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Triaxial accelerometer sensor trials for bat swing interpretation in cricket

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Abstract

Analysis of bat swing is important to the assessment and understanding of effective batting in cricket. The key features of a bat swing include the spatio-temporal position of the bat before contact with the ball and the bat velocity. The current methods of bat swing analysis such as video tracking and coach observation are labor intensive and expensive. This work examined the use of small, low-cost, three dimensional motion sensors as a replacement to existing methods. Using two bat-mounted accelerometer sensors, two experiments were conducted: a set of ball-free, straight drives by an amateur batter at nominal constant speed, and a set of straight drives at different speeds by the same batter accompanied by video tracking. In all cases the bat swing was in the x-z plane of the sensors placed on the reverse face of the bat. The bat face remains in the z direction. The objective was to minimize accelerations perpendicular to the swing plane. Data analysis revealed consistent acceleration profiles with minimal acceleration perpendicular to the plane of the swing (x-z plane). The time lag between the z acceleration peak and the x acceleration peak is related to the speed of the bat. The highest peak in x acceleration results from the higher centrifugal force with minimum radius of gyration while the bat was close to the batter (confirmed by the video footage). This is the dominant rotational component plus an additional gravitational force in the x direction when the bat is aligned to gravity. The sensor attached to the on-side edge of the bat showed higher peak magnitude in x acceleration compared to that from the off-side edge, which indicated variation between the two edges of the bat during swing. The tilted position of the stationary bat at the start of each swing was determined from the x and z axis profiles from minus one g and zero respectively. Different peak accelerations were evident for different swing intensities. This study indicated that the accelerometer sensors can provide reliable bat swing information.

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Keywords: Cricket; bat swing; sensors; accelerometers; skill assessment.

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1. Introduction

Cricket batting is a dynamic interceptive task involves the batter perceiving relative motion of the bowled ball and formulating a response for a desired goal [1, 2]. High degree of accuracy in spatial and temporal motion of the bat and batter before and at the instant of ball contact is critical for achieving the goal [2]. The motion of the bat created by the batter is termed as bat swing.

To date several research have been conducted on bat swing in sports other than cricket included base ball, softball, golf, tennis etc. For instance, Cross [3] worked on baseball bat to extract the basic mechanics of swing and provided a realistic model of the swing in terms of the forces and torques acting on the bat. The theoretical results (calculated from the model) and the experimental results (data taken using video camera) indicated the same hypothesis that a batter must apply a small positive couple to start the swing of a baseball bat and a large negative couple to complete the swing. Cross [3] suggested for future research to investigate whether maximizing the angular velocity of the bat or the linear velocity of the center of mass is more important to maximize the velocity at the impact point on the bat. Fleisig *et al.* [4] while investigating the relationship between bat mass properties (mass and moment of inertia) and bat velocity (linear and angular) for baseball and softball commented on the bat motion concluding that bat motion could be described as either rotation about a moving instantaneous centre of rotation or a combination of linear and angular motion of a fixed point on the bat. Koenig *et al.* [5] conducted two experiments to measure the swing speed of college baseball and fast-pitch softball batters. Using weighted rods and modified bats they considered the influence of bat moment of inertia on swing speed. Presenting an analytical model based on pure rotation about a body axis, this work demonstrated that bat inertial properties, moment of inertia about a body axis and mass principal among them, played important roles in bat speed. Body translation and rotation about a wrist axis were important.

Busch *et al.* [6] checked the possibility of estimating the angular velocity and position of the bat and bat twist during cricket bat swing at any instant using triaxial accelerometer. They worked on the off drive, straight drive and on drive first ball-free and then balling machine condition. A large spike in both x-and z-axes acceleration profiles from accelerometer data were evident in the swing duration. This study differentiated off drive and on drive shots from the difference of the bat angle recognized from the y-axis acceleration profile differences. Various key features of a drive such as shot power, shot direction and angle of elevation of the bat during swing could be extracted using inertial sensors. Their work did not use any motion capture system to validate the results.

Davey *et al.* [7] showed that accelerometers can respond to minute changes in inertia in the linear and radial directions with comparable precision to laboratory based systems. The sensors can be attached directly to the back of the bat using sticky tape. In this study, two of those sensors were attached to the bat and data were collected during the straight drives. The current work was conducted with a set of ball-free, straight drives by an amateur batter at nominal constant speed, and a set of straight drives at different speeds by the same batter accompanied by video tracking. This work was intended to fill some gaps in cricket bat swing literature compatible with other swing analysis.

2. Experimental Procedure

The inertial sensor used is capable of measuring acceleration of ± 6g in three dimensional space. As true DC accelerometer devices, they report a static 1g response due to gravity if oriented vertically. As shown in the Figure 1(a), two PCBs [7] were attached to the middle part of the back of the bat's blade length. Figure 1(a) describes the orientation axes also, where $+X^B$ axis refers to the acceleration along the length of the bat, while $+Y^B$ axis lies in the direction of the bat edges and $+Z^B$ axis is perpendicular to the face of the bat, that is, in the direction of a typical swing. As observed Figure 1(b), the sensor axes $+Y^S$

and $+Z^S$ are not aligned to the bat axes ($+Y^B$ and $+Z^B$). The angle θ is the angular displacement of sensors to the bat face. The real bat acceleration along $+Z^B$ axis and $+Y^B$ axis differs from the sensors $+Z^S$ (Z^{S1} and Z^{S2}) and $+Y^S$ (Y^{S1} and Y^{S2}) axis accelerations by a factor of cosine of the angle (θ). There was no difference between $+X^B$ and X^S (X^{S1} and X^{S2}) axes.

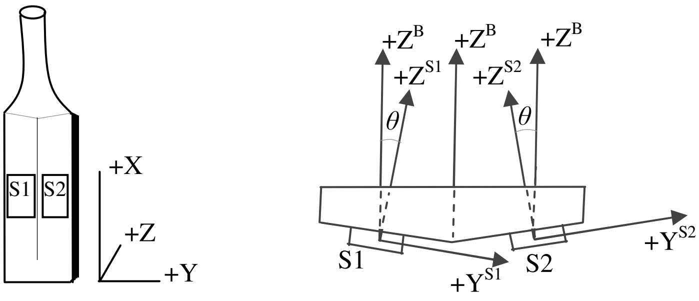

Fig. 1. (a) Accelerometer placement and X, Y and Z bat axis definitions; (b) Orientation of accelerometer and bat axes

Data were recorded in S1 and S2 accelerometer as a_{x1}, a_{y1}, a_{z1} along S1 axes (X^{S1}, Y^{S1}, Z^{S1} respectively) and a_{x2}, a_{y2}, a_{z2} along S2 axes (X^{S2}, Y^{S2}, Z^{S2} respectively) during straight ball-free bat swings in ZX-plane (perpendicular to the ground YZ-plane as stated in Figure 1(a)). The straight bat tapping on the ground was used to synchronize the timing between the video and sensor data. A video camera was placed at a height of 1.4 m from the ground and 5 m lateral from the batting arc to make full trajectory of the bat swing visible. The camera was operated at frame rate of 100 f/s to minimize image blur. Each frame consisted of two interlaced images which were separated by software to a frame rate of 200 f/s in the swing footage.

3. Results and discussion

Figure 2(a) and Figure 2(b) show the acceleration profiles obtained from a set of ten consecutive ball free drives along the X, Y and Z axes (a_{x1}, a_{y1}, a_{z1} along X^{S1}, Y^{S1}, Z^{S1} axis and a_{x2}, a_{y2}, a_{z2} along X^{S2}, Y^{S2}, Z^{S2}) from sensor S1 and S2. Prior to the drives calibration and straight tapping was done. Each drives of Figure 2 consist of two bat tapping before starting of the swing and the swing of the first drive started at 89.68s commencing with backlifting. Figure 3(a) and Figure 3(b) show acceleration profiles along X- and Z-axis respectively for five repetitive drives (D1, D2, D3, D4, and D5) for S1. Similar profiles were obtained from S2. The large negative X-axis acceleration profiles, minimal variations in Y-axis acceleration in Figure 2 and five unswerving peaks in Figure 3 show good consistency. The peak prior to large negative peak in Figure 2 came from the back-lift and followed two bat tap peaks in drive 1 of a_{x1} before 89.68s and confirmed by the video footage. The plots in Figure 3 aligned in time by the large negative peak.

Strong linear variation ($R^2 = 0.999$) in both $T1_{Xmn}$ and $T2_{Xmn}$ and almost similar time differences between each adjacent of $P1_{Xmn}$ and $P2_{Xmn}$ of all the consecutive drives shows better competency. However, there was time and magnitude differences between $P1_{Xmn}$ and $P2_{Xmn}$ peaks as observed from the Table 1(a). For all the drives peak $P1_{Xmn}$ from sensor S1 have greater magnitude (except drive 10) and occurred earlier than S2 peak, $P2_{Xmn}$. Similar result was obtained from five repetitive drives as realized from the Table 1(b) except drive D2 in which $P2_{Xmn}$ is more in magnitude than $P1_{Xmn}$. These differences came from the fact that '*on-side*' edge of the bat is dominant in producing more velocity compared to the

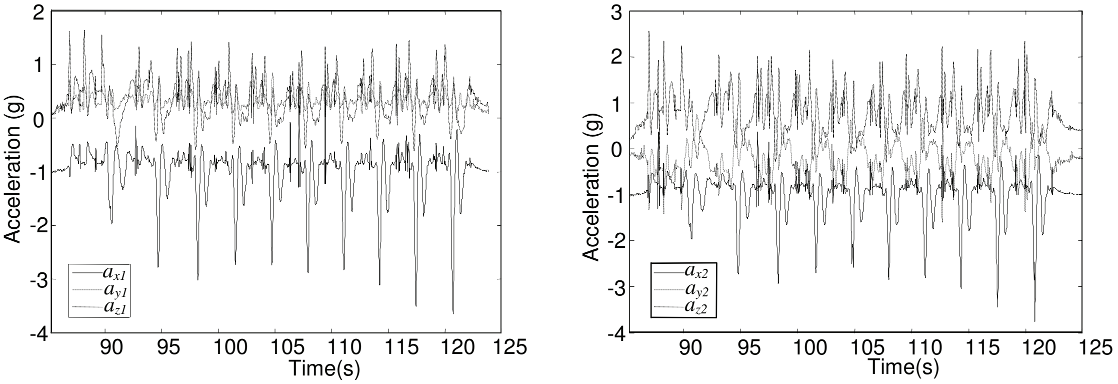

Fig. 2. (a) Acceleration profiles from S1 for 10 consecutive drives; (b) Acceleration profiles from S2 for ten consecutive drives

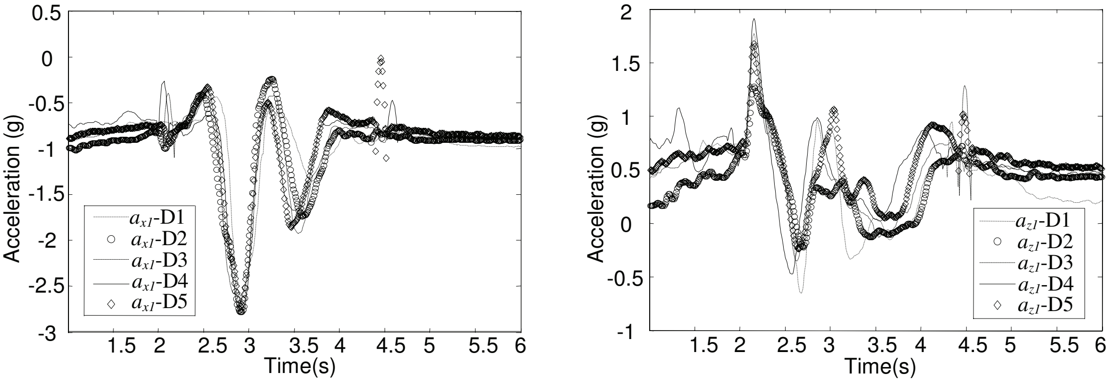

Fig. 3. (a) X-axis acceleration profiles, (b) Z-axis acceleration profiles from sensor S1 for five repetitive drives

'*off-side*' as S1 was attached '*on-side*' of the batter. This fact is reinforced by the similar results obtained from peak to peak Z-axis acceleration (PP1$_Z$ from S1 and PP2$_Z$ from S2) differences in five repetitive drives as shown in Table 1(b). In these drives shown in Figure 3 the tilted position of the stationary bat at the start of each drive is easily realized from the Z-and X-axis acceleration values which differs from zero and minus one g value respectively for straight vertically stationary bat. For instance, at drive D4 the bat was tilted more and at D2 it tilted very little compared with other drives.

The acceleration profiles from three different speeds straight drive ('*Slow*', '*Medium*', and '*Higher*') from S1 by the same amateur batter is shown in Figure 4 (similar trend of S2 profiles is not shown to avoid overcrowding of figures). Each drive commenced after three bat tapping evident from the three spikes prior to swing. Different speed variation is realized from the magnitude difference in the acceleration profiles.

Table 2 shows the maximum negative value of a_{x1} and a_{x2} (P1$_{\mathrm{Xmn}}$ and P2$_{\mathrm{Xmn}}$ respectively) and peak to peak value of a_{z1} and a_{z2} (PP1$_Z$ for S1 and PP2$_Z$ for S2 respectively) during stroke swing period at *Slow*, *Medium* and *Higher* speed. It is evident that the variation of the acceleration is more along Z-axis than X both for S1 and S2 for different speed. The reason for these differences in variability came from the fact that was related to the effect of straight drive speed on tangential and radial direction of the swing arc. As the novice accomplished the straight drives at almost the same radius of curvature during the swing keeping his body same position for all three speed drives (confirmed by the video footage), the centripetal

Table 1. Temporal and magnitude data from the two sensors S1 and S2 for (a) Ten consecutive drives, (b) Five repetitive drives

	1	2	3	4	5	6	7	8	9	10
$P1_{Xmn}$ (g)	-1.977	-2.785	-3.029	-2.728	-2.748	-2.887	-2.828	-3.111	-3.512	-3.652
$T1_{Xmn}$ (s)	90.61	94.71	98.21	101.5	104.8	107.9	111.1	114.3	117.5	120.7
$P2_{Xmn}$ (g)	-1.961	-2.726	-2.93	-2.703	-2.582	-2.847	-2.8	-3.039	-3.444	-3.762
$T2_{Xmn}$ (s)	90.71	94.8	98.3	101.6	104.9	108	111.2	114.3	117.6	120.9
$P1_{Xmn}$ - $P2_{Xmn}$	-0.016	-0.059	-0.099	-0.025	-0.166	-0.04	-0.028	-0.072	-0.068	0.11
$T2_{Xmn}$ -$T1_{Xmn}$	0.1	0.09	0.09	0.1	0.1	0.1	0.1	0	0.1	0.2

	$P1_{Xmn}$ (g)	$T1_{Xmn}$ (s)	$P2_{Xmn}$ (g)	$T2_{Xmn}$ (s)	$P1_{Xmn}$ - $P2_{Xmn}$	$T2_{Xmn}$ - $T1_{Xmn}$	$PP1_Z$ (g)	$PP2_Z$ (g)	$PP1_Z$ -$PP2_Z$
D1	-2.939	28.88	-2.824	29.01	-0.115	0.13	2.4287	2.1484	0.2803
D2	-2.781	36.82	-2.792	37.2	0.011	0.38	1.4833	1.23832	0.24498
D3	-2.626	30.6	-2.58	31.35	-0.046	0.75	1.9685	1.6414	0.3271
D4	-2.816	29.36	-2.75	30.29	-0.066	0.93	2.4026	1.8561	0.5465
D5	-2.783	27.05	-2.661	27.64	-0.122	0.59	1.9215	1.40286	0.51864

force in radial direction (X-axis direction) was affected less than compared to tangential direction force. This is because of the straight drives and the speed variations were in tangential direction of the swing arc, then the centripetal force with similar radius of curvature in each drive was not affected much by different speed. However, in each of the three speed drives and also in the previous set of drives (ten consecutive, five repetitive), the X-axis profiles got maximum value of acceleration while the bat was

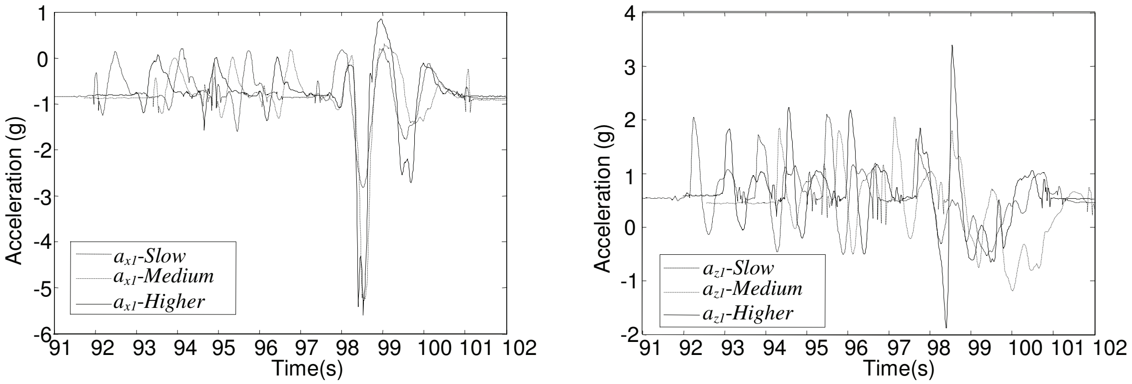

Fig. 4. (a) X-axis acceleration profiles, (b) Z-axis acceleration profiles from sensor S1 for three speed straight drives

Table 2: Magnitude data of three speed drives

	$P1_{Xmn}$ (g)	$P2_{Xmn}$ (g)	$PP1_Z$ (g)	$PP2_Z$ (g)
Slow	2.82	2.81	0.83	1.28
Medium	5.23	4.95	1.55	1.80
Higher	5.60	5.72	5.28	6.45

aligned to gravity (confirmed by the video). This is because of higher centripetal force while the bat was closed to the batter resulting minimum radius of gyration and maximum value of gravitational force.

4. Conclusion

Several set of cricket straight drives were recorded in triaxial accelerometer sensor together with video tracking to interpret bat swing. Acceleration profiles from the sensor data revealed nice consistency for all the drives. The time and magnitude difference between the '*on-side*' and '*off-side*' positioned sensors data for all the drives indicated the swing speed difference between the two sides of the bat. Highest magnitude of the acceleration along bat length direction was found while the bat was aligned to gravity during the swing according to the video footage. This was interpreted as result of the highest centripetal force and maximum gravity at this time of swing while the bat was very close to the batter resulting smaller radius of gyration. However, different speed in the straight swing did not affect much in this acceleration (along bat length) variation but speed variation was clearly realized from the acceleration in the straight swing direction. This resulted from the fact that the radius of rotation in the three speed drives was almost similar, so could not affect much on centripetal force but affected much on tangential direction of the bat swing arc for the straight drives. The tilted position of the stationary bat was realized from the initial acceleration values before commencing each drive. These results show that tiny triaxial accelerometer can be the replacement of existing bulk, labor and cost intensive batting research technology. However, these results needs to be more investigated using more batters and the video data analysis to finding out whether the same acceleration profiles could be resulted.

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