Poster: Assessing Header Impacts in Soccer with Smartball

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CCS Concepts

•**Human-centered computing** → *Ubiquitous and mobile computing systems and tools;* •**Computer systems organization** → *Sensors and actuators;*

Keywords

Smartball, Soccer, Header Impact, Concussion, Accelerometer

1. INTRODUCTION AND MOTIVATION

Due to the popularity of soccer and the purposeful use of the head during play, traumatic brain injury to soccer players has been a concern for decades. However, there is a sense of urgency now in understanding and preventing concussions better, due to raising public awareness. Towards that end, intra-oral devices such as Vector MouthGuards are being studied [3] to measure the athlete's head's linear and rotational accelerations from impacts experienced in practices and games. But given the players' natural distaste for such intra-oral devices, more palatable alternatives for head impact monitoring are being developed [2]. X2 Biosystems xPatch is an electronic skin patch that is worn behind the ear. Reebok Checklight embeds the impact sensor in the back of a skullcap which can be worn with or without a helmet. Triax SIM-P is placed inside a headband for non-helmeted sports and a skullcap for helmeted sports. While all these devices are much more convenient to wear than intra-oral devices, it is yet to be seen whether they gain wider acceptance, particularly by the millions of amateur soccer players all over the world.

Instead of mounting sensors on the players' heads, we wondered, why not embed the sensors and smartness in the ball? Such a smartball is ideally suited for soccer, since headers, which involve contact with the ball, can cause concussions[1]. Therefore, it is conceivable that impact of headers can be measured by the sensors inside the smartball. Imagine a smartball that beeps (perhaps literally during practice and wirelessly to a monitor on the sideline during official games) upon a "dangerous" header, indicating that the corresponding player needs attention.

[1]While head-to-head and head-to-ground impacts also cause concussions, cumulative effect of frequent headers can be quite significant. To avoid potential concussions due to headers, the US Soccer Federation has banned headers for players under 11.

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There are many advantages with such a smart soccer ball. 1) Instead of 22 players in a game wearing head mounted devices (without forgetting), a single smartball can help monitor impacts on all of them. 2) Once the technology is proven to be accurate, it will likely be deployed rapidly in professional leagues, as there will be less resistance to adoption from players. 3) Rapid adoption of the smartball leads to mass production, bringing down its cost significantly. 4) Affordable price brings the technology within the reach of millions of amateur players too, extending safety features to a wider population of soccer players. For all these reasons, it is worth investigating the potential for a smart soccer ball to measure header impacts and mitigate concussions.

2. ADIDAS MICOACH SOCCER BALL

While there is no smart soccer ball that fits our vision perfectly, Adidas recently released the micoach soccer ball [1], shown in Figure 1(a). It is a size 5 regulation weight soccer ball marketed for dead-ball kick training. Upon a kick, the companion iOS app displays the speed, spin, and flight pattern of the ball. But, this information is inadequate for our purpose of studying header impacts. Therefore, we need to develop a new app to estimate the force of a header of impact. Unfortunately, the ball's internal hardware and its API are not publicly available. Hence, we have to infer the operation of the smartball first. In the following, we present our observations about the micoach soccer ball.

Hardware: The smartball contains LSM3032 chip with tri-axial digital linear acceleration sensor, MSP430F5328 micro controller, and nRF8001 Bluetooth chip. These three components are on a single board which is enclosed in a plastic sphere of about 1.5 inches in diameter. This sphere is suspended in the middle of the ball by 12 bands, which are connected evenly around the surface of the sphere, in the same configuration as the faces on a regular dodecahedron. In addition to these 12 connections, there is a power cable that connects the board to the induction charging coils on the interior of the ball's surface.

Communication Protocol: The smartball communicates with the companion app (we call it as RealApp) via Bluetooth Low Energy (BLE). To decipher the protocol between them, we develop two Android apps using standard BLE libraries: one to emulate the companion app (called EmuApp) and another to emulate a

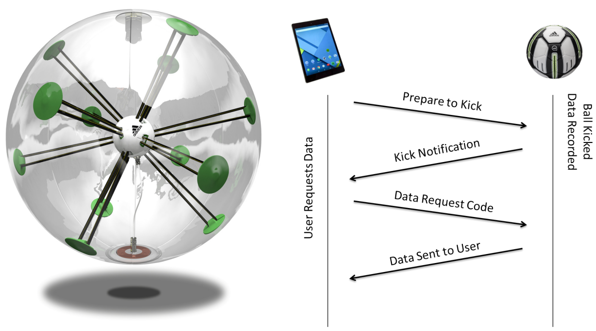

Figure 1: (a) Adidas micoach smartball; (b) The (inferred) protocol between the app and the ball to initiate a kick and gather the corresponding accelerometer readings.

smart ball itself (EmuBall). To eavesdrop on the communication between smartball and RealApp, when RealApp sends a message, it is recorded by EmuBall which passes it to EmuApp, which relays it to the smartball. Similarly, the response from the smartball is received by EmuApp and relayed to RealApp via EmuBall. The inferred protocol between RealApp and smartball to initiate a kick and get accelerometer readings is shown in Figure 1(b).

Recording Headers: Given the current operation sequence of the micoach ball, that records kicks when the ball is stationary, an improvisation is needed to measure the impacts of headers. Once our app issues a prepare-to-kick command, the ball notifies the app the moment it has been kicked. Next, instead of requesting the accelerometer readings, the app issues another prepare-to-kick command, when the ball is midair. Then, the ball treats the header (or any other contact) as equivalent to kick and notifies the app. Now, the app requests for the accelerometer readings and derives the force of the header impact.

Accelerometer Readings: We find that the acceleration samples given by the ball are represented as signed (2's complement) 16 bit integers, with maximum and minimum values of 2040, and -2039, respectively. To map them to the real acceleration values, we need to know the maximum measurable acceleration range. The smartball's accelerometer chip, LSM3032, offers 4 options for selecting the acceleration range (and sensitivity per least significant bit): $\pm 2g(1mg)$, $\pm 4g(2mg)$, $\pm 8g(4mg)$, and $\pm 16g(12mg)$. To infer the smartball's accelerometer range setting, we consider the stationary acceleration, which is found to be around 511. By mapping 511 to $1g$, we can infer that acceleration range and sensitivity of the smartball to be $\pm 4g$. We also observe that after an impact, we receive 1000 samples of accelerometer data per second.

3. IMPACT FORCE ESTIMATION

A key challenge in estimating the force from the accelerometer data from the smartball is that the range is only $\pm 4g$, while the acceleration after even a small impact is much higher. By comparing with the acceleration experienced by an external sensor stuck on the surface of the ball, we have observed that the peaks, particularly those immediately after the impact, are truncated in the accelerometer data of the smartball. Fortunately, the variation in the acceleration experienced by the onboard sensor has a relationship with the impact force. Hence we can predict the impact force with the help of one time training with the labelled data. To exploit the causal linear relationship between the observed acceleration and the exerted force, we pick *multiple linear regression* as our machine learning method.

To avoid overfitting, we extract a few features that have linear relationship with the impact force and train our model with these handpicked features. These features include the width of the first peak which is proportional to the impact time, the amplitude of the subsequent peaks which is a function of the damping factor and the magnitude of the acceleration until the total energy drops below the 10% of the first peak.

We conduct a preliminary evaluation of our force estimation method using a piezo-electric sensor based force estimation setup commonly used in mechanical engineering labs for precision force measurement. This device – referred to as *force-pad* – uses three force sensors to record the varying force at 500 KHz and log it in a oscilloscope in realtime. We simultaneously collect the acceleration data from the smartball and the impact force from the forcepad as the ground-truth. We trained the model with 175 samples and then tested with another 175 samples. Figure 2 compares the estimated force with the ground-truth when the ball was dropped on the force-pad from different heights. All the points are somewhat closer to the diagonal, indicating the promise of our approach and also the need for further investigation.

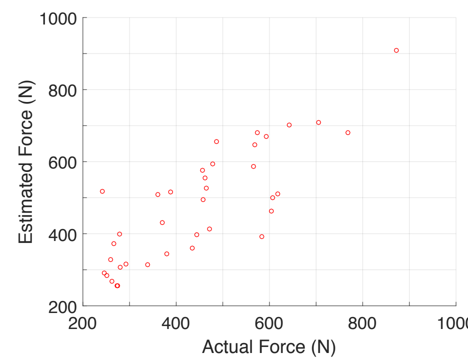

Figure 2: Actual vs estimated force when the soccer ball is dropped on the *force-pad* from various heights.

4. ON-GOING AND FUTURE WORK

The above evaluation considers only the simple case of dropping the ball, as it is easier to obtain the ground truth. We are currently in the process of validating our approach with headers and improving the accuracy of force estimation. Our long term objectives are as follows: Does there exist a threshold that can be applied to the force measured by the smartball to separate potentially unsafe impacts from the rest? Study the relative merits of smartball and head mounted sensors for measuring impacts. Are there scenarios in which each one is better than the other? In case smartball and head mounted sensors sense different aspects of a header impact, a hybrid scheme that inherits the best of both would be a successful outcome of this project.

5. REFERENCES

[1] Adidas miCoach: The Interactive Personal Coaching and Training System. http://micoach.adidas.com/smartball/.

[2] Wu LC, Nangia V, Bui K, Hammoor B, Kurt M, Hernandez F, Kuo C, and Camarillo DB. In vivo evaluation of wearable head impact sensors. *Annals of Biomedical Engineering*, 44(4):1234–45, Apr 2016.

[3] Wu LC, Zarnescu L, Nangia V, Cam B, Camarillo DB. A head impact detection system using SVM classification and proximity sensing in an instrumented mouthguard. *IEEE Trans. on Biomedical Engineering*, 61(11):2659–68, Nov 2014.