I-Ball: A Programmable Sporting Aid for Children with a Visual Impairment to Play Soccer

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Abstract. The Interactive Ball ("I-Ball") is a programmable tonal soccer ball that varies its output based on measurements from an inertial sensor. As a sporting aid for children with blindness and low-vision it makes participation in team sports more accessible without a conspicuous constant tone and in a manner the provides information when stationary. The paper presents the design rationale of the system. Exploitative evaluation with visually impaired users indicates that the encoded information provides utility, but also that noise and wind are complicating external factors that can limit perceptual range.

Keywords: Accessibility, adaptive user feedback, HRI, sporting aids

1 Introduction

"Smart" sporting aids have long been an area of research interest in the sports sciences and biomechanical domains, especially for the analysis and support of elite sports. Commercially, while a plethora of sporting goods and toys is available, they tend to be a rather motley collection of designs and, in general, focused on being entertaining. Instead, the focus of this research is to introduce a programmable sporting aid to make the field sports, chiefly soccer, more accessible to children with visual impairment by assisting with ball localization and motion estimation tasks.

Current solutions have children with visual impairment participate by using special balls with conspicuous noise makers (i.e., bells or simple buzzers) that engender alienation, and provide sparse feedback to the player. Specialized sports, such as goalball [1] and beeper base-ball [2], while active and fun, do not easily allow for a normative experience in which they are able to play alongside their fully-sighted peers [3, 4]. Instead, it is preferable to make common team sports, such as soccer, more accessible. These activities are not only fun, but conducive to the development of interpersonal skills (e.g., sporting terms are part of the vernacular) [5]. From a social perspective, it is important that the players with blindness or low vision have a normative experience and be able to play alongside their fully-sighted peers as team members [3].

Towards this, the paper presents a programmable sporting ball with an integrated inertial sensor module that provides motion information to players via a piezo beeper. It varies tones in response to motion and then focuses on how changes in the tone (pitch, frequency, volume) and action (the extent that various motions couple to output sounds) affect the interaction of both the players and their team members. This paper presents initial tests on the operation and performance of the ball in both an indoor gymnasium environment and an outdoor field. It shows that the adaptive tones do improve mean localization time, but that noise and wind are complicating external factors that can color results.

The ball is programmable. While not explored in depth in this work, one of the advantages of this is that the relationship between the tone and the motion could be varied (e.g., to user or environmental conditions). This additionally allows for more dynamic mappings between the motion and the tone beyond a linear relationship, particularly if the output device (speaker) allows for a wide range of tones.

This paper introduces the basic concept of a programmable sporting aid for field sports such as soccer. A brief background of this domain is given in Section 2. Section 3 presents the design of the "Interactive-Ball" or "I-Ball" as based on a small circuit assembly embedded in a foam soccer ball. Initial trials from this unit are presented in Section 4. The paper concludes with some considerations on the current design and areas for future work from both accessibility and robotics interaction perspective.

2 Background

Sport is an inherently dynamic and spatial exercise. While it may be contended that vision is the spatial system par excellence, people with visual impairments are capable of acquiring a fully global conception of space [6] and may build up a set of spatial relations that are functionally equivalent to those of sighted people [7]; however, due to the limited sensory channels, they do so more slowly and by different means [8].

While a host of electronic aids has been developed [9], these have mostly concentrated on mobility, and primarily towards sensing obstacles in or near the traveler's path and include "robotic" devices such as sensorized canes [10] and range-measuring glasses [11]. Even within the realm of sports, current aids are limited. Beeper balls [12] produce a fixed tone regardless of the balls motion and thus can lead to confusion or frustration [1]. Balls with an embedded bell [13] or those covered in a plastic bag [14] can not be heard when stationary and effect the motion and game-play of the ball as they are often rigidly attached to the ball's exterior. Despite this, there is evidence that these are less frustrating to sighted team-mates and thus allow for a richer form of interaction.

Previous work on "smart" assistive devices for people with visual impairment focused on detecting objects that may obstruct the person and providing navigation guidance [15–17]. Such capabilities alone are not sufficient to play soccer; players need to identify and track the ball while it is moving quickly through the air, on the ground, bouncing, etc.

There is a more global problem of absolute orientation and navigation that is separate from mobility. The wide-availability, compact size, and self-contained operation of commercial inertial sensing elements has led to diverse applications in robotics [18] and embedded systems in general. Yet, reliable in-field motion tracking of agents over extended durations (while close) is not available due to drift and model variation over time. Video based solutions, such as motion capture, are not practical as they are expensive and require a structured environment. Thus, for this particular case, relative motion rates are used as these are less sensitive to absolute localization errors. This is consistent with a non-speech sonification approach as this is better at providing information about an object's relative motion [19].

Robotics provides tools and frameworks to allow for a programmable interface to facilitate adaptive modulation of the (sound) output so as to the encode sensory information needed to conceptualize ball position and spatial motion in a manner that is robust to noise from bystanders and the environment.

3 Design of a Programmable Sporting Ball

An interactive ball (or "I-Ball") has been developed to assist people with visual impairment play sports. It comprises a hollow foam soccer ball and uses a microcontroller to vary the tones emitted by a miniature buzzer based on a motion sensor (see Fig. 3). Since it is programmable, it provides a richer and more diverse form of interaction by allowing the tones to be changed easily.

(a) I-Ball Adaptive Tonal Interface (b) I-Ball User

Fig. 1. (a) The I-ball features a smart embedded circuit, a rechargeable battery, and a gyro to provide an adaptive tonal assistance (in inset: ball with circuit installed). (b) A child with total vision impairment playing soccer using the I-ball

Based on this, the I-Ball produces a quiet background tone that is increased in pitch and volume depending on the roll rate of the ball as measured using the MEMS gyro, in this case an Invensense MPU-9150. The design of the ball is based on the needed to present location information about the ball when stationary (hence the base tone) and to information about the motion of the ball (hence a second variation pitch varying tone tied to roll rate). The microcontroller, in this case a PIC 18F14K22, mixes the tones in a smooth manner so as to minimize conflicting harmonics and minimize dissonance.

3.1 Modes of User Interaction

As noted, sport is not only important for physical exercise, but also social development and peer interaction. The programmable interface affords many degrees of freedom to the designer from playing music files to varying operation by time of day. For simplicity, the study uses simple tones and focuses on the relative interaction via user studies of various tonal couplings to roll rate against a baseline control of a fixed tone (i.e., the standard beeper ball). The buzzer period (T_{buzzer}) in microseconds (μs) is determined from the magnitude of the gyroscopic motion ($\mathbf{g}_x$, $\mathbf{g}_y$, $\mathbf{g}_z$) in (degrees/second) and is given by the following relationship:

$$g_{\text{mag}} = \sqrt{\mathbf{g}_x^2 + \mathbf{g}_y^2 + \mathbf{g}_z^2} \quad (1)$$

$$g_{\text{val}} = min(0, max(g_{\text{mag}}, 2000)) \quad (2)$$

$$T_{\text{buzzer}} = \frac{125000 \cdot 16}{((3/196) \cdot g_{\text{val}}) + (19/10))} \quad (3)$$

Operation of this approach is assessed by monitoring the motion rates of the ball and via user feedback surveys and camera footage that is subsequently analyzed to determine game durations and the level of teammate interaction.

4 Evaluation

The I-Ball has been prototyped within a foam ball and is undergoing field testing. Initial feedback on the ball suggests that the extra interaction flexibility afforded by the programmable interface allows for a richer interaction and longer periods of play by both the visually-impaired and fully-sighted. Exploitative evaluation of the I-Ball was conducted in collaboration with several experts from Vision Australia and Sporting Wheelies in both indoor conditions with younger children and in more dynamic field tests conditions (in this case with adults).

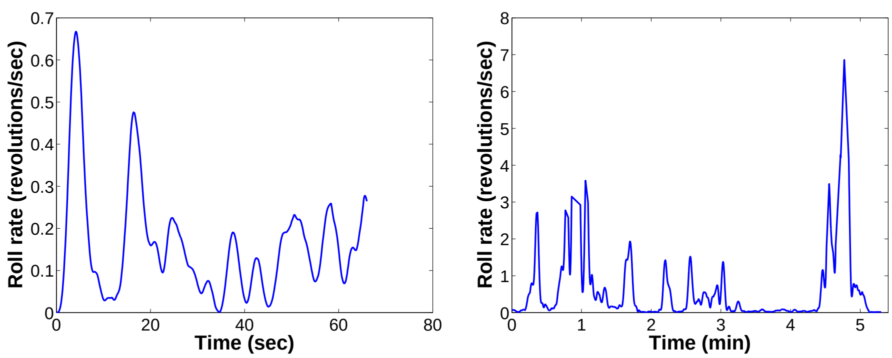
4.1 Gymnasium Testing

An initial, indoor evaluation of the I-Ball was performed in a gymnasium as part of a regular set of sporting exercises conducted by Sporting Wheelies in which there were 12 participants (not including staff). The ball was evaluated in two sporting activities. The first one was a team ball passing game in which the ball is kicked back and forth between a coach in the center and participants on an outer ring (see also Fig. 2(a)). In this activity the user is blind-folded (as some of the visually impaired retain partial eyesight and as the game includes participation of their siblings) and has to rely on the sound of the ball as well as cues given by the (sighted) coach when passing the ball. The tones helps the user assess the location and rate of the ball. The second activity is individual dribbling (shown in Fig. 2(b)) of the ball towards a soccer goal whose location is known in advance. Here the tones help the user track the ball and its reaction (chiefly angular speed) to being kicked.

(a) Team Ball Passing Game (b) Individual Dribbling Game

Fig. 2. (a) After locating the ball, a participant is about kick the ball back to the coach in the center who will then kick it to the next player in the circle. (b) An expert evaluates I-Ball dribbling.

The response of the ball as measured using videographic analysis shows that playtimes and play frequencies as compared to a conventional beeper ball are increased. The I-Ball's internal IMU shows a relatively rapid gameplay with the ball being kicked about once every 10 seconds. With regards to (sighted) teammates, it is found that after the players get familiar with the ball and over its novelty that they find it less distracting than a standard beeper ball. The motion as recorded by the I-Ball is low-pass filtered (3^{rd}-order Savitzky-Golay) to remove noise and bias. Figs. 3(a) and 3(b) illustrate the motion as seen in both exercises.



(a) Ball Motion: Team Ball Passing (b) Ball Motion: Individual Dribbling

Fig. 3. (a) Ball passing using the I-Ball shows a relatively smooth gameplay with little downtime and relatively quick passing cycles (∼10 seconds). (b) In the case of dribbling the distance is longer and the ball needs to be dribbled multiple times. The I-Ball supported the relatively swift/strong style engaged due to the distance which results in higher roll rates.

Subjective evaluation of the ball was positive, but noted that the sound of the beeper could not be heard clearly from a distance. Simply making the ball louder can be distracting at close range and is not efficient. Thus suggesting the use of an adaptive volumes and/or tone depending on an estimate of how far the ball is from the user.

4.2 Field Testing

More dynamic field testing of the I-Ball was performed outside in a grass field. In these initial tests several experts from Vision Australia examined the more dynamic performance of the I-Ball. This involved both rolling and throwing motions between three players arranged in a 20-meter triangle.

(a) Throwing (b) Catching

Fig. 4. Initial outdoor evaluations of the I-Ball have been done for dynamic ball motions associated with (a) throwing and (b) catching. These tests confirm that sonic localization can be challenging when the ball is moving quickly and that noise and wind are complicating external factors that can limit perceptual range.

These tests helped refine assumptions on the sonification of the ball and on the perceived loudness of sound. For example, the use of a buzzer, while more energy efficient than a speaker, has limited tone pattern variations and its sound can be masked by other similar sounds (such as the warning buzzer of a reversing vehicle). Mechanical issues are also non-trivial as the forces and velocities encountered can be large, which particularly stresses the packaging and closures (in this case, Velcro). Unlike indoor spaces, there is no structure for the sound to reverberate, thus resulting in an apparent attenuation and more challenging localization, particularly for catching tasks. As with indoor sports, the tests show the importance of communications between the players as part of relaying information about the ball's motion.

4.3 User Surveys

Participants additionally were able to provide qualitative design feedback via user surveys. Some highlights of the feedback received (as categorized by function) include:

- Sound emission effectiveness and directional feedback:
  - The sound emission allows participants to hear where the ball is coming from almost all of the time
  - Intermittent beeping transitioning into beeps which are closer together when the rate of the ball increases does help
- Judgment of Ball Speed:
  - When the ball is moving back and forward within a small space 3-4 metres, the ability for the alternation in sound is hard to pick up and hence cannot be used that well within this range to judge speed/rotations.
  - Once participants are further apart (5m or more) the ability for participants to pick up changes in rate of motion are more readily made
- Ball location when it is possessed by another player:
  - The ability to judge the location of the ball of course becomes more difficult the further the participant is away from it
  - Open spaces compared with closed indoor spaces naturally decrease hearing levels due to a number of factors such as lack of sound reverberation and the inclusion of more background noise.

5 Conclusions

The I-Ball is introduced as a programmable, adaptive sporting aid to beneficially assist those with a visual impairment participate gently in social sporting activities such as passing motions in soccer. Exploitative evaluation of the I-Ball has shown that while an adaptive tone does provide motion guidance, it can be masked by environmental and mechanical factors. Motion analysis of the ball shows engagement and that a diverse set of users can quickly intuit the motion and positional information conveyed by the buzzer. Qualitative user feedback indicates that the I-Ball is interactive and fun, but there is scope for a better methods of sound transmission to the user.

6 Future Work

Future work will consider hardware usability improvements based on the current analysis. For example, the use of a speaker array would produce sound more uniformly, could provide greater levels of sensory substitution by more richly modulating motion information in the sound, and would allow for customization of the tones so as to better address environmental conditions and user needs.

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