ | Maximum speed of sword tip (m/s) |
| $X$ | Coordinate direction of acceleration sensor equipped with right wrist indicated in Fig. 2 |
| $Y$ | Transverse coordinate of acceleration sensor equipped with right wrist indicated in Fig. 2 |
| $Z$ | Perpendicular coordinate of acceleration sensor equipped with right wrist indicated in Fig. 2 |
| $\alpha_x$ | Acceleration in $X$-direction (m/s$^2$) |
| $\alpha_y$ | Acceleration in $Y$-direction (m/s$^2$) |
| $\alpha_z$ | Acceleration in $Z$-direction (m/s$^2$) |
| $\omega$ | Angular velocity (rad/s) |
| $\omega_x$ | Angular velocity around $X$-direction (rad/s) |
| $\omega_y$ | Angular velocity around $Y$-direction (rad/s) |
| $\omega_z$ | Angular velocity around $Z$-direction (rad/s) |

## 1. Introduction

We are often impressed by various sports players, in particular, with the splendid skills that professionals show. The evaluation of these skills, namely their techniques, is generally left to the feelings, sensitivity, or experiential knowledge of those who watch the performance of the players. There are studies on such skill evaluation that aim at the quantitative evaluation based on the data analysis of motion measurements as opposed to the qualitative evaluation based on experience or intuition, and such studies have recently attracted attention of those engaged in providing sports instructions [1]. These studies often employ an analysis of 3D (three-dimensional) motions based on images recorded with a video camera or a high-speed camera. For example, there are studies that analyzed how dancing was learned [2] and those that examined the batting technique in baseball [3].

Iaido, commonly known as iai, is a modern Japanese martial art/sport. Iaido is associated with the smooth, controlled movements of drawing the sword from its scabbard or saya, striking or cutting an opponent, removing blood from the blade, and then replacing the sword in the scabbard or saya. Iaido encompasses hundreds of styles of swordsmanship, all of which subscribe to non-combative aims and purposes. Iaido is an intrinsic form of Japanese modern budo. Because

**Corresponding author:** Satoru Okamoto, Ph.D., professor, research fields: fluid dynamics, energy system, visualization, and biomechanics.

iaido is practiced with a weapon, it is almost entirely practiced using forms or kata [4].

A tri-axial acceleration and gyro sensor was installed to the right wrist of a test subject who swings a sword in order to perform simultaneous measurements using the high-speed video camera. Examining the video picture with the corresponding angular velocity waveform enabled it to identify characteristic points in the angular velocity waveform during sword swinging as well as those points where the characteristics of angular velocity waveforms were different between the more experienced practitioners and new practitioners of iaido. Next, the swing motion with the blunt edged sword, called iaitō, was measured using the gyro sensors installed to the right wrist so as to evaluate the essential swing skills. To examine the degree of the proficiency, more experienced practitioners and new practitioners of iaido were evaluated on the basis of the velocity of the sword forward end obtained from the image analysis of the high-speed video camera, and the peak value and motion time of the waveform measured with the gyro sensor.

In this way, the acceleration and gyro sensor measurement enabled detailed motion information at the installation points to be displayed in a short time, thus making it possible to easily extract the objective problems. Although it was not possible to confirm by the acceleration and angular velocity measurements the detailed motion of the entire body as obtained in the 2D motion analysis with the high-speed cameras, it was confirmed that the acceleration and gyro sensor is an evaluation means that can be installed easily and can provide the exercise information in a short time as an objective index. Furthermore, this method can offer a means to develop an exercise support system for new practitioners of iaido and those who aim at improvement their kata practices. The paper is organized as follows: Section 2 explains the experimental apparatus and method; Section 3 prresents experimental results and discussions; and Section 4 gives conclusions.

## 2. Experimental Apparatus and Method

### *2.1 High-Speed Video Camera Recording*

Fig. 1 shows a schematic diagram of the experimental apparatus and the measuring equipment. A series of sword swing motions was quasi-two-dimensionally recorded using one high-speed video camera (DITECT HAS-L1 Digital high speed camera, recording speed of 500 images/s). The camera was connected to a personal computer and a lighting instrument with a cable. The camera recorded the test subject from a side direction, while the personal computer recorded the images from the camera. To calibrate the camera, the calibration unit of a tetrahedron with a base side of 1,000 mm and a height of 1,450 mm was used [5].

The control point markers used for the image analysis were affixed by Velcro tapes on the main points of the body of the test subject, who was wearing the white uniform suit of iaido. To prevent the marking tapes from shifting during the measurement, elbow pads and knee pads were used on the joints of the body. In addition, the marking tapes were also provided at the forward end and grip of the sword. The total number of the marking tapes was 15: two at the sword, one at the right wrist, one at the left wrist, and so on.

The data recorded using the high-speed video camera were transferred to an image analysis software. For the analysis of the data with an exclusively used

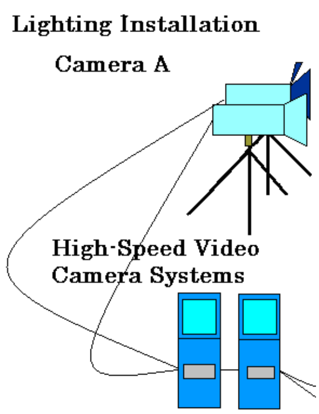


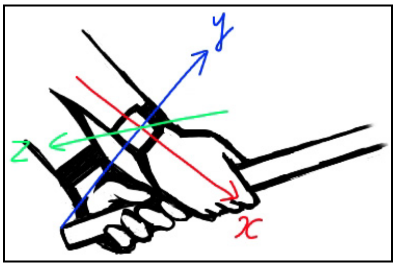

**Fig. 1 Experimental apparatus.**

plotter, the motion appearing on the monitor was digitalized and taken into a personal computer from the start of swinging to its end. As for the processing of the waveforms including high-frequency noises that were produced during the image analysis, the noises were eliminated using a low-pass filter, which removes high-frequency area but passes low-frequency area.

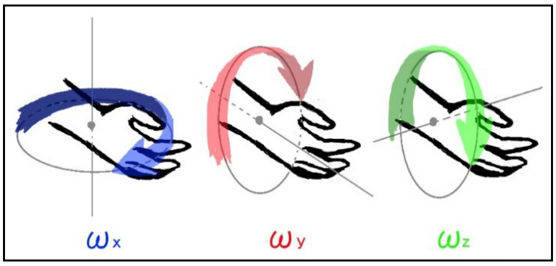
*2.2 Acceleration and Angular Velocity Measurement*

The acceleration and angular velocity measurement [6] was performed using one tri-axial acceleration and gyro sensor, each of which is able to measure acceleration, $\alpha_x$, $\alpha_y$, and $\alpha_z$ in three directions of $X$, $Y$, and $Z$ axes and angular velocity, $\omega_x$, $\omega_y$, and $\omega_z$ around the three axes (MicroStone, external dimensions: 45 mm × 45 mm × 18 mm, weight: 5 g, acceleration: ± 20 / ± 60 m/s$^2$, angular velocity: ± 300 rad/s), and a waveform analyzer (ONO SOKKI DS-0264). The number of sampling points was 2,048.

The acceleration and gyro sensor was installed with machined jigs at one point of the right wrist, where they were expected to see a conspicuous difference in their kata practices. Fig. 2a shows the coordinate system of the acceleration sensor equipped with the right wrist, while Fig. 2b shows that of gyro sensor equipped with the right wrist. The sensors were belt-installed to the




(a) Right wrist equipped with acceleration sensor




(b) Right wrist equipped with gyro sensor

**Fig. 2 Acceleration sensor and gyro sensor.**

respective points so that they would not move out of place during their kata practices. The arrow headed direction in each of the three axes, and the clockwise rotation around each of three axes were positive each other. The directions opposite to them were negative. The acceleration and angular velocity signals were measured simultaneously by high-speed video camera recording and were then analyzed. In this recording, the start signal was inputted as an external trigger for the acceleration and angular velocity measurements for synchronizing both timings.

*2.3 Test Subjects*

Two male and one female undergraduates who were on the university iaido club (height: 171.0 cm ± 4.0 cm, weight: 65.8 kg ± 8.8 kg) were selected as the more experienced, iaido practitioners. Three male undergraduates who had no experience in iaido practice (height: 168.5 cm ± 3.5 cm, weight: 67.0 kg ± 9.0 kg) were selected as the new practitioners of iaido. While new practitioners of iaido may start learning with a wooden sword (bokken), most of the practitioners use the blunt edged sword, called iaitō. As for the swing motion using the sword, all these players were right-handed when they used the wooden sword (bokken) and the blunt edged sword 10 times each.

## 3. Experimental Results and Discussions

*3.1 Motion Analysis by High-Speed Video Camera*

Fig. 3 shows the trajectories of the forward end of the sword during the model swing by more experienced practitioner and new practitioner. These results were obtained by the motion analysis software with the images recorded using the high-speed video camera. These results are very similar to the more experienced, iaido practitioners of the literature [4] and show the evidence of reliability of the measurements.

Since the high-speed video camera used in this experiment uses the hard-disks as the recording medium, it is necessary to set the forwarding width of

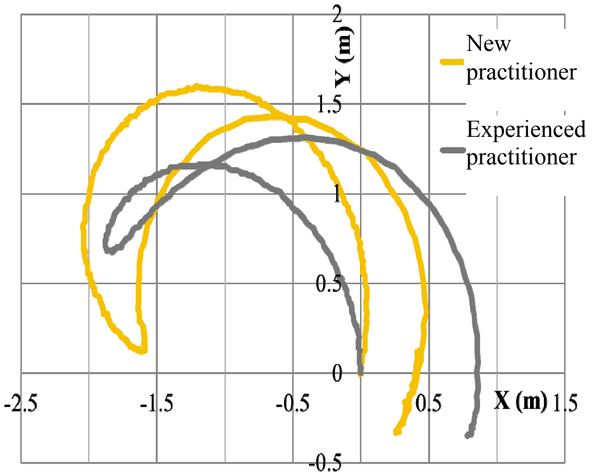
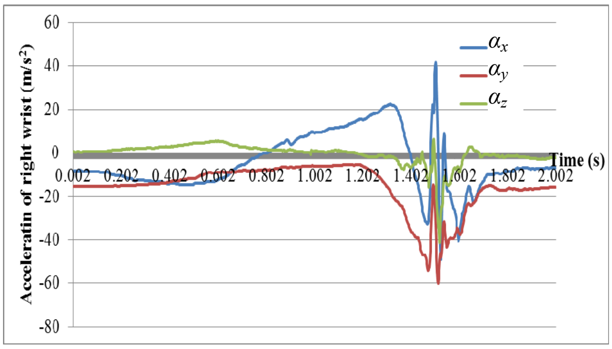



**Fig. 3 The trajectories of the swing motions by more experienced practitioner and new practitioner.**

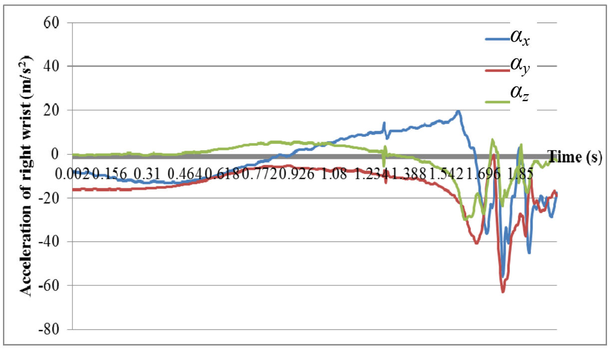
the disks. The recording speed was 500 images/s. As such, the forwarding width per frame was set to 0.002 s. In this analysis, the motion of the marker at the forward end of the wooden sword (bokken) being swung was digitalized at intervals of 0.002 s by an exclusive plotter and taken into the personal computer. Waveforms that included high-frequency noises generated during the image analysis were processed by a low-pass filter, where the waveforms were smoothened with a cutoff frequency of 20 Hz.

### *3.2 Measurement of Swing Motion by Accelerometer and Gyro Sensor*

Figs. 4a and 4b show typical waveforms of the tri-axial acceleration sensors installed at the right wrists of an experienced, iaido practitioner and an inexperienced player when each of them swung his sword. Fig. 4a is 3-axis acceleration in the $X$, $Y$, and $Z$ directions for the right wrist of the experienced, iaido practitioner. The change in acceleration was observed almost at the same time as that for the three axes. The acceleration for the inexperienced player was found to be smaller than that of the experienced, iaido practitioner, as shown in Fig. 4b. In other words, the acceleration in the $X$-axis and $Y$-axis directions of the right wrist of the experienced, iaido practitioner had a greater change than that in the $Z$ directions. In addition, the acceleration for experienced, iaido practitioners




(a) Experienced iaido practitioner



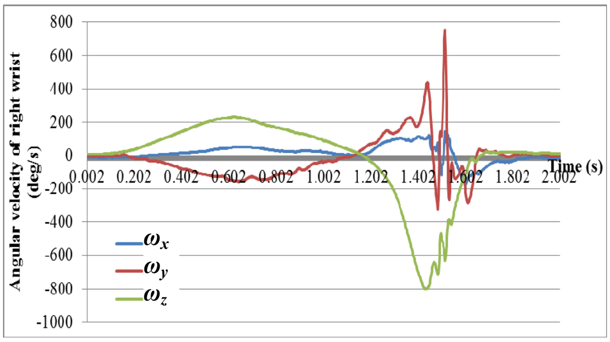

(b) Inexperienced player

**Fig. 4 Acceleration waveforms for right wrist.**

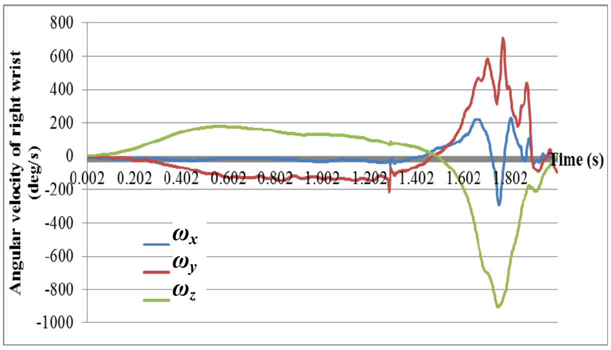
was greater than that for inexperienced players. The same tendency was observed for other subjects.

Figs. 5a and 5b show the waveforms of the gyro sensor installed at the right wrist of the same subject. The waveforms for the inexperienced player shown in Fig. 5b show almost the same degree of angular velocity around all the three axes. On the other hand, the 3-axis angular velocity waveforms of the experienced, iaido practitioner shown in Fig. 5a were different from those of the inexperienced player. The angular velocity value around the $Z$-axis, which is the rotating direction of the right wrist, was higher than those around the $X$- and $Y$-axis.

To know at which part the swing had clockwise and counterclockwise rotation, especially when a change in the angular velocity waveform was observed or when experienced, iaido practitioners and inexperienced players showed their characteristics, the relationship between the angular velocity waveforms and the high-speed video camera recording was investigated. A static picture was made for the swing motion on the basis of the images recorded. Also, the relationship




(a) Experienced iaido practitioner




(b) Inexperienced player

**Fig. 5 The relationship between the swing motion and the angular velocities of the right wrist.**

between the angular velocity (rotation) around the *Z*-axis for the right wrist provided by the gyro sensor was investigated as shown in Fig. 6. Fig. 6 shows the result for the experienced, iaido practitioner. The video recording for points at which the fluctuation in the angular velocity of the right wrist around the *Z*-axis was seen, was observed in detail. It was discovered that the rotating motion around the *Z*-axis occurred at the same time with turning over of the right wrist. It is well known that the rotating motion around the *Z*-axis by turning over of the right wrist had usually a greater change than that around the *X*- and *Y*-axis [4]. In order to confirm this estimation, the angular velocity of the wrists of the experienced, iaido practitioners was measured. The angular velocity around the *Z*-axis of the right wrist of the experienced, iaido practitioner had almost a greater change than that around the *X*- and *Y*-axis. The same tendency was observed for other subjects.

In addition, at points that had the angular velocity peak around the *Z*-axis of the right wrist in the case of

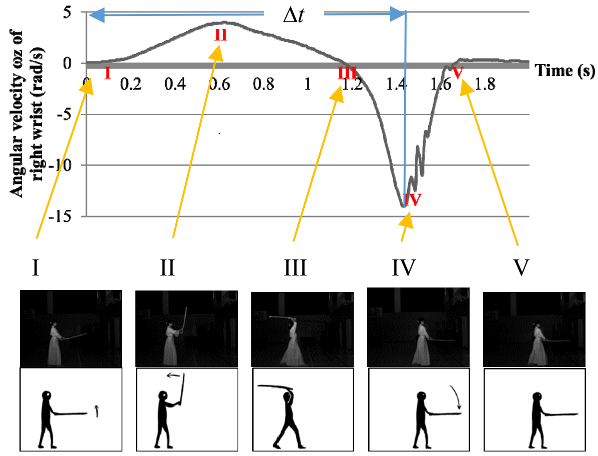



**Fig. 6 The relationship between the swing motion and the angular velocities of the right wrist.**

the experienced, iaido practitioner, the corresponding video recording was analyzed. It was found that the peak was a result of the angular velocity generated when the rotation of the right wrist was stopped. It was confirmed that the swing motion can be categorized into five stages: I, II, III, IV and V [4], based on the maximum and minimum value of waveforms provided by the gyro sensor shown in Fig. 6.

Fig. 7 shows the averaged velocity value at the sword forward end in 10 times using the blunt edged sword for a more experienced, iaido practitioner. The figure indicates that the maximum velocity at the sword forward end coincides with the maximum angular velocity around the *Z*-axis, which occurred

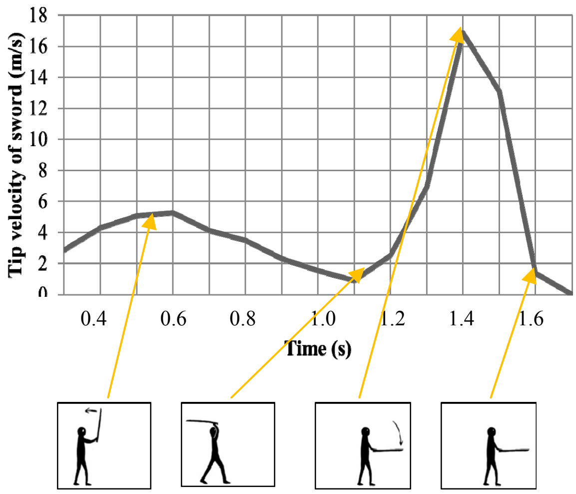



**Fig. 7 The relationship between the swing motion and the velocity of the sword forward end.**

when the rotation of the right wrist was stopped. Please note that the measurement results of Fig. 6 and Fig. 7 do not have the same starting time as the simultaneous recordings with the high-speed video camera during sword swinging. Therefore, the time on the lateral axis in each figure did not correspond with the elapsed measurement time of Fig. 6 to Fig. 7. Then, using the maximum velocity $V$ [m/s] at the sword's forward end at that particular sword swing was about 17 m/s.

### *3.3 Grouping of More Experienced Practitioners and New Practitioners of Iaido*

Since the angular velocity information proved to be an effective means to evaluate the technical difference and degree of maturity in kata practice of iaido, the swing motion was measured in the blunt edged sword for three more experienced, iaido practitioners and three new practitioners of iaido. As an example, Fig. 8 shows the angular velocity waveform around the $Z$-axis for the right wrist of a certain player, which has been enlarged in the time-axis direction. The time $\Delta t$ elapsed from the moment I to the moment IV when the sword striking or cutting an opponent, the angular velocity waveform around the $Z$-axis for the right wrist, after having decreased once and reached its minimum value was calculated for 10 swinging motions of each test subject. Then, the time difference $\Delta t$ between the times for the more experienced practitioners and the new practitioners of iaido, at the peak value of angular velocity at the sword's forward end was produced and data for the two players were plotted as shown in Fig. 8.

In this measurement, to demonstrate the superiority and inferiority of essential skills, the motion measurement was performed around $Z$-axes of the right wrist, because that showed the changes and characteristics in the waveforms. As typical examples, Fig. 8 shows the angular velocity waveforms around the $Z$-axis, which were the rotational components of the right wrist of the more experienced and new

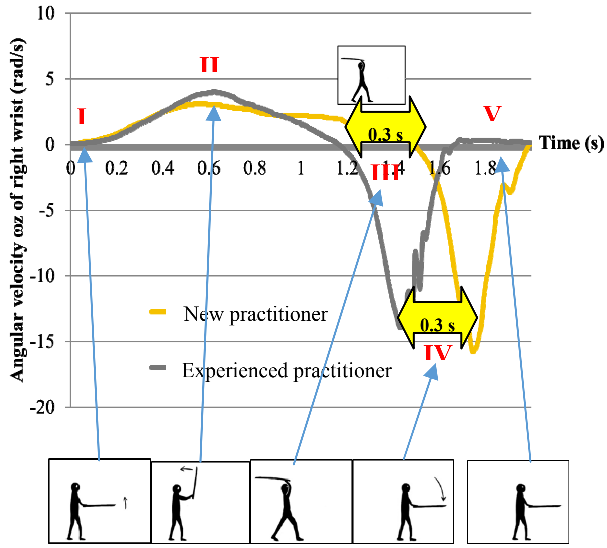



**Fig. 8 The angular velocities around the *Z*-axes for the right wrist of the experienced practitioner and the inexperienced player of iaido.**

**Table 1 Average value, M and standard deviation, S.D of maximum acceleration along *X*-axis and elapsed time Δ*t*.**

| | $\alpha_x$ (M ± S.D) | $\Delta t$ (M ± S.D) |
|---|---|---|
| Experienced practitioner 1-3 | 40.1 ± 8.2 m/s$^2$ | 1.42 ± 0.28 s |
| New practitioner 1-3 | 19.9 ± 10.9 m/s$^2$ | 1.72 ± 0.32 s |

practitioners of iaido. For both cases, IV shows the symbol for the moment of the impact that the sword is striking or cutting an opponent. It is observed that the subsequent waveform greatly vibrated because of the sword striking or cutting an opponent. Furthermore, an increase of the angular velocity caused by turning over of the wrist after the impact is observed.

Concerning the angular velocity waveform around the $Z$-axis, where a difference was observed in the measurement of the angular velocity of the right wrist during sword swinging, Fig. 8 shows a comparison of waveforms for more experienced and new practitioners of iaido in their blunt edged sword, called iaitō. As both groups were compared in the iaitō, it was also found that the peak value of the angular velocity generated when the rotation of the wrist was stopped (II) appeared faster for the more experienced practitioners than for the new practitioners of iaido. In this way, the gyro sensor measurement enabled detailed motion information at the installation points to be displayed in a short time. For example, in the swing motion, the angular velocity values for the wrist can be the important indexes when evaluating the skills. Please note that the measurement results of Fig. 8 have the same starting time as the simultaneous recordings with the high-speed video camera during sword swinging. Therefore, the time on the lateral axis in this figure corresponds with the elapsed measurement time of Fig. 6 to Fig. 8.

Concerning the characteristic parts of the acceleration and angular velocity waveforms obtained in the image analysis, data of the experienced, iaido practitioner (Experienced practitioner 1-3) and the inexperienced players (New practitioner 1-3) were acquired for each of the 10 swings. The average values were obtained for the maximum acceleration along the *X*-axis and maximum angular velocity around the *Z*-axis, which occurred when the rotation of the right wrist was stopped. The data results are shown in Table 1. When the averages of the acceleration value in Table 1 were compared, it was found that both values became higher for the experienced, iaido practitioners than for the inexperienced players. The peak value of the angular velocity for the experienced practitioners appears faster than for the inexperienced players. Since the second law of Newton suggests that the torque applied to the wrist during swinging was in proportion to the angular velocity, the torque applied to the wrist of the experienced practitioner might have been converted faster into the swinging motion than the inexperienced players. In addition, the experienced iaido practitioners have a lower standard deviation of the acceleration values and elapsed time in Table 1 and have a smaller fluctuation, showing that they were stable in motion.

## 4. Conclusions

Results show that the accelerometer and gyro sensor measurement enabled detailed motion information at the installation points to be displayed in a short time. They also indicate that in swing motion, the angular velocity values of the wrist can be important indexes for evaluating the techniques. It has become possible to estimate the sword's forward end velocity and extract objective characteristics of the swing motions of more experienced practitioners and new practitioners of iaido. Although it was not possible to confirm the detailed motion of the entire body in the acceleration and angular velocity measurements as obtained in the 3D motion analysis using motion capture, it is believed that an easily installed acceleration and gyro sensor can provide motion information as the evaluation index in a short time, and that this method will offer effective means for automatically evaluating by using a computer the techniques of sports players in the future.

## Acknowledgments

The authors thank then-graduate students of the Shimane University for their cooperation concerning the enforcement and data analysis of this experiment and undergraduates for being the test subjects.

## References

[1] Furukawa, K. 2004. "Skill Science (in Japanese)." *Journal of Japanese Society for Artificial Intelligence* 19-3: 355-64.

[2] Ishikawa, k., Yamamoto, T., and Fujinami, T. 2006. "An Analysis of Skill Acquisition Process for Rhythm of Samba Dance." In *Proceedings of the 20th Annual Conference of Japanese Society for Artificial Intelligence*, 2D1-2, 1-3.

[3] Shirado, T., and Nagayama, I. 1999. "A Study on Quantitative Analysis of Batting Form of Baseball." *Technical Report of the Institute of Electronics, Information and Communication Engineers*, HIP99-39: 37-42.

[4] James, D. A., Uroda, W., and Gibson, T. 2005. "Dynamic of Swing: A Study of Classical Japanese Swordsmanship Using Accelerometers." In *The Impact of Technology on Sport*, edited by Subic, A., and Ujihashi, S. Australasian Sports Technology Alliance Pty Ltd: 355-60.

[5] Ishida, M., Hirokawa, S., Miyazaki, S., Ae, M., and Hayashi, T. 2002. "Biomechanics of Human Movement." *Japanese Society for Medical and Biological Engineering* ed., in Japanese, Corona Publishing Ltd: 129-32.

[6] Makikawa, M. 1998. "Ambulatory Monitoring of Human Behaviour in Daily Life." *Journal of the Japan Society of Mechanical Engineers*, 101-950: 14-6.