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Determination of Spatiotemporal Parameters in Straight Drive Cricket Bat Swing using Accelerometer Sensors

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Abstract

The position, velocity and timing of a cricket bat swing measured in practice and during a match can provide a coach with details of batting skill. A straight drive was analyzed using data from two triaxial accelerometers mounted on the rear face of a bat and a video. The spatiotemporal details from the video were used to match the accelerometer data using rigid body dynamics in the plane of the swing. Discriminating the drive from the backlift and the return, the key issues of the swing motion and bat posture was investigated. The start and the end of the drive can be readily determined from the accelerometer data, and from this, the maximum bat swing velocity was determined. The accelerometer technology can be deployed during practice and match batting for skill assessment.

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1. Introduction

Cricket batting, a striking sport, is a typical dynamic interceptive action composed of interactions between perception and execution [1]. A high level of accuracy in spatial and temporal motion of the bat and batter limbs before and at the instant of ball contact is critical [2]. Some researchers [3 - 6] have focused on the coordination and control, skill acquisition, the importance of vision and cue utilization. Few papers on bat swing analysis discuss show swing kinetics influence shot power, shot direction, and the angle of elevation of the bat and what key signatures in

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the bat swing for a particular shot (i.e. Block, Drive, Pull, Cut, Hook etc.) that might be used as an ideal batting template. This work endeavored to fill this gap beginning with the straight drive shot. Two issues addressed in this work were, firstly to judge whether tiny inertial sensors could identify the spatio-temporal parameters (validated by video). Secondly was to check the ability to document a straight drive shot. Because of the complex three-dimensional acceleration profile, a decision matrix was formulated together with the video frames to match the video data and sensor data so that an ideal movement template might be formulated. At the start of an innings and often between strokes, batters commonly practice an ideal bat swing in the air (ball-free) for a particular stroke as imprinted in their sub conscious.

2. Experimental

2.1. Accelerometer procedure

Two PCB inertial sensors [7] were taped to the middle part of the back of the bat blade as shown in [8]. The sensor axes, the bat axes, the drive direction and the plane of swing were the same as that shown in [9]. Thus the +X-axis refers to acceleration along the length of the bat, the +Y-axis is across the face of the bat and the +Z-axis is perpendicular to the face of the bat, that is, in the direction of a typical swing. The sensor axes +a_x and +a_y do not coincide with bat’s +Z- and +Y-axes, rather they tilted by an angle, say δ (similar to θ as shown in [9]). This is because of the angle δ between the hitting surface of the bat face and back of the bat where the sensors was placed. The real bat acceleration along +Z-axis and +Y-axis is related to the sensor recorded acceleration (+a_z and +a_y) by a factor of cosine (δ). For the X-axis accelerations, the real bat acceleration and sensor recorded acceleration (+a_x) is the same.

The sensor data in the form of a_x, a_y and a_z were collected during straight ball-free bat swings in the vertical plane (referred as ZX-plane with respect to bat’s axes in the world reference frame as shown in [9]) by an amateur batter. Ethics approval ENG/16/10/HREC was obtained from Griffith University Ethics Committee.

2.2. Video procedure

The bat motion was simultaneously filmed using a video camera placed 5 m away from the batting arc at a height of 1.4 m from the ground so that the full trajectory of the bat swing was recorded. The camera was operated at frame rate of 100 f/s to minimize blurring. Each frame consists of two interlaced images which were separated by HD converter software to having a frame rate of 200 f/s in the swing. Image pixels were converted into two dimensional distance co-ordinates using software. The top left most corner of the video footage window was taken as reference for measurement. A scale factor was used to convert the coordinates of the two ends of the bat image at its different positions during the swing. This scale factor was calculated from the physical length of bat and the number of pixels forming the image bat in that particular direction. For instance, the total number of pixels forming the image bat length along one dimension (horizontal or vertical) were counted, then the scale factors (SF_v for vertical and SF_h for horizontal) for pixel-to-millimeter were calculated using the linear scaling factor:

\[
SF_v = \frac{\text{Bat length (mm)}}{\text{Pixels}_v}, \quad SF_h = \frac{\text{Bat length (mm)}}{\text{Pixels}_h}
\]

Here \(\text{Pixels}_v\) and \(\text{Pixels}_h\) are the total number of pixels forming the bat length in the vertical and horizontal direction in the video footage. The real bat length was 850 mm. The bat length in pixels in the vertical and horizontal direction of a typical video frame was 283 and 298 respectively. The values of \(SF_v\) and \(SF_h\) were 3.00 mm and 2.85 mm respectively. Once the coordinates of two points in the video footage are known in terms of pixels, the length between those two points and the slope with respect to the vertical reference in the video was calculated by converting the pixels to millimeters using the scale factors. A LED (Light Emitting Diode) at the end of the bat and a point formed by reflective tape at the top of the bat were connected by a straight line to identify two points on the bat image. Using the equation 2 for a rigid body the total acceleration \(\ddot{a}\) for rotation was calculated as in [10]. In
this study \(r'\) was taken from the top of the handle of the bat from the reference point for the video image measurements. The magnitude of \(l'\) was the length of the bat. In equation 2 the last two parts are the tangential \(a_t\) and centripetal acceleration \(a_c\) of the bat due to rotation having magnitudes of \(|a_t|\) and \(|a_c|\) respectively, where \(|a_t|\) was the magnitude of angular acceleration and \(|\omega|\) was the magnitude of angular velocity. To estimate the overall total acceleration \((AT_X\) for X-axis, \(AT_Z\) for Z-axis), the translational acceleration \((\tau_x\) for X-axis, \(\tau_z\) for Z-axis) was taken into account along with the acceleration components stated in equation 2.

\[
\vec{a} = \frac{d^2r'}{dt^2} - g + \frac{d\omega}{dt} \times l' + \omega \times (\omega \times l')
\]

Where \(g\) is the gravitational acceleration and \(t\) is the time.

3. Results

3.1. Video

The two ends of the bat in each video frame were plotted beginning from the start of the back-lift. This provided the full bat trajectory in the entire swing range (see Fig. 1(a)). The temporal events of different phases of the swing, i.e. the back-lift, the drive (equivalent to downswing plus follow-through as in [11]) and the return (reverse drive till the bat touches the ground after the entire swing) were extracted at 0.025 s intervals using the video footage. The angle \(\theta\) (Fig. 1(b)) and the angular velocity were calculated. The \(\theta\) was measured from the direction of negative X-axis.

Table 1 shows a decision chart used to categorize the acceleration components according to the bat position during the swing. \(X_B\) and \(X_T\) represent the abscissa (along \(Z\)-axis direction as shown in [9]) and \(Y_B\) and \(Y_T\) are the ordinates (along opposite to \(X\)-axis direction as in [9]) of two points (‘B’ for bottom and ‘T’ for top handle of the bat). The variables \(DX_B, DY_B, DX_T\) and \(DY_T\) indicate the differences between the adjacent abscissas and ordinates.

In Table 1 the zero for these variables (say \(DX_B=0\)) means no change and one (say \(DX_B=1\)) means there is a change from one frame to the next frame. A batter was instructed to swing the bat straight in the ZX-plane without twisting the bat or any bat movement in the Y-direction. The X-axis and Z-axis acceleration and their constituents shown in Fig. 2(a) and Fig. 2(b) were estimated using equation 2 and the decision chart in Table 1 (the sign differed from that in equation 2 is due to sensor’s axis orientation and swing direction). In Fig. 2 the ‘drive’ phase is highlighted and discriminated from other phases by the colored shaded bar.
The rotational components of the acceleration (centripetal, $a_c$, for X- and tangential, $a_r$, for Z-axis) were calculated using the angular velocity $\omega$ and the angular acceleration $\alpha$ in Equation 2, where $|l|$ is the instantaneous radius of rotation for all the cases in Table 1 except for the last one (when $DX_B$, $DY_B$, $DX_T$ and $DY_T$ all equal 1) for which the physical length of the bat was used for $|l|$. The translational accelerations ($\tau_x$, $\tau_z$) for all cases except the last in the Table 1 were calculated as the second derivative of $X_B$ and $Y_B$ for $AT_Z$ and $AT_X$ respectively. The instantaneous radius of rotation was calculated from the data points from the bottom of the bat ($X_B$, $Y_B$) using the geometry (Cross [12]). To improve the match between video and accelerometer data, the value of the instantaneous radius, $R$ (used for $|l|$ in calculating $a_c$ and $a_r$) was adjusted to achieve the best fit to the data.

Table 1. Decision codes and total acceleration according to the bat location and orientation from the video.

<table>
<thead>
<tr>
<th>DXB</th>
<th>DYB</th>
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<td>$A_{TX}$-g$<em>x$-$a_x$, $A</em>{TZ}$-g$_z$-$a_z$</td>
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<td>$A_{TX}$-g$<em>x$-$a_x$, $A</em>{TZ}$-g$_z$-$a_z$</td>
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*the situation is not possible or race inhabitants

3.2. Accelerometer with Video

The accelerometer data was converted to gravity units ($g$) after the sensors were manually calibrated. The data are shown in Fig. 3(a) and 3(b) together with video data for comparison. Using the Matlab toolbox named ADAT [13] a low pass filter with a cut off frequency of 5 Hz was used to smooth the curves.

The X-axis acceleration was calculated from video data and obtained during the swing duration as shown in Fig. 3(a). The equivalent Z-axis data are shown in Fig. 3(b). It is evident from Fig. 3(a) and 3(b) that the video data matches the sensor data in magnitude and time with minor variations. Correlation coefficients 0.92 and 0.87 were found for Z-axis and X-axis accelerations respectively between video and sensor data.

4. Discussion

The drive started at 1.0s (large single red dot at the bottom of the bat in the left part of Fig. 1(a) and at 1.0s in Fig. 2) and ended at 1.52s (larger single red dot at the bottom of the bat trajectory in the right part of Fig. 1(a) or at 1.52s in Fig. 2) with duration of 0.52s (shown by the shaded region in Fig. 2). The back-lift started at 0.575s (large single green dot at the bottom of the bat trajectory in Fig. 1 and at 0.575s in Fig. 2) and the duration was 0.425s. The duration of the drive is identified between the start of the linear negative slope of $a_x$ before going to a deep minimum to the end of the trough (shaded region in Fig. 2(a)). To match the video data, the radius of rotation ($R$) was varied manually to obtain the best match. The value of $R$ determined for the entire swing was plotted together with $a_x$, $a_z$ and gravity in X-axis ($g_x$) in Fig. 4.
The maximum peak of $a_z$ occurred at the maximum value of $R$ in the drive and $a_x$ while the magnitude of $g_x$ was maximum and $R$ was close to minimum as shown by the three dots in Fig. 4. These observations suggest that the maximum drive velocity in the swing direction occurs when the radius of rotation is maximum [14]. The batter has more control over the bat (by having more centripetal acceleration) when the bat is very close to batter (smaller $R$), and aligned vertically to take advantage of full gravity.

Inspection of the static, rotational and translation components of the X-axis acceleration ($g_x$, $a_{x\theta}$, $\tau_x$) and Z-axis acceleration ($g_z$, $a_{z\theta}$, $\tau_z$) shown in Figs 2(a) and 2(b) revealed that during the drive and return phase the rotational component was dominant for both $a_x$ and $a_z$. This finding validates the literature of swinging an implement [15]. The analytical model presented in that study assumed pure rotation of the batter/bat system about a vertical axis. The assumption proved acceptable as there was reasonable agreement between the model and the measured speeds. The pure rotation of the bat in the drive and return phase in Fig. 2 is evident because the translational components ($\tau_x$, $\tau_z$) are almost zero. In this case the $a_{z\theta}$ rotational component ($a_{z\theta}$) was dominant, whereas before the drive $a_x$ translational component ($\tau_x$) was dominant. The dominant $\tau_x$ indicated the ‘on guard’ posture of the bat. At the start of the drive both $a_x$ and $a_z$ have a translation component.
5. Conclusion

The feasibility of using a small, bat-mounted accelerometer was investigated to replace the bulky, expensive motion capture system. Work on ball free straight drives by an amateur batter and a 3-axis accelerometer was validated with video analysis by adjusting the radius of rotation. A good match was obtained (0.92 and 0.87 correlation coefficients). These acceleration components (rotational, translational and gravity) showed that the rotational component was dominant during the drive. The drive time duration, the posture of the bat at maximum gravity, and the instant of maximum swing velocity and its magnitude with respect to radius of rotation can easily be determined from accelerometer profiles. Further investigation is required on a larger number of subjects with different skill levels to generate concrete decisions on the effect of the radius of rotation on swing velocity and temporal events of straight drives. Future work is planned for other strokes by professional batters.

References