Measuring bat-ball impact location from acceleration

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The ball speed after impact is an important metric in baseball and strongly depends on the bat speed, which can be obtained from an inertial measurement unit (IMU) attached to the knob of a bat [1]. The bat-ball impact location is also important, but in comparison to the bat speed, is difficult to measure. This study considered a novel method to determine the bat-ball impact location from accelerations at the bat knob.

Modal analysis is the study of dynamic properties of systems in the frequency domain [2]. An accelerometer was attached near the knob of the bat and impacted with a force measuring hammer along its length. Bat acceleration and hammer force were recorded at each impact location, from which a frequency response function (FRF) that normalizes the response (acceleration) to the input (force) in the frequency domain was computed [3]. Plotting the FRF magnitude as a function of impact location at a resonant frequency produces a mode shape corresponding to that frequency. The amplitude of a vibrational mode increases with the distance of the impact from the vibrational mode's node location, forming the basis for the proposed bat-ball impact location measurement.

Two batters were asked to swing three different bats (described in Table 1) at a stationary ball. To consider the effect of batter ability, participants were asked to swing with medium and maximum effort (14.6 or 28.5 m/s 150 mm from the distal end of the bat). The study was IRB approved, and the participants gave informed consent. Acceleration in the direction of the ball path was obtained from a wired 2000 g triaxial accelerometer (Endevco 7264H) and sampled at 50kHz for one second before and after impact. An FRF was obtained from each swing. The bat-ball impact location was independently measured using an eight-camera motion tracking system (Vicon Motion Systems, Oxford, UK).

Peak FRF values were taken at the frequencies corresponding to mode 1 and 2 (approximately 300 and 1080 Hz, respectively) for each impact. Figure 1a shows the peak of FRF for each mode as a function of the impact location. Lines were fit to the FRF in Figure 1a on either side of the node locations for mode 1 and 2 (150 and 110 mm, respectively). The peak mode 1 and 2 FRF values from each impact were used to calculate an impact location from the four linear fits. The impact was identified as distal or proximal to the vibrational node by taking the side with the

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smallest difference between the mode 1 and mode 2 impact locations. The reported impact location was the average of the mode 1 and 2 fits. Figure 1b compares the impact location from the acceleration measurements to the impact location from the motion tracking system for bat 2, which had the strongest correlation of the three bats considered.

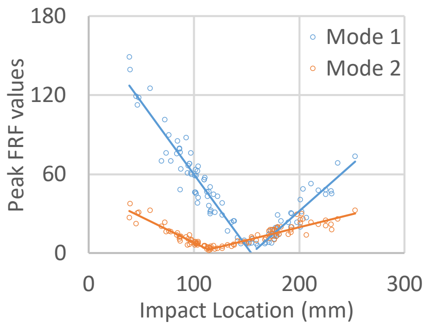

Figure 1a. The peak FRF as a function of impact location for Bat 2. (The distal end of the bat is 0 mm.)

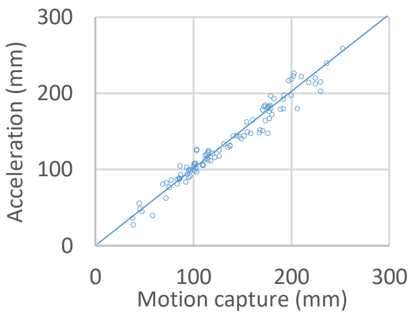

Figure 1b. Impact location comparison for Bat 2. The solid blue line indicates a perfect correlation.

The comparison in Figure 1b was quantified using the Concordance Correlation Coefficient (CCC) for all three bats as summarized in Table 1 [4]. Bat 2 showed the best correlation of near unity, while Bat 3 showed the worst correlation. The low correlation of Bat 3 was because 14 out of 100 impacts were identified on the wrong side of the vibrational nodes. By removing those 14 points the CCC increased to 0.97 for Bat 3. Thus, for this method to be robust, the FRF slopes shown in Figure 1 should not be symmetric about the vibrational node locations.

Table 1. Description and correlation of the measured impact location of each bat.

Code	Category	Material	Length (cm)	Mass (g)	# swings	CCC
Bat 1	Softball	Aluminum	86.4	737	116	0.89
Bat 2	Baseball	Aluminum	83.8	879	101	0.98
Bat 3	Baseball	Composite	83.8	907	100	0.24

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