Measurements of the 3-D kinematical motion in sports

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ABSTRACT: This paper describes the how to quantitatively evaluate sport skill from the data of the sports motions. We focus our discussion on the golf driver swing. The five skill criteria linguistically written in the internationally famous golf lesson text books are quantitatively expressed. The data for the criteria by a novice golf player and a middle class player show the reasonable and appropriate results.

1. INTRODUCTION

The sports of ball hitting such as baseball, golf and tennis are those to fly the ball faraway toward to goal direction by the energy stored around the body axis. The power of the above sports motion depends substantially on the twisting energy. The importance of some rotation motion in the golf swing is described in some internationally famous text books written by Jack Nicolas¹ and Ben Hogan². However the rotation motions measurement is difficult. Several researches have reported in this field³–⁷, but did not alleviate the difficulties.

This paper describes a new 3-D rotation measurement method of sport forms in conjunction with the skills.

2. PROBLEM DESCRIPTION

2.1 GOLF DRIVER SWING

A golf driver swing can be classified into several actions from address to finish. The textbooks by Jack Nicolas and Ben Hogan describes the criteria of the ideal motion as follows;

[Rotary motion]
(R1) Angle of the body axis must be maxim at the top of swing. Maximize the twist angle.
(R2) At the top of swing, the shoulder angle must be 90° and the waist angle must be 45° from the angles at the address.
(R3) From the down swing to impact, the rotation is decelerated from waist to shoulder sequentially.

[Translation motion]
(R4) The curvature drawn by the shoulder point and the club head in swing must be in a linear plane.
(R5) The translation motion of the waist, shoulder and head must be minimal in the sequential motions from address to impact.

2.2 ASSUMPTIONS AND PROBLEMS

Assume;
(A1) Criteria (R1) to (R5) are correct.
(A2) Human body for golf swing can be given by a rods-and-link model.

Under the assumptions above, we consider the following problems;
(P1) What are the motions necessary to evaluate the skill in the driver swing?
(P2) How to measure the motion by simple and easy manner?
(P3) How to build the measurement system?
(P4) How valid the measurement system is?

3. THREE-DIMENSIONAL MEASUREMENT

3.1 NECESSARY PHYSICAL VALUES

Here, we can consider Problem (P1).

![Fig.1 Global and local coordinate and kinematic model](image)

Under assumption (A1), what are the motions necessary to evaluate the skill is the problem. From criterion (R1), twist angle of the body axis, from criterion (R2), the rotary angle of shoulder and waist themselves, from criterion (R3), the angular velocity of shoulder and the waist, from the criterion (R4), the up and down translation motion of shoulders and from the criterion (R5), 3-D translation motions of the waist, shoulder and the head are the physical values necessary.
Fig.1(a) shows the local coordinate at the head. The angular velocities and angles in the local coordinate and the positions in the absolute coordinate are defined as follows. The suffix $i$ corresponds; 1 to waist, 2 to shoulder and 3 to head. The suffix $u$ and $U$ corresponds to $x$, $y$, $z$ and $X$, $Y$, $Z$.

**[Local coordinate system]**
\[
\omega_u(i) : \text{angular velocity around u-axis of part } i \\
\theta_u(i) : \text{angle around u-axis of part } i
\]

**[Global coordinate system]**
\[
U_i(i) : \text{position of the U coordinate}
\]

Fig.1(b) shows the model coordinate. The origin O is the intersection point of plumb line from point F at the attitude of the address and horizontal line. From Assumption (A2), the lengths between O and F, between F and W, between W and S and between S and H are all constant. The initial coordinate of each part is calculated by the angle between rigid rods at the address attitude and the length of the rods. Define:

**[Angles and length]**
\[
\begin{align*}
\text{OF} : l_o, & \quad \text{FW} : l_1, \quad \text{WS} : l_2, \quad \text{FH} : l_3 \\
\theta_w : \text{waist angle}, & \quad \theta_s : \text{shoulder angle}, \quad \theta_h : \text{head angle}
\end{align*}
\]

### 3.2 MEASUREMENT METHOD

Here we can consider problem (P2).

The system measures the 3-D angular velocities \([\omega_1(t), \omega_2(t), \omega_3(t)]\), $i=1,2,3$ around each axis of the local coordinate system by rate gyros. From the gyro data the angular velocity at each part is obtained as follows:

**Waist:**
\[
[\omega_{w1}, \omega_{w2}, \omega_{w3}] = [\omega_{w1}, \omega_{w2}, \omega_{w3}]
\]

**Shoulder:**
\[
[\omega_{s1}, \omega_{s2}, \omega_{s3}] = [\omega_{s1} - \omega_{w1}, \omega_{s2} - \omega_{w2}, \omega_{s3} - \omega_{w3}]
\]

**Head:**
\[
[\omega_{h1}, \omega_{h2}, \omega_{h3}] = [\omega_{h1} - \omega_{s1}, \omega_{h2} - \omega_{s2}, \omega_{h3} - \omega_{s3}]
\]

Integrating of the angular velocities above from the initial link angle in the attitude of the address yields the angle of rods around the axis of the local coordinate.

\[
[\theta_w(t), \theta_s(t), \theta_h(t)] = \int [\omega_{w1}(t), \omega_{s1}(t), \omega_{h1}(t)] dt
\]

Define the coordinate of the rod head position as \([X(t), Y(t), Z(t)]\), its initial coordinate as \([X_0, Y_0, Z_0]\) and the angles of the rod from the axis x-y-x in local coordinate as \(\theta_w(t), \theta_s(t), \theta_h(t)\). Then these are related by the Euler transformation leads to the following relations:

\[
\begin{align*}
X(t) &= \cos \theta_w(t) - \sin \theta_w(t) \\
Y(t) &= \sin \theta_w(t) \cos \theta_s(t) \\
Z(t) &= 0
\end{align*}
\]

The initial coordinates are obtained as follows:

**Waist**
\[
(x_w, y_w, z_w) = (0, l \cos \theta_w, l \sin \theta_w)
\]

**Shoulder**
\[
(x_s, y_s, z_s) = (0, l \cos \theta_s, l \sin \theta_s)
\]

**Head**
\[
(x_h, y_h, z_h) = (0, l \cos \theta_h, l \sin \theta_h)
\]

**Supporting point**
\[
(x_{sp}, y_{sp}, z_{sp}) = (0, l, 0)
\]

Substitution of the angles obtained by eq.(2) and the initial values in eq.(4) into eq.(3) yields the coordinates of waist \([x_1(t), y_1(t), z_1(t)]\), shoulder \([x_2(t), y_2(t), z_2(t)]\) and head \([x_3(t), y_3(t), z_3(t)]\) respectively. Synthesis of these coordinates is the global coordinate at the address gives the coordinates of these as follows:

\[
\begin{align*}
[x_1(t), y_1(t), z_1(t)] &= [x_1(t) + x_1(t), \\
y_1(t) + y_1(t), \\
z_1(t) + z_1(t)]
\end{align*}
\]

\[
\begin{align*}
[x_2(t), y_2(t), z_2(t)] &= [x_2(t) + x_2(t) + x_2(t), \\
y_2(t) + y_2(t) + y_2(t), \\
z_2(t) + z_2(t) + z_2(t)]
\end{align*}
\]

\[
\begin{align*}
[x_3(t), y_3(t), z_3(t)] &= [x_3(t) + x_3(t) + x_3(t), \\
y_3(t) + y_3(t) + y_3(t), \\
z_3(t) + z_3(t) + z_3(t)]
\end{align*}
\]

### 3.3 MEASUREMENT SYSTEM

Problem (P3) is solved here.

Fig.2 shows the measurement system: Fig.2(a) shows the sensor by three gyro set on the axes of the coordinate; and Fig.2(b) shows how the sensor are set on the waist, shoulder and head. The gyro sensors were produced by Murata Corporation Ltd with the production number of ENC-03J. A sensor measures 22mm 9mm 8mm and weighs 207g. The sensors were set by a holder that subjects can easily wear. Fig.3 shows the data processing system.

### 4. EXPERIMENT

### 4.1 GOLF DRIVER SWING FORM
We measured the golf driving form by the proposed system. Fig.4(a), (b) and (c) shows the angular velocities, the angles and the displacements in the global coordinate system at the waist, shoulder and head in the local coordinate system, respectively. Fig.4(d) shows the loci of the sequential motions from address to finish. The circle in Fig.4(d) shows position at the impact timing.

Fig.4(a), (b) and (c) shows the angular velocities, the angles and the displacements in the local coordinate system, respectively. Fig.4(d) shows the loci of the sequential motions from address to finish. The circle in Fig.4(d) shows position at the impact timing.

4.2 QUANTITATIVE EVALUATION OF GOLF DRIVER SWING FORM

Problem (P4) is solved here.

Under the criteria in Assumption (A1), we quantitatively evaluate the skill of the form from the measurement results in Fig.4. The evaluation results by the novice golfer who has practiced golf only a few times and the experienced golfer whose results is shown in Fig.4 is shown in Table1.

Table1 The attributes of examinees
(a) The maximum angle [deg]

<table>
<thead>
<tr>
<th>Body parts</th>
<th>Head</th>
<th>Shoulder</th>
<th>Waist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axis y axis</td>
<td>Middle</td>
<td>20</td>
<td>80</td>
</tr>
<tr>
<td>Novice</td>
<td>30</td>
<td>92</td>
<td>75</td>
</tr>
</tbody>
</table>

(b) The angular velocity at impact timing [deg/s]

<table>
<thead>
<tr>
<th>Body parts</th>
<th>Head</th>
<th>Shoulder</th>
<th>Waist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axis y axis</td>
<td>Middle</td>
<td>110</td>
<td>131</td>
</tr>
<tr>
<td>Novice</td>
<td>121</td>
<td>389</td>
<td>210</td>
</tr>
</tbody>
</table>

(c) The maximum displacement [m]

<table>
<thead>
<tr>
<th>Body parts</th>
<th>Head</th>
<th>Shoulder</th>
<th>Waist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axis x</td>
<td>Middle</td>
<td>-0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Novice</td>
<td>-0.09</td>
<td>0.27</td>
<td>-0.05</td>
</tr>
<tr>
<td>Axis y</td>
<td>Middle</td>
<td>-0.14</td>
<td>0.03</td>
</tr>
<tr>
<td>Novice</td>
<td>-0.27</td>
<td>0.18</td>
<td>-0.05</td>
</tr>
<tr>
<td>Axis z</td>
<td>Middle</td>
<td>-0.07</td>
<td>0.01</td>
</tr>
<tr>
<td>Novice</td>
<td>-0.07</td>
<td>0.02</td>
<td>-0.05</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

This paper described simple 3-D sport form measurement method and system for the sports accompanying the body twist motions. Following results were obtained:

(1) Under the assumption that the contents of golf lesson textbook are correct, the necessary motions to evaluate the skill are the 3-D rotary and translation motions of the waist, shoulder and head.
(2) The measurement method of 3-D rotary motions of the waist, shoulder and head and calculation method of the translation motion from the measured data by Euler transformation are presented.

(3) The measurement system based on the rate gyro sensors are presented.

(4) Based on the data measured by the proposed system, the five criterion linguistically given are reasonably quantified.

**REFERENCES**

1) Ben Hogan (1985) The Modern Fundamentals of Golf SIMON and SCHUSTER INC.


Fig.4 Measurement results of driver swing