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ANALYSIS OF CRICKET SHOTS USING INERTIAL SENSORS

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Using bat-mounted, tri-axial accelerometers, data is collected from multiple positions on a cricket bat at a high frequency. Using this information, a number of useful characteristics of a batsman's swing can be extracted, including shot power, point of impact, bat angle, and angular velocity. From these characteristics it is possible to provide an objective, statistical evaluation of performance in both training and match situations, enabling fast and efficient feedback to be provided to the athlete. The sensors are lightweight and completely self-contained, allowing for minimum inconvenience to the batsman.

1 Introduction

Striking a cricket ball effectively is a complex movement involving many parameters. Measuring the quality of such shots has to date been a purely subjective measure based on visual assessment by an expert observer. Such metrics are prone to errors due to differences in observers, the inability of the human visual system to accurately perceive high-speed motion, and other human factors. It is also not unusual for different batsman to have markedly different batting techniques, which further reduces the accuracy of human assessment.

By taking advantage of the advancements in microelectronics and other micro technologies it is possible to build instrumentation that is small enough to be unobtrusive for a number of outdoor sporting applications with comparable precision to laboratory based systems (James *et al*., 2004). One such technology that has seen rapid development in recent years is in the area of inertial sensors. These sensors respond to minute changes in inertia in the linear and radial directions. These are known as accelerometers and rate gyroscopes respectively. When combined with absolute positioning technologies such as magnetometers and even GPS, laboratory equivalent performance analysis can be obtained.

Accelerometers and gyroscopes have in recent years shrunk dramatically in size as well as in cost (~$US20). This has been due chiefly to industries such as the auto-mobile industry adopting this technology in airbag systems to detect crashes. Micro electromechanical systems (MEMS) based accelerometers like the ADXLxxx series from Analog Devices (Weinberg, 1999) are today widely available at low cost. The use of accelerometers to measure activity levels for sporting (Montoye *et al*., 1983), health and gait analysis (Moe-Nilssen and Helbostad, 2004) is emerging as a popular method of biomechanical quantification of health and sporting activity. With the increasing capacities of portable computing, data storage and battery power due to the development of consumer products like cell phones and portable music players this is set to be a rapidly developing technological area in health and sport.

2 The Monitoring Platform

The cricket bat sensor is based heavily on the nCore, a scalable, generic monitoring platform developed using the work by James *et al*. (2004). This platform contains two embedded accelerometers each of which is capable of measuring acceleration forces of ±10g in two perpendicular directions. This enables collection of data in full three dimensional space. These are true DC accelerometer devices, meaning that they will report a static 1g response due to gravity if oriented vertically. Whilst this poses a number of challenges when processing some types of data, it is necessary in order to obtain accurate reading in slowly varying systems.

The PCB is then attached directly to the top part of the back of the bat using screws, ensuring a stable connection and thus a good transfer of inertial forces. Using the external input pins on the nCore board, two more accelerometers are attached to the bottom part of the bat, providing the same three axis readings at that location. The other system components such as the battery and memory card are also firmly affixed to the bat in a convenient location.

3 Data Collection and Extraction

Data was collected during a number of experiments from subjects of varying skill levels. Six separate streams of data are collected during each session, those being the x, y, and z axes at both the top and bottom of the bat. In this context, the x axis refers to forces along the length of the bat, while the y axis represents forces operating in the direction of the edges of the bat. The z axis corresponds to forces operating perpendicular to the face fo the bat, that is, in the direction of a typical swing.

Each subject, after an adequate warm-up period, was first asked to perform a number of practice shots for the off drive, straight drive and on drive, without actually hitting a ball. Following this, the batsman faced a set number of balls to which various shots were played, and relative statistics for each shot noted. Such data included the assessed power of the shot, the direction of ball travel, approximately where on the bat the ball struck, and the elevation of the shot. An independent assessment of the shot quality was also recorded. In order to create a standardized testing environment, a belt-driven bowling machine was used during testing, meaning that each batsman faced bowling of almost the same speed and direction. The data from a typical shot is shown in figure 1. Features which can be readily identified from this example are the time during which the swing occurs, evident from the large spike in both the x and z axes, the actual time of ball impact, evidenced by a small dip in these same axes during the swing, and the bat tapping on the ground, which is shown as small spikes immediately prior to the swing.

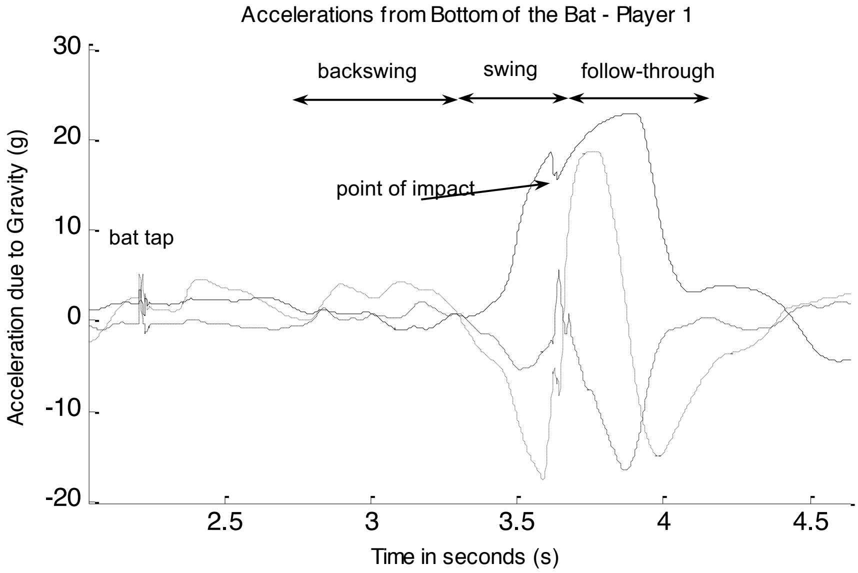

Figure 1. Data extracted from a typical shot. Note the small dip in acceleration in the *x* and *z* axes (solid and dotted lines respectively) at the tie of impact, and the large spike during the swing. Twisting of the bat at the point of impact and follow-through is noted in the *y* axis (dashed line).

Of particular interest in these acceleration traces is the *z* axis. The large spike on this graph does not represent the swing itself, but rather the deceleration of the bat after it has reached maximum velocity. The smaller negative peak immediately prior to this is the actual forward acceleration from which the shot power is generated.

4. Calculating Shot Characteristics

Previous research has shown that the use of inertial sensors attached to a sporting implement can gather significant performance related data (James *et al*., 2005). Although the motion of a cricket bat during a shot is typically not well constrained as is the case in sports such as golf, such instrumentation can still enable the collection of a number of useful shot parameters. To date, this research has concentrated solely on the so-called 'straight bat' shots, during which the bat remains in an approximately vertical position. Such shots include the on drive, straight drive, and cover drive, and are amongst the most commonly played cricket strokes in most forms of the game. By limiting analysis to these shots, it can be assumed that all bat motion during the period of interest is limited to a single plane, allowing a number of useful assumptions to be made when processing the data.

4.1. *Bat Angular Position and Velocity*

Calculating absolute velocity or position values using inertial sensors is a difficult task, due to the need for at least one integration and the resulting summation of errors. When the object to be measured is also subject to rotational motion, as is the case with a cricket bat, gravitational forces are also varying with respect to each axis, meaning that unless the exact angular position is known at each instant, additional errors are introduced. As a cricket swing can be characterized as a roughly circular motion, angular velocity is also a very important quantity when assessing characteristics such as shot power and elevation. The calculation of angular velocity is also considerably simpler than for absolute velocity, due to the presence of two sensors on the bat.

Assuming a roughly circular swing motion, one method of estimating the angular velocity of an object is to measure the resulting centrifugal force. This is a real force, as the accelerometers are measuring forces from a rotating reference frame, and is given by

$$a_c = \omega^2 \mathbf{r} \tag{1}$$

where a is the centrifugal acceleration, ω is the angular velocity of the bat, and $\mathbf{r}$ is vector representing the distance from the centre of rotation. Due to differing methods of playing shots between batsmen, the centre of rotation, and thus $\mathbf{r}$, is often quite different, stemming from rotational forces generated by the wrists, elbows and shoulders. Using the position of the accelerometers on the bat, it is possible to estimate these values using equation (1) above and the known separation distance between the top and bottom sensors, which in our test case was 0.48m. Rewriting (1) for both sets of sensors and solving simultaneously for ω gives

$$\begin{aligned} a_{ct} &= \omega^2 \mathbf{r} \\ a_{cb} &= \omega^2 (\mathbf{r} + d) \\ \omega &= \sqrt{\frac{a_{cb} - a_{ct}}{d}} \end{aligned} \tag{2}$$

where a_{ct} and a_{cb} are the centrifugal acceleration forces (x axis) at the top and bottom of the bat respectively, and d is the known distance of separation. Solving these equations simultaneously gives and estimate of both ω and $\mathbf{r}$, quantities which are both useful in assessing the quality of a batsman's shot. It should be noted that the estimates of centrifugal acceleration are affected by the presence of gravity, which is not a constant force due to the rotation of the bat. Due to the identical orientation of the sensors, however, the gravitation component of the centrifugal acceleration should be equal for both top and bottom sensors, meaning that it will cancel due to the subtraction term in (2).

Another method of estimating the angular velocity of the bat is to use angular kinematics. From these equations, it can be shown that the angular acceleration α, is given by:

$$\alpha = \frac{(a_t - a_b)}{d} \tag{3}$$

where a_t and a_b are the acceleration values in the direction of bat motion (nominally, the z axis) at the top and bottom of the bat, respectively, and d is the distance separating them. Integrating the angular acceleration with respect to time will give the instantaneous angular velocity, and if required, a second integral will provide an estimate of the angular position of the bat. Due to the inevitable drift when performing integration using inertial sensors, the estimates of angular velocity achieved using this technique cannot be considered accurate in an absolute sense. Using heuristic measures to zero the angular velocity at known points in the swing such as the tapping of the bat can greatly improve these estimates, effectively resetting the drift at short intervals.

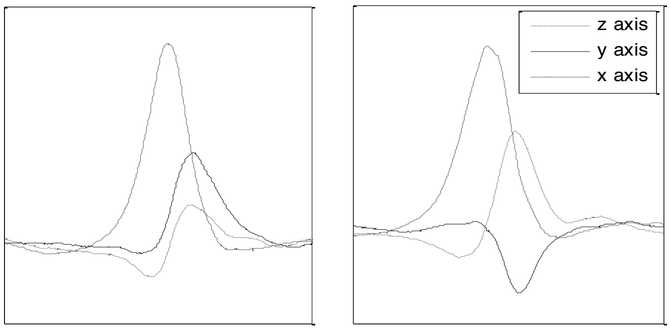

Figure 3. Accelerometer responses for a simulated on drive (left) and off drive (right). Note the difference in the y-axis response (solid line), representing the twisting of the bat during the shot in opposite directions.

4.2. *Bat Twist*

During a typical cricket shot, the angle of the bat relative to its forward motion is quite important. In order to maximize the chance of successfully striking the ball, the face of the bat should be perpendicular to the direction of the ball, allowing for the maximum possible contact area. In order to direct the ball, however, the batsman must often change this direction. For example, when playing the off drive, the bat will be oriented in order to face towards the "off side", that is to the right side for a right-handed batsman. Conversely, when playing an on drive, the face of the bat will be more closed, and thus angle more to the left. This can be accurately determined using the inertial sensors by detecting the amount of acceleration in the y axis during the swing. As the bat face is opened, the component of the swing acceleration along the y axis is increased, while closing the face will have a corresponding negative effect on this value. In this way, the angle of the bat during the swing can be accurately determined by the relative strength of the y axis. This is illustrated in figure 4, which shows two example swings for a batsman playing both an off drive and on drive. This figure clearly shows the difference in bat angle between the top types of shot, and was repeatable for all batsman tested during the experiment when playing straight bat shots.

4 Conclusions and Future Research

In this paper we have presented work showing the usefulness of inertial sensors in helping to characterize cricket shots. Using two tri-axial bat-mounted accelerometers, we have shown that it is possible to estimate the angular velocity and bat twist at any instant during the swing, as well as detect the time of impact and other important events. Conducting field tests on a variety of subjects has shown that these results are highly repeatable across a wide range of batting standards and conditions. It is expected that future research will enable to extraction of such features as shot power, shot direction and angle of elevation.

In order to assess the accuracy of such measurements, future research will also utilize a high-speed motion tracking system, which is capable of recording human movements from multiple angles in a laboratory setting. Although it is not possible to utilize such equipment in a match environment, it will serve to verify and further refine the data obtained by inertial sensors, and provide a more accurate basis upon which future research can be conducted.

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