Miniaturized Wireless IMU Enables Low-Cost Baseball Pitching Training Aid

Ryan S McGinnis
Wake Forest School of Medicine

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[1]Ryan S. McGinnis, [1]Noel C. Perkins, [2]Kevin King

[1]University of Michigan, Ann Arbor, MI, USA
[2]94fifty Sports Technologies, Dublin, OH, USA
email: ryanmcg@umich.edu web: http://www-personal.umich.edu/~ryanmcg

INTRODUCTION

Baseball pitching is one of the most unforgiving positions in sports; one mistake, like a hung curveball or a fastball that tails out over the plate, often results in a run for the opposing team. As a result, there has been considerable research on the free flight behavior of a baseball, and specifically in identifying how a pitcher's input to the ball (i.e. the ball's velocity and angular velocity at release) causes it to break [1-3]. Experiments reveal that the total break of the ball during free flight is proportional to the aerodynamic lift coefficient of the ball [1], is dependent on the seam orientation [1], and is a function of the magnitude of the ball's angular velocity [2]. These studies obtained their experimental data by tracking the position of the baseball in free flight using high speed video analysis systems. This method for data collection is expensive, time consuming, and requires an operator skilled in both the collection and analysis of the data. For these reasons, using high speed video analysis systems in baseball pitcher training is not an option for all but professional baseball programs. However, it is easy to imagine that an inexpensive and non-intrusive method for measuring the velocity, angular velocity, and orientation of the baseball would provide the foundation for an effective training aid for baseball pitching. To this end, we propose a highly miniaturized wireless inertial measurement unit embedded within a baseball (Figs. 1A-B) as a low cost, highly portable and minimally intrusive approach for measuring the baseball's release conditions.

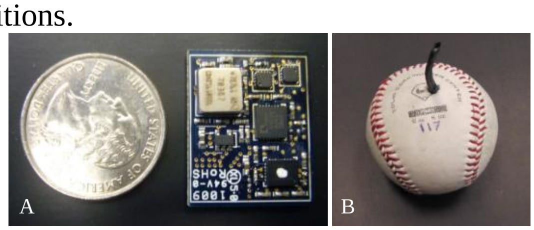

Figure 1: The miniaturized wireless IMU (Fig.1A) is embedded within a baseball (Fig.1B). The black "tail" protruding from the baseball is a switch/recharging jack which, when removed prior to pitching, allows power to flow to the board.

METHODS

The inertial measurement unit (IMU, Fig. 1A), which provides three-axis sensing of linear acceleration and angular velocity, measures a mere 19 X 24 mm and weighs only 4.5 grams including a small lithium ion battery. The unit transmits data wirelessly using a proprietary RF protocol to a USB-enabled receiver which facilitates data collection on a host (laptop) computer via custom software.

Subjects were instructed to pick the ball off of a tee, come to their set position on the mound, and then throw the ball to the catcher in an otherwise unencumbered manner. This sequence of events is readily identifiable in the example data shown in Fig. 2 where the ball motion is also divided into five distinct phases.

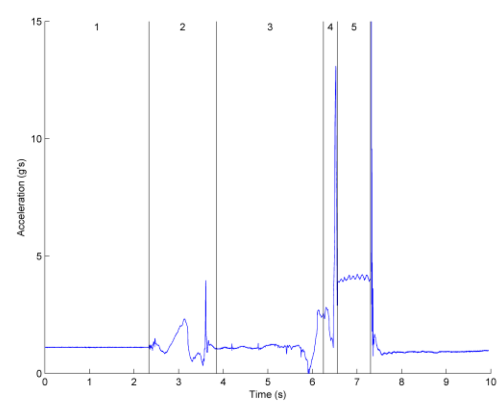

Figure 2: Magnitude of the acceleration measured by the IMU embedded in the baseball for a typical trial. The 5 phases of the motion, as defined by our experimental protocol, are also indicated.

Phase 1 corresponds to the ball being at rest in the tee (Accel. Magnitude of 1g) and ends once the ball is picked off the tee by the subject. Phase 2 begins when the subject picks the ball off the tee and ends when the set position is first reached. Phase 3 is the backward portion of the throwing motion, starting at the start of the set position and ending when the pitcher reaches full arm extension away from the catcher. Phase 4 is then the forward throwing motion starting from the furthest extension position and ending when the ball is released. Finally, phase 5 extends from ball release to impact; the free-flight phase of the ball's motion. These phases were confirmed independently using high-speed video (frame rate of 300 Hz.) which was synchronized with the IMU data using a custom Matlab™ program and using the instant the ball is released as the synchronization event. A video showing the synchronized high-speed video and IMU data is available at http://www-personal.umich.edu/~ryanmcg/BaseballProject.html.

As indicated in Fig. 2, it is clear from the acceleration data where the ball is released from the pitcher's hand. At this instant, the IMU provides direct measurement of the baseball's angular velocity and enables the calculation of its linear velocity and the orientation of the seams with respect to the velocity vector (Fig. 3) following the methods outlined in [4,5].

RESULTS AND DISCUSSION

The difficulty in using an IMU to determine baseball release conditions lies in determining the linear velocity at release, a calculation which relies on integrating inertial sensor data that includes drift error. However, a drift error estimate can be constructed using knowledge of the kinematics of the ball and in doing yield accurate results as illustrated in Fig. 3.

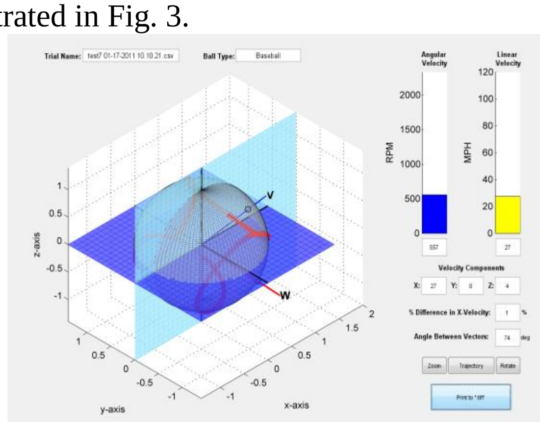

Figure 3: Graphic which displays the linear and angular velocity vectors, and the orientation of the ball at release. These values ultimately determine how the ball breaks during free-flight.

The trial whose results are shown in Fig. 3 was a fastball thrown at slow speed so as to avoid exceeding the measurement range of the sensors. The angular velocity vector's orientation suggests a ball thrown with largely backspin which is consistent with published information about the release conditions of a fastball [3]. The component of the ball's velocity in the direction from the pitcher to catcher is calculated to be within 10% of the value determined by estimating the ball's velocity based on the distance from the point of release to the catcher and the time that the ball is in free-flight.

CONCLUSIONS

The methods employed in this study enable one to determine a pitched baseball's release conditions using an embedded IMU. Specifically, analysis of the acceleration and angular velocity data provide the 1) ball angular velocity, 2) ball orientation, and 3) ball center linear velocity at the instant of release. For the example shown, these values are consistent with those published for fastballs. Additionally, it is shown that the major component of ball velocity is determined with only a 10% error as compared to an independent measure of that quantity.

This novel training aid will allow pitchers to understand, in a matter of seconds, why their last curveball didn't break or why their fastball tailed out over the plate. It offers an immediate and quantitative analysis of a pitch and should prove valuable in helping pitchers learn to consistently throw effective pitches.

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