An instrumented thumb slug for determining a bowling ball's axis of rotation

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Ten Pin bowling is one of America's most popular hobbies and serves as a competitive sport for millions worldwide [1]. One of the most important skills is learning how to spin the ball so that it "hooks." Understanding the ball's rotation can help competitive bowlers improve their shot and the probability of knocking down all of the pins. In the past, inertial measurement units (IMUs) have been used to calculate the kinematics of different objects (e.g., cricket balls [2] and baseballs [3]). Implementing an IMU in a bowling ball has been explored [4]; however, these designs have been bowler and bowling ball specific and not easily adapted for bowlers who use multiple bowling balls. This study aims to design an instrumented, interchangeable thumb slug to overcome these limitations.

We designed a prototype of an instrumented, interchangeable thumb slug capable of measuring the angular speed and axis of rotation of a bowling ball (Fig. 1). The prototype consists of the slug, the IMU housing, and the outer sleeve. The outer sleeve had a diameter of 31.75 mm and was glued into the bowling ball thumb hole. The slug and IMU housing had an outer diameter of 31.75 mm and an inner diameter of 25 mm (note: the inner diameter of the slug would be adjusted to fit the bowler's thumb size). The prototype is similar in size to two popular interchangeable thumb slugs on the market (i.e., the Turbo Switch Grip® and the

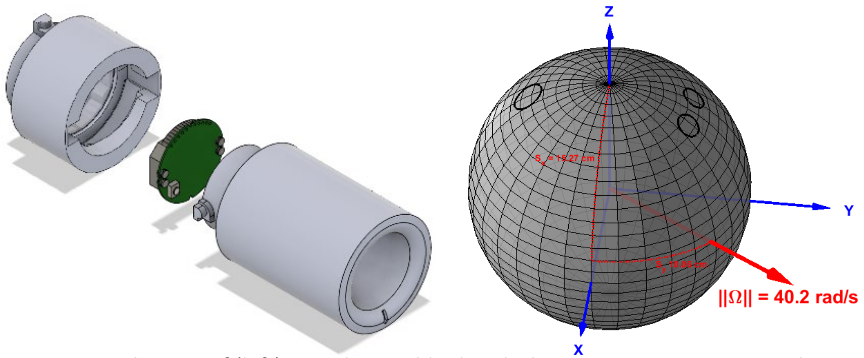

Fig. 1: Visualization of (left) interchangeable thumb slug, MetaMotionC IMU, and IMU housing, and (right) angular velocity vector of trial 4 showing the estimation of the vector occurring 15.27 cm to the right and 10.06 cm above the center of the grip.

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Vise IT©). The prototype was instrumented with a 25 mm diameter MetaMotionC IMU (www.mbientlab.com), which fit tightly in the IMU housing. The slug interlocked into the IMU housing, which interlocked into the sleeve, each using a twist locking mechanism. The IMU was placed 59.9 mm below the bowling ball's surface when interlocked. The prototype was created using a Dremel DigiLab 3D45 3D printer with 1.75 mm Eco-ABS filament.

We tested the feasibility of our design on an 18.29 m bowling lane. Gyroscope and accelerometer data were collected at 200 Hz and transferred to an Android smartphone using Bluetooth. The prototype was able to interchange and lock into two different bowling balls and record data while the ball rolled down the lane and back through the ball return. MATLAB 2019a was used to construct an angular velocity vector in the thumb slug (IMU) fixed reference frame using each time sample of the gyroscope data. Angular velocity vectors were transformed into a ball-fixed reference frame (at the ball's geometric center aligned with the center of grip as shown in Fig. 1) by a rotational transformation using a rotation matrix.

We tested the accuracy of our algorithm using an Innovative© High Speed Bowling Ball Spinner (www.innovativebowling.com). In four trials of spinning the bowling ball about a known axis using the bowling ball spinner, the sensor predicted the axis of rotation with an error of fewer than 0.38 cm (Table 1), with a visualization of the estimated axis of rotation seen in Fig. 1.

Table 1: Actual and estimated positions and corresponding error in the position of the axis of rotation measured as surface distances (S_x and S_y) from the middle of the grip.

Trial	**Actual Position [cm] (S_x,S_y)**	**Estimated Position [cm] (S_x,S_y)**	**Error in Estimation [cm] (S_x,S_y)**
1	(-10.16,0)	(-10.19,0.1)	(-0.03,0.1)
2	(-10.16,10.16)	(-10.11,9.93)	(0.05,-0.23)
3	(15.25,0)	(15.09,0.38)	(-0.15,0.38)
4	(15.24,10.06)	(15.27,10.06)	(0.03,-0.1)

This study shows that an interchangeable thumb slug can be instrumented with an IMU to provide kinematic feedback about the bowling ball. Further studies will investigate the ability to estimate translational velocity and track the ball's path.

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