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# Cricket Bat Acceleration Profile from Sweet-Spot Impacts

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### Abstract

The sweet spot on a cricket bat is defined as the point where the ball receives maximum acceleration. Sweet spot impacts are accompanied by minimal jarring of the hands and forearm. Using 3 axis accelerometers mounted on the bat and the wrists, ball strikes were recorded for defensive drives along the ground. There is significant evidence that sweet spot hits have low levels of vibration in the wrist sensors so that small, battery powered, accelerometers can be used to discriminate sweet spot hits during normal match play and practice.

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### 1. Introduction

The art of bat/ball contact in cricket batting is the key factor to ensure the most effective hit for the desired goal in striking the ball. There is an optimum location on the cricket bat blade; batters feel little force when they strike the ball and the impact point in that location is termed as sweet spot [1]. Cross [2] defined the sweet spot of a tennis racquet as the impact point for which the impulsive forces transmitted to the hand is the minimum. From the measurements and calculation, Cross [1] mentioned the sweet spot for a tennis racquet is the narrow impact zone where the total (translation+rotation+vibration) energy in the handle was minimal and that was likely to coincide with the location indicated by the players. Adair [3] pointed out that the "sweet spot" of a baseball bat is not a physics term, and is determined by the batter and not by physicists. This work seeks to categorize the sweet spots hits from the cricket bat/ball contact. Two experiments for cricket bat/ball contact were undertaken to determine the impact location and sweet

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spot hits using triaxial accelerometer. Fallon [4] found accelerometers and microphones can be used to determine the impact location from the collision of a baseball and bat. Busch et al. [5] checked the possibility of cricket shots analysis using accelerometers. The first experiment was done with an accelerometer mounted on a stationary hand-held cricket bat in which three hits at the middle, upper and lower were conducted. The second experiment was to identify the sweet spot hits from defensive drives along the ground by five novice player. Accelerometers were attached to the wrists (left and right) and also the upper part of the back of the bat (opposite to hitting surface). The acceleration profiles from these experiments were used to identify the impact location in the hand-held bat, and sweet spot hits.

## 2. Experimental Procedure

Accelerometers respond to minute changes in acceleration in the linear and radial directions with precision comparable to laboratory based systems [6]. As true DC devices, they report a static 1g response from gravity if oriented vertically. Accelerometer sensors capable of measuring acceleration of  $\pm 10g$  in three dimensional spaces were used in this work. Fig. 1(a) and Fig. 1(b) show the sensor (S) location in the bat for first and second experiment respectively. The sensors' and bat axis orientation is similar to [7]. The bat blade was divided into three regions measured from the toe of the bat; a low hit impacted that bat between 11-22 cm, a middle hit between 22-33 cm and the top between 33-44cm. The centre of mass of the bat was at 34.5 cm. The bat swing was along the ZX plane (perpendicular to the ground YZ-plane) in which X-axis was opposite to gravity direction as shown in Fig. 1(a). The wrists sensors were oriented in a similar direction. The recorded bat acceleration along Y- and Z-axis differs from sensor Y- and Z-axis acceleration by a factor equal to the cosine of the angle between the sensor and bat axes. There was however, little difference in X-axes of the sensors and the bat [7]. In the first experiment bat was suspended above the ground with hands placed in the normal batting position. The hits were performed at the middle, bottom and top position by throwing a cricket ball having almost similar speed at the stationary hand-held bat. In the second experiment, the novices were asked to hit the thrown ball using a defensive stroke. All ball-contacts were assessed and written down by an independent observer, with the drives captured by a video camera positioned 1.4 m from the ground. The video record was used to confirm the ball-contact location.



(a)

(b)

Fig. 1. Accelerometer placement in (a) hand-held bat for first experiment; (b) wrists and bat for second experiment

# 3. Results and discussion

The acceleration profiles from the first experiment are shown in Fig. 2. Fig. 2(a) shows the profiles from the sensor positioned on in the bat player side of the bat (left sensor in Fig. 1(a)) from ball hits on the stationary hand-held bat at middle, bottom and top positions on the blade. The acceleration before and after the hits was constant at -1g for X-axis and 0g for Z- and Y-axes. The spikes in the figure represent the hit. Fig. 2(b), (c) and (d) shows the expanded profiles during the hits. The contact points of the ball during the hits were measured manually (a reflective tape was used to locate the impact point): the middle hit was 29 cm from the toe of the bat, the bottom hit was 24 cm, and the top hit was 34.5 cm. The X-, Y- and Z-axis acceleration values for the middle, bottom and top hits are shown in Table 1. For the top and middle hits, the X-axis orientation. However, for the bottom hit the X-and Z-axis accelerations have small values because that hit occurred close the sweet spot. While the centre of sweet spot region was defined in [8] at about 15 cm from the toe of the bat, the region bat-dependent and extends for a significant range along the vertical axis of the blade.



The results from the second experiments are shown in Fig. 3. The Fig. 3(a) shows the spikes from the

Fig. 2. Acceleration profiles for (a) all three hits on a stationary bat; (b) expanded for a middle hit; (c) expanded for a bottom hit; (d) expanded for a top hit

Table 1. Magnitude of the acceleration spikes for the hits in first experiment

	Middle hit	Bottom hit	Top hit
X-acceleration	4.884g	-1.380g	2.748g
Y-acceleration	1.026g	1.431g	-6.031g
Z-acceleration	5.123g	-0.557g	5.874g



Fig. 3. Second experiment's acceleration profiles from 1<sup>st</sup> novice's ten hits in (a) bat mounted sensors; (b) wrists' sensors

bat mounted sensor for 1<sup>st</sup> novice's 10 hits and Fig. 3(b) shows those from the wrists' (right wrist, left wrist) sensors. Total 61 hits were made by five novices (1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> novice made 10 hits each in two sessions, and 4<sup>th</sup>, 5<sup>th</sup> novice made16 and 15 hits respectively in three sessions each); only 1<sup>st</sup> novice's hits spikes are shown. The novices were instructed to hit the ball around the middle of the bat. The three different zones in the bat were marked by tape (middle, bottom and top). Before each session the novices were instructed to tap the ground (see Fig. 3) for a timing reference with the video. The exact value of time for the spikes in three sensors' profiles in Fig. 3 differed from each other due to the timing difference in switching the sensors 'on' for recording the data. However, the time differences among the spikes in each sensor are similar. Fig. 4 (a) shows the total wrists' acceleration normalized by bat's acceleration for all novices' hits. The green dashed vertical lines indicated points in Fig. 4 show the good contacts assessed by the independent assessors and the red lines indicated points are for no ball contact. The minimum values of the acceleration from the right wrist are observed for the good contacts with an exception for last two contacts. Converting the acceleration in velocity by integration, Fig. 4 (b) shows the total wrists' velocity (V1<sub>LWR</sub> ~ V5<sub>LWR</sub> for left and V1<sub>RWR</sub> ~ V5<sub>RWR</sub> for right wrists) plotting against bat velocity for all novices' hits. The integration constants were taken similar for all the novices and the units of velocity shown in Fig. 4 are thus chosen arbitrary (arb.). Linear relationship was obtained between the wrists and bat velocity, meaning that wrists' vibration are resulted from bat vibration for the ball contacts.

The Y-axis acceleration data from the right and left wrists ( $Y_R$  and  $Y_L$  respectively) and the resultant of X-,Y- and Z-axis acceleration from right and left wrists ( $TOT_R$  and  $TOT_L$ ) for all of the novices (N1~N5)' hits (C1~C16) are shown in Table 2. The red colored figures in the tables represent very good contact around middle (about 18~22 cm from the toe of the bat) assessed by the independent assessors and also looking at the video, the blue figures represent good contacts assessed visually. From the table, it is evident that for very good contacts both the left and right wrists have a minimum value of Y-axis



Fig. 4. Wrists' (a) acceleration (normalized by bat's acceleration), the vertical lines show the sweet spot hits and (b) velocity for all hits by all novices

acceleration; that is, perpendicular to the swing plane accountable for the dominant component of jerking of hands when the bat twists during ball contact. In the table, the starred figures represent the swings with no ball contact. These events show a minimum Y-axis acceleration value.

The resultant acceleration from right wrists only also has a small value for both excellent and good contacts with an exception of contact C1, C3 by 3<sup>rd</sup> novice (N3) and C3, C13 by 4<sup>th</sup> novice. As in the coaching manuals for defensive stroke it is stated that on impact the bottom hand should act as shock absorber [9], so the total acceleration came from right hand (bottom hand) for excellent and good bat-ball

		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
N1	$Y_R$	2.94	1.56	5.59	-2.45	-4.47	0.70	1.12	0.34	2.39	-5.78						
	$Y_L$	0.34	-1.11	4.52	-0.06	-1.54	1.49	1.15	1.14	0.08	-0.69						
N2	Y <sub>R</sub>	-0.23	-4.79	-1.47	-5.40	0.98	0.05	-0.12*	-4.65	5.66	2.69						
	$Y_L$	4.88	1.75	8.12	-1.61	8.12	-0.86	-0.26*	1.80	-1.14	4.43						
N3	$Y_R$	0.64	2.67	-1.10	2.47	-4.56	-0.16	0.68	-8.02	0.10*	-1.50						
	YL	-1.21	-1.04	-0.88	1.25	0.62	2.37	1.08	-3.98	0.78*	0.64						
N4	$Y_R$	0.27	0.12	0.60	-3.61	-2.72	0.65	-0.09	3.40	2.40	4.05	3.19	-4.01	0.52	-4.01	-4.01	0.01
	$Y_L$	2.24	-2.33	-0.18	-3.98	1.49	4.01	0.67	1.52	-1.32	-3.98	-1.59	4.01	1.05	-3.98	-3.13	-3.98
N5	$Y_R$	-1.57	-0.39	4.05	0.87	-3.08	-0.31	0.01*	-2.30	-2.03	-0.84	3.52	1.04	-2.16	2.65	-3.47	
	YL	-3.98	-2.50	1.12	1.80	-2.24	0.32	0.99*	-2.68	-3.98	-2.02	-3.98	-3.98	4.01	4.01	4.01	
		<b>C</b> 1	00	00	~ .			07									
		CI	C2	C3	C4	C5	C6	C/	C8	C9	C10	C1	l C12	2 C13	3 C1	4 C15	C16
N1	TOT	4.35	2.16	6.66	6.14	C5 7.24	C6 2.04	2.82	C8 3.55	C9 5.09	C10 8.91	C1	l C12	2 C13	3 C1	4 C15	C16
N1	TOT <sub>F</sub> TOT <sub>I</sub>	4.35 7.98	2.16 6.50	6.66 4.89	6.14 7.96	C5 7.24 5.42	C6 2.04 6.45	2.82 5.84	C8 3.55 6.50	C9 5.09 1.72	C10 8.91 5.75		l C12	2 C13	3 C1	4 C15	C16
N1	TOT <sub>F</sub> TOT <sub>I</sub> TOT <sub>F</sub>	4.35 7.98 6.50	2.16 6.50 4.83	6.66 4.89 8.79	C4 6.14 7.96 10.39	C5 7.24 5.42 5.78	C6 2.04 6.45 1.40	2.82 5.84 2.45*	C8 3.55 6.50 6.63	C9 5.09 1.72 7.39	C10 8.91 5.75 9.75		l C12	2 C13	3 C1	4 C15	C16
N1 N2	TOT <sub>F</sub> TOT <sub>I</sub> TOT <sub>F</sub> TOT <sub>I</sub>	4.35 7.98 6.50 5.63	2.16 6.50 4.83 5.05	6.66 4.89 8.79 11.36	C4 6.14 7.96 10.39 3.85	C5 7.24 5.42 5.78 8.54	C6 2.04 6.45 1.40 3.94	2.82 5.84 2.45* 1.73*	C8 3.55 6.50 6.63 8.48	C9 5.09 1.72 7.39 6.90	C10 8.91 5.75 9.75 9.45	C1		2 C13	3 C1	4 C15	C16
N1 N2	TOT <sub>F</sub> TOT <sub>I</sub> TOT <sub>F</sub> TOT <sub>I</sub>	4.35 7.98 6.50 5.63 4.52	2.16 6.50 4.83 5.05 2.99	6.66 4.89 8.79 11.36 4.95	C4 6.14 7.96 10.39 3.85 2.71	C5 7.24 5.42 5.78 8.54 5.32	C6 2.04 6.45 1.40 3.94 2.22	2.82 5.84 2.45* 1.73* 0.90	C8 3.55 6.50 6.63 8.48 8.69	C9 5.09 1.72 7.39 6.90 0.46 <sup>3</sup>	C10 8.91 5.75 9.75 9.45 * 2.17			2 C13	3 C1	4 C15	C16
N1 N2 N3	TOT <sub>F</sub> TOT <sub>I</sub> TOT <sub>F</sub> TOT <sub>F</sub> TOT <sub>F</sub>	$\begin{array}{c} 0.1 \\ 4.35 \\ 7.98 \\ 6.50 \\ 5.63 \\ 4.52 \\ 5.26 \end{array}$	2.16 6.50 4.83 5.05 2.99 2.40	6.66 4.89 8.79 11.36 4.95 7.21	C4 6.14 7.96 10.39 3.85 2.71 1.92	C5 7.24 5.42 5.78 8.54 5.32 4.36	C6 2.04 6.45 1.40 3.94 2.22 4.01	2.82 5.84 2.45* 1.73* 0.90 1.96	C8 3.55 6.50 6.63 8.48 8.69 5.86	C9 5.09 1.72 7.39 6.90 0.46 <sup>3</sup> 2.26 <sup>*</sup>	C10 8.91 5.75 9.75 9.45 * 2.17 3.70	C1		2 C13	3 C1	4 C15	C16
N1 N2 N3	$TOT_{F}$ $TOT_{I}$ $TOT_{F}$ $TOT_{I}$ $TOT_{F}$ $TOT_{I}$ $TOT_{F}$	$\begin{array}{c} C1 \\ 4.35 \\ 7.98 \\ 6.50 \\ 5.63 \\ 4.52 \\ 5.26 \\ 8 \\ 5.60 \end{array}$	2.16 6.50 4.83 5.05 2.99 2.40 4.96	C3           6.66           4.89           8.79           11.36           4.95           7.21           5.72	C4 6.14 7.96 10.39 3.85 2.71 1.92 6.51	C5 7.24 5.42 5.78 8.54 5.32 4.36 6.22	C6 2.04 6.45 1.40 3.94 2.22 4.01 4.69	2.82 5.84 2.45* 1.73* 0.90 1.96 1.48	C8 3.55 6.50 6.63 8.48 8.69 5.86 5.31	C9 5.09 1.72 7.39 6.90 0.46 <sup>3</sup> 2.26* 5.37	C10 8.91 5.75 9.75 9.45 * 2.17 3.70 6.99	) C1	2 6.8	2 C13 8 5.72	3 C1 2 6.8	4 C15	C16
N1 N2 N3 N4	$TOT_{F}$ $TOT_{F}$ $TOT_{F}$ $TOT_{F}$ $TOT_{F}$ $TOT_{F}$ $TOT_{F}$ $TOT_{F}$	$\begin{array}{c} C1 \\ 4.35 \\ 7.98 \\ 6.50 \\ 5.63 \\ 4.52 \\ 5.26 \\ 5.60 \\ 4.89 \end{array}$	2.16 6.50 4.83 5.05 2.99 2.40 4.96 2.88	C3           6.66           4.89           8.79           11.36           4.95           7.21           5.72           5.59	C4 6.14 7.96 10.39 3.85 2.71 1.92 6.51 4.76	C5 7.24 5.42 5.78 8.54 5.32 4.36 6.22 2.16	C6           2.04           6.45           1.40           3.94           2.22           4.01           4.69           6.70	2.82 5.84 2.45* 1.73* 0.90 1.96 1.48 1.08	C8           3.55           6.50           6.63           8.48           8.69           5.86           5.31           4.46	C9 5.09 1.72 7.39 6.90 0.46 <sup>5</sup> 2.26 <sup>*</sup> 5.37 4.07	C10 8.91 5.75 9.45 * 2.17 3.70 6.99 5.60	) C11 5 5 6 7 9 6.52 9 6.52	2 6.8 9 4.6	8 5.72 4 2.2	2 6.8 1 5.4	4 C15 8 6.88 1 3.44	C16 4.13 6.88
N1 N2 N3 N4	TOT <sub>F</sub> TOT <sub>I</sub> TOT <sub>F</sub> TOT <sub>I</sub> TOT <sub>F</sub> TOT <sub>I</sub> TOT <sub>F</sub>	C1           4.35           7.98           5.63           5.63           5.26           5.60           4.89           5.79	C2           2.16           6.50           4.83           5.05           2.99           2.40           4.96           2.88           4.05	C3           6.66           4.89           8.79           11.36           4.95           7.21           5.72           5.59           6.87	C4           6.14           7.96           10.39           3.85           2.71           1.92           6.51           4.76           4.12	C5 7.24 5.42 5.78 8.54 5.32 4.36 6.22 2.16 5.42	C6 2.04 6.45 1.40 3.94 2.22 4.01 4.69 6.70 3.31	2.82 5.84 2.45* 1.73* 0.90 1.96 1.48 1.08 1.04*	C8 3.55 6.50 6.63 8.48 8.69 5.86 5.31 4.46 5.05	C9 5.09 1.72 7.39 6.90 0.46 <sup>3</sup> 2.26* 5.37 4.07 4.57	C10 8.91 5.75 9.45 9.45 * 2.17 3.70 6.99 5.60 5.60	6.52 6 7 7 7 7 7 7 7 7 7 7 7 7 7	2 6.8 9 4.6 9 5.6	8 5.72 8 5.72 4 2.2 8 6.00	2 6.8 1 5.4 0 6.1	4 C15 8 6.88 1 3.44 9 6.58	C16 4.13 6.88

Table 2. Contact point Y-axis and Total accelerations from right and left wrists' sensors for all novices

contact should be minimum.

#### 4. Conclusion

Two experiments were undertaken to identify the accelerometer profiles for sweet spot hits on a cricket bat. The contact location of the ball on the bat was identified using tape, video and subject assessment methods. These experiments revealed that sweet spot hits can be identified from minimum values of total wrist acceleration. Ball contacts at the bottom, middle, and top in the bat were distinguishable from the sign of the acceleration along the bat axis (X-axis acceleration). The Y acceleration of both the left and right wrists was small for sweet spot contacts. The minimum acceleration was observed for contacts made in the range of 18 to 22 cm from the toe of the bat. These experiments were limited by the visual contact assessment and inconsistent ball throw velocity. The identification of sweet spot hits from the wrists showed promise. Future work requires accurate sweet spot hit location and a larger pool of batters and a ball machine for consistent ball velocity and trajectory.

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