Analysis of stroke technique using acceleration sensor IC in freestyle swimming

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ABSTRACT : We had measured tri-axes wrist accelerations in freestyle swimming on Japanese top level college swimmers using a micro accelerometer. For our experiment, we had developed a new device with a built in two ADXL250's, which is the bi-axes acceleration sensor IC. Simultaneously, we had taken underwater stroke motion by two VTR cameras. From these cinematographical data, the hand path during underwater stroke were calculated by DLT method. The acquired acceleration data were examined with the hand paths of the stroke. Results of experiment show that the underwater stroke phase which was defined by Maglischo, such as entry, stretch, downsweep, insweep and upsweep is discriminated by the swimmer's wrist acceleration.

INTRODUCTION

Now, a real time motion analysis is available to analyze human movement on land using infrared light or magnetic sensors. But in underwater environment, these sensor devices do not work. Therefore, we must digitize object's coordinates manually still. Liu, et. al. analyzed swimmer's hand path of freestyle by DLT method[2]. Cappaert, et. al. analyzed three dimensional swimmer's hand path on freestyle at Olympic game[1]. They quantified the hydrokinetic force which was exerted to the swimmer's hand. The digitizing routine takes much time. Moreover, it is impossible to recognize all of under-water stroke motions, because of air bubbles. New innovation will be expected to analyze swimmer's stroke technique.

In this study, we propose new methodology to analyze and evaluate swimmer's stroke technique using micro accelerometer. We had developed a waterproofed device with a built in two monolithic acceleration sensor IC's. We had measured the wrist acceleration in freestyle swimming using this device. Then we had made inquiries about the acceleration and hand movement which was represented as a hand path in underwater.

METHOD

ACCELERATION SENSOR IC

The acceleration sensor IC was ADXL250(Analog Devices, Inc.). The ADXL250 is monolithic bi-axes acceleration sensor IC(W9.0, D10.0, H5.4mm). The maximum capacity of each axis acceleration is ±50[G]. We arranged two ADXL250's on the basal plate. One of those IC was mounted on the basal plate horizontally. Another one was attached to the edge of the basal plate perpendicularly. Thus, we could measure three different axes' accelerations. These two ADXL250's and operational amplifier IC chip were sealed up in the wrist watch case and waterproofed. This device was attached tightly to the right wrist of the swimmer.

The direction of each axis is illustrated in Fig.2. Here, X-axis represents the direction from right hand little finger to thumb, defined as ulnar-radial direction. Y-axis represents the direction from the wrist to elbow joint, distal-proximal direction. Z-axis represents the direction from palm to the back of hand, planar-dosal direction. In Fig. 2, each arrow shows the positive sign of it's acceleration signal when the hand moves to each direction from horizontal rest position.

UNDERWATER CINEMATOGRAPHY

Two video cameras were equipped to take the underwater stroke motion. One of those was set over underwater window and took the side view of the swimmer. The another one was set on the bottom of the pool and took the bottom view. The video outputs were recorded by Hi8 video recorder. A video frame counter overlaps sequential time code to every video frame and outputs TTL pulse simultaneously. This TTL pulse was used as the synchronized signal of A/D conversion.

One male and one female swimmers were involved to this experiment. Both swimmers had high skill level enough to be a finalist of the national college championships. In this study, the stroke style was freestyle swimming only. Subjects swam at their maximum speed. We defined these swimming speed as fast speed.

RESULTS

WRIST ACCELERATION

We had analyzed the acceleration data during one cycle whose underwater stroke was completely taken by video. Only right hand acceleration and hand path were involved in this analysis. The examples of results are shown in Fig. 3 and Fig. 4. Fig. 3 shows results of sub.M., who is a freestyle male swimmer at national top level. Fig. 4 shows

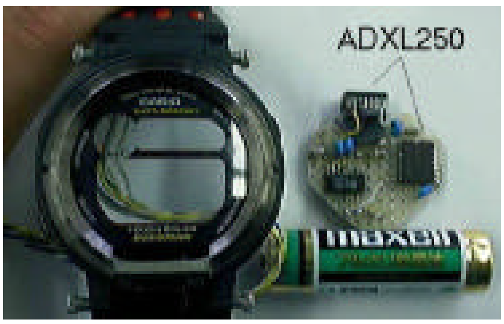

Fig. 1 A photograph of accelerometry device with a built in two ADXL250 acceleration sensor IC chips.

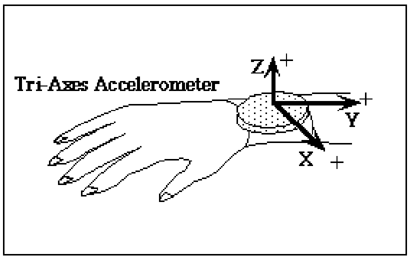

Fig. 2 Axes configuration of the measurement device. Each arrow indicates the acceleration sign when the accelerometer moves it's direction from the horizontal rest position.

results of sub.H. who is a gold medalist of women's individual medley at national college championships. Horizontal axis represents time in second. The origin of the time means the right hand entry moment.

THREE DIMENSIONAL VIDEO ANALYSIS

DLT analysis method was applied in this study. The accuracy, defined as the mean squared errors, was 12mm. We had marked subjects' right middle finger. Hand path which was represented by middle finger coordinate were analyzed. Because of the air bubbles, the marker was sometimes invisible, especially after entry. After DLT calculation, we had eliminated these unreliable coordinates from original data. After elimination, we had approximated the rest of coordinates to a six ordered polynomial function. Then we had reconstructed the all coordinates by this polynomial function. Fig. 5 and Fig. 6 show the reconstructed hand path at each swimmer's fast speed. These figures show three dimensional representation and it's projection view to the XY, YZ, XZ plain. The each dot represents the coordinate of the right middle finger at every frame about absolute coordinate system. The origin of these figures are the right hand entry location.

DISCUSSION

MAGLISCHO'S STROKE PATTERN DEFINITION

Here, we will examine our experimental results, according to the Maglischo's stroke phase definition[3]. First, a swimmer enters his hand into the water and stretches his arm forward. He had defined these motion as entry and stretch. Then swimmer moves his hand downward. He defined this motion as downsweep. The extension of shoulder joint and the slight flexion of elbow joint of the swimmer cause this curvilinear downsweep motion. When the elbow rise up above the hand is defined as catch. Right after the catch, swimmer extends shoulder and flexes elbow joint with body roll. The swimmer's hand moves to midline of his body. This motion is defined as insweep. During the insweep, the palm gradually rotates from out and back to in and up. After the insweep, the further extension of the shoulder joint and elbow extension cause upward hand motion. He defined this motion as upsweep. During the upsweep, swimmer must change his hand pitch angle properly in order to produce sufficient propulsive force. During the upsweep, swimmer extends his elbow joint. Finally, the swimmer's

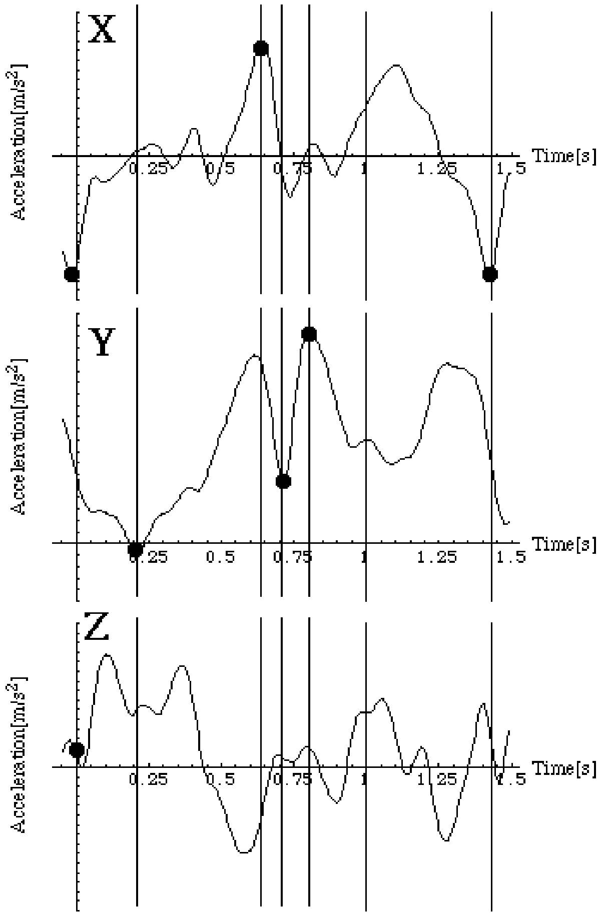

Fig. 3 An example of the wrist acceleration during one stoke duration in freestyle swimming on sub.M..

hand releases from the water. He defined it as release. In this study, we will discuss the relationships between the wrist acceleration data and hand movement under the Maglischo's stroke pattern definition.

RELATIONSHIPS BETWEEN ACCELERATION AND HAND MOVEMENT

X-axis Acceleration

Fig. 3 and Fig. 4 show that the X-axis acceleration has global minimum at 0sec instant. This minimum peak is most likely caused by the impact force of the right hand entry. It repeats cyclically. Therefore we can calculate every stroke duration exactly by the minimum peak timing of the X-axis acceleration.

Both subjects share certain similarities in that there are X-axis minimum peak at 0sec. On the other hand, about Z-axis acceleration, sub.M. has small positive value nearly $0ms^{-2}$. But sub.H. has large positive value about $25ms^{-2}$. Actually, sub.H. enters

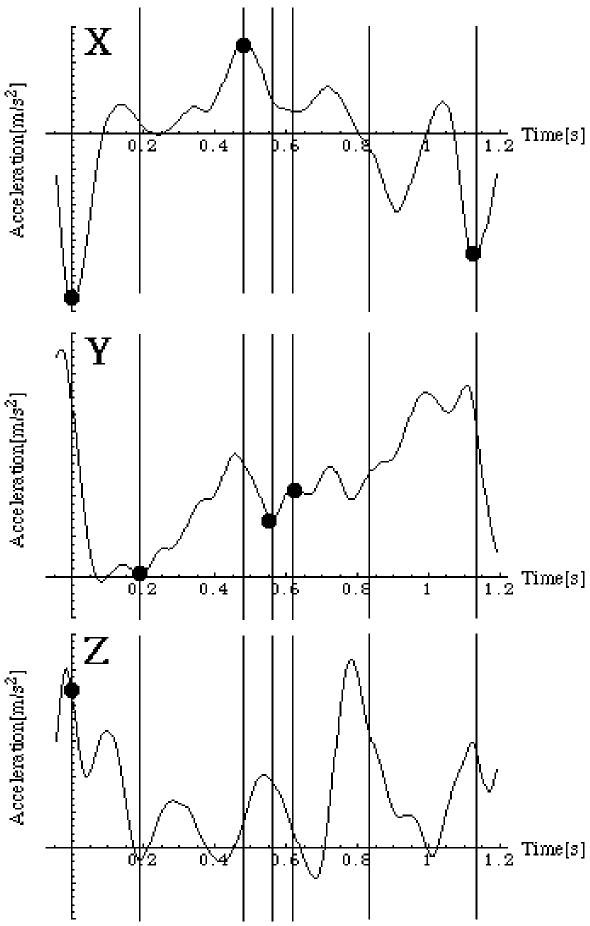

Fig. 4 An example of the wrist acceleration during one stoke duration in freestyle swimming on sub.H..

with her palm horizontally. Maglischo said that a swimmer's palm should be pitched out as it enters. This pitched palm motion would lead to efficient propulsive force production. The angle of attack is influenced to the Z-axis(planar-dosal) acceleration’s sign and value. The Z-axis is perpendicular to the palm plain. Therefore, smaller the angle of attack, larger the Z-axis acceleration absolute value. If the angle of attack was 90 degree, that is, palm would entry into the water from the thumb, Z-axis acceleration would be nearly 0ms^{-2} theoretically. Fig. 7 explains the relationships between the angle of attack of the palm and X and Z axis accelerations.

A maximum peak of X-axis acceleration appears at C in Fig. 3 and Fig. 4. This maximum peak appears before middle of the duration. This timing corresponds to symbol C in Fig. 5 and Fig. 6. Maglischo stated that the catch should be made at the last phase of the downsweep with flexed elbow configuration. After catch moment, the insweep motion is made by shoulder rotation and elbow flexion. The palm should pitch in and back and sweep from outside to the midline of the swimmer's body. From Fig. 5, at the timing C, the hand of sub.M. was at the most farthest location from his body.

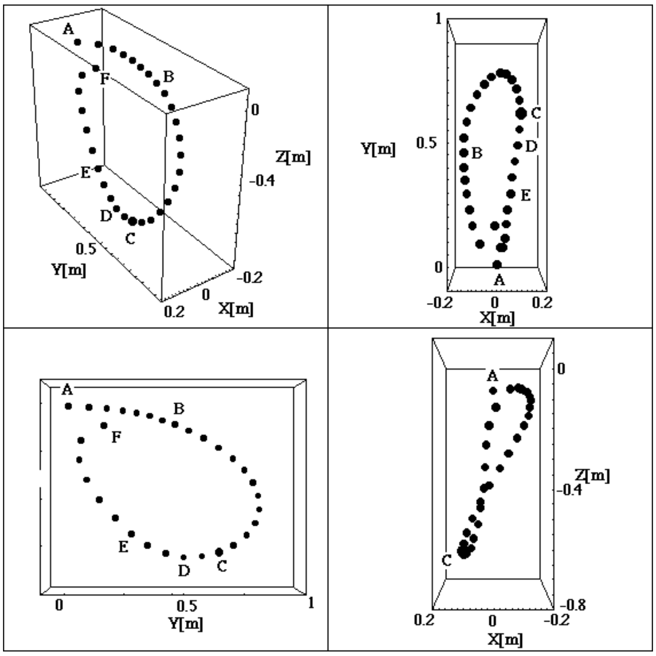

Fig. 5 The result of DLT analysis about sub.M..

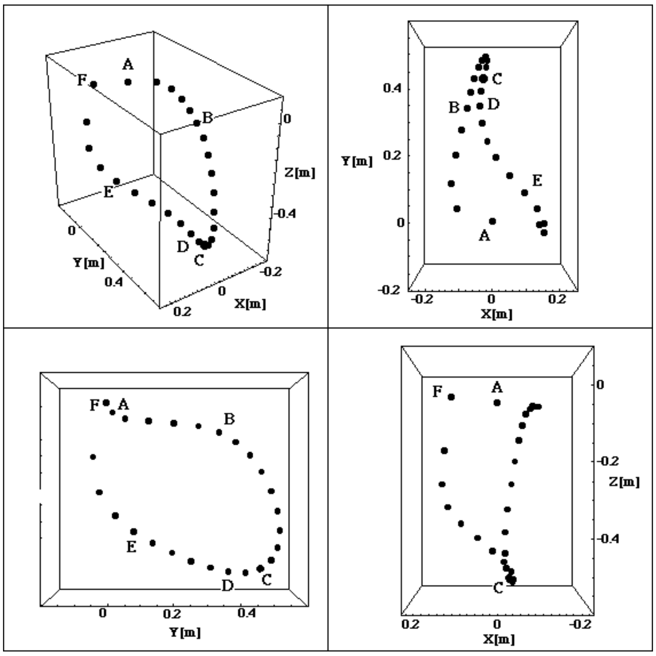

Fig. 6 The result of DLT analysis about sub. H.. Three dimensional illustration of the underwater hand path and it's projection to the XY, YZ and XZ plain. Each dot indicates the coordinate of the hand at every 1/30 second.

Therefore, we can conclude that the beginning of insweep motion caused the maximum peak of X-axis acceleration about sub.M.. On the other hand, about sub.H., it does not correspond to the most farthest X coordinate of the hand. But it has the similarities that the location of the hand in YZ-plain. Swimmer's motion which cause the X-axis maximum peak may be as Fig. 8. This is probably the beginning of the insweep motion (Fig. 8).

Y-axis Acceleration

During recovery, the hand rotates about the shoulder joint. We see from Fig. 3 and Fig. 4 that the Y-axis acceleration keep large positive value during recovery. It is most likely influenced by the centrifugal acceleration. After entry, the swimmer stretches his arm forward, then the Y-axis acceleration decreases gradually to almost $0ms^{-2}$. When the Y-axis acceleration intersected $0ms^{-2}$, the hand was at location B in Fig. 5 and Fig. 6. The phase between location A and B almost corresponds with the Maglischo's stretch phase. Therefore, stretch motion most likely cause the decrease of the Y-axis acceleration. Thus, we can see stretch duration by the minimum peak of the X-axis acceleration and the zero intersection time of the Y-axis acceleration.

After the maximum peak of X-axis acceleration, Y-axis acceleration decreases rapidly and make it's local minimum at location D. The location D is the most deepest coordinate of the hand in underwater stroke. After the hand reached there, upsweep motion starts. The local minimum of the Y-axis after the global maximum of X-axis acceleration indicates the beginning of the upsweep. Therefore, we can get stroke phase information such as stretch phase and the beginning of the upsweep by Y-axis acceleration.

Z -axis Acceleration

We already mentioned that Z-axis acceleration's sign and value at entry moment are useful information. Little is known about the actual propulsive force production mechanism on whole segment of upper extremities through experimental study and hydrodynamics simulation study. However, it is clear that the swimmer must change the angle of attack of his palm to velocity vector of the palm during underwater stroke.

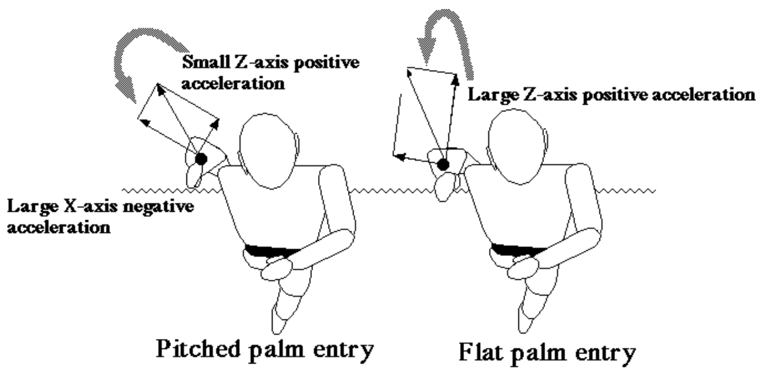

Fig. 7 An explanation of the relationship between X and Z-axis accelerations and the alignment of the palm at the entry. The angle of attack between the palm and the water surface on pitched palm entry is larger than that of flat palm entry.

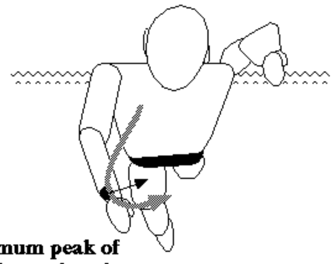

Fig. 8 An explanation of the maximum peak of the X-axis acceleration during underwater stroke. The maximum value of X-axis acceleration indicates the beginning of the insweep motion.

Therefore, it is reasonable to suppose that Z-axis acceleration should change it's sign and value one after another. Our experimental results suggests this hypothesis.

CONCLUSION

The results of our experiment shows that the wrist acceleration on freestyle swimming can discriminate stroke phase which is defined by Maglischo. Those are as follows;

1) X-axis acceleration global minimum indicates Entry.
2) Between X-axis acceleration global minimum and Y-axis acceleration zero intersection time indicates Stretch.
3) X-axis acceleration global maximum indicates the beginning of the Insweep.
4) Y-axis acceleration local minimum after insweep indicates the beginning of the Upsweep.
5) Z-axis acceleration's sign and value at entry moment indicates the angle of attack of the palm to the water surface.

The wrist accelerations have some useful information about underwater stroke phase and swimmer's skill level.

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