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Estimation Algorithm for Angle and Velocity of Grip end in Golf Swing by using an Acceleration Sensor and Gyro Sensor

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Abstract

This paper describes a novel method for analyzing the angular motion and speed of a golf swing in a global coordinate system measured by a 3D acceleration sensor and a 3D gyro sensor at the grip end of a golf club. The conventional method for measuring motion in sports is optical Direct Linear Transformation (DLT). However, this method requires infrared high-speed cameras to be set in the test field and infrared reflectors to be attached to the moving object. Furthermore, the system and its fine-tuning are expensive. In this paper, we propose an alternative method that is more easily set and fine-tuned, and is also cheaper than the DLT method. The results of the proposed method are more accurate than those of the DLT method.

Keywords: Golf motion measurement, direct linear transformation (DLT), acceleration sensor, gyro sensor;

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1. Introduction

Current studies on the golf swing include kinematic and dynamic measurement and analysis of human movement using a link structure [1][2], grip-force measurement using pressure-sensitive conductive rubber [3][4], and measurement and simulation of golf ball rotation and flight direction [5][6]. However, in the limited studies on the measurement of golf club loci, Direct Linear Transformation (DLT) is the main method applied. The DLT method measures the light from infrared reflecting markers set at several points on the golf club using multiple high-speed infrared cameras set at precise points in the test field, and locates the positions by mathematical linear transformation. However, high-speed infrared cameras are expensive and require careful calibration, which prohibits their use by ordinary players in various fields. In this study, we propose an alternative method that is more easily set up and fine-tuned, and is also less expensive than the DLT method. The proposed method, which uses wireless transmitters that enable noninvasive measurement, measures the overall angular velocity and angle of motion from address to impact using a motion sensor set at the grip end of the golf club.

2. Proposed Method

In this study, we consider the golf swing in both local and global coordinate systems. Figure 1 shows the global and local coordinates of the address position in the golf swing. We let the origin of the global coordinates be the position of the grip end when in the address position. The global coordinates would be fixed at the same position regardless of the golf swing motion. The angle seen from the front view is □(t), from the side view □(t), and from the top view □(t). The origin of the local coordinates is the position of the grip end. The local coordinates move along with the golf swing motion.

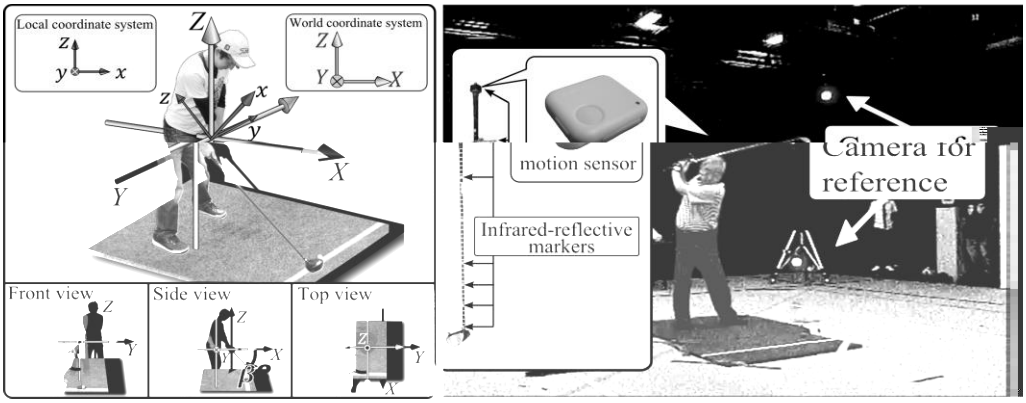

Fig. 1. (a) Definition of global and local coordinate systems; (b) Experimental setup

To calculate the angle and velocity, we obtain the posture matrix *N(t)* as follows:

$$N(t) = \begin{bmatrix} X_x & Y_x & Z_x \\ X_y & Y_y & Z_y \\ X_z & Y_z & Z_z \end{bmatrix} \tag{1}$$

This posture matrix *N(t)* is obtained by using the Euler rotation matrix *T(t)*:

$$N(t+\Delta t) = N(t)\cdot T(t) \tag{2}$$

Equation (2) is a difference equation for $N(t)$ and shows updates of the posture matrix for each sampling. Next, we determine the initial posture matrix $N(0)$. At $t = 0$ during the address motion, the acceleration includes only the gravity component. Thus, $\sqrt{a_x^2 + a_y^2 + a_z^2}$ = 9.8 m/s^2 and the address angles from the gravity direction are calculated as follows:

$$\theta_x^{add} = \cos^{-1}(a_x(0)/9.8), \theta_y^{add} = \cos^{-1}(a_y(0)/9.8), \theta_z^{add} = \cos^{-1}(a_z(0)/9.8) \tag{3}$$

The vertical elements [$Zx(0)$ $Zy(0)$ $Zz(0)$] in $N(0)$ can be directly calculated from the address angle in Eq. (4) as follows:

$$Z_x(0) = \cos\theta_x^{add},\ Z_y(0) = \cos\theta_y^{add},\ Z_z(0) = \cos\theta_z^{add} \tag{4}$$

The unknown element in $N(0)$ is defined as follows: when $\theta = \theta_x^{add}$, $\phi = \theta_x^{add}/\theta$, ψ = 9.8/sin□□is defined, then using the Euler transform relationship, we have

$$Y_x(0) = -\sin\varphi\cdot\cos\psi - \cos\varphi\cdot\cos\theta\cdot\sin\psi,\ Y_z(0) = -\sin\theta\cdot\sin\psi \tag{5}$$

Also, using the exterior product relationship, we have

$$X_y(0) = Y_y(0)Z_x(0)\ Z_z(0)Y_x(0),\ Y_y(0) = Z_z(0)X_x(0)\ X_x(0)Z_z(0) \tag{6}$$

Finally, using the identity matrix relationship, we have

$$X_x(0) = \sqrt{1 - Y_x(0)^2 - Z_x(0)^2}\ ,\ X_z(0) = \sqrt{1 - Y_y(0)^2 - Z_y(0)^2} \tag{7}$$

From the posture matrix $N(t)$, we can obtain the angles in the global coordinate system as follows:

$$\alpha(t) = \arctan(Y_y(t)/ Z_z(t)),\ \ \beta(t) = \arctan(X_x(t)/ Z_z(t)),\ \ \gamma(t) = \arctan(X_z(t)/Y_y(t)) \tag{8}$$

Lastly, we obtain the velocity. The acceleration obtained in the golf swing includes the gravity element, so we remove this. The posture matrix is changed from local coordinates to global coordinates. To obtain the local coordinate system, we calculate the posture matrix's transposed matrix. This transposed matrix is multiplied by the gravity, and we obtain the gravity of the local coordinate system. When the gravity is g, the gravity of the local coordinate system G is as follows:

$$G(t) = N^T(t)\cdot[0\ 0\ g]^T \tag{9}$$

The gravity is removed from the local acceleration $a(t)$ = [$a_x(t)$ $a_y(t)$ $a_z(t)$], and we obtain the acceleration $a'(t)$, which does not include the gravity.

$$a'(t) = a(t)\ G(t) \qquad (10)$$

Using the posture matrix, the acceleration in the global coordinate system $A(t) = [A_x(t)\ \ A_y(t)\ \ A_z(t)]$ can be obtained as follows:

$$A(t) = N(t) \cdot a'(t) \qquad (11)$$

The velocity in the global coordinate system $V(t) = [V_x(t)\ \ V_y(t)\ \ V_z(t)]$ can be obtained by integrating A(t). However, complete integration amplifies the noise element and low-frequency drift. Here, we reject the noise by offsetting the velocity at the top of the swing to 0 m/s^2. The velocity obtained by complete integration is V'. The time of the top of the swing is T_{top}, and the value of the velocity is Atop. The velocity is obtained as follows:

$$V(t) = V'(t)\ Atop/Ttop \cdot t \qquad (12)$$

In addition, the synthesized velocity $V_{all}(t)$ is obtained as follows:

$$V_{all}(t) = \sqrt{V_x(t)^2 - V_y(t)^2 - V_z(t)^2} \qquad (13)$$

3. Experiment

The angles and velocities in the global coordinate system obtained by the proposed method were compared with those measured by the standard DLT method using fully calibrated cameras. Figure 1 shows the employed golf club, the sensor that measures 3D acceleration and 3D angular velocity and the cameras. The sensor was set at the grip end of the golf club. For the DLT method, eleven infrared reflective markers were set at the positions shown in the figure. The DLT system uses twelve high-speed infrared cameras: eight set in front and four set behind the player. Five subjects (A–E) participated in the experiment. We let the subject swing the golf club after the address position. The sampling interval of the sensor was 3 ms and the measured data was transmitted to a PC via wireless Bluetooth connection.

Figure 2 shows the results for the angle and velocity of Subject A's first swing. The proposed method is indicated by black waves and the reference DLT method is indicated by grey waves. The address time is set to 0 s, the timing of the top of the swing is shown by the vertical dotted line (around 1.5 s), and the impact time is shown by the vertical dotted line to the right. The root mean square error (RMSE) between the angle seen from the front ⍰(t), the side ⍰(t), and the top ⍰ (t) is 3.68°, 7.24°, and 3.71°, respectively. The RMSE of the synthesized velocity, X-axis velocity, Y-axis velocity and Z-axis velocity is 0.16, 0.17, 0.18 and 0.12 m/s, respectively.

4. Result

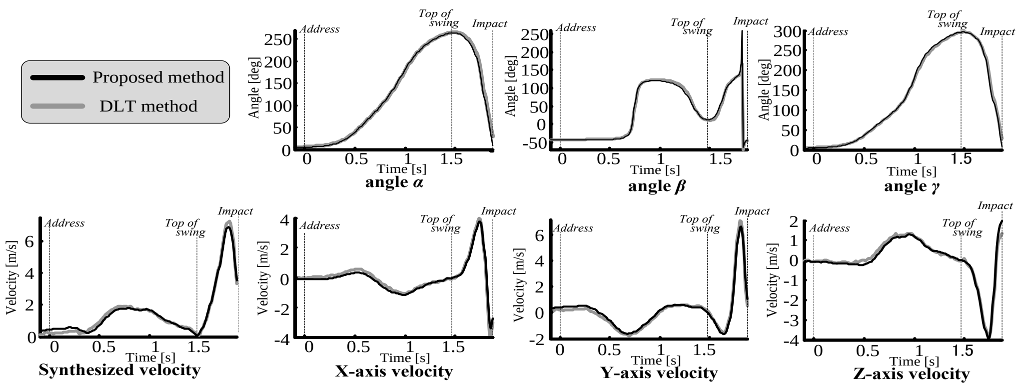

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Fig. 2. Results for the angle and velocity of the golf swing

Table 1. Mean RMSE of 10 trials

Subject	(*t*) [deg]	*β*(*t*) [deg]	*γ*(*t*) [deg]	Mean [deg]	$V_{all}(t)$ [m/s]	$V_x(t)$ [m/s]	$V_y(t)$ [m/s]	$V_z(t)$ [m/s]	Mean [m/s]
A	3.33	5.62	3.64	4.20	0.23	0.28	0.26	0.12	0.22
B	4.91	47.11	9.41	20.47	0.23	0.25	0.24	0.19	0.23
C	6.20	40.26	6.90	17.79	0.26	0.20	0.26	0.19	0.23
D	4.91	10.57	5.19	6.89	0.25	0.18	0.33	0.25	0.25
E	4.77	15.69	4.55	8.34	0.27	0.14	0.25	0.27	0.23
Mean	4.82	23.85	5.94	11.54	0.25	0.21	0.27	0.21	0.23

5. Discussion

In our proposed method, the RMSE results of 4.82° for (t) and 5.94° for (t) show very close agreement. However, the angle in (t) generated a large error due to the use of the trigonometric function. Integral acceleration generated a large error due to the inclusion of considerable noise such as centrifugal force, but our proposed method can reduce this noise and obtain close agreement with the reference method. The impact timing has a large error due to the 4-ms sampling interval of the DLT system resulting in inaccurate measurement of the impact timing.

6. Conclusion

This paper described a method for measuring the angle and velocity of the grip end in the global coordinate system by using an acceleration sensor and a gyro sensor set at the grip end of the golf club. As a reference, the angle and velocity were measured by the DLT method, which uses high-speed infrared cameras and infrared reflective markers. As a result, the RMSE of the angle and velocity is 11.54° and 0.23 m/s, respectively.

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