Visualization and motion analysis of swimming
Shinichiro Ito\textsuperscript{a}\textsuperscript{*} and Keisuke Okuno\textsuperscript{b}
\textsuperscript{a}Shinichiro Ito, 1-24-2 Nishi-sinnjuku, Shinjuku-ku, Tokyo, 163-8677, Japan
\textsuperscript{b}Keisuke Okuno, Waseda University, 2-579-15 Mikashima, Tokorozawa, Saitama 169-8050, Japan
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Abstract

It is an advantage to film a swimmer’s whole body in order to grasp the swimmer’s technique. However, it is difficult to understand details, such as twisting arms or stroke paths. Equipment was constructed which provides a continuous image of swimming motions by blending underwater and overwater images with a video mixer. Underwater and overwater images were taken by cameras loaded onto a cart placed on a poolside rail track. The view from above the swimmer was observed by an overhanging camera to observe wave resistance. In order to grasp detailed swimming motions, logger data were synchronized with the actual motion images. Wavelet transform, a chronological frequency analysis, was also performed on these logger data and the dominant frequency was viewed chronologically with different swimming styles.

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1. Introduction

Swimming is the successive motion of propulsive and recovery movements in the water. Analysis of the swimming motion can be provided to swimmers and coaches for improvement of performance. It is important to understand the underwater motion in order to improve swimming technique. Tracking underwater cameras are often used in competition but are not generally used in training because of their installation and cost. Morouço \textit{et al}. [1] and Soons \textit{et al}. [2] were able to produce a continuous image of the swimming movements by blending underwater and overwater images with a video mixer. One of the author, Ito [3], have also developed a same kind of devices and can capture the swimmer’s whole body motion including recovery overwater both for training and research. Both underwater and overwater images were recorded by the cameras loaded onto a cart placed on a poolside rail track. The view from above the swimmer including the waves generated around the swimmer could not be seen in this

* Corresponding author. Tel.: +81-90-8461-0487; fax: +81-3-3340-0108.
E-mail address: ito@cc.kogakuin.ac.jp
recording. In order to compensate for this deficit, a view from above the swimmer was recorded, to consider wave resistance.

It is still difficult to observe detailed movement, such as twisting arms underwater. In order to observe these detailed motions of the forearm in swimming, Ohgi [4] captured 3D accelerations and 3D angular velocities by a data logger and analyzed change in movement caused by fatigue. However, no actual motion images were used in analyzing their data.

In this study, a whole body swimming image including a view from above, was taken and also synchronizing the three-dimensional acceleration and the angular velocity data on the forearm and analyzed them to understand subtle differences in S-shaped and I-shaped movements in free style. A chronological dominant frequency was obtained by using wavelet transform in these obtained data.

2. Method

The experiments were performed in the 50m × 25m indoor swimming pool, Aqua Arena, at Waseda University. The subject of the experiments was an elite swimmer of breast stroke who had won a gold medal in 4 × 100m medley relay in Universiade Belgrade 2009.

2.1. Observation device

Figure 1 shows the outline of the form observation device in this study. It consists of an underwater cameras and an overwater one in a frame installed on a cart placed on metal pipe railing with 38mm in diameter. A crane tripod and a camera over the swimmer were installed on the same cart to capture the overhead images. The respective images of the underwater and the overwater were synthesized as a whole body image by a video mixer. The images taken over the swimmer were inserted into the video mixer image using a function of 4 image dividers. All of these images were captured by 29.97Hz with normal video cameras. The cart can run with the swimmer at 2m/s.

2.2. Data logger

Figure 2 indicates a data logger of motion sensors which has 3 components of accelerometers, 3 components of gyroscope, a depth sensor and propeller system speedometer built-in (PD3G3Gy made by Little Leonard company). It is composed of a CPU, 256MB memory, 8 components of A/D converters in a cylindrical shape, has cylindrical shape of 23mm in diameter and 235mm in length. The data logger can measure 8 hours continuously in 128Hz. The data logger was set on the backside of the left forearm on a three-dimensional coordinate axis as shown in Fig. 3.

2.3. Data Analysis

Each data were sampled in 128Hz. A part of the data corresponding to swimming motion for the three-dimensional acceleration and the angular velocity data taken from the data logger were extracted with Igor ProVer.6
of the Wavemetric Co. Ltd. These wave data were synchronized with the swimming motion images by Pixel Runner of Tellus Image Co. Ltd. by matching the motion image with the time at the arm’s entering the water and the peak point of the data waves.

Regarding the logger signal processing, the wavelet transform was performed by using free macro software of Ethographer (Sakamoto KQ [5]) on Igor Pro. The wavelet transformation is one of the techniques of the chronological frequency analysis. The Morlet function of 15 cycles shown in Fig. 4 was employed as mother wavelet in this study. A key advantage over Fourier transforms is temporal resolution. On the other hand wavelet transforms capture both frequency and location information.

3. Results and Discussion

Figure 5(a) shows the composite picture of the swimming motion of underwater and overwater obtained by the observation device. This image is captured by the underwater and overwater cameras loaded on a cart moving with the swimmer. Top view through the overhung camera is shown in Fig. 5 (b). Generated wave around a swimmer is observed clearly.

The composed image was viewed as if the swimmer in a water tank had been observed through plexiglas wall. Figure 6 shows the composite underwater and overwater image of the swimming motion obtained by the observation equipment. The picture shows as if the swimmer had been observed in a water tank through a window. Figure 6 also
shows the three-dimensional accelerations and the angular velocity obtained by the data logger attached on the forearm synchronized with the motion image. In the case of the breaststroke shown in Fig. 6, a sequence of opening and closing motion of the arm appeared in Arm Slide in Fig. 6-1. Concerning the acceleration information of Arm Extension in Fig.6-2, two peaks were seen in one stroke, although the motion of the arm itself was carried out smoothly. Since the accelerometer has also gathered gravitational acceleration, the negative peak was obtained when the arm was moving downward. The effect of gravitational acceleration was seen as well in the acceleration of Arm Pull in Fig.6-3. On the other hand, three component angular velocity of Arm Pitch, Arm Roll, and Arm Yaw was carrying out the complicated revolution shown in Fig.6-5,6,7 respectively.

![Chronological 3D acceleration, 3D gyro and depth data of arm stroke synchronized with whole body image of under and over water](image)

![Gyro sensor data of x-direction, wavelet transform for the same wave and transition of depth acquired with the sensor attached on the forearm in the freestyle stroke.](image)
In order to understand these data better, synchronizing this motion image and the data waves was a very effective mean to grasp the differences in details of an individual swimmer’s strokes even in the same swimming style.

The graph at the top of Fig. 7 shows the transition of flexion/extension motion of the forearm described with angular velocity. The graph in the middle indicates the wavelet transform for the same data and the graph at the bottom shows the transition of depth. Each of them was acquired with the sensor attached on the forearm in the freestyle stroke. Compared the graphs at the top and the bottom, the angular velocity in the stroke phase is almost constant, while that in the recovery phase decreased rapidly. The Fourier transform converts a spectrum space of a certain period into a frequency space. On the other hand, The wavelet transform is the time series data of the momentary frequency conversion in the same time space. In other words, the Fourier transform is less useful in analyzing non-stationary data, where there is no repetition within the region sampled. The wavelet transform allows the components of a non-stationary signal to be analyzed better. In the middle of Fig. 7, the thick striped pattern appears in the dominant cycle for about 2 seconds of the respective movements. The output of wavelet transform can be sliced in x and y direction. Figure 8(a) and 8(b) are the sections of Fig. 4 at Time A and B respectively. These sliced sections show momentary cycle (=1/frequency) analyses. In these figures, the primary peak indicates the stroke cycle. The secondary peak appears in the cycle of S-shaped stroke. Figure 9 shows cycle sliced section data of wavelet transform output at Slice Section C in Fig. 7 in Cycle 2.2 sec. This is a stroke cycle of freestyle in this case. The bottom peak shows the turn phase.

Thus, the wavelet transform converts motion waves to pattern designs. Three acceleration waves and three angular velocity waves acquired with a motion logger indicate six motion patterns. Four swimming events, such as freestyle, breaststroke, backstroke and butterfly stroke, consist of 24 pattern pictures. The difference of picture
patterns should lead to another motion analysis with wavelet transform. Figure 9 shows the transition of flexion/extension motion of the forearm described with angular velocity, the wavelet transform for the same data and the transition of depth in the butterfly stroke. Two stripe patterns appear in the wavelet transform picture. Each stripe shows the basic stroke cycle and the cycle of a keyhole shaped stroke in the butterfly stroke.

4. Conclusion

The motion filming equipment was developed to show the whole body, a synthesized swimming image of the underwater and overwater motion. Furthermore, this synthesized swimming image was synchronized with the data obtained with the data logger which samples the 3D acceleration and 3D angular velocity of the forearm movement. The wavelet transform was performed on the motion data and the various motions were visualised as a new motion analysis method. As the implication of the wavelet transform, it should becomes possible to express the difference in the strokes even in the same event or to express a collapse of the form by fatigue by showing the motion as picture patterns.

References