Master's Thesis (2013)

Augmentation of Ball Sports using a Wireless Sensor Ball System

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Abstract

The digital evolution of sports allows for new, interactive, experiences and opportunities for investigation, especially in areas of entertainment. Technologies that integrate seamlessly into sport, like officiating systems, digital referees and slow motion playback has created a higher demand for sports-related content. Recent development in Augmented Reality as an application of sports-based interfaces have also sparked a movement-based interactive entertainment boom.

By applying interactive technology to sport, we discuss the notion of "Digital Sports"; where the sports themselves offer not only the physical competitive entertainment, but digitally enhanced features that are context-sensitive. For example, in professional tennis, the service speeds of the ball are displayed to show spectators and players alike quantitative skill of the player. Similarly, by applying this approach to games with the intent of interactive entertainment - we can explore the possibilities of both new novel interactive sporting interfaces as well as contribute to the enjoyment of traditional sports.

In this research, we investigate the digitalisation of sport using Dodgeball as a pioneer case study. We first look at Dodgeball as a sequence of atomic events that makes Dodgeball a playable game and sport, and use these metaphors as a building block for Augmented Sport. We then develop a throwable interface using wireless embedded sensor systems to capture real-time quantitive data in order to detect these metaphors mechanically using heuristic methods. We employ wireless modules for both Ball-Player and Ball-Host communication to detecting nearby players whilst relaying sensor data to a host PC system. We propose methods using such data to detect events such as throwing, catching and bouncing - all of which have significant value within the game of Dodgeball. Using these method, we add value to Dodgeball via the addition of sound effects as our application, and evaluate this in areas of timing and user feedback.

Throughout the design and development processes of our system, we found that

hardware limitations should be considered in low latency, high performance sports. Player recognition via proximity RF health sensors network, ANT+, is also feasible however were found to have low reliability with regards to responsiveness and accuracy. Deterministic methods developed for the classification of impact events such as catching and bouncing gave a very high accuracy in controlled conditions.

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Chapter 1

Introduction

1.1 Technology in Sports

Sports has been around for centuries and with the growth of human ability, the requirement of technology to accurately measure this movement (as well as supplement it) has also been growing. With the Olympics and FIFA, and other sporting authorities creating a growing demand for technology, the advances of systems to support the growing participation and spectating of sports cannot be overlooked.

One other area of research that has experienced explosive growth is the Augmented Reality in movement-based interactive entertainment. Ping Pong Plus [21] pioneers this idea with novel application of Augmented Reality using a Sport as a base environment. We then ask the following question, is it possible to argue the trend of technology in sports to introduce augmented features to traditional sports?

Sports can be considered a form of play, where the play is physical, competitive [13] on top of being organised (making it a official physical competition). However, on the other side of this spectrum is intellectual contest; where the growing competitive video gaming such e-sports is starting to make an appearance.

In a digital game, the rules and gameplay are all decided digitally and there is no real need for a human to decide the winner as the game itself is designed to automate this decision. However, in sports this decision is made by referees, whose job is solely to keep the decisions strict and non-biased. In ball sports, there has been emerging technologies that help supplement the decision-making process. In Professional Sports, the Hawkeye System [14] uses high speed camera technologies to assist in giving a non-biased accurate decision as well as provide users with additional, quantifiable (ball speeds, spin rates) information that cannot be obtained by spectating alone (Figure 1.1).

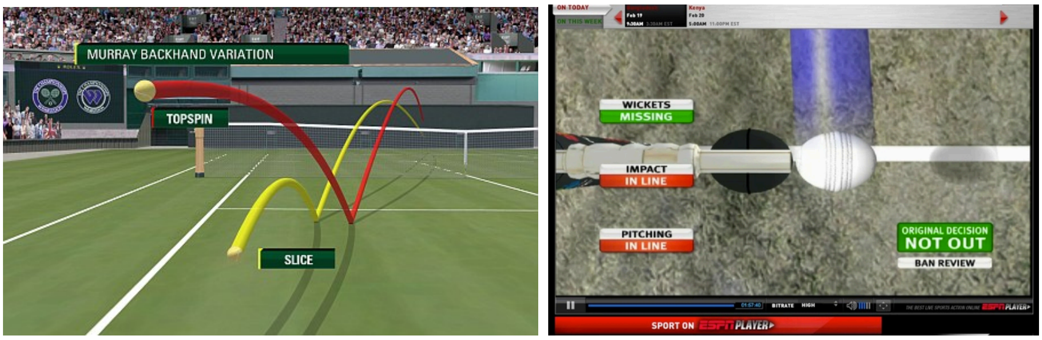


Figure 1.1: Hawkeye system using vision technology to supplement spectator sports like tennis (left); and assist in decisions (right)

Izuta [22] et. al initially suggested the idea of "Digital Sports", where digital technology would be used to make Sports into a more interactive experience. The example in their research is a throwable ball with digital sensors that are able to detect ball contexts such as bouncing and location. This created a novel attraction where users would enjoy an interactive ball throwing experience. Although there is an obvious gaming and entertainment aspect that can be derived from this direction of research, a further step can be suggested to apply such technology to traditional ball sports.

This research investigates a case study of Dodgeball, a ball sport that is internationally known and has been played for years. By applying digital technology to dodgeball, it aims to present an design approach to bring quantifiable data into the context of sports, to build a foundation toward digitally enhanced experiences for players, spectators and organisations alike.

Figure 1.2: Video Game Dodgeball : Super Dodgeball Brawlers (2008)

1.2 Problem Definition

Figure 1.2 is a screenshot from a digital game called "Super Dodgeball Brawlers" [36] released in 2008 that uses the concept of Dodgeball in a video game. Classified as an action sports game, players of this game are to defeat their opponents by striking them with balls until the opponent's health is depleted. Characters are able to use special effects, to deal greater damage to or reduce damage from their opponents using very novel game mechanics. The traditional aspects of Dodgeball (as a sporting activity) are still evident, but appear now to be more of a game due to the digital transformation.

In the physical dodgeball equivalent, players are normally eliminated on a single strike. Players are then rotated out and in depending on the rules of gameplay. Rules that officiate how balls are handled and fouls are called have a deciding factor for player elimination. In general game play, referees make these calls and are subject to bias and incorrect decisions. Here, the introduction of digital technology in this sense will not only assist referees to determine correct calls, it will also allow data that is not normally quantifiable (such as impact strength, or ball speeds) data, much like in the example given earlier.

1.3 Research Objective

This research attempts to build upon the digitalisation of sport by taking a case study of Augmented Dodgeball as a step toward the conceptualisation of the idea, "Digital Sport". It will explore various processes that focus on the breakdown of Dodgeball as a form of play, digitalisation of events and measurable content, and augmentable features of dodgeball as both a physical game and competitive sport.

With the increase of technology in sporting tools and equipment[26], it is not surprising to see sensors inside balls [20]. By using a modified sensor ball similar to that of the Bouncing Star [22], it is possible to obtain context-sensitive, near real-time quantifiable data that can be used as insight toward transforming a traditional sport into a digital playground for the Digital Sports concept.

To summarise, this research offers insight into the process of digitalising a sport by:

1. Identifying key elements and contexts of a sport (in this case Dodgeball) that can be subject to augmentation and quantifiable, mechanical sensing.
2. Designing and constructing a Wireless Sensor Ball System that achieves this mechanical sensing.
3. Applying the mechanical sensing as a means to Augmentation of said sport, Dodgeball.

1.4 Document Structure

This chapter generally introduces the nature of the research, including the problems that are observed/assumed to exist. It also has a look at the objective of the research in regards to the defined problem.

The second chapter discusses related research and previous work. It will go into detailed solutions that have been provided in the past or trends in movement-based interactive technology and discusses areas of improvement as well as justifying the approach that this research will take to solve the research problem as well as its positioning.

The third chapter introduces a detailed proposal of the research. It will illustrate the idea of Digital Sports that will be used as the underlying theme that is the motivation of this research. This chapter will then describe in detail, the approaches and clear goals that the remaining bulk of the paper will attempt to solve.

The fourth chapter looks at the dynamics of dodgeball as a sport. It will analyse and breakdown the rules and events within dodgeball. It will then illustrate the areas of augmentation that is possible within the scope of this research.

The fifth chapter illustrates the ball prototyping for the system developed to augment dodgeball. It discusses both hardware and software processes that was used in this research.

The sixth chapter talks about the features that were added to supplement the data analysis, namely the detection of players through the use of wireless sensor devices.

The seventh chapter introduces the methods of data analysis of the system. It focuses on the development of algorithms that will allow the research to achieve the goals set in the third chapter including a discussion and evaluation where appropriate.

The eighth chapter will introduce an application that was created to demonstrate a proof of concept of the device. It will also discuss issues that arose during practical application of the system as well as user feedback that was obtained regarding the direction of the research.

The ninth chapter will enter discussion in regards to the results of the previous sections. It will look at several issues that arose and can arise during the design process and expand on areas of future work and applications.

The tenth chapter concludes the research and comments on the strengths and weaknesses of the process.

Chapter 2

Related Work

In this section we discuss the recent development of areas of interactive technologies within sporting fields and digital play (by association of augmented reality applications). As the notion of digital sports encompasses a large application area, literature from both movement-based interactive systems as well as sports-centric design will be reviewed.

Firstly, this paper will discuss movement-based interactive entertainment, in particular those of a digital gaming-based nature. To first discuss the placement if this research we must first aim to create a understanding of human movement-centric interactive gaming, namely Exergaming and Exertion interfaces. It will then move onto device-based solutions for digital play, in particular throwable interfaces and other sports-specific examples. We then move to look at commercially available sporting assistive technologies as emergent technologies in sport.

2.1 Movement-based Interactive Entertainment

As we are faced with the increasing obesity epidemic, research regarding the encouragement of physical activity to sustain physical fitness in everyday life is in high demand. By integrating the requirement of active physical activity in technology, researchers aim to promote health in everyday situations. One particular area of this is entertainment: by engaging the user of a technology both physically and mentally, users can achieve healthier lifestyles without the focus on fitness.

Exergaming is designed around the deliberate requirement for physical effort [29] to promote health in gaming, which is a growing sedentary activity in daily life of children and adults alike. Exertion Interfaces, introduced by Mueller et al. [25] suggests that this promotion can be taken further; with such interfaces requiring intensive physical exertion as a base interaction metaphor for gaming and digital play.

2.1.1 Exergaming

Exergaming is now a common term used to denote [34] video games that are a form of exercise. Although exergaming does not completely overtake in the role of exercise, it is used as a motivator for physical movement in an environment where activity is not required (couch and TV gaming). Examples of such commercial developed exergaming systems such as the Nintendo Wiimote (Figure 2.1, right), or Sony EyeToy®. One notable example of an exergame would be Dance Dance Revolution®(DDR) (Figure 2.1, left) in 1988. An international survey conducted in 2006 by Hoysniemi [15] suggests that an exergame such as DDR has positive effects on areas such as player physical health and social interaction.

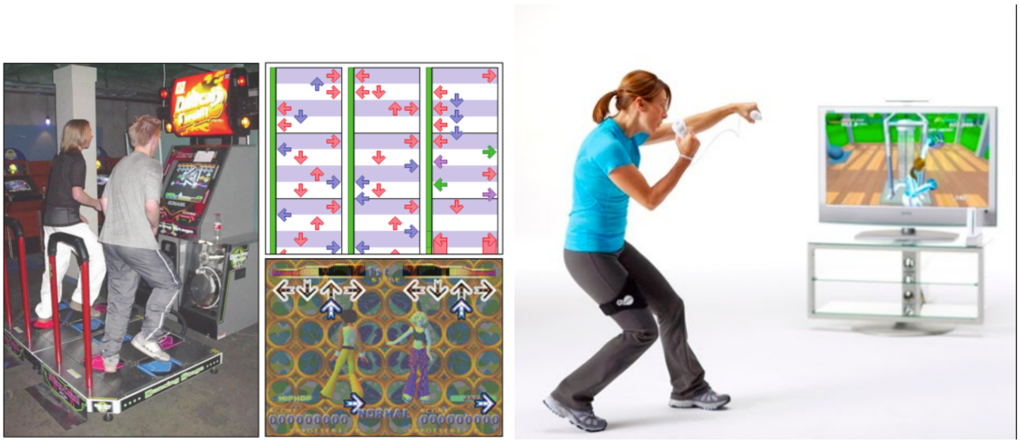


Figure 2.1: Commercial exergaming: Dance Dance Revolution (left) ; a Wiimote®-based video game (right)

2.1.2 Exertion Interfaces

Exertion interfaces branches from Exergaming where exertion of physical effort is essentially required and a necessary element for gameplay. Controllers of exergaming, such as the dance mat from DDR, or motion controllers of other gaming systems can be considered forms of Exertion Interfaces given their application. The notion of an Exertion Interface was initially explored by Mueller et al., discussing the application of long distance sporting activities [25] that build on traditional sports using computer interaction. Digital Sports brushes against this concept with the idea of sports having the requirement of player movement and actions in order to be played (as a part of the game), and thus this section will discuss the implications of these types of interfaces and how they related to the idea of digital sport.

Mueller asserts that the exertion of effort in a physical activity, commonly found in a sporting context, promotes enhanced enjoyment of said activity as well as improved social interaction between participants. One example of this is the initial prototype of "Breakout for Two"[25], where two players would throw or kick a ball against a wall as a form of remote co-operative play. Each player would see their partner via video-conferencing (Figure 2.2) using the projected image on the wall at which they would kick the ball (Figure 2.3). The players would co-operate to clear tiles that were overlaid over the video.

Later examples included "Jogging the Distance", [27], which explored a similar concept using a standard exercise of Jogging and voice communication to connect remote player and increase the sense of awareness using sensors such as heart-rate monitors and pedometers. Users found that by being aware of one another's physical statistics; they were more inclined to compete and exert as well as communicate and encourage one another during the exercise.

The research in Exertion Interfaces strongly suggest that aspects of external motivators, such as a social interaction, encouragement from others, and comparison of performance are key to encouraging sustained active physical behaviour.

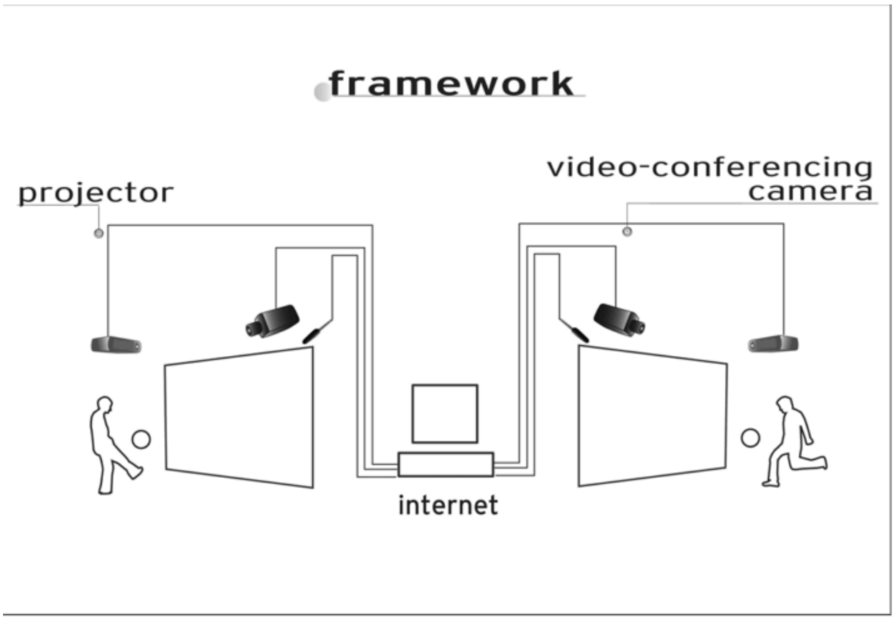


Figure 2.2: Exertion Interfaces: "Breakout for Two" framework

Figure 2.3: Exertion Interfaces: "Breakout for Two" remote play example

2.1.3 Augmented Physical Play

Interfaces that augment an existing or even establish a new physical sporting-like activity can be considered a form of digital sports, considering the integration of technology to sporting metaphors. This form of augmented play or sports stems from the perspective of the activity rather than the interface. Here, we investigate systems that augment play using digital devices with examples of hardware, contributions and discussions regarding augmented play as a form of movement-based interactive entertainment.

PingPong Plus, a pioneer in computer-supported physical play, introduced by Ishii et. al [21] provided an augmented version of a standard sport, table tennis. This system achieved augmented play without physically modifying the game or disturbing the gameplay by customising a table with microphones to detect ball position using sound triangulation (Figure 2.4, 2.5 (left)), and a video projector to overlay appropriate information. Later iterations [37] of this system also offered elements of player and game-sensitive information such as scoring, tactical information such as successful hitting areas and explored crowd-sourced elements such as group-gameplay and full virtualisation (replaying physical game data in a full virtual world (Figure 2.5, right).

In recent research in augmented physical play, BouldAR [7], is work in progress that explores a mobile application that augments a specialised rock-climbing activity called bouldering. It introduces the use of smartphones and vision-based system that overlays special challenge routes sourced by the participants. This idea supports the overgrowing use of technology in sport training for tracking as well as computer-supported collaborative physical play.

A digital map of the climbing wall is synthesised from an actual photo of the wall. The holds on the wall are based on a grid system that can be seen in Figures 2.6 and 2.7. Various paths (sourced by users and trainers) are programmed into the system and over-layed over the video image from the smartphone camera (Figure 2.7).

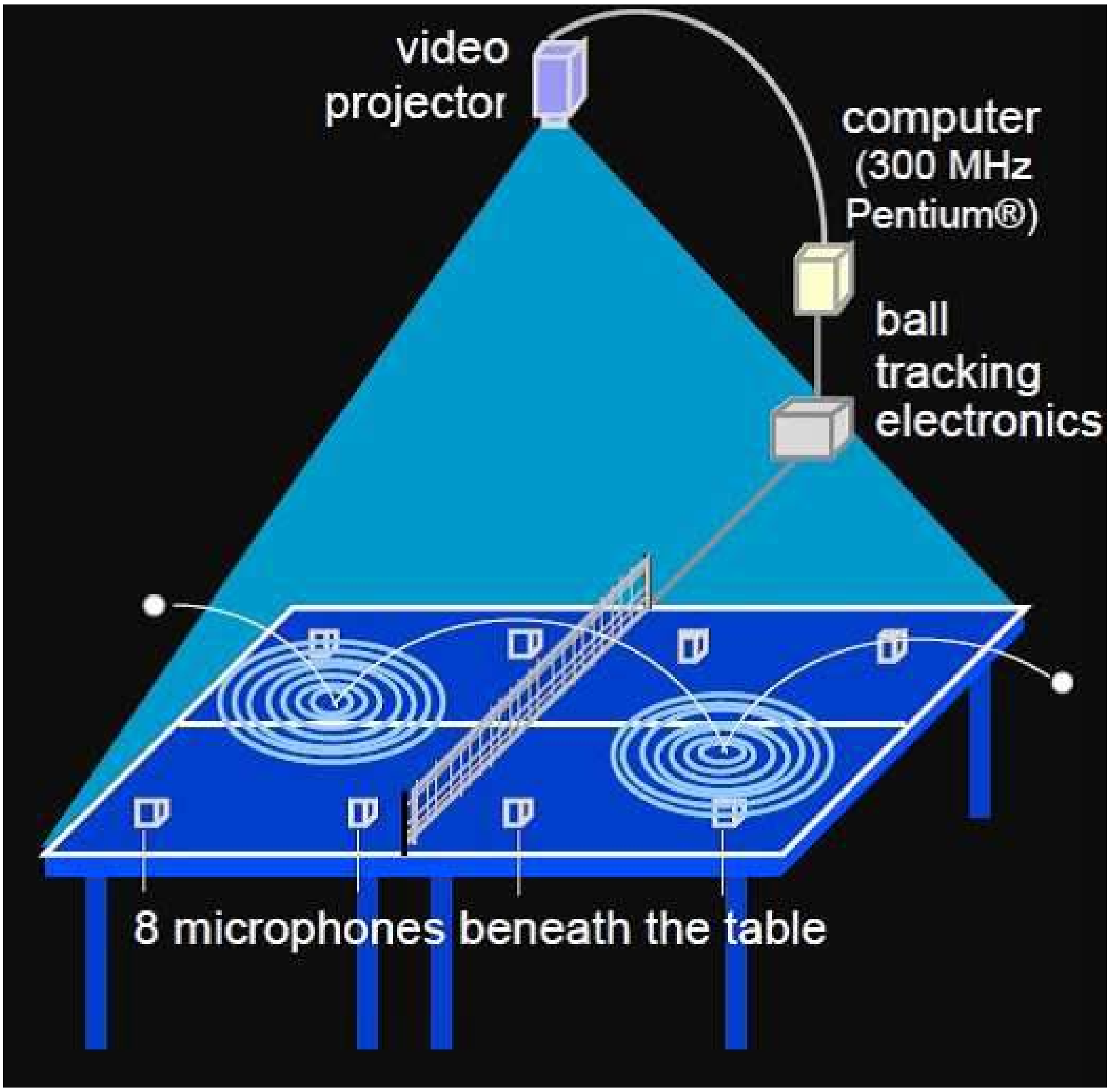


Figure 2.4: PingPong Plus: system overview

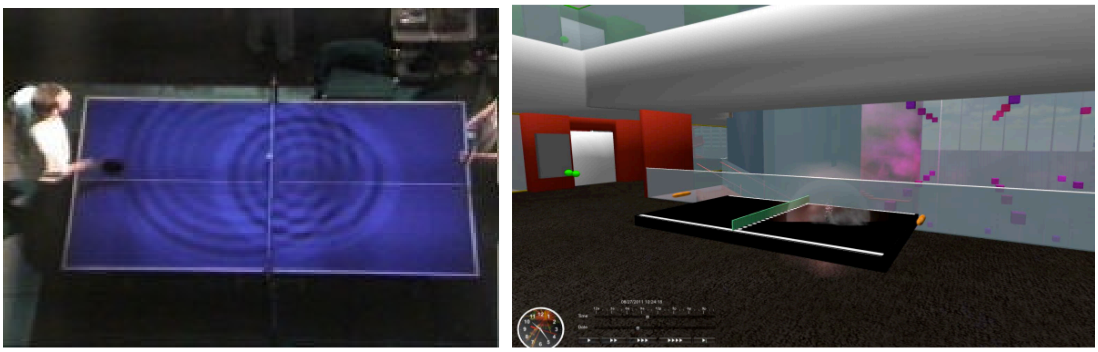


Figure 2.5: PingPong Plus: Demonstration of visual effects (left); PingPong++: virtual playback (right)

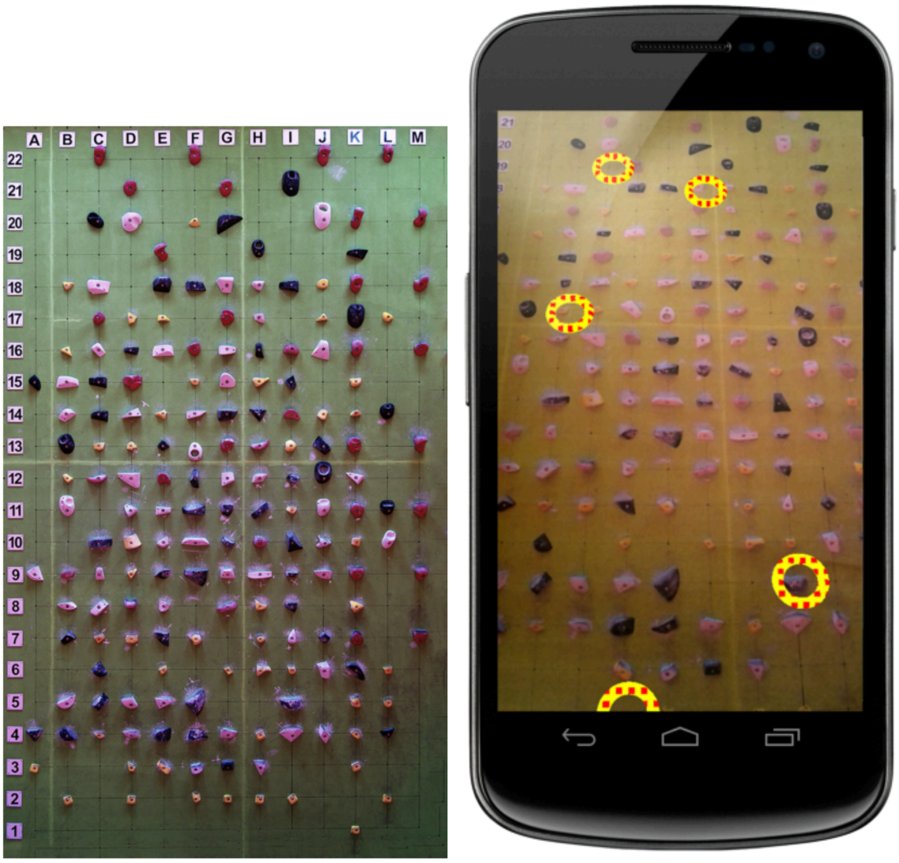


Figure 2.6: BouldAR: Actual climbing wall grid (left); Augmented path overlay (right)

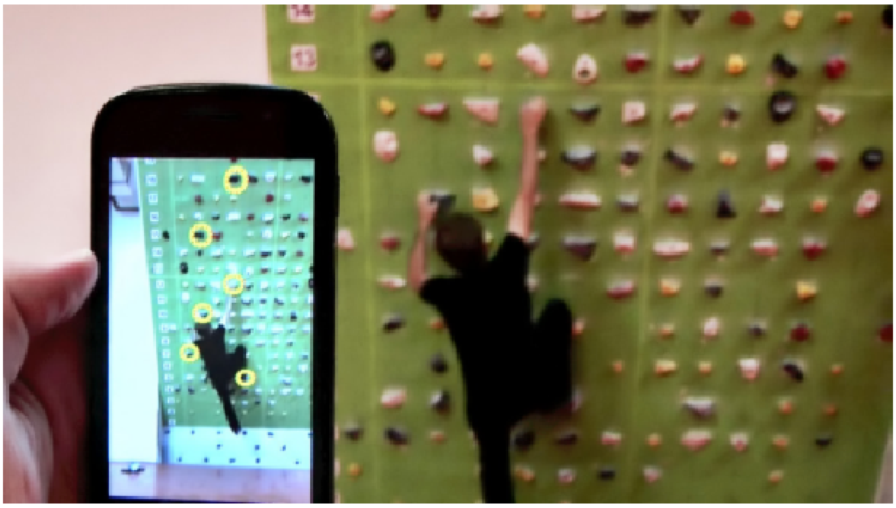


Figure 2.7: BouldAR: Collaboration through a smartphone

2.2 Throwable Interfaces

To date, there exist several throwable interfaces that are used in both fitness-related applications as well as vision-based perspective enhancement. There are several approaches for research this area that concentrate on specific hardware usage such as cameras or sensors. Given that ”throwing”, ”catching” is afforded by the ball, building an interface around the ball on the assumption that it will be thrown gives the ball inherent qualities as a Exertion Interface as mentioned in the previous section (Section 2.1.2).

One notable work is Izuta’s Bouncing Star [22], which initially introduces the idea of digital sports using a throwable LED sensor ball interface. The Bouncing Star consists of a central core consisting of infrared and visible light LEDS, an accelerometer, a microphone and a wireless Zigbee RF module enclosed in a rubber shell (Figure 2.8). Upon contact with the ground, the Bouncing Star will bounce and glow various colours depending on the state of the ball as seen in Figure 2.10.

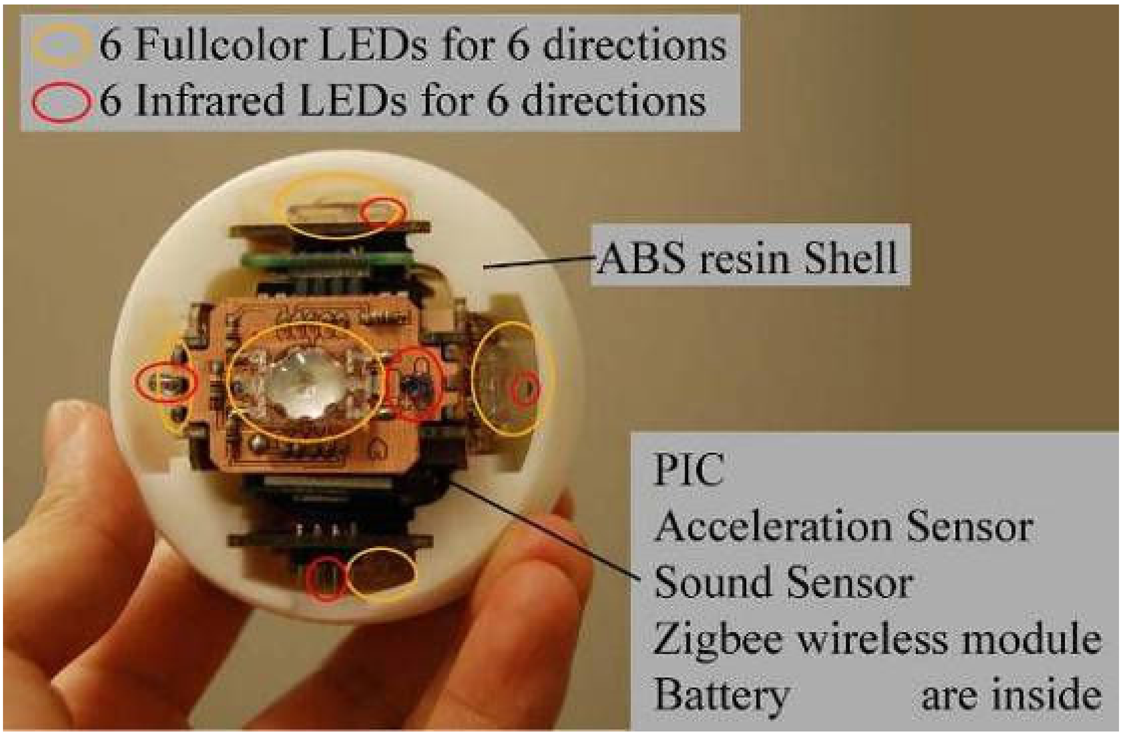


Figure 2.8: Bouncing star hardware

The system was also supported with external vision-based technology on top of embedded sensors and lights to allow for position tracking and field visuals. By applying IR camera detection (Figure2.9), the Bouncing Star system was able to give users unique visual feedback around the position of the ball and also allowed for augmented play with multiple players.

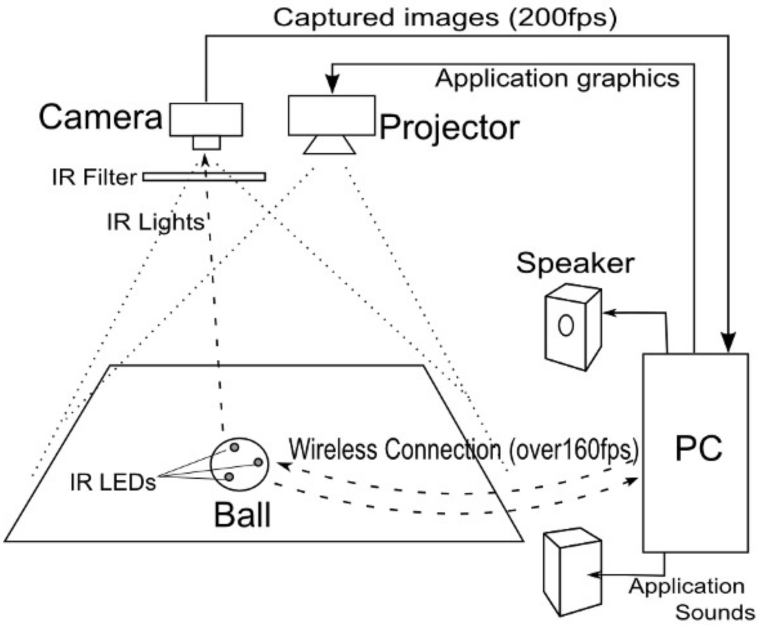


Figure 2.9: Bouncing Star: system overview

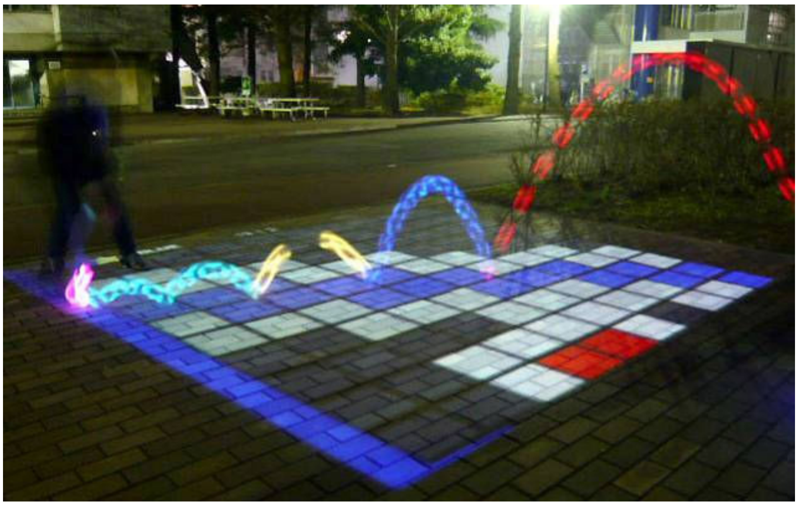


Figure 2.10: Bouncing Star: LED colour change on bounce

Similar to the Bouncing Star, Shootball [31] is a novel gaming system where players throw a ball sensor at a wall to gain points. The system uses a camera to detect the location of the ball strike out of the 4 possible walls in the playing field shown in Figure 2.12. A shock sensor embedded in the ball sends a signal to a controlling PC via bluetooth upon contact with the target wall to determine if the wall is struck (Figure 2.11). This signal is then processed and the image displayed on each of the 4 walls via a project changes accordingly depending on game mode (Figure 2.13).

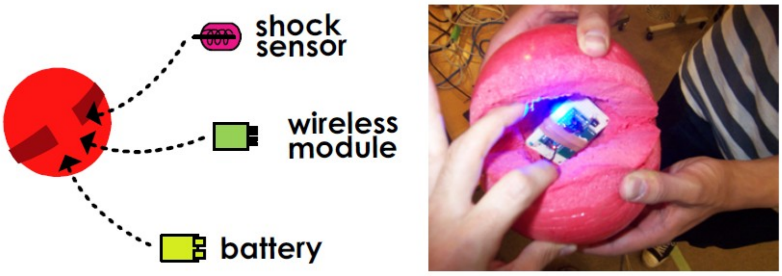


Figure 2.11: SHOOTBALL: System hardware

Figure 2.12: SHOOTBALL: Playing field

The gameplay in Shootball mixes various elements of ball-based game elements. For example, bouncing the ball in Shootball will allow the possessing player to increase their points upon scoring a goal (Charging). There are also virtual variables such as reverse wall panels and special tiles similar to that of a video game or a card game, where if these tiles are struck points are not given but the gameplay is changed.

An example of a ball interface that does not require cameras for position detection is PALLA [32]. PALLA uses "3DI", three dimensional interaction, using a

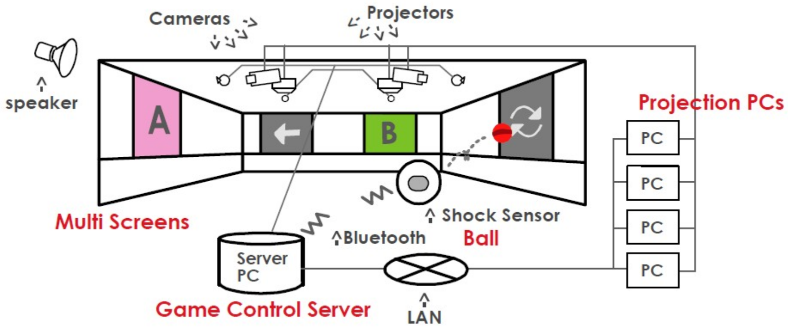


Figure 2.13: SHOOTBALL: System overview

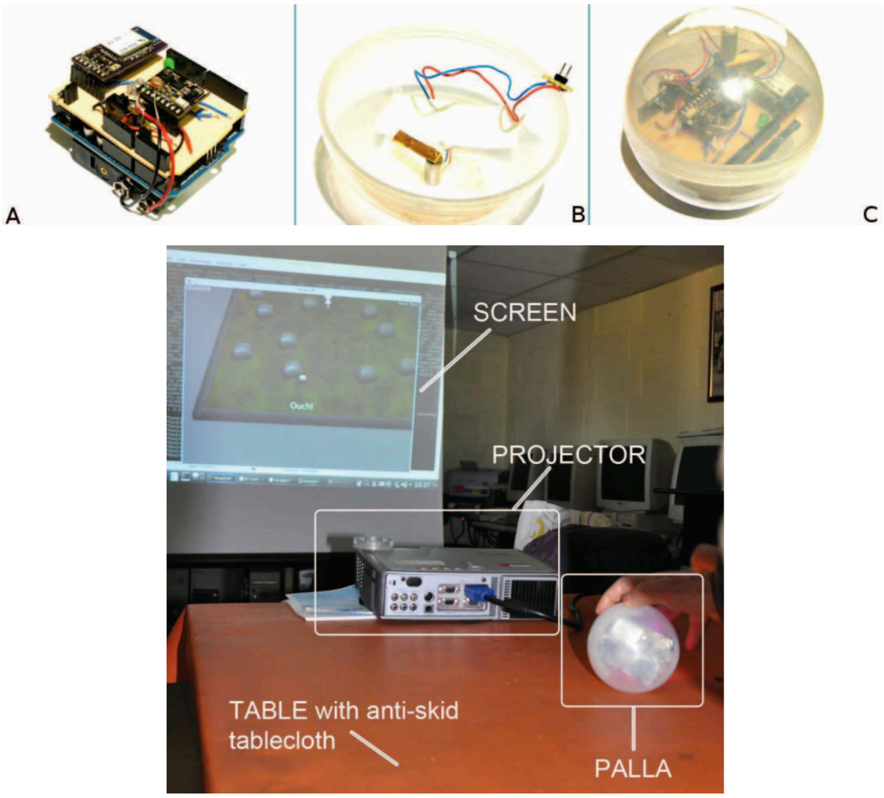


Figure 2.14: PALLA: Hardware construction (top); Wireless rolling control for maze navigation for the elderly (bottom)

wireless embedded inertial measurement unit (IMU) and magnetic sensors allowing for 9-10 degrees of freedom. The IMU is composed of a 3-axis magnetometer, 3-axis gyroscope, and 3-axis accelerometer as well as a high resolution barometer (Figure 2.14, top). PALLA achieves sensor fusion using mathematical algorithms to determine system orientation by adding distortion compensation. It can also calculate position even when the sensors themselves are rotating on the ground allowing for positional information independent of device orientation. This interface allows for a high degree of movement detection and was demonstrated in the form of a 3D motion controller used for elderly users for computer interaction in the form of a maze game (Figure 2.14, bottom).

Digital cameras that are embedded in throwable devices have also been in popular in recent research, revolving around applications in action filming or spectator sports. Dynamic view synthesis using a spiral flight camera, developed by Kitani et. al [23] introduces to spectator sports a novel way of enjoying sports by capturing the perspective of an airborne American football. By integrating this technology into sports, the spectators are also capable of enjoying a new perspective in live sports spectating. This is very similar to the dynamic changing of camera angles in video gaming and supports the concept of digital sports with respect to the enhancement of the spectator experience.

2.3 Sports Assistive Technologies

Another application of technology within sports, one that is growing a very fast rate, is those of technology-assisted refereeing nature. These technologies exist for assisting the decisions and judgements made during play that require human referees to make the call. However, humans by nature do not always provide accurate judgement and thus the introduction of computers to support these decisions is also under consideration. Such systems apply digital technologies such as cameras and computer vision or embedded sensors within sport hardware such as goal posts or player uniforms. Training and coaching is also one other possible application as

Figure 2.15: BallCam!: Image synthesis via a Spiral Flight Camera

players and coaches can track and review their performance.

The Hawkeye system [14] is one system that is widely used in professional ball sports nowadays ranging from Tennis, Football, Cricket, etc. By using an array of high-speed digital cameras with a combination of computer vision for real-time officiating of sporting events. As seen in Figure 2.16, several cameras capture the position of the ball, as well detect relative boundaries of the field, at frame rates reported of up to 1000fps. For example, the system can provide line calling decisions for tennis that can be made 5 seconds after the ball lands.

Similar to Hawkeye, GoalControl [12] aims to provide Goal Line Technology (GLT) for sports such as soccer. The requirements of GLT stemmed from the growing number of incorrect calls in sporting events like FIFA. The GoalControl GLT system concentrates on 7 cameras aiming at the goal area, sampling at 500 frames per second with an accuracy of up to 5mm (Figure 2.17). Results of the decision by the system are sent to digital receiver watches worn by the referee to make the call. This system has been decided by the FIFA body to be used in the official soccer championship that will be played in Brazil in 2014 [10].

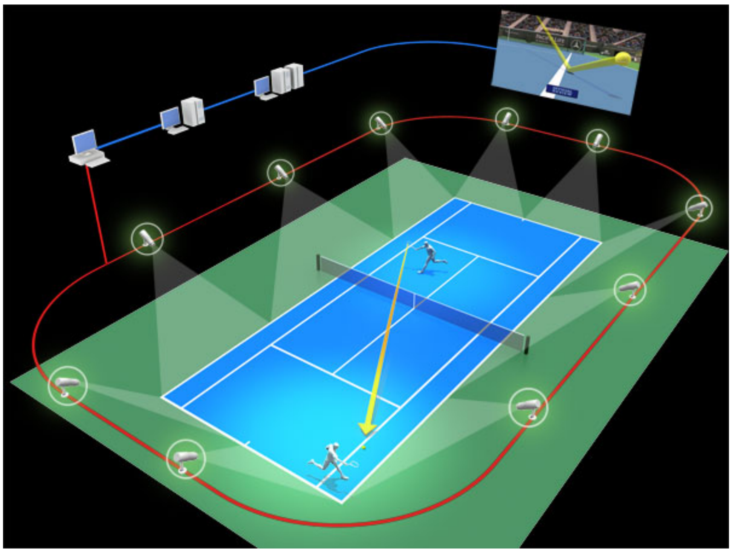
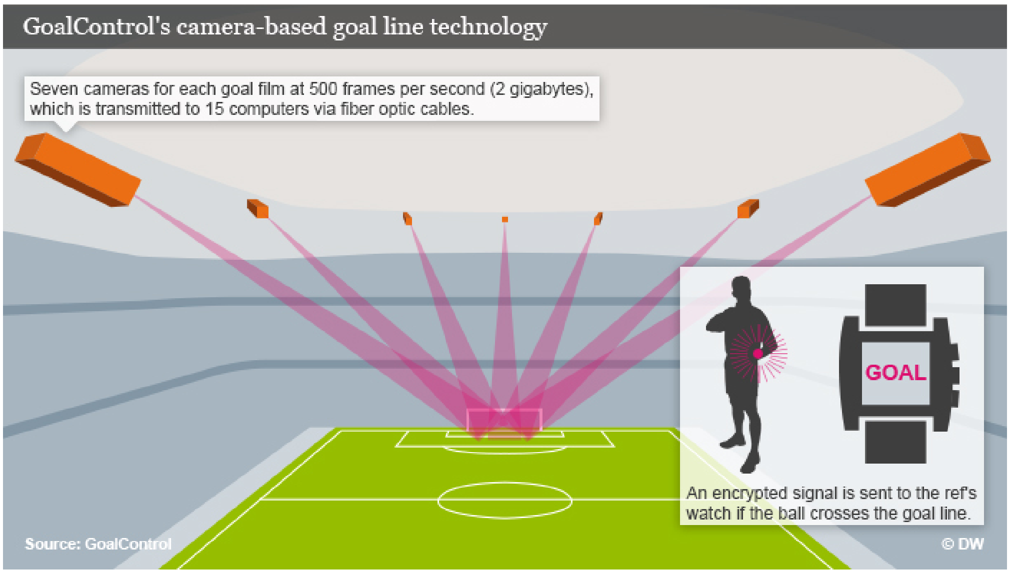


Figure 2.16: Hawkeye officiating system



GoalControl's camera-based goal line technology

Seven cameras for each goal film at 500 frames per second (2 gigabytes), which is transmitted to 15 computers via fiber optic cables.

An encrypted signal is sent to the ref's watch if the ball crosses the goal line.

Figure 2.17: GoalControl officiating system for soccer

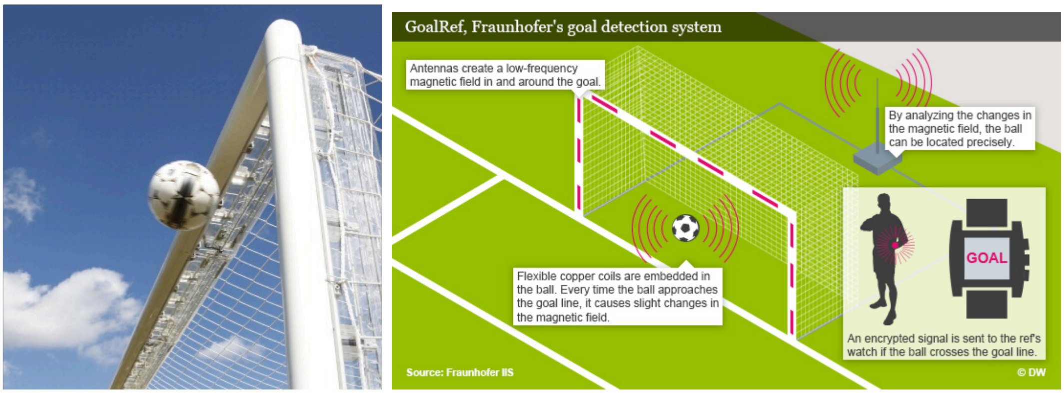


Figure 2.18: GoalRef: Officiating system using magnetic Fields

Another system is the GoalRef system, which uses a magnetic field localised around the goals to detect the ball when it enters within the goal boundaries (Figure 2.18). In this system, the ball is modified slightly such that it creates magnetic disturbance. Goalposts are also modified with antennas to create these magnetic fields seen in Figure 2.18 (left).

Technology used for training, or coaching purposes have also been under the research spotlight. One such area of development that is currently gaining momentum is the Catapult System [6], which uses GPS technology to track players wearing special tags on their uniforms (Figure 2.19). These tags are also used to collect player-intrinsic information such as running speed, exertion direction and tackle power etc. Combined with sport science and motion algorithms, the training experience is enhanced with the use of quantitative tracking of sport-critical information, which then can be used for both physical and tactical improvement.

2.4 Summary

We can summarise from what is mentioned above that technology in sports covers a wide range of applications. It is notable that vision-based technologies are very prominent in movement-based interfaces as well as professional sporting technologies. Vision-based solutions not only offer new perspectives of physical activity but can also provide accurate and reliable proof of movement (as well as

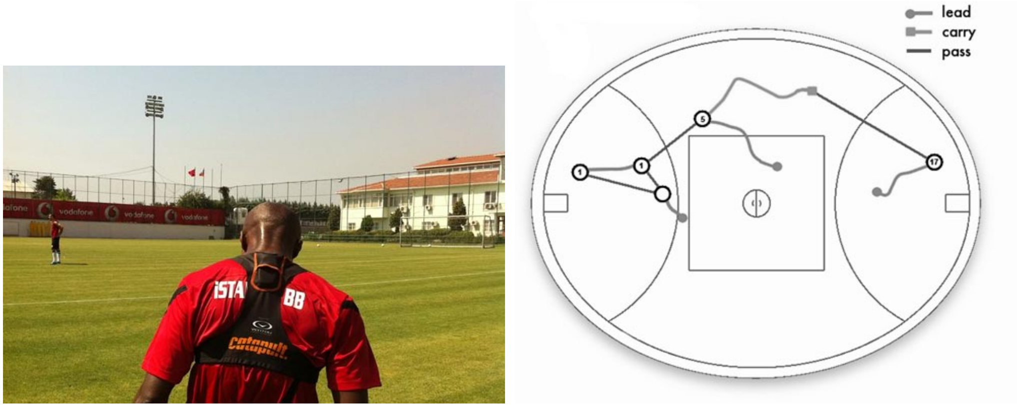


Figure 2.19: Catapult: Professional sports GPS tracking system

disprove incorrect calls) rather than relying solely on human judgement (sports assistive technologies). These technologies benefit the stakeholders of sport in that the sport itself is not affected.

However, moving toward gaming and movement-based entertainment; the use of sensors becomes more common as the application requirements change. Quantifiable data can also be used a motivator, as well as triggers for social interaction as seen with Exertion Interfaces where players communicate their data remotely to motivate and encourage one another. Trends in throwable technology also suggest that the use of sensors within throwable devices (balls) can be used for more than just data retrieval and analysis. Augmented Play such as table tennis (Ping Pong Plus) and simple catch ball (Bouncing Star) can be explored even further with the digital technology described above. However, specific player actions (throwing, catching, striking) as well as ball-player relationships (ball being thrown, ball not in proximity) were not explored.

Applications of wireless, non-intrusive devices in fast-paced, physical activities like in Shootball, Bouncing Star, and Palla as well as GoalRef in the commercial sector encourages communication between a controlling body (a server, or relay PC) and sensor data tracking. Considering the amount of information that can be collected from wireless sensing technologies, it is possible for researcher to obtain a stronger grasp on context information of the sport or activity in real-time.

2.5 Research Positioning

The concept of this research falls into both categories of movement-based interactive entertainment (as an application of the system) deriving from the method applied in Ping Pong Plus, which works off traditional sports as an origin. Having a wireless sensor ball will allow players to freely throw and pass the system, while the system collects information from both its movement and the surrounding players. This system would then open the possibilities into various applications such as sport assistive technologies (supporting referees in judging calls) as well as an interface for augmented reality (augmented ball sports).

Cameras have been shown to increase the complexity of the system by introducing fixed variables such as play boundaries and occlusion when players are moving around quickly (Hawkeye GLT). In a ball-sport, occlusion will happen very often and can often be the cause for incorrect judgements by referees. Thus, it is worth exploring a non-vision-based solution for contextual information, with a plus of increasing the flexibility of the system.

With the goal of Augmented Ball Sports, this research looks on design and implementation of a:

1. wireless
2. camera-less
3. sensing
4. throw-able

interface that can be used to detect key events in a sporting context and thus augment sporting activities such as dodgeball. Discussed in the next chapter, we look to develop a Wireless Sensor Ball System much like that of the Bouncing Star, which also achieves player recognition and context-awareness that can then be applied in competitive ball sports like Dodgeball.

Chapter 3

Research Proposal

In the previous section, the positioning of the theme of this research was briefly introduced. In this section we follow up with the theme by proposing the design, implementation and evaluation of the research. As this research covers a wide area of investigation, we look into exploring the theme of ”Digital Sports” and the implementation and design of a throwable interface as a means to Augmented Sports.

3.1 Digital Sports: Augmented Sports

Digital sports technically the use of technology is sporting applications that are remotely related to traditional sports. Then we have systems like Bouncing Star and Shoot Ball reviewed in the previous section that introduce types of interactions that suggest information retrieved from sporting equipment (e.g a ball) can be used to augmented the reality in which we play sports.

The vision for this research can be illustrated in Figure 3.1. The case study used in this research is based on Dodgeball. Dodgeball essentially is a game where players throw balls at one another with the intention of striking a player rather than a goal. In this augmented example, the quantitative measurements from the ball, as well as those from the player, both of which do not have much significance in traditional game play will be exploited.

For example, in the vision, Player 1 will throw a ball; the ball will detect extrinsic elements such as speed, spin and acceleration as well as extrinsic elements relating to gameplay such as throwing player, and targeted player. By introducing "hit points", common of that found in video games, Player 1 will deal "X" damage to Player 2, dependant on measurable variables from the ball; all of these will can be managed by the ball and the player tags possibly independent of that of a central controlling computer.

What makes this Digital Sports, is that it has a strong reliance on the traditional rules of Dodgeball; we do not aim to create a new game but build upon a current game using technology. The methodology is very much similar to Ping Pong Plus [21] using an implementation approach similar to that of Bouncing Star [22]. We build on these two approaches by adding additional sensing technologies on top of exploring various design aspects that are specific to ball sports.

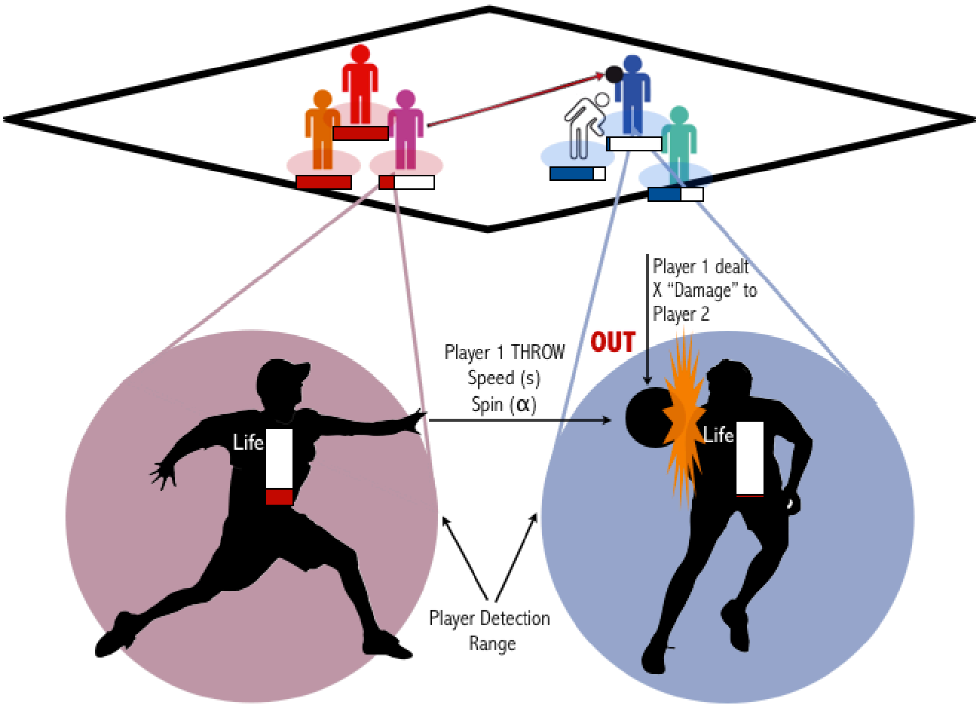


Figure 3.1: Digitalising dodgeball into a augmented sport

3.2 Research Approach

This research aims to apply digital inertial sensing technology in throwable sports equipment for:

1. Automatic sensing of events (and possibly quantifiable data) that occur in sporting activities

2. Using these sensed events, augment sports in such a way that enhances the experience of players and spectators alike.

As previous technologies also used camera-based approaches, we wish to avoid camera based approaches with the assumption that sporting activities such as dodgeball experience a lot of occlusion. Also, by removing the dependency on vision, it is possible to de-centralise the system to only a single ball and player tags. This assumption will also allow us to verify to what extent a sensor-only system is capable of.

By analysing the raw data that we retrieve from sensor data over the course of the study, we aim to be able to automatically identify and classify events that are key to Dodgeball (actions that determine the outcome of dodgeball, like throwing, dropping and catching the ball). With the introduction of sensor fusion [32], we also look to explore various methods in sensor fusion using wireless RF technology as well as inertial sensing in the context of ball sports.

Wireless RF technologies have been previously used (Zigbee) as a means for transportation of data and events to a centralised system that controls effects and logic [22]. However, using multiple RF technologies for connection between players in the field as well as a centralised system has yet to be explored. For example, an extra channel that communicates with player sensors is most definitely possible: this would allow the system to not only obtain information about its state (position, acceleration, impact) it will also be able to communicate information with corresponding players (player activity, heart rate, player status).

3.3 Research Goals

The goals this research can be summarised as follows:

1. Research the case study sport, Dodgeball, and determine the atomic events that can be mechanised.
2. Design and Implement a system that allows real-time mechanical detection methods of these atomic events.
3. Evaluate the system with respect to real-time detection.
4. Evaluate the methods applied using this system for mechanical detection.
5. Demonstrate a feasible application, or identify possible use case scenarios for the developed system or methods.

We also hope to comment on interesting areas that require further investigation.

Chapter 4

Augmenting Sports Case Study - Dodgeball

In this chapter we look at a case study of dodgeball, which will be used as the base template of augmentation for our digital sports approach.

4.1 Background of Dodgeball

Dodgeball is a very traditional physical sport and has been played for centuries throughout the world, most often as a leisure activity and not an official professional sport. It is most common within the demographic of school children to teenagers and is played very often in schools even today for physical exercise (Figure 4.1). There are also professional tournaments for dodgeball, governed by official organising bodies that decide on fixed rules and regulations of how dodgeball should be played as a sport. Each region, however, has very differing rules that will also be detailed in this chapter.

Most ball sports do not involve direct physical attacks on players (Football variations (Rugby, American Football, Australian Rules) do allow targeted tackles however striking the other players with the ball is not permitted) and thus dodgeball is one example of players actively targeting other players as a part of the game. It traditionally teaches skirmish tactics and teamwork and encourages precise movements, quick reflexes and hand-to-eye coordination.

Figure 4.1: Children playing the western variation of dodgeball

4.1.1 Variations

In dodgeball, regardless of the rules the idea is to defeat the opposing team by reducing the player count to zero. This is done by striking the opposing team's players with a throwable ball without the ball contacting the ground. That is, once the ball touches the ground, the offensive effect is negated. Avoiding the thrown balls is one of the key points of the game, hence the name "dodge"-ball. Players hit by the ball that is thrown "on the full" (without touching the ground) by an opponent are normally removed from the game depending on rules. Any balls that strike another players face or head are considered fouls and do not result in elimination. Each region of the world has varying rules for dodgeball. These variations will be discussed in this section.

General Western

The standard court for general western-style dodgeball can be seen in Figure 4.2. As the western variation uses multiple balls initially placed on the center line, each team must first rush to the center area called the Neutral Zone to retrieve a ball to be used for attacking. Throwing the ball is from this area or entering the area of the opposing team is not permitted.

Rules for calling eliminations can be summarised as follows:

1. A player gets hit by a ball thrown by an opposing player (within the field)

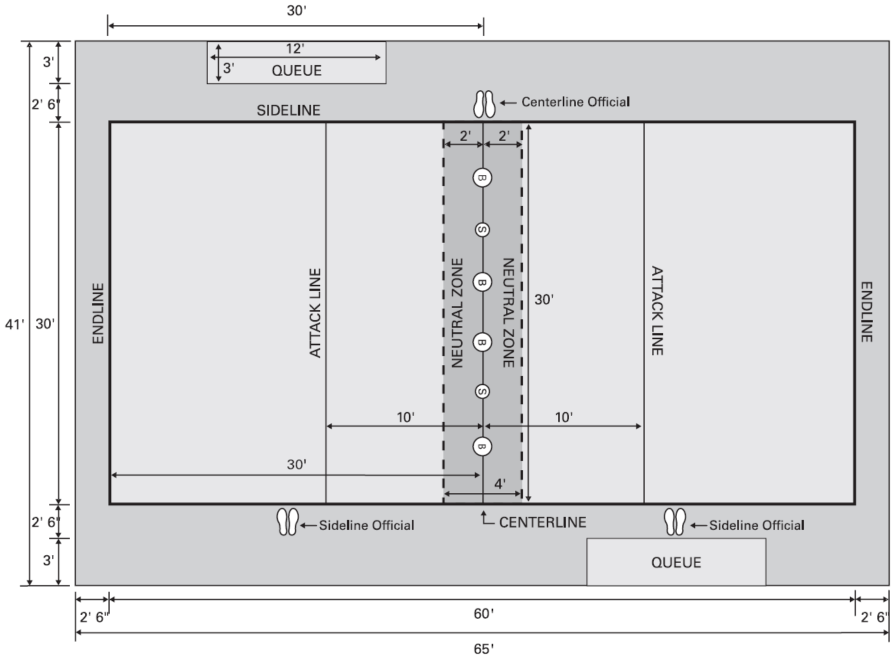


Figure 4.2: Western dodgeball court using 6 balls

   - If the ball lands on the ground, that player is eliminated.
   - if the ball is caught by a friendly player, that player is reinstated and the throwing player is eliminated.

2. A player successfully catches a ball thrown by an opposing player (within the field)

   - The throwing player is eliminated if the ball is held for 2 seconds.
     In this case, one eliminated player from the catching player's team can be brought back into play. (Resurrection)
   - If the catching player drops the ball before 2 seconds, the catching player is eliminated.

3. A player gets hit by a ball that bounces off another player or ball (chain collision)

   - If the ball lands on the ground after hitting the player, that player is eliminated.

- If the ball is caught by a friendly player, then all players hit by that ball are reinstated and the throwing player is eliminated.

In addition to these basic rules, there are novel variations that allow for different game play such as having a medic who can 'tag' people who have been eliminated to reinstate them into play, or players losing the ability to throw or move after being struck once, or no boundaries where players can free roam.

Japanese

The Japanese variation of dodgeball only uses one ball. The elimination rules for the Japanese dodgeball is similar to that of the western version however has several differences:

1. Players whom have their thrown ball caught are not eliminated.
2. If two or more people are hit with an opposing ball, only the first hit player will be eliminated.
3. Players whom are eliminated continue to participate from the rear of the opposing team.
   These players may return to play when they successfully eliminate a player from the opposing team.

This variation introduces the idea of an In-field and Out-field . Players whom are eliminated move to the Out-field (the red area in Figure 4.3) of the opposing side and continue to play: this would mean that the losing team will have a stronger advantage due being able to attack from the rear. Balls can be passed from the In-field to the Out-field for offensive strategy and thus creating a more balanced, challenging variation of a skirmish type game. The yellow sections of the field are used for moving between in-fields and out-fields when players are eliminated or reinstated.

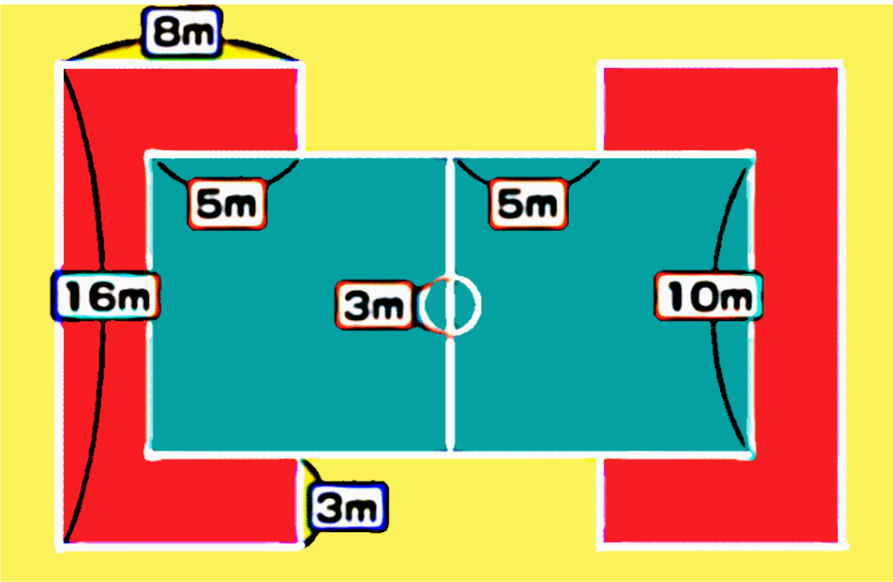


Figure 4.3: Japanese dodgeball court: In-field (green) and Out-field (red)

In western dodgeball, players from a losing team will be overwhelmed by the remaining players in the winning team. However with Japanese dodgeball, since only a single ball is in use and the eliminated players at the rear of the opposing team, balancing is still possible as the remaining players can still pass the ball to the Out-field for offensive support.

4.2 Design Breakdown: Dodgeball

In relation to the goals of this research, the japanese variation of dodgeball was used for the reason that the key element of the game (the ball) consists of a single entity: there is only one ball in play at any given time. This allows the flow of events within Japanese dodgeball to be much more simple to follow, and must more likely to be able to mechanise and subsequently augment. This section looks at the rules, and how we can break down the elements of dodgeball into atomic, detectable events that can be used in mechanisation and augmented play.

4.2.1 Official Rules

The official rules from JDBA (Japanese DodgeBall Association) [4] state that teams consist of 12-20 players, while a normal match is 12 players versus 12 players. There are various foul balls, the main fouls will be summarised in this section:

Overline The ball cannot be thrown while stepping over the boundary.

Double Pass The ball cannot be passed between In-field players, or between Out-field players.

Five Pass The ball cannot be passed more than 4 times between In and Out field. After 4 passes, these must be an offensive throw.

Keep for Five The ball cannot be possessed for more than 5 seconds.

Head Attack The ball cannot strike a players head or face.

Holding The ball cannot be taken from an opposing teams area (players are not allowed to pick up the ball unless it is in their respective boundary)

Touch the Body No player is allowed to make physical contact with an opposing player.

Any of the above fouls will result in the ball being surrendered to the opposing in-field.

4.2.2 Triggers

By investigating the game further, we can understand that the game can be broken down into various atomic events that can be considered in this research. This will also be key for analysing dodgeball gameplay as well as building upon the design of the augmented version of dodgeball.

Ball Caught

A ball being caught, by any player will trigger a type of judgement. This event can be connected to players throwing the ball, passing the ball or bounding off a player.

Ball Thrown

A ball being thrown, can be by a player who is either passing or attacking. There can be assumed that there is no other circumstance where a ball is thrown.

Ball Strike

A ball striking another player would indicate that a player may be a candidate for elimination, depending on the event that occurs after.

Ball Bounce

A ball bouncing off the floor is also very important in the context of dodgeball. It can indicate whether a ball is on the full or a player is out (after getting hit).

Ball Out

A ball going out of bounds can also be used to control the ball's effectiveness. It can also determine the ownership of the ball.

Ball Posession

A player whom is approached by the ball, or picks up the ball, or contests for the ball can be considered an event where the ball possession changes players. This can change the mode between safe throws and 'dangerous' throws that will result in elimination.

4.2.3 Game Flow

We will investigate the game flow as an example of breaking down the events to determine the mechanics behind the game play (as well as the requirements of this research). An example will be given to illustrate how these events will determine the game output. We look at this on an atomic level that can be possibly be mechanised by an automated body. Thus we have a look at the bare atomic events. These events can be identified by \[*event*].

Example 1

```
Ball /possessed by Player 1 (Team A)
Player 1 /throws ball
Ball /strike Player 2 (Team B)
Ball /bounce off the ground
Player 2 declared OUT
```

Example 2

```
Ball /possessed by Player 1 (Team A).
Player 1 /throws ball
Ball /strikes Player 2 (Team B)
Ball /caught by Player 3 (Team B)
Player 2 not declared OUT
```

This will illustrate two events that demonstrate the rules that were defined previously in this chapter that states the deciding judgement for a player who is struck by a ball thrown by the opposing team. *Example 1* describes, in atomic events, Player 2 being struck out by player 1 whilst *Example 2* describes the event of Player 2 being 'saved' by a teammate, Player 3.

4.3 Areas of Augmentation

Using the game flow and triggers described in the previous design breakdown (Section 4.2). One example of this augmentation can be taken from the world of digital play - namely gaming. The game title, Super Dodgeball, developed by Technos Japan Corp as an arcade game shows an excellent example of virtual elements applied to a physical game/sport (however depicted in a video game)[35].

A screenshot of the game depicted in Figure 4.4 shows the video game version of dodgeball that can be used a point of reference for augmentation.

In Figure 4.4, the character indicated with the 1 is receiving quantifiable damage (i.e 9) that will be reduced from that character's corresponding hit points (quantifiable health). Players can control the characters freely and the damage dealt or speed thrown (difficult to dodge) can vary from character to character. The game is played by eliminating the players of the opposing team by reducing their health to zero by repeated attacks. Techniques such as dash throwing, jump throwing as well as dodging techniques such as crouching and lying down etc adds virtual elements that are not usually available in physical play.

Figure 4.4: Super Dodgeball (JPN 1987, NA 1989) game screenshot

From this video game example, we can possibly shift the virtual gameplay elements and portray them in an augmented fashion. As the real nature of dodgeball (reducing the opposing players numbers to zero) and the majority of the rules remain intact, it is worth exploring a physical version of this video game as an ideal concept to represent augmented sports (Digital Sports Application).

4.3.1 Variables

Variables that appear in the game play example can be mapped to values that can be detected by sensors in the physical world. These can be roughly divided into two sections: Physical and Non-Physical.

Physical

Ball Status

The ball's current extrinsic variables: such as a speed of movement, acceleration, impact force, spin, etc.

Possessing Player

The player whom currently possesses the ball. This can also be interpreted into which team has ball possession.

Non-Physical

Player Skill

If the player is more skilful at throwing, dodging, movement around the field, etc.

Player Stamina

How many 'hits' the player is able to withstand before eliminated. If the player's stamina is eliminated then they are removed from the game: thus the player numbers can also derived from this value (so long as the player numbers are known)

By using the game flow example specified in the previous section (Section4.2.3), we can attempt to integrate these variables to create an augmented example:

(+ depicts the augmented elements of the game)

Example 1:Augmented

```
Ball /possessed by Player 1 (Team A)
Player 1 /throws ball
+Ball detects /speed S and /spin X
Ball /strike Player 2 (Team B)
+Ball detects /strike with /force F
Ball /bounce off the ground
+Player 2 /sustains f(X, S, F) damage
(Player 2 stamina reduced to 0)
(Player 2 OUT)
```

In this example, *f(X, S, F)* can be considered a function of real-time data based on force, speed and spin of the ball during the given event.

4.4 Participation-based Research

We conducted mock-dodgeball activities in order to understand the game mechanics and flow. These activities were conducted with a total of 8 people over several games. Statistics such as total number of throws, passes and types of fouls were recorded for standard games (played by researchers).

4.4.1 Experiment: Casual Dodgeball

In the first observation we conducted, 8 participants (Male, aged 22-27 years) played 4 versus 4 dodgeball over 4 matches. The total play time totalled less than 10 minutes. The observations made aim to count the number of significant events (triggers) similar to that illustrated in the Game Flow example in Section 4.2.3.

In Table 4.1, the number of throws and catches were noted. Offensive catches are catches where players successfully take possession of their opponents ball (avoiding

Figure 4.5: Dodgeball casual play experiment

Table 4.1: 4 v 4 Casual dodgeball (4 games) statistics

Game(time)	Throws	Catches	Offensive Catches	Avg. Throws per Catch
1 (1m:02s)	15	3	1	5:1
2 (3m:00s)	30	15	2	2:1
3 (2m:39s)	40	18	4	2.22:1
4 (4m:43s)	63	20	4	3.15:1

a rally between In and Out field players). The ratio of average throws per catch is also noted, where the number is the number throws needed for one catch (can be any sort of catch, e.g. a pass catch or an offensive catch).

In overall observation, there were two types of fouls that were pick up during the games. One of which was the Overline foul (where one of the players threw a ball while over a boundary), and the other the Holding (where a ball is taken from another teams boundary and used to attack) foul. An interesting point to note is that the occurrence of the situation illustrated in *Example 2* (Section 4.2.3) did not occur during the experiment.

There were no particular trends that could be seen in this experiment in terms of player tactics. Once a player would possess the ball, the time of possession was fairly short ($\leq$ 3 seconds) as well as the time it takes for a *bounce* to occur after a *strike* was $\leq$ 1 second.

4.5 Summary

One noticeable point for this case study is that Dodgeball, although having simple rules, can be broken down into atomic events that occur in sequence given the availability of one ball. Even though each region has its own variations, it is possible to systematically decompose these atomic events in relation to both the player and the ball on the assumption that line-outs can be decided externally. The game flow example mentioned above is a clear, easily understandable deconstruction of these events and can be used as a guideline for event detection and automation for the foundation of this research.

Using this foundation, we can then integrate physical and non-physical elements of the sport into a design draft for an augmented sport. This draft will allow us to suggest various augmentation examples as seen in Section 4.3.1 using the variables obtained in real-time from the physical world.

By breaking down the design of Dodgeball, and then observing several casual matches; it was clear that definition and automation of triggers for this particular sport is a key element to any further augmentation. Having a look at the types of augmentation available given these triggers and events has given an insight into how important these triggers are for determining the gameplay of a sport. Therefore, work toward designing a prototype that is able to sufficiently detect these events is important, and we will look at several techniques to achieve this as well as validation for these methods.

Chapter 5

Ball Prototyping

In this section we describe the hardware and software prototyping of a ball system. The section consists of an overview and devices the ball into two sections, namely the hardware and software configuration. As the ball underwent various iterations of prototyping, these improvements will be also be discussed as the functionality is introduced. The proximity detection feature, for player detection is one feature that will be discussed at the end of this section, as well further in detail in a separate chapter in this paper.

5.1 Throwable Ball

In this research we look to present a throwable system. This system that is capable of wireless transmission of real-time sensor data that can be used in a fast-paced, impact sensitive environment (i.e Dodgeball). Our proposed system is required to be designed with the target goals defined in the previous chapter: to be able to determine atomic events relevant to dodgeball with the intention of augmenting these events with real-time sensor data. We would then require the engineering of both hardware and software aspects, which will be discussed in detail in this section. Figure 5.1 shows the general system set up for the ball system.

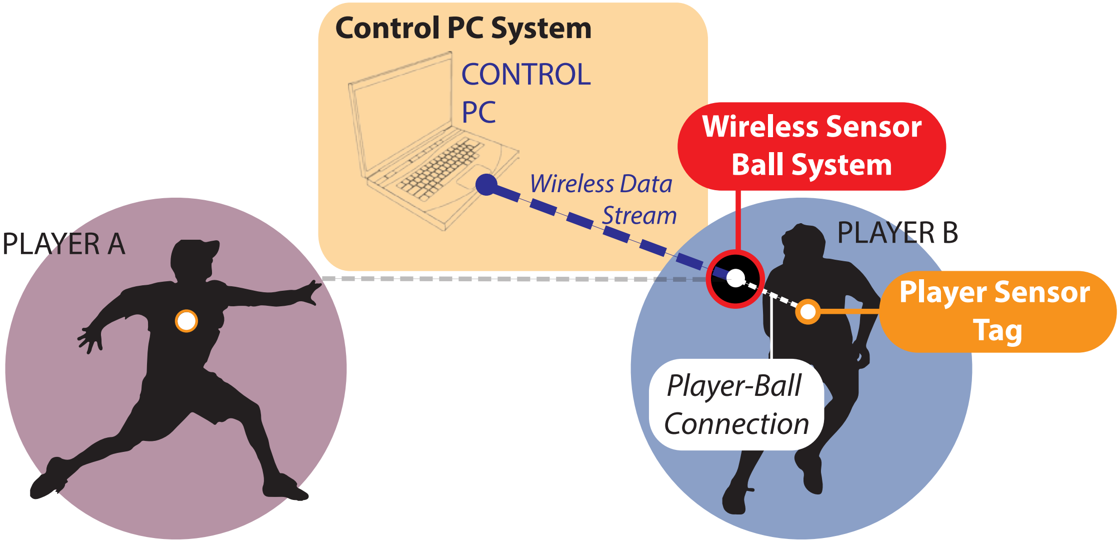


Figure 5.1: General overview for wireless ball system

5.2 System Architecture

The overall system architecture can be illustrated roughly in Figure 5.2. The hardware configuration consists mainly of a microprocessor connected to sensors and wireless modules while the software modules for each particular platform handles the data processing from sensors or wireless communication.

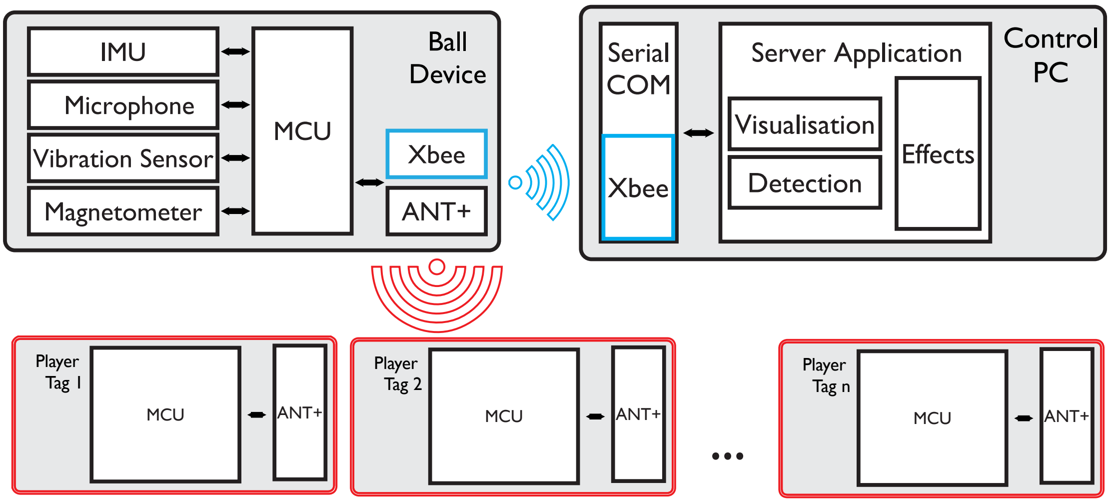


Figure 5.2: Modular system architecture

5.3 Hardware Configuration

Hardware of the system can be broken down into several modules. We can consider the sensor interfaces to the microprocessor as one module (each of which has individual modules to read from each sensor). There are also two communication modules (Near and Far) and sensors with the latest prototype. These are described in the following sections. The early prototypes are also introduced as a bridging point to arrive to the current prototype.

We use two particular micro controllers in our prototype. The first generation prototype used an AVR-based Arduino [2] electronic prototyping microcontroller, and as the iterations went on, we shifted to use an mbed [24] prototyping controller to enable communication via the near (ANT+) protocol. The third revision of the hardware can be seen in Figure 5.3.

5.3.1 Digital Sensors

Initially, several digital sensors were integrated into the system as a means of retrieving live information from the ball during play. These sensors consisted of a combination of inertial sensors, as well as vibration sensors and an electret microphone.

IMU *6 Degrees of Freedom*

The inertial measurement unit, IMU, is packaged as a gyroscope and an accelerometer. These measure up to ± 16 g with a rotational speed of 2000°/second; a combination of these two components are complimentary and result in 6 degrees of measurable freedom namely: *x-axis, y-axis, z-axis* acceleration and angular velocities around these axes; *roll, pitch, yaw.*

Accelerometer *Analog Devices ADXL345* [16]

The ADXL345 is a 3-axis accelerometer capable of detecting measurements of up to ±16g of acceleration in 3 axes, it is also capable of sensing various types of activity (tap, free fall, etc). It is accurate of up to 3.5*m*g (0.034m/s^2) depending on resolution (±2g).

Gyroscope *Invensense ITG3200* [18]

A 3-axis gyroscope, ITG3200 is a MEMS gyroscope capable of detecting angular velocities with an accuracy of 14.375°/s. 16-bit resolution is available with this device allowing for high resolution on top of high accuracy.

Both of these devices use a I^{2}C interface, which is a 2-pin interface for micro controllers to send commands and retrieve data.

Magnetometer *FreeScale MAG3110* [17]

The MAG3110 is capable of measuring magnetic fields with an output data rate up to 80 Hz equalling sample intervals of up to 12.5 ms. The magnetometer is used for detection of magnetic fields and generally used for detecting the orientation of devices. Sources suggest that it can be used for alignment and calibration of gyroscope skew.

Microphone

The microphone is simple sound sensor that detects sound pressure levels that occur within the ball. In an enclosed device, the microphone may even pick up the smallest of movements due to friction occurring within the ball.

Vibration Sensor

Similar to the microphone, analogue sensors such as the vibration sensor is set to detect vibrations that will be supplemented in the future section.

5.3.2 Wireless Radios

There are two wireless configurations that is built into the ball system. As mentioned before, one is to cover long range, low latency data communication and the other close range, low power proximity detection.

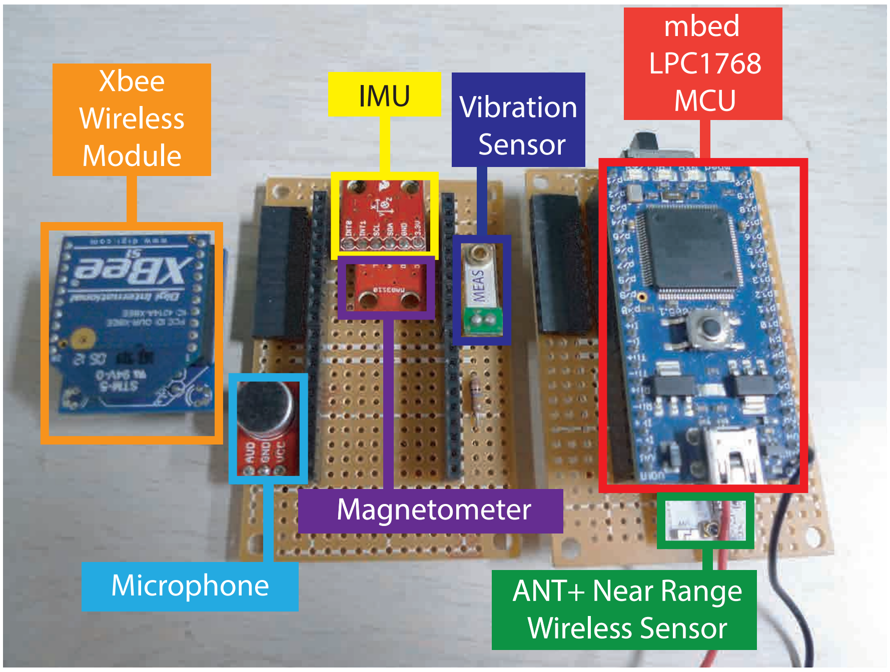


Figure 5.3: Third generation prototype supporting ANT protocol

ANT^{TM}+ supported wireless RF radio *nRF24AP2* [19]

The wireless module used for ANT [9] connectivity is a breakout board built on around the Nordic Semiconductor low power 2.4GHz nRF24AP2-8CH transceiver chip. The libraries used to support these were developed by the BeatCraft project [5]. This protocol is growing in the area of sensor networks with sports and health sensors; and thus is ideal to employ with future prospects of player sensors.

Xbee®802.15.4 wireless RF radio *XB24-API-001* [8]

Xbee adheres to a IEEE specified 802.15.4 protocol, over a similar frequency of 2.4GHz that supports various network topologies such as point-to-multipoint and peer-to-peer. This module acts as a direct connection bridge to a control system for the streaming of live data.

Both these systems use a serial UART interface (2+pin) to communicate with the microcontroller.

5.3.3 Sponge Casing

As standard dodgeball in Japan uses a safe, sponge ball, we chose to use a similar ball as our base. This base is commercially available and can be purchased in various sizes that confirm to the standards set by JDBA. The specifications of a JDBA-certified dodgeball can be seen, as well as a comparison to our prototypes can be seen in Table 5.1.

Table 5.1: Dodgeball and prototype physical specifications

	JDBA-Certified	Ball System (Rev.1)	Ball System (Rev.3)
Circumference(cm)	65-67	65	65
Radius(cm)	21	21	21
Weight(g)	370-390	230-240	375-385

The Rev.1 and Rev.3 (Figure 5.4) systems of the prototype are the Arduino and Mbed versions respectively. The difference in weight through the revisions is mainly through addition of parts, and substitution of microcontroller architectures (3.3V Arduino to 5.0V (9.0V powered) mbed) as well as hollowing out of the of base sponge (MIKASA STD21 to MOLTEN STS21).

5.4 Software Configuration

The software for the system is spread over two platforms, one that exists within the PC as a streaming server and the other being the firmware to extract data from the sensors as well as configure connectivity between the wireless modules. Each of the software systems will be outlined overall, followed by an in-depth explanation of each of the software modules for data extraction. This data is then compiled into a serialisable packet, and then transferred over the air via the wireless serial line

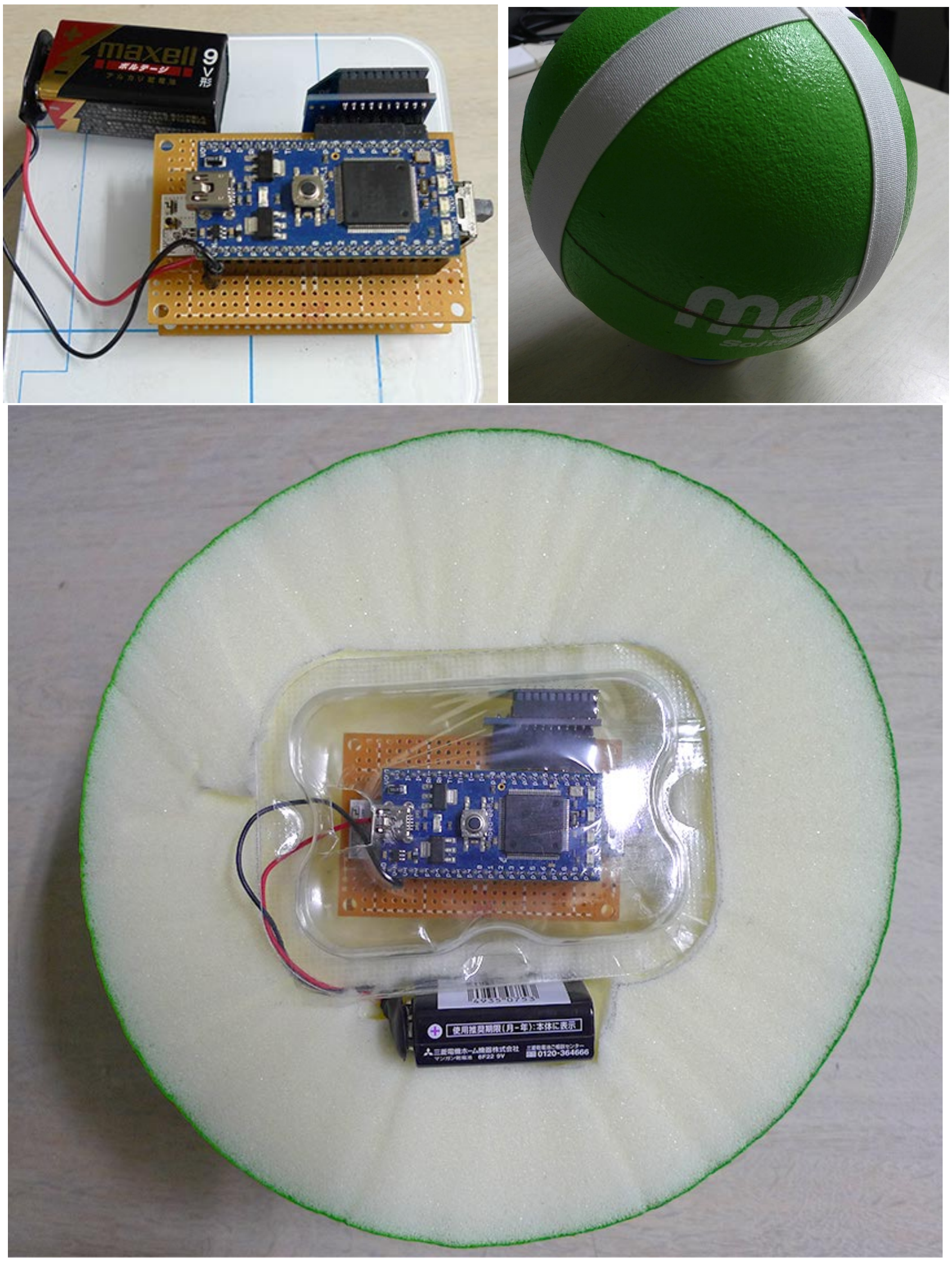


Figure 5.4: Third generation prototype (Rev. 3) embedded into sponge ball

to the PC. Figure 5.5 illustrates the simple flow of logic within the microcontroller to obtain the data from the sensors and wireless modules.

5.4.1 Serial Communication

In the prototype system, data was streamed via serial UART communication over the air through a wireless channel created by the Xbee Network to a PC (using an Xbee reciever [1]). The MCU's key role in this implementation was to relay the sensor information as promptly as possible over the air to the receiving computer. As seen in the flow diagram (Figure 5.5), the communication is of simplex nature as there requires no commands to the microcontroller from the governing system in the streaming application.

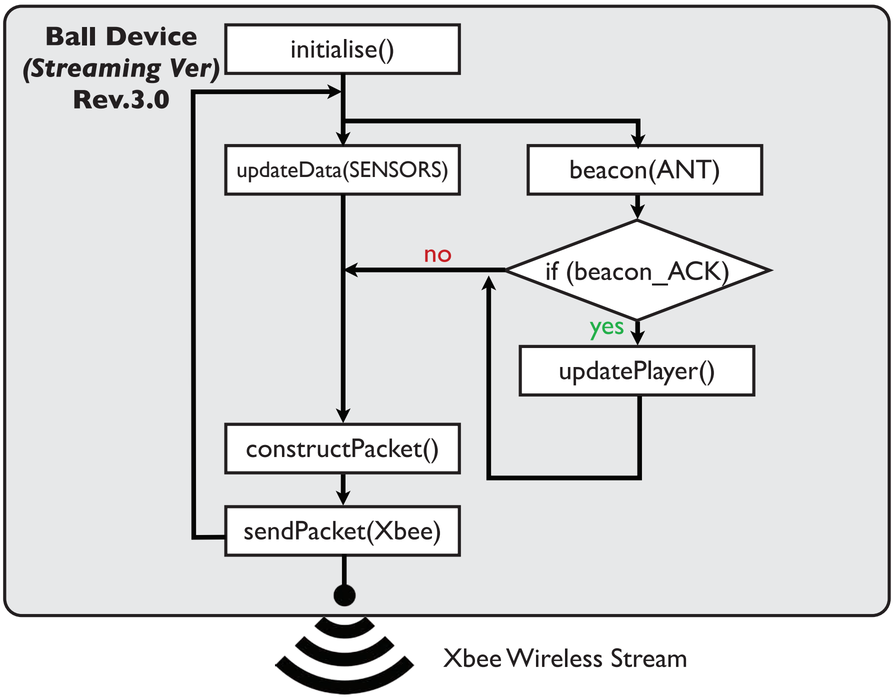


Figure 5.5: Software flow diagram for ball data communication

The *beacon(ANT)* function noted in the streaming flow diagram depicts the ANT+ searching for nearby players. This logic will be explained in more detail in later chapters (Chapter 6).

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[1] Xbee Explorer USB via Virtual Serial COM Port

updateSensors use the I^2C protocol to obtain data from the ADXL345, ITG3200, and MAG3110 using a static delay of 1ms (arbitrary delay to allow the timing of all sensors to settle).

constructPacket compiles all the data into a serialised character packet with standard delimiters. The packet, in the form of a unsigned character array, is transmitted via *sendPacket(XBee)* to the XBee network.

5.4.2 Hardware Interrupt-based Events

One unique feature for the hardware used in this system are the hardware-based interrupts, one of which can be particularly used for detecting instantaneous movements (or taps). As mentioned earlier, the IMU (the accelerometer in particular) is capable of detecting various acceleration-based events: tap, double tap, free fall and inactivity. There are two particular types of hardware interrupts that were investigated during development. The list below the two hardware interrupts that are supported by the ADXL accelerometer to be used in this system. Each have two variables that can be adjusted for appropriate interrupt triggering.

Tap (*DURATION (ms), THRESHOLD (g)*)

The triggering of a tap interrupt would require the adjustment of two variables: *Duration* and *Threshold*. *Threshold* is at what level the trigger can fire, and if this threshold is held for a within a certain specified *Duration*, the interrupt will fire as seen in the example (Figure 5.6). Double Tap is not considered in this system, however can be an area of exploration in the future.

Freefall (*DURATION (ms), THRESHOLD (g)*)

Similar to tap, if the all axes of the accelerometer experiences acceleration under a certain *Threshold* within a certain *Duration* the free fall interrupt will fire.

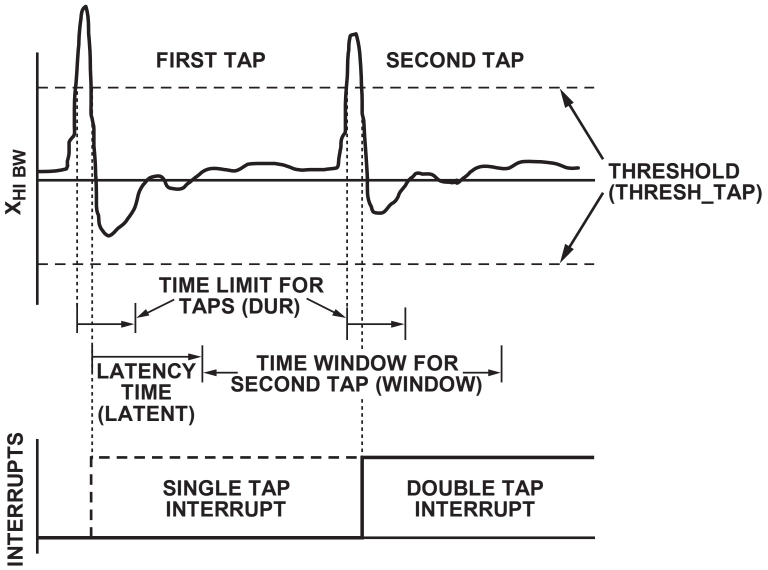


Figure 5.6: ADXL345 single tap interrupt detection

5.4.3 Streaming Data with Interrupts

Given the two interrupts that we add to the system. We can continue to use the data streaming with the added features of interrupts. These interrupts will be discussed in the next chapter, alongside the data analysis.

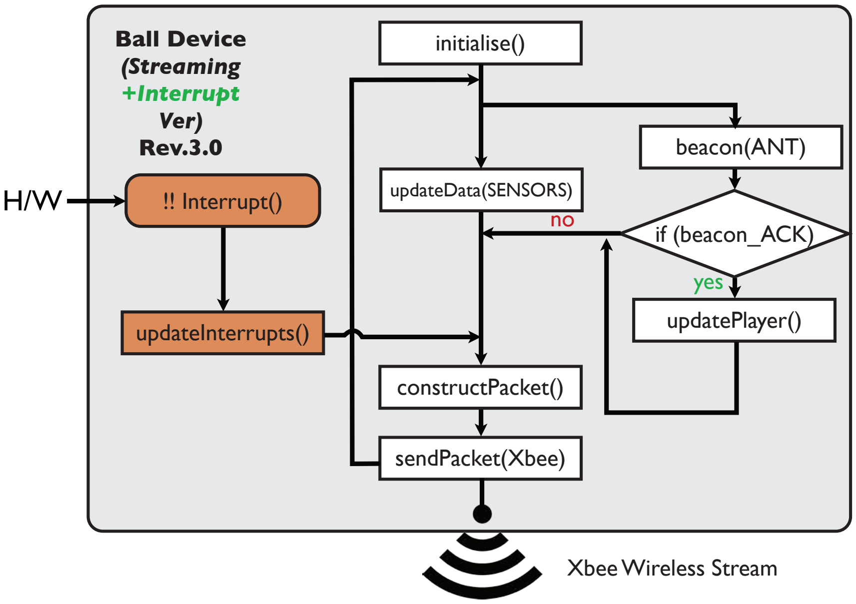


Figure 5.7: ADXL345 interrupt-integrated software streaming

5.5 Data Streaming

Data streaming was considered to be the first step toward the analysis of data; the easiest of applications to demonstrate the real-time aspect of the information is visualisation. In this section we look at the process of visualising the sensor data in real time and contribute enhancements to the base prototype that was introduced in the previous chapters through the analysis of latencies and sensor data comparisons with respect to atomic events mentioned earlier.

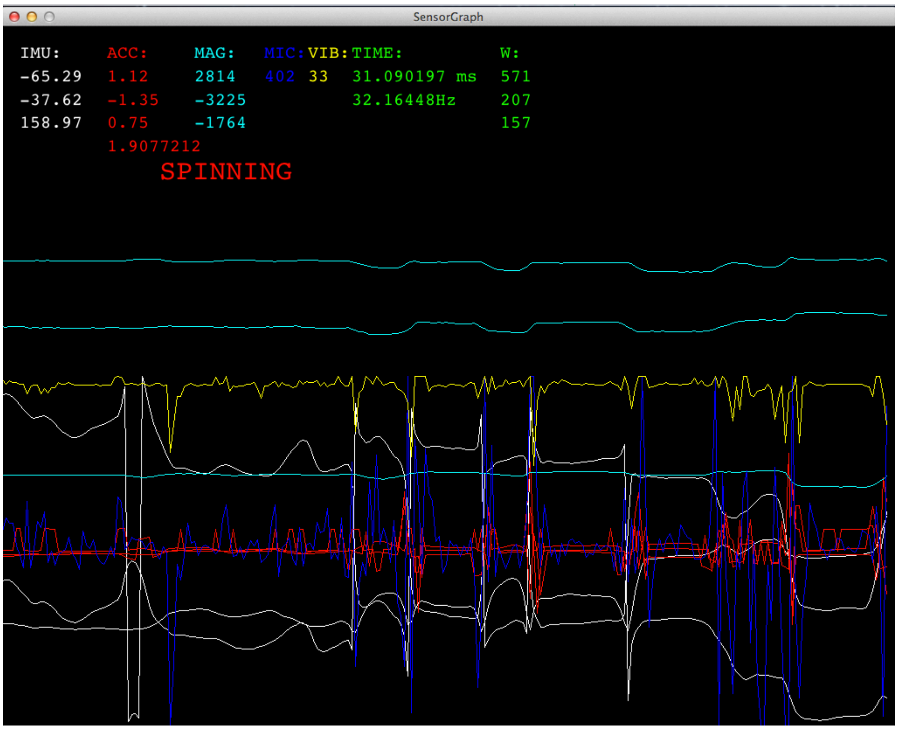
5.5.1 Visualisation Software

Several iterations of visualisation software were developed over the progress of this project. The first being the system consisting of Processing Software [28] running on the Host PC and Arduino-revision of the Ball Device. The serialised data stream was received via a virtual serial com port and opened via a supporting prototyping framework for interactive applications. The first type of application developed is visualisation software to display the statistics of the ball in real time. A sample screenshot of the application can be seen in Figure 5.8.

5.5.2 Evaluation: Prototype Rev.1 Latencies

The first prototype (labelled Rev.1), used a Processing software application for data streaming. We investigated the sources of latency during the streaming process using the following process.

1. First measure the total update time to obtain new information for the visualisation application (update loop).
2. Measure the timing for updating the data between reads using time stamps on the Arduino.
3. Toggle sensors for each of the first two steps to determine the read times for each sensor and sensor combinations.



```
IMU:     ACC:      MAG:    MIC:VIB:TIME:            W:
-65.29   1.12      2814    402  33  31.090197 ms    571
-37.62   -1.35     -3225            32.16448Hz      207
158.97   0.75      -1764                            157
         1.9077212
            SPINNING
```

Figure 5.8: Visualisation application prototype screenshot

The hardware setting is as follows:

- PC: Macbook Pro (Core i7, 2.4GHz)
- Software: Processing (Java)
- Serial Baudrate = 57600 bps
- MCU Fixed I/O Delay = 5ms

Tables 5.2, 5.3, and 5.4 summarise the information for the visualisation refresh rate/period, MCU refresh rate/period, as well as improved MCU refresh rate/period respectively. Each value represents the update period for the corresponding sensors. For example, it would take 18ms for the visualisation to update with just the IMU data set only while it would take 22ms for both the Magnetometer *and* the IMU visuals to update.

The differences between the two MCU-centric tables is that the Wire library used to read from the I^2C interface of the Arduino [3] was modified for a faster read from the sensors. It was feasible as both sensors and the MCU was able to support a 400Hz fast-read I^2C interface.

From the results, it can be seen that the largest contributor for the total latency for the visualisation system is the visualisation system itself (23ms update time). Upon investigation of the Ball Device (MCU reads), we found that the update time could be reduced to 7ms from a standard of 12ms using an improved fast read (Wire @ 400Hz). If we subtract this update rate (12ms) from the overall update (23ms) time we obtain a figure of 11ms (Wire @ 100Hz); if we apply the Wire enhancement we can obtain a theoretical 18ms update time or 56 Hz update rate (7ms MCU update + 11ms transmission & visualisation).

The MCU sensor reads do not contribute greatly to the system latency in this application. The data transmission from the Ball Device to the Host PC over the XBee as well as the visualisation software rendering may also be one cause of latency that can be reduced. Therefore we can consider these variables as candidates for latency improvements.

5.5.3 Hardware Evolution

With the transition to ANT, we decided on upgrading the hardware for greater adaptability and processing power. This would also allow for other MCU intensive applications such as a ball-side processing of events (instead of the streaming solution). Our next prototype was based on the mbed system, which is described in the previous chapters. This prototype is the 3rd generation, which was given the label Rev.3.

The difference in specifications can be summarised in the following table. We conduced various experiments to test the performance as well as characteristics such as battery drain.

Table 5.2: Total time to update visualisation for sensor combinations

(Hz/ms)	MAG	IMU	VIB/MIC
MAG	66/15	45/22	66/15
IMU	-	**55/18**	55/18
VIB/MIC	-	-	100/10

PC Full Sensor Update Rate ≈ 43Hz/23ms

Table 5.3: MCU: Total time to update packet w/ sensor values (Wire @ 100Hz)

(Hz/ms)	MAG	IMU	VIB/MIC
MAG	250/4	100/10	250/4
IMU	-	**125/8**	125/8
VIB/MIC	-	-	500/2

MCU Full Sensor Update Rate ≈ 83Hz/12ms

Table 5.4: MCU: Total time to update packet w/ sensor values (Wire @ 400Hz)

(Hz/ms)	MAG	IMU	VIB/MIC
MAG	667/1.5	147/6.8	500/2
IMU	-	**192/5.2**	178/5.6
VIB/MIC	-	-	≈2000/≤0.5

MCU Full Sensor Update Rate ≈ 142Hz/7ms

Table 5.5: Rev.1 system specifications vs. Rev.3 system specifications

	Rev.1 (Arduino)	Rev.3 (mbed)
MCU Sensor Latency (Hz/ms)	**142/7**	90/11
Visualisation Latency (Hz/ms)	56/18	**68/14**
Battery Drain (mA)	**65**	150
Unit Weight (gm)	**62**	100
Min Input Voltage (V)	3.3	5

5.5.4 Evaluation: Live Testing (Rev.3)

To demonstrate the prototype capabilities in terms of data collection, as well as attempt to discover limitations in areas of hardware we conducted a game of amateur dodgeball outside in an open field. Using the Rev.3 (mbed) prototype ball, we conducted this experiment under the following conditions. However, in this field test, as there was a shortage of player tags the player recognition (introduced in the Chapter 6) functionality was removed from this test.

Hardware

- PC: Macbook Pro (Core i7, 2.4GHz)
- Software: screen (serial read to file)
- Ball Prototype: Rev. 3 (mbed) @ 9V battery (Figure 5.11)

Environment

Open Grass Field (Figure 5.9, 5.10)

Players

4 Players on each team, with 1 player from each side in each respective out-field. (3 players in-field, 1 player out-field; first out swaps with out-field: total 4 outs).

Game Time

2 games (02 min: 28 sec and 08 min: 36 sec)

Main Goals

To test sensor ranging, distance limitations and extract event specific data information.

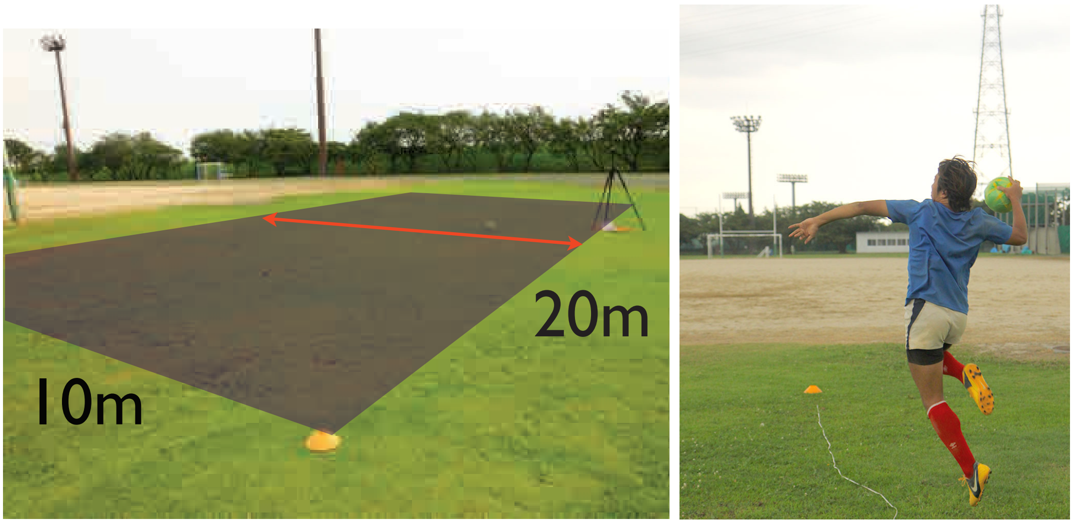


Figure 5.9: Field testing layout (left) ; Player throwing Rev.3 ball prototype (right)

Figure 5.10: Field testing layout: Playing field and PC positioning

Results

Wireless Range

It was discovered that using the Xbee for wireless communication had range

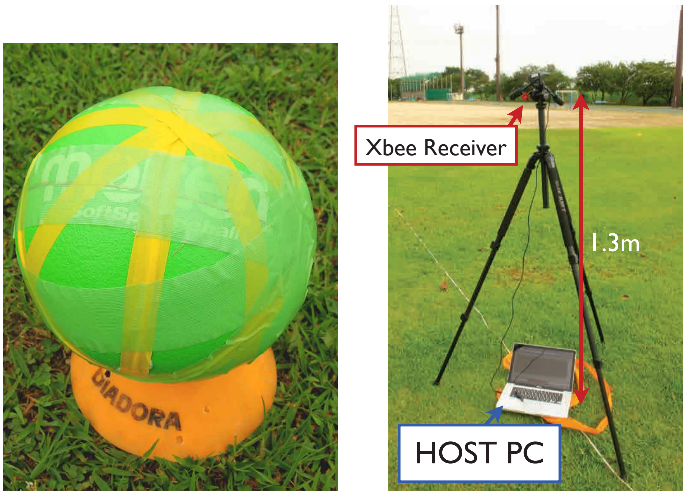


Figure 5.11: Field testing hardware: Reinforced sponge ball (Rev.3) (left); Host PC station (right)

limitations. An on-chip antenna was installed in this prototype, which allowed for slim profiling. However, as the device was mounted inside the sponge casing, there is no line of sight and thus the wireless capability of the hindered. During play, it was observed that when the ball goes past the out-field line the ball ceases or has difficulties transmitting reliably. This happened very often when players in the out-field failed to catch a pass or a dodged ball; this "dead" zone can be illustrated in 5.12.

Figure 5.12: XBee transmission dead zone

Data Limitations

The data from the accelerometer was analysed by extracting the raw data into a time series. One main issue that was found was that the acceleration experienced during throwing and catching actually surpass the limitations of the accelerometer's possible range (currently configured ±16g). This can be seen by the plot showing X, Y, and Z-axis accelerometer response of a throw within the bracket of *500ms* (Figure 5.13). It can be seen that all of the accelerometers peak and plateau at 512, the signed integer limit for 10-bit values. Since the accelerometer has a max resolution of 13-bits; this means that the measurement send across the wire is either losing bits or read incorrectly at the time. This is discussed in more detail in Section 9.1.2.

Data Representations

The data collected from these exercises were analysed for atomic events that can be extracted for analysis. Details regarding these results can be summarised in Section 7.2.1.

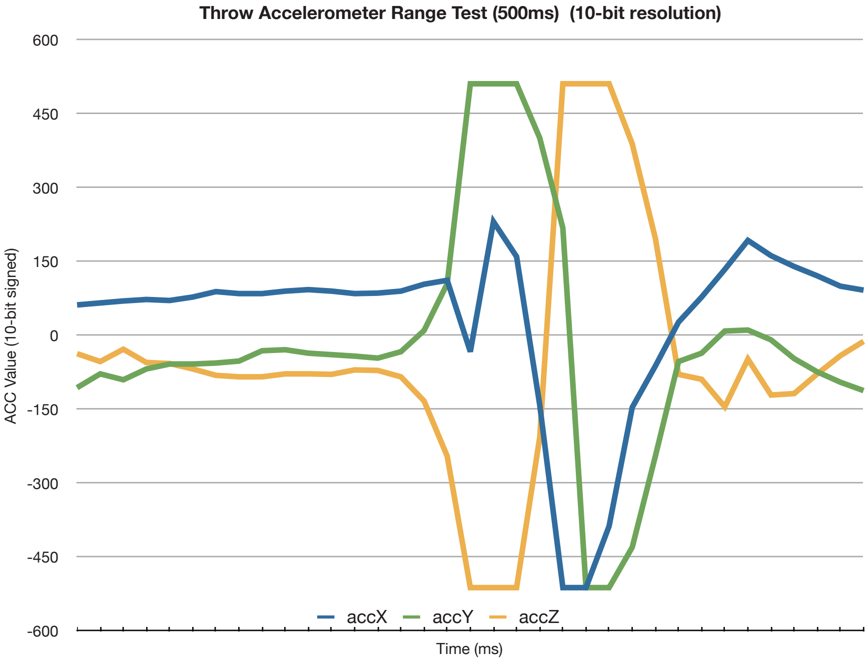


Figure 5.13: 500ms preview of accelerometer Data during a throw

5.6 Summary

In this chapter, we discussed the development of a wireless ball system that can be used to extract and analyse real-time information from inertial sensors from the ball during play. By first starting with the hardware architecture, the ball went through various phrases and two embedded architectures, namely Arduino and mbed.

The key sensors used in this device are the accelerometer and gyroscope, followed by the vibration sensors and microphones, and then the magnetometers. Two wireless architectures were installed onto the system to provide for dual protocol communication: one between players and the other between the host system. The hardware was then fitted into a sponge casing. The resulting weight of the systems were comparable, if not lighter, than the JDBA-certified ball models.

Software that was developed for the system was broken up into various modules: the streaming logic and interrupt logic. These were both used to relay data to the host PC.

To evaluate the data streaming, we developed a visualisation application that was thoroughly scrutinised to determine data streaming latencies and areas where latencies can occur. We discovered that the overall system latency was found to be 23ms for the early system, which improved to 18ms using a faster Wire library. However when we switching hardware architectures to mbed, the system improved to 14ms, allowing for a 71Hz update rate.

Field testing was then conducted to test the usability of this hardware prototype. Dodgeball was played over two games using the prototype to collect data as well as test for flaws in sensor ranging, wireless limitations and possible data representations for key dodgeball game events. It was found that there were wireless limitations due to the use of an antenna that an obstructed field of view as well as issues with the sensors with their range being maxed out due to the nature of the ball movement (and context of the sport). The wireless data stream found dead zones of transmission whenever the ball went past the out-field whilst the sensor data hit a maximum measurable value when the ball is being thrown and spun at high speeds.

Chapter 6

Player Recognition

In this section we have a look at the player recognition using proximity detection. Player recognition is a very important part of this system given that the context of the situation determines the ultimate judgement passed down by the ball.

6.1 Proximity Sensing with ANT

ANT+ is a open access interoperability function that is built on top of ANT [9], a RF wireless sensor network-based protocol. ANT+ can be used in health sensors, cadence meters and wireless heartbeat monitors. Given the nature of the use of this network, it may be possible to apply this network to independent wireless nodes to determine the movement of players and balls within a sporting field. We attempted to use this technology for player recognition on the assumption the players will carry wearable personal sensors.

6.1.1 ANT$^{\mathrm{TM}}$+ Protocol

Seen in Figure 6.1, the ANT+ protocol can be used for sensors concerning human health. It is possible for any ANT device to become a node in a network and communicate with other nodes with very little topological restructuring. The protocol itself allows for periodic synchronous duplex communication between moving sensors across multiple channels (if hardware allows). It also allows for multiple complex topologies, and is very robust to desynchronisation. Given these points, it is a very ideal protocol for use in sports devices, in the consideration of our application (proximity sensing using a ball and player sensors) it is a very appropriate solution.

In the system developed for this research, the topology similar to that of a 'star' is used. The main master (center node) is the ball, and this master acts as a host for multiple slave nodes (the players). A single ANT+ channel is used to communicate between player and ball when the link is active, otherwise the ANT slave may act as a master node for other player sensors (pedometers and heartbeat monitors).

Figure 6.1: ANT$^{\text{TM}}$+ protocol use case scenarios

The adaption of the ANT protocol used in this research, in terms of topology can be seen in the following Figure 6.2. Each of the player tags act as 'masters' to any slave nodes operating on a different channel (*blue channel*) and can obtain information such as heartbeat, activity etc. The ball master connects with these player tags once in range, and use this information within the context of the ball (player possession, player status).

6.2 Hardware

The hardware module (BC-ANT-SERIAL) that comprises ANT is conveniently packaged into a breakout board that communicates through SERIAL/UART. Given that these tags are in early development, the size of the tags are currently under improvement. Figure 6.3 show two prototypes are were used in testing. These prototypes, similar to the main ball sensor were built on top of the mbed prototyping architecture and use the BC-ANT-SERIAL (nRF24AP2) via UART. The BC-ANT-SERIAL must first be configured for the particular baud rate (57600 bps).

6.3 Software Development

In order to develop within ANT, we had a look at various hardware solutions that used the particular serial port. We found that mbed was an appropriate candidate, given it has high processing power and multiple I/O possibilities. We developed the third and fourth prototype to cater for these needs (although it was not physically necessary).

At the current point in time it was possible to port the ANT network over to the Arduino architecture, which is still considered future work as the current prototypes are still a long way away from completion.

6.3.1 ANT Master: Ball Device

As seen in Figure 6.4, the master device operates two stacks. The main loop of the stack transmits *beacons* as seen in the streaming flow diagram in Section5.4.1. As the nature of the beacon is a *ANT_Broadcast_Data*, all slaves in the detectable

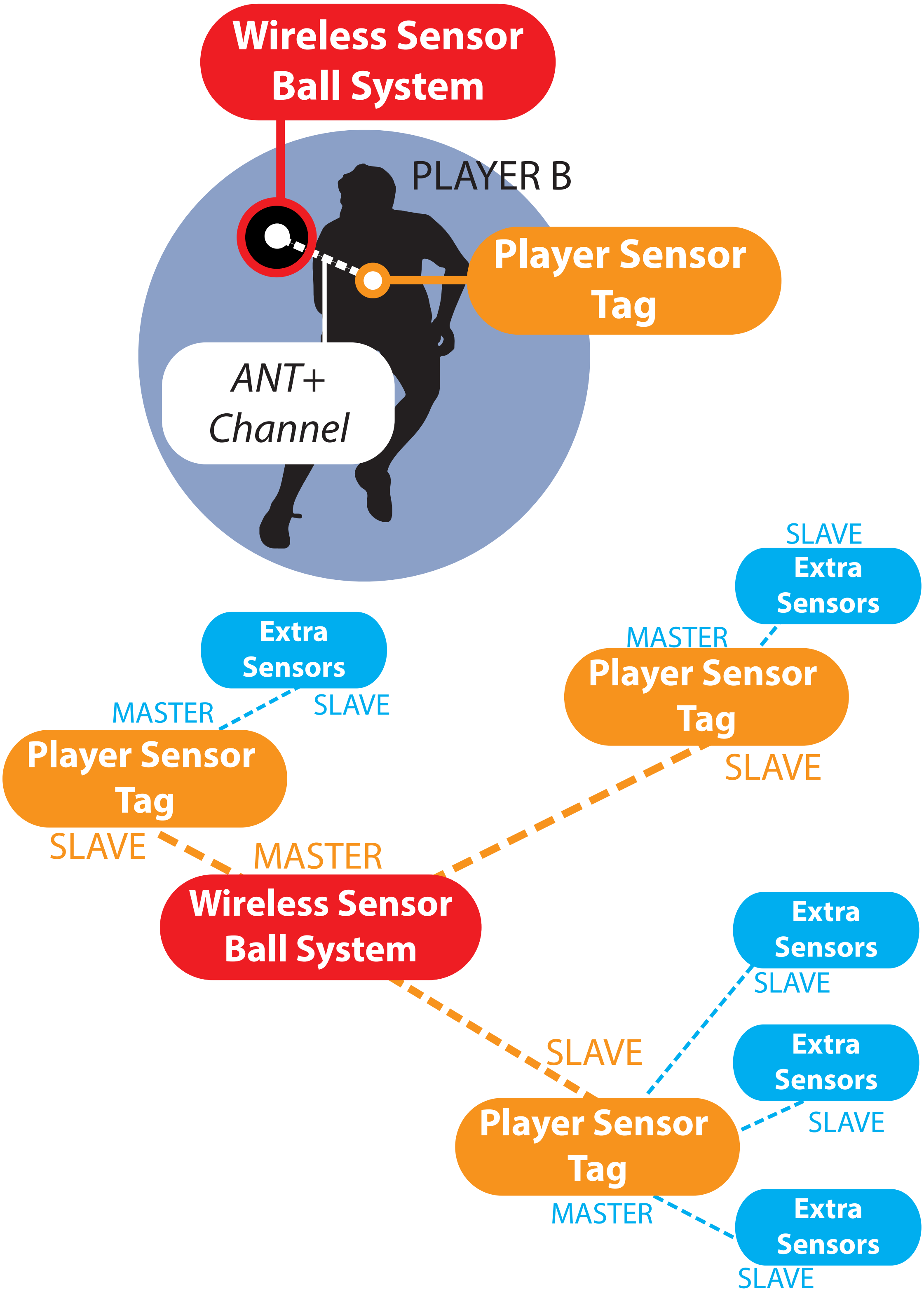


Figure 6.2: ANT$^{\text{TM}}$+ protocol in application of Augmented Dodgeball

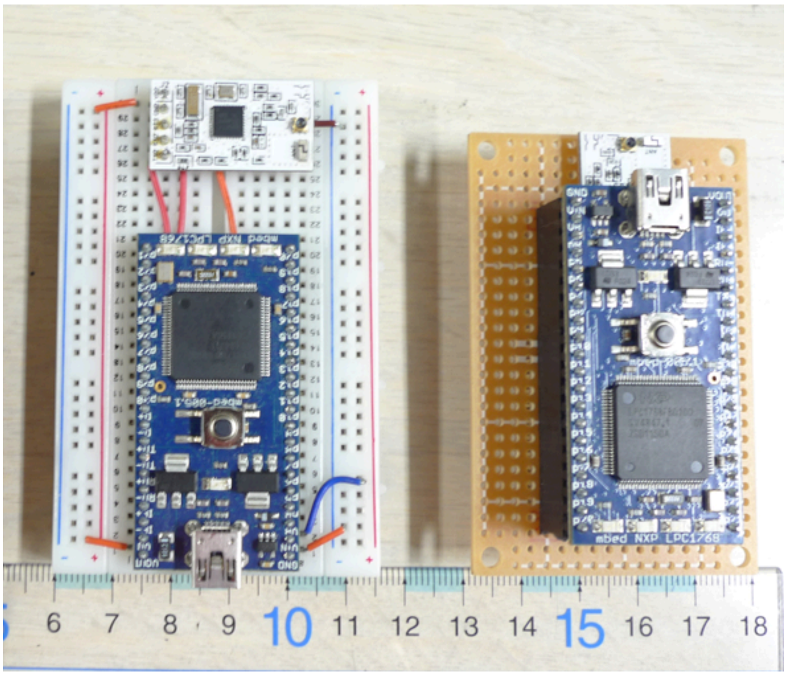


Figure 6.3: ANT player tags: (left) Prototype Rev.1: (right) Prototype Rev.2

area are able to detect the beacon (consisting of a *beacon_SYN* packet request). The master will continue to beacon until a player comes into range, and will use this logic to continuously update the closest player using a beacon response *updatePlayer()*. If the player is not updated, the player will default to 0 after 3 failed listens (3 x channel period = 30ms).

6.3.2 ANT Slaves: Player Devices

Slave devices (i.e. Player Tags) have a much more simple program flow. As the ANT+ protocol automatically listens after a channel is open for master requests, it will continuously loop until *ANT_Broadcast_Data* with a *beacon_SYN* arrives: this would mean that a master (The Ball) is both in synchronous range with the slave (The Player).

send(beacon_ACK) would then construct an *ANT_Acknowledged_Data* packet with the player information (Player ID) to begin transmission with the master. After the acknowledgement has been sent, the slave would then continue to listen

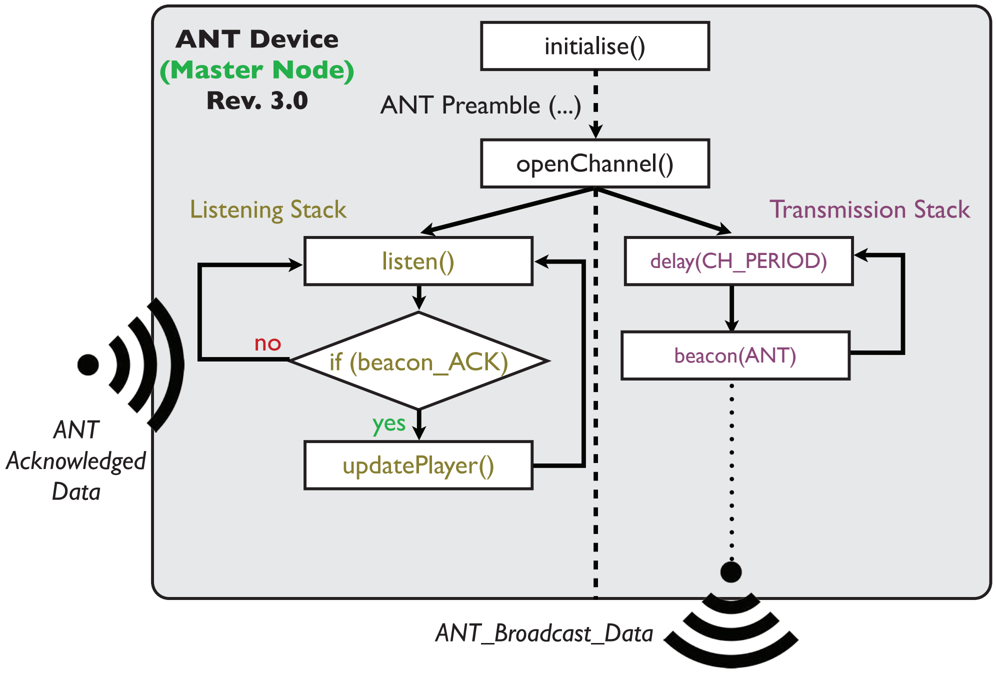


Figure 6.4: Ball Master device: Software flow diagram

on the same channel for another beacon. If the player is still in range, then an acknowledgement would be sent in a similar fashion, continuously updating that the player in range is the current slave.

6.3.3 Consideration: ANT Topology

Upon testing with the above topology, with the master being a ball co-ordinating with multiple slaves over the same channel was a much better option than a master being a player, and coordinating with a slave ball.

As the relationship with between ball-player (1:N relationship) suggests a master-slave relationship, the reverse will not work as many masters will not be able to communicate with the same slave over a single channel (ANT limitation, can be considered with address sharing of masters). In the attempt to adhere to a strict one player with one slave at any given time (1:1 relationship despite 1:N) there was an issue with the minimum time to detect due to the slave (the ball) having to timeout before connecting to a new master (player). Figures 6.6 and 6.7 illustrates

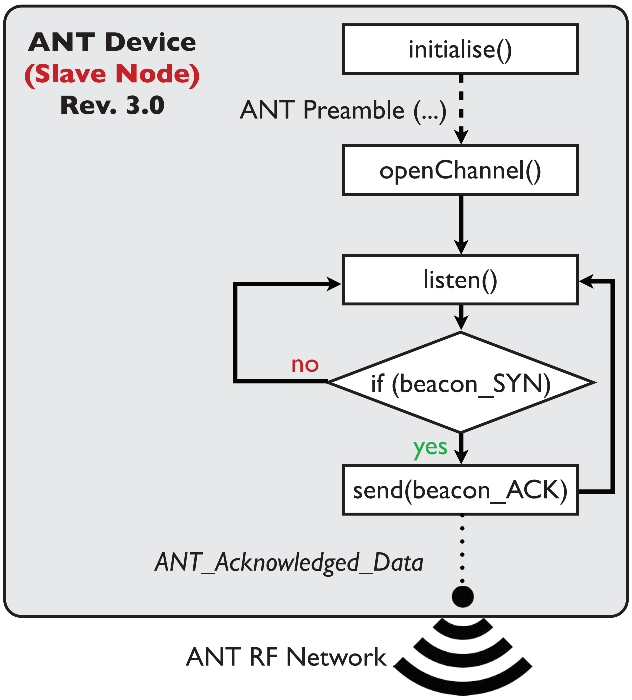


Figure 6.5: Player Slave device: Software flow diagram

the timing flow for each of the topology differences: the grey area in the ball slave:player master topology results in a (hardware dependent) minimum 2 second lag until timeout.

6.4 Evaluation: Simple Range Testing

To determine the possible range of the player tag and ball communication or the detectable area of the players, an experiment was conducted to test the response at certain distances. This is to evaluate and quantify the range that the ball can be in before it is detected by the player tag.

6.4.1 Evaluation Environment and Flow

For a controlled environment, the experiment was conducted indoors using fixed positions based along a tape measure line. Both devices have clear line of sight of one another (the ball device is encased in sponge), and set along the tape measure

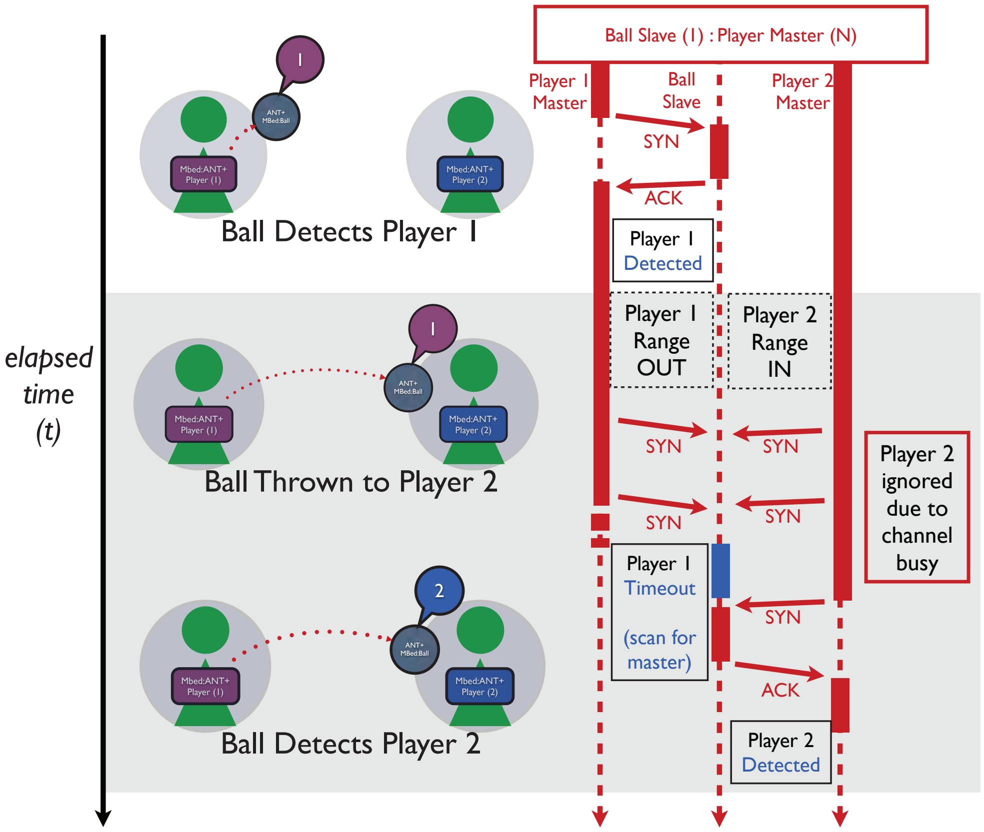


Figure 6.6: ANT Topology: Ball Slave : Player Master logical flow

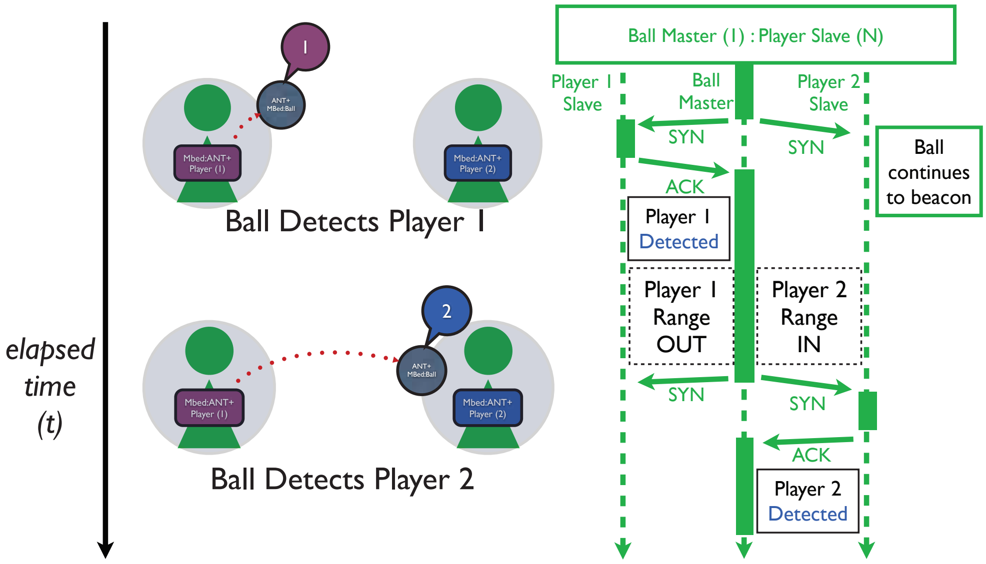


Figure 6.7: ANT Topology: Ball Master : Player Slave logical flow

at varying intervals. The player tag remains at a fixed point, 0, however the ball is gradually moved away from the player tag. Upon each iteration, the recognised player indicator is viewed for 10 seconds for any fluctuation (Player 1, to Player 0 (No Player Detected) or vice versa) that indicates that the range is unstable. This is repeated 5 times, and that range will be marked stable if and only if all repetitions result have no observed fluctuations. A visual of the environment can be seen in Figure 6.8.

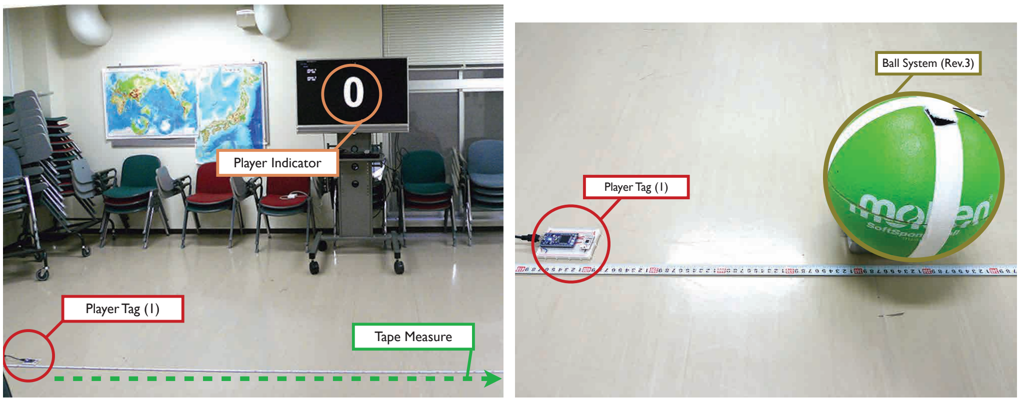


Figure 6.8: ANT-based player detection timing test environment (top); Ball and Player Tag (bottom)

6.4.2 Evaluation Results

The results for this evaluation can be summarised in Figure 6.9. The inner circle represents an approximate area where there is stable detection of the player by the ball. The outer circle represents an approximate area where there is unstable communications, or where fluctuations were detected. This can be used as a guideline to determine areas of possible noise and stable player possession events.

A very important comment to make regarding these results is that the detection stability depends strongly on the positioning of the wireless module. As the player tag modules were fully exposed and in line of sight of the ball (not the ball wireless module), these results may vary depending on the environment. There is also the factor of orientation, as per the ANT+ specifications, orientation of the ANT+

module's antenna is very crucial when it comes to detection ranges and given the behaviour of RF waves it is difficult to determine a solid reliable range.

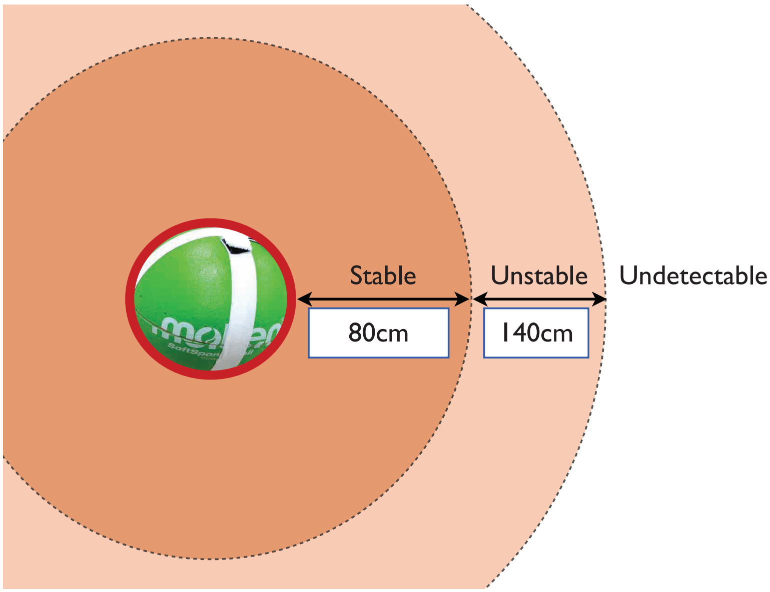


Figure 6.9: Ball detection range summary (10 second stability)

6.5 Evaluation: Timing Testing

This evaluation was conducted to determine the latency between the ball entering the players range until the system detects the player (and updates the display). As illustrated in Section 6.3.3, the timing between stable player detection was evaluated in this experiment.

6.5.1 Evaluation Environment and Flow

The experiment was conducted indoors much like the previous experiment, with two participants passing the ball to one another seen in Figure 6.10 standing approximately 4m apart. The ball used was the Rev.3 Prototype. Both participants are male subjects ages 23-28. Each player had the player tag placed at floor level where they stand. The data from the ball was relayed to the computer set up at the half way mark under the player indicator shown.

Results were then reviewed after the experiment was complete using a video review system. Frames from the video were analysed. We considered the frame where the ball is leaving the user's hand being out of range (about 30cm away from the body) and a similar measurement for the ball entering the range of the player. The player detection was tested for: the accuracy of the first player response (as well as interim responses (Player 0 update) being the correct as well as its timing, as well as the time to stabilise to a correct answer.

6.5.2 Evaluation Results

The results can be summarised in Table 6.1. On first glance there is a very large variance in the values given the standard deviations (σ). The accuracy of the system on first detection after the ball is caught is quite low at 44%, however the system stabilises around a mean time of 820ms after entering player range. Given 2σ (P = 0.95+), stability would be then occur at a minimum of 1820ms or approximately 2 seconds after entering player range.

Table 6.1: System timing and accuracy for player recognition

N = 33 (Throws)

Percentage of First Correct Detections (%)	44
Mean Time for First Correct Detections (ms)	450 (σ = 220)
Mean Time to Correct Detection (ms)	820 (σ = 500)
Percentage of Correct Interim (player 0) Detection (%)	26
Mean Time to Correct Interim (player 0) Detection (ms)	740 (σ = 410)

Figure 6.10: ANT-based player detection timing test flow

6.6 Summary

In this chapter we looked at the possibility of player recognition using a sensor network protocol, ANT+. ANT+ is widely used in health sensing applications and thus appeared to be a very good candidate for player detection as it could also be improved to allow for cross-communication with personal sensors such as heartbeat, pedometers, and calorie meters etc. As ANT+ supports a wide range of network topologies, our implementation uses a star-like topology using a single channel.

In our star-topology, there is one ball that works as the Master node over the single channel that other Slaves, which are the player devices, will connect to. The reason for this is that ANT+ does not allow for slaves with multiple masters and over the same channel: a forced timeout is then required before a new master is detected that we investigated to be at least 2 seconds for a change. Instead, an 1:N implementation of Master:Slave was more appropriate and thus implemented which allowed for very prompt switching between slaves as the ball moves across different players.

This system used a beacon-type algorithm, where player tags that are in range will respond with an acknowledgement to a master that is consistently broadcasting. This means that any slaves on the channel that will receive the broadcast will respond, and thus create a connection with the master. In most cases, this is the nearest node.

Our system was tested in areas of both timing and range. With timing, there was a very large variance observed between the time it takes to detect the player after the player possesses the ball. The mean time for a correct detection was 820ms, however the first correct detection would come almost half the time at 44% accuracy. This can be due to the instability of RF radio, or possibly the implementation of the network protocol itself. A similar issue can be seen with range, where the approximate ranges for stable and unstable detections are between 0-80cm away from the tag, and 81-240cm away from the tag respectively.

Chapter 7

Data Analysis and Classification

In this chapter we have a look at the methods used and applied for the analysis and subsequent classification of data. Firstly we have to discuss the types of data we will handle (atomic events) and their meaning. We then propose methods that are deduced from heuristics, that is, using the data provided previously and basing a proposal from this collected data.

7.1 Target Atomic Events

As this paper has defined a large scope of augmentation, we must first narrow down the atomic events that were defined in the previous chapter, defined in Section 4.2.2 and elaborated Section 4.3.1. This section will introduce these atomic events.

7.1.1 Impact

When a ball strikes any surface including that of the ground or a player, an impact event can be assumed. In the context of dodgeball, this can either be when someone is catching the ball or when the ball makes contact with the ground or wall and experiences a instantaneous force. Here it can be then further classified into two possibilities (both of which can be visibly confirmed).

These are *Catch* and *Bounce* impacts.

Catch

When a player catches a ball, they will experience impact when the ball makes contact with their hands. However, once the ball makes contact the forces are absorbed by the counter-force the body in order to stop the ball's motion. This can continue until the ball comes to a complete stop and is held by the player - this is recognised as a catch.

Bounce

A bounce occurs either when the ball makes contact with the player or any surface and fails to stop its movement, that is, the ball bounces off the surface or player. Here, the momentum of the ball is retained to an extent and the ball experiences acceleration in another (usually the opposite) direction. One point to note is that there is no external force acting on a bouncing ball whilst there is on a caught ball.

7.1.2 Throw

When a player throws a ball, it can indicate several context changes within dodgeball. One of which is attacking, the player will throw the ball at an opposing player usually with the intent of striking the player. One is passing the ball to another teammate. Both of these context changes result in a change of possession (player) of the ball.

Ball Extrinsic Information

When a ball is thrown, the sensors within the ball are capable of detecting extrinsic information such as acceleration and spin. Given this information, we can look to investigate detectable ball status changes such as spin as the ball is thrown.

However, considering that it may be difficult to obtain accurate information using the accelerometer alone, due to the range limitations described in the previous chapters.

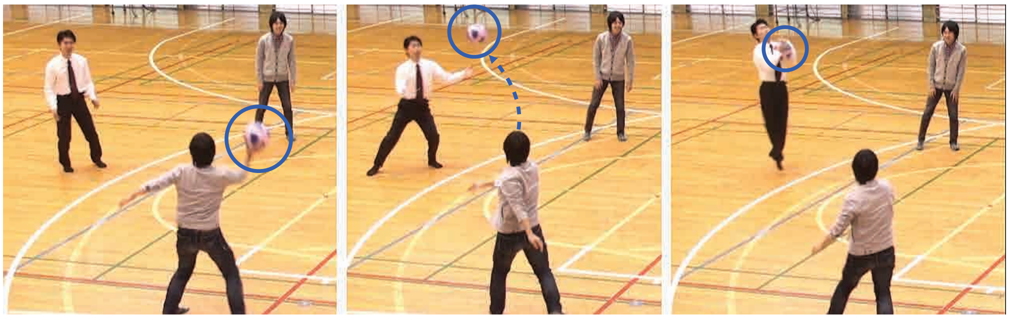


Figure 7.1: Examples of Impact: Caught by a player

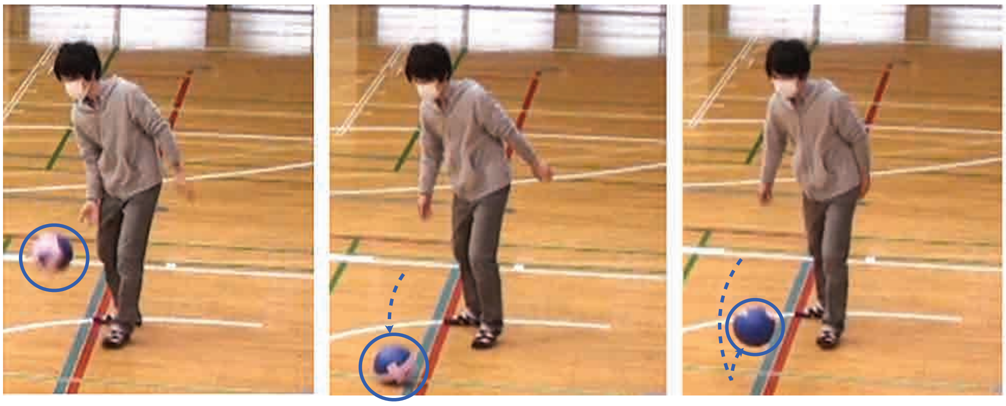


Figure 7.2: Examples of Impact: Bouncing off a surface

Figure 7.3: Examples of Impact: Bouncing off a player

7.1.3 Player Possession

When the ball moves from player to player, regardless of the means, the context of the dodgeball game will also change. Once a ball is in a player's possession, the player can decide whether it would be an offensive throw or a pass depending on the next player who comes in possession, or range, of the ball. Therefore, players whom touch the ball, or ideally is close to the ball should be detected as a change of possession. This would mean that detecting any player near the ball, regardless of whether that player is holding the ball or not, would be a suitable for a player possession change event.

7.2 Classification: Deterministic

One approach that was developed in this research for event classification using sensing data is a deterministic approach. That is, by using historical observations on appropriate values and timings for each event, it is possible to classify the triggers via declarative means. The data collected from previous experiments, as well as exercises performed in controlled conditions can be used as a base for analysis with a combination of threshold and timing variations can be used for event classification. This process is illustrated in this section.

7.2.1 Data Representation

From previous experiments, we observed that particular atomic events have corresponding sensor responses. If we can use these responses as data representations for each event, it may be possible to extract particular features unique to each event, thus allowing for classification between events. Here we will discuss these features as well as provide some visual aids.

As we have described the atomic events earlier in this chapter, we will focus on said events and their sensor responses within a particular frame. As these events are temporal (the response has a time-series data structure), we will illustrate them in graph form with respect to time.

These are taken from the experiment conducted in Section 5.5.4 as well as a series of controlled experiments. This data group unfortunately does not have record of the magnetometer measurements for unknown reasons, presumably hardware issues.

Throw

The throw event is illustrated in Figure 7.4. The photographs show the frames from the footage sample, and the corresponding response signals from all the sensors except the magnetometer. Activity can be seen when the player throws the ball as seen from the responses in most of the sensors.

Catch

Catching is shown in Figure 7.5. This catch is the reciprocal event for the previous throw event (eg. the graphs on in Figure 7.4 can be linked to these graphs). The catch event occurs when all sensors, as well as the tap detection shows strong activity.

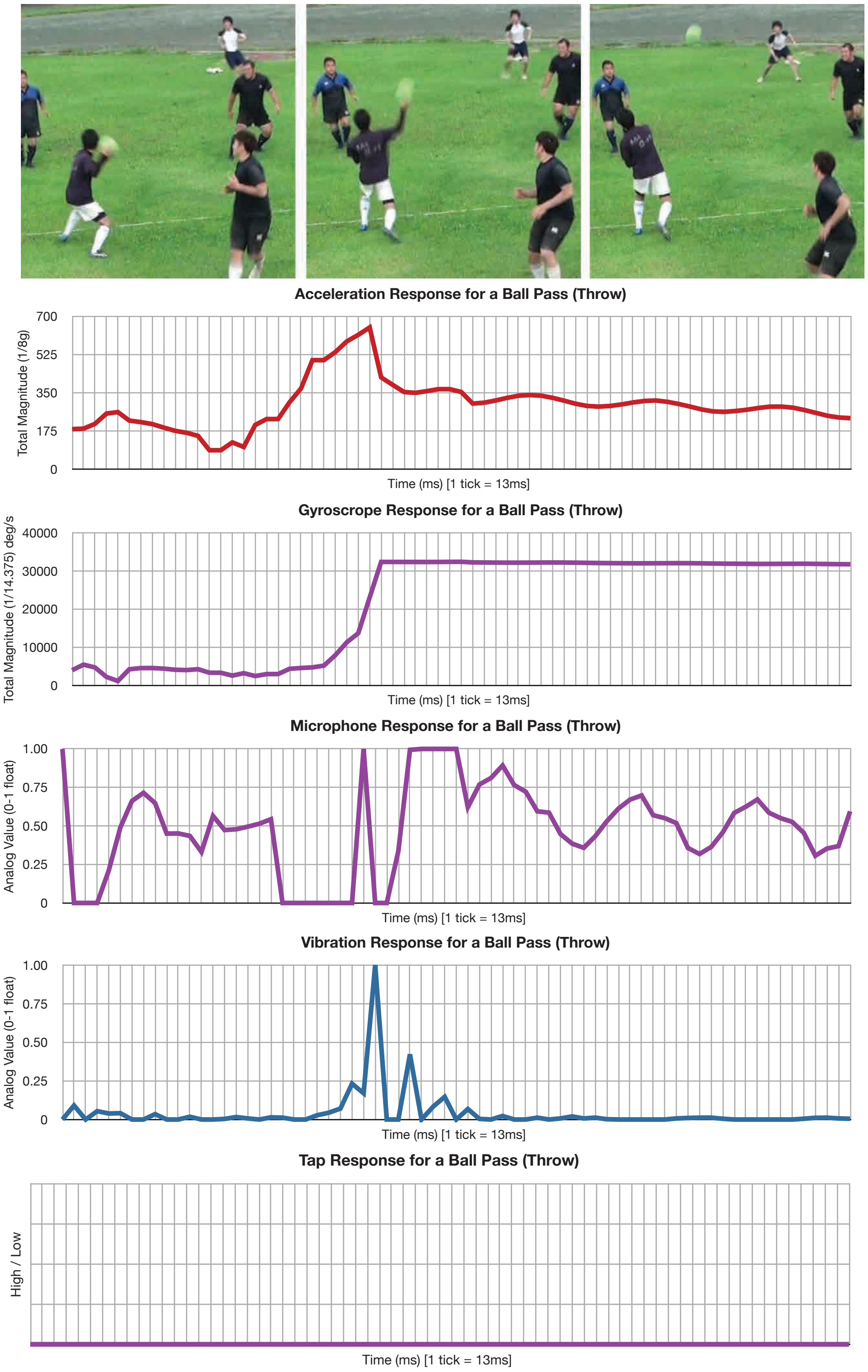
Bounce

Figure 7.6 shows the event and response signals for a captured bounce event. Similar to the catch event, the bounce event occurs at the point where there are peaks in all but the gyroscope response, which happens to experience a great drop in angular velocity.

Comments

As can be seen in the sensor response figures, it is worth investigating in more depth which sensors can be used in a deterministic method to classify each particular atomic event.

For example, between the three particular events, the microphone response does show very particular responses but consistency was not evident especially when considering that the mic will respond even when a player is grabbing the ball. It



Acceleration Response for a Ball Pass (Throw)

Gyroscrope Response for a Ball Pass (Throw)

Microphone Response for a Ball Pass (Throw)

Vibration Response for a Ball Pass (Throw)

Tap Response for a Ball Pass (Throw)

Figure 7.4: Throw event and corresponding response signals

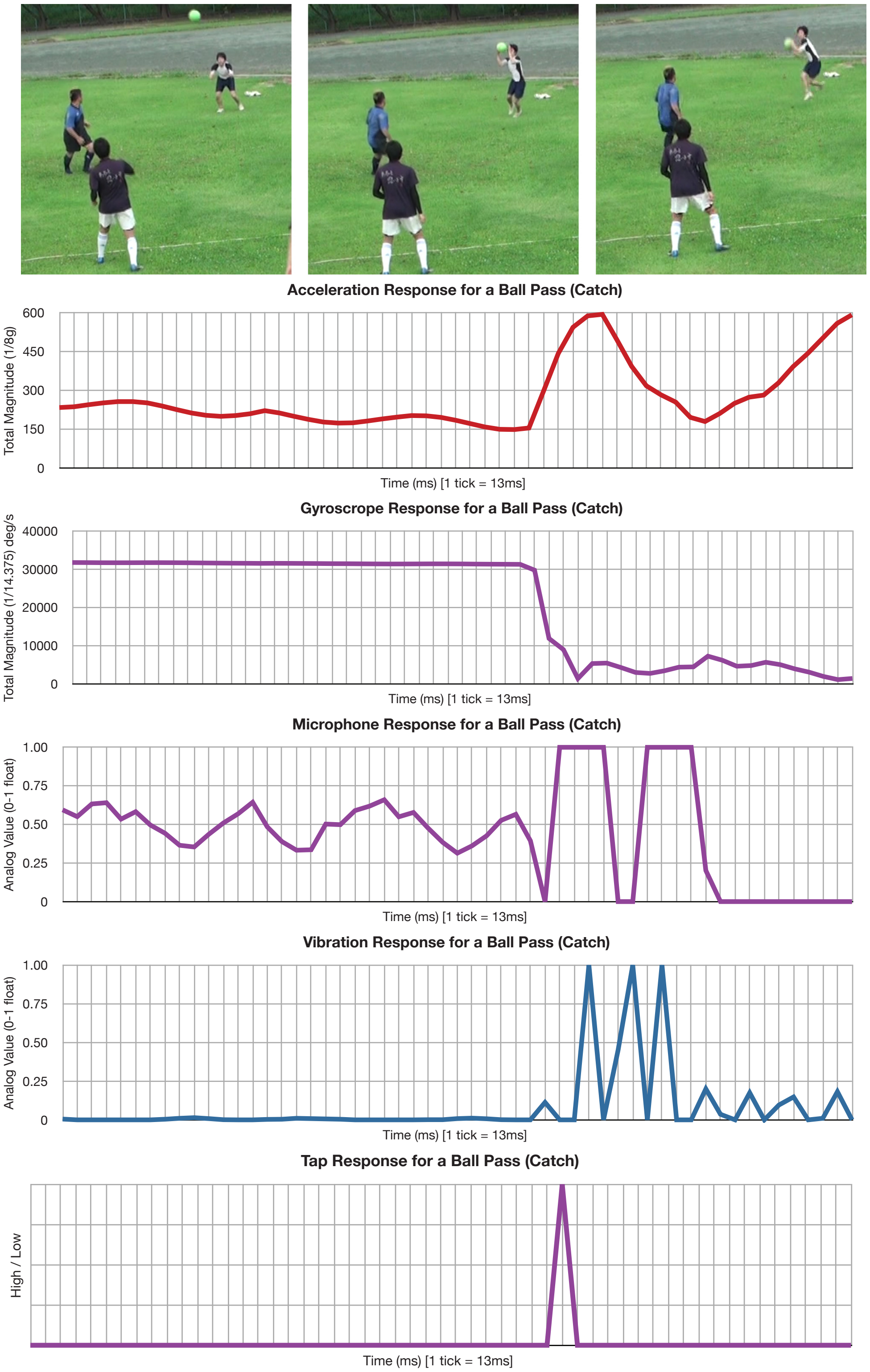


Figure 7.5: Catch event and corresponding response signals

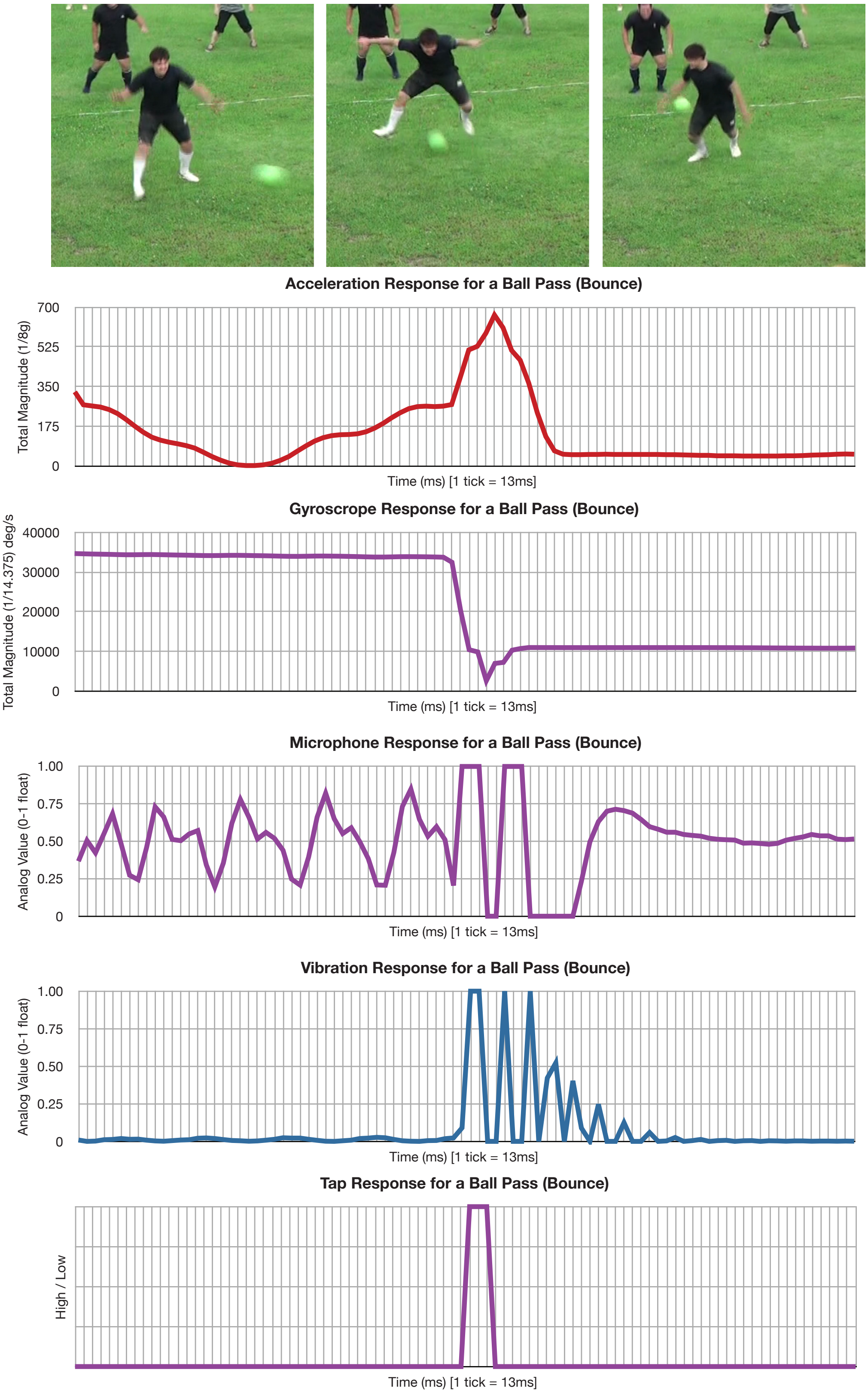


Figure 7.6: Bounce event and corresponding response signals

can also be observed the Microphone over limits at particular peaks but does so at a very high frequency due to the fluctuation of sound pressure (to create noise).

The vibration sensor also shows insight into the *Impact* event; in each Figure (7.4, 7.5, 7.6), the vibration responds when there is evident impact. This can maybe be used for impact detection, however the differences between an impact from catch, throw and bounce is not very clear but worth looking into.

Tap responses (from the accelerometer hardware interrupts) are very clear in separating throwing to catching and bouncing. There is a single instantaneous signal when the event occurs and thus we can use this to help classify, or differentiate between these events.

The gyroscope shows that the ball is spinning faster than measurable values when it is thrown and while it is airborne (between throw and catch events). This can be also attested to the wave-like acceleration whilst the spin rate plateaus. However when the gyroscope drops greatly in value, a event is most likely to occur however the differences between the gyroscope response of catch and drop are very similar.

One very significant, and notable signal to study is the accelerometer. We can see that throwing, catching and bouncing the ball produce similar accelerometer responses, however what happens after the event occurs can be the object of investigation.

7.2.2 Corollary and Trends

Here we look at the corollary and trends between the above given events. The differences between throw and impact events such as a catches and bounces can be separated using the following observations and assumptions.

Throw vs. Impact (Catch and Bounce)

Provided that the player does not strike the ball while throwing, the tap detection should not respond to a throw. We can use this as a general separator between throw events and bounce events as mentioned in Section

7.2.1. In most circumstances, a throw event also results in a large increase in angular velocity as well as a slight vibration response - this can be a base for a deterministic classifier.

Catch vs. Bounce

The key signal that will help to determine the differences between catching and bouncing can be observed to be the acceleration. Other signals may affect the outcome and can be used to fine-tune the classification method on further investigation.

We conducted catch and bounce exercises in a controlled environment (A pair of male subjects, ages 22-28, standing 3 meters apart to throw and catch a ball at a standard rate, with a fixed speed as possible; one of these subjects were then asked to drop the ball repeatedly) to collect data to investigate the discrepancies between the two events. Please refer to Section 7.2.6 for more exercise environment details.

Figures 7.7 and 7.7 show two examples of look closer at the event and response signals for catching and bouncing. One clear identifiable feature is that when the ball is caught, the tap detection will trigger (sometimes more than once depending on the axes of tap detection). The total acceleration does not fall below a certain value ($\leq$100) after this event has occurred. The red bars indicate that for the bounce events, the total acceleration drops below this threshold while the green bars indicate that for the catch events, within a certain time period, this thresholding condition is met.

Using the above information, it is possible to determine a method to generalise impact events into bounce and catch events depending on their acceleration response. By using heuristics, we propose a method to classify catch events and bounce from events deriving from an impact event.

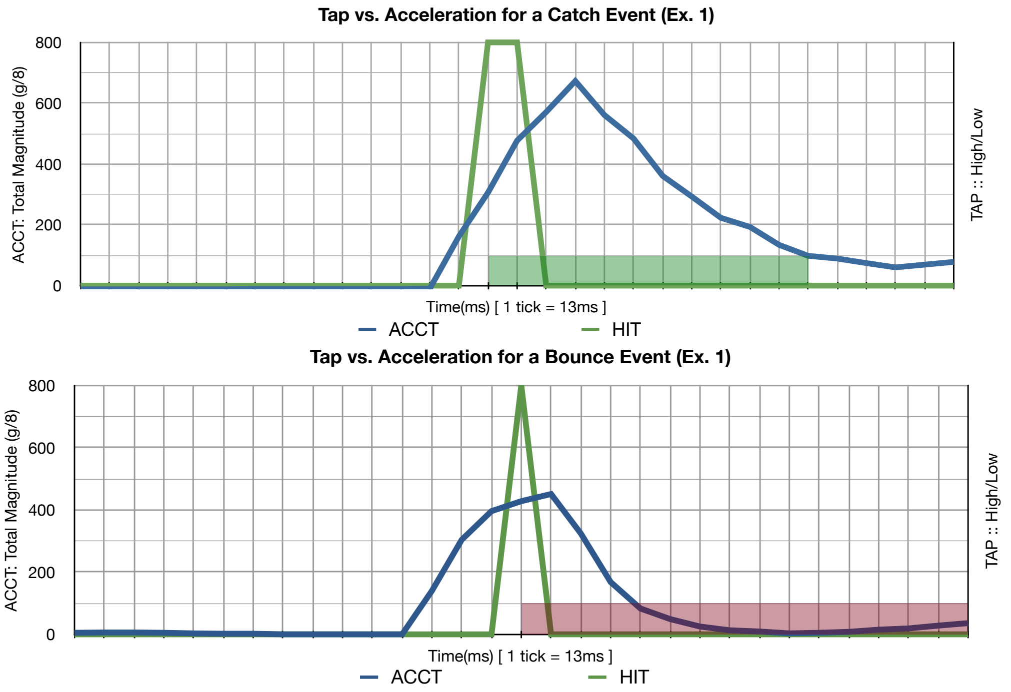


Figure 7.7: Detailed Catch and Bounce: Example 1

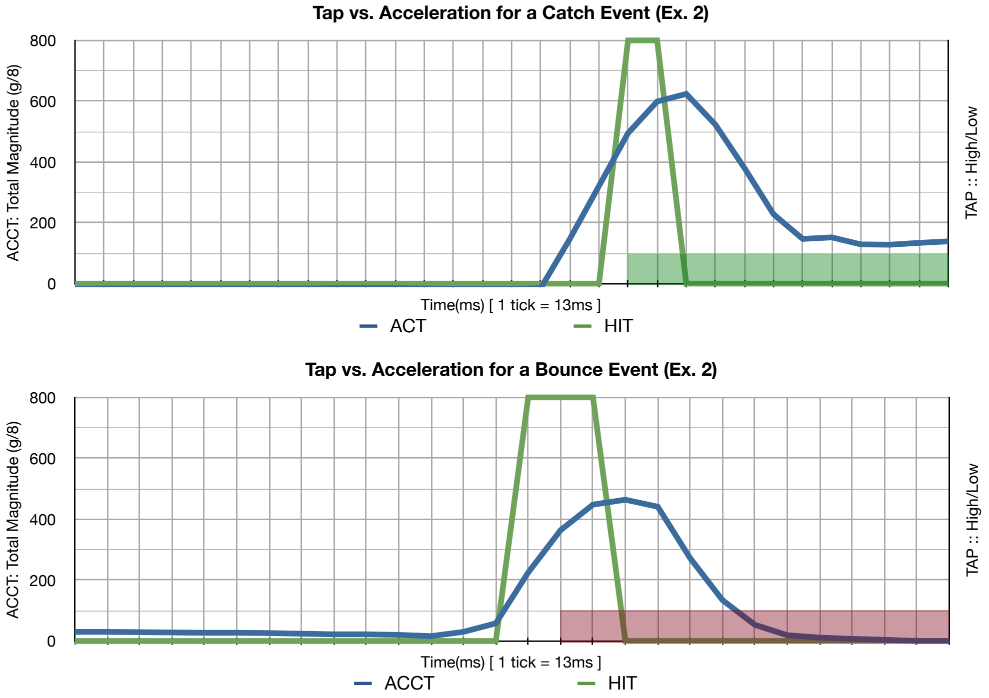


Figure 7.8: Detailed Catch and Bounce: Example 2

7.2.3 Proposal: Determinsitic Method: Catch vs. Bounce

Using heuristics, this proposed method uses thresholding with a combination of timing evaluation in an attempt to classify *Impact* events into *Catch* and *Bounce* events in a Dodgeball scenario. Evaluating this method will give further insight into the quantifiable elements of the game, as well as assist in automatic refereeing and decision-making. Figure 7.9 summarises the method that is proposed for this classification.

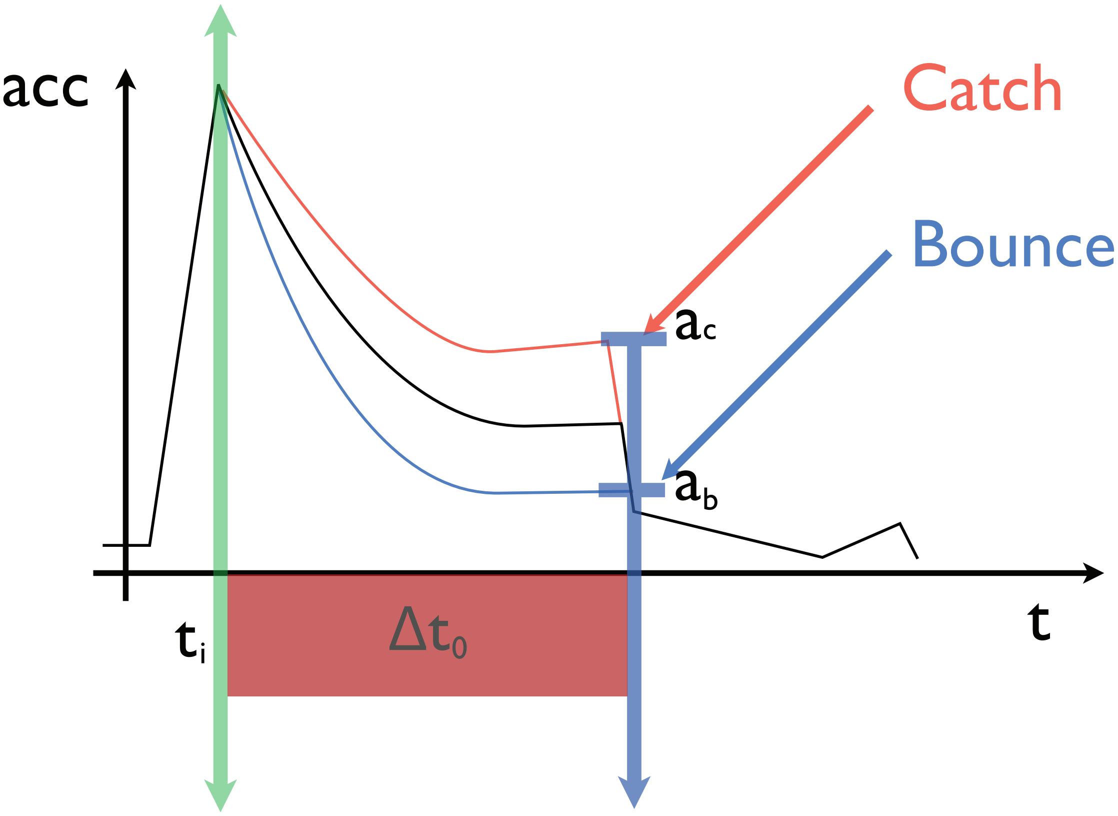


Figure 7.9: Classification proposal for Catch vs. Bounce

The graph illustrates a model of the total accelerometer magnitude response with respect to time. The peak would represent the point where the acceleration would be at the greatest, and thus would indicate sudden movement in a certain direction. Here we can assume that this would be the time of impact, t_i.

t_i would then be the predicted time where the tap event would be detected. The observed differences from the previous section (Section 7.2.2) have suggested that there is a degree of damping between a catch and a bounce after impact. In this example, a_b and a_c are the two threshold values that, after a particular period Δt_0, separate the two events.

An estimated range for these two values: Δt_0 and a_b can been seen to be 60ms-80ms and 120-140 respectively.

7.2.4 Implementation: Catch vs. Bounce

The following flow diagram illustrated in Figure 7.10 shows the software process for the above proposal algorithm.

The system will set a timer when an incoming interrupt is a tap detection. A timer will be started on a correct detection. If this timer is going, the system will continually check the accelerometer value on every update of the sensor data until t_0 has elapsed. If the accelerometer value is below the catch threshold a_c, then the decision will be flagged as a *bounce*. Otherwise, if t_0 has elapsed and the value stays above the threshold, then it will be flagged as a *catch*.

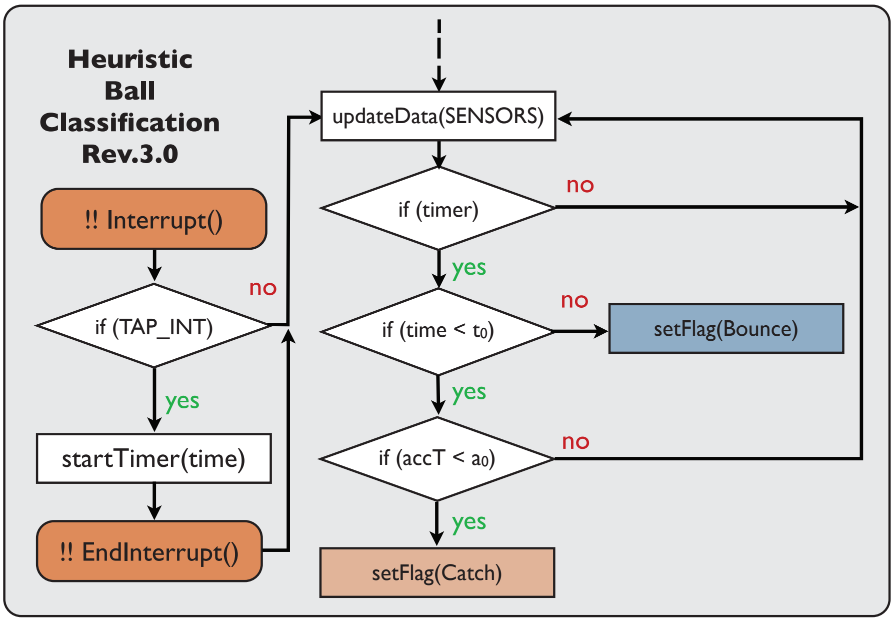


Figure 7.10: Software flow for Catch vs Bounce classification

7.2.5 Evaluation: Deterministic Method: Bounce

An experiment was conducted to determine the accuracy in controlled conditions of this proposed method. The experiment was conducted with 1 participants, a 22 year old male unfamiliar with the system, both right-handed, in a closed room with a tiled floor. The experiment flow was as follows, the environment can be seen in Figure 7.11.

1. Each player will pass the ball to one another until 20 catches are recorded. Passes are to be chest passes at shoulder level
2. The classification result from the ball is recorded for each combination t_0, and a_b.

Figure 7.11: Experiment Flow for Classification Success Rate: Bounce

7.2.6 Evaluation: Deterministic Method: Catch

Similar to the previous evaluation, another experiment was conducted in similar controlled conditions to test for catch success. This time, the experiment had 2 participants, ages 22-28, both right-handed, in a closed room similar to that of the previous experiment. The experiment flow can be described by the following steps and seen in Figure 7.12.

1. Both participants stand 3 meters apart.
2. Each player will pass the ball to one another until 20 catches are recorded. Passes are to be chest passes at shoulder level.
3. The classification result from the ball is recorded for each combination t_0, and a_b.

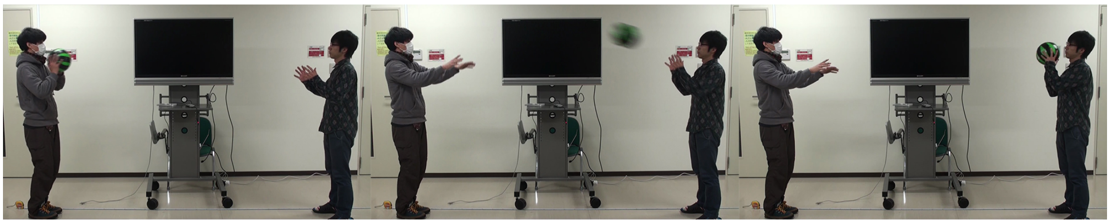


Figure 7.12: Experiment Flow for Classification Success Rate: Catch

7.2.7 Results

The results for each evaluation can be seen in the following tables (Table 7.1, 7.2). Generally, the success rate is high on the assumption that the tap detection is accurate; this dependency may also be a limitation that will be discussed in later chapters.

Using the software flow described before, it appears that the success rates for the two variables are at relative maximum with the combination of $t_0 = 120, a_b = 80$ at an expected success rate of 95% given the controlled conditions.

This method, however, given the conditions brings forth many limitations, which will be discussed in later chapters.

7.3 Summary

In this chapter we investigated the possibility of using data analysis and heuristic techniques to classify atomic events in real-time from sensor data retrieved from our prototype. By first defining such atomic events, and then observing these

Table 7.1: Success rates for Catch classification (N=20)

(t_0/a_b)	120	130	140
50	50%	75%	50%
60	80%	70%	90%
70	**95%**	90%	85%
80	80%	85%	85%

Table 7.2: Success rates for Bounce classification (N=20)

(t_0/a_b)	120	130	140
50	75%	90%	100%
60	90%	95%	95%
70	**95%**	95%	95%
80	80%	95%	85%

events occurring in real gameplay, we were able to model various sensor responses with outstanding features that can be used to model classification.

Firstly, these atomic events can be defined as *Throws* and *Impacts*. For *Impacts*, we have found that there are two types of impacts – *Bounces* and *Catches*. Each of these types of impacts have their own value within Dodgeball and must be separated from one another for correct data analysis.

We then moved to observe the data responses for each of the given atomic events with a live testing experiment. This experiment was conducted under realistic situations to give an insight as to the main features of the sensor data responses with respect to the atomic event. We have found that for each atomic event, the accelerometer, gyroscope, tap detection show very unique responses that can be further analysed. For example, *throw* events are the only events that do not incur a tap-detection response.

By proposing a classification method using a heuristic method, that is, by looking at the sensor responses and estimating timings and threshold values for acceleration, we assert that was it possible to classify *catch* events to *bounce* events. Catch and Bounce events differ by their acceleration response after an impact occurs, there is a damping fact that can be observed after impact that will ultimately effect the total acceleration value that the system will stabilise to.

Using this declarative method, we conducted several experiments to test two particular variables: the time after impact (t_0) where the total acceleration magnitude falls below a certain value (a_b). From observation of data, we claimed that these values can be estimated between 60ms-80ms and 120-140 respectively. The experiment adjusted these variables to find the configuration with the greatest success rate: resulting to $t_0 = 120, a_b = 80$ at an expected success rate of 95% in controlled conditions.

Chapter 8

Application

A possible application scenario that can be used to demonstrate the system's features was developed to illustrate the possible use cases. However, given that the system is still under development, the game design is very limited however did attempt to demonstrate and conduct a user study to investigate the reception of Digital Sport.

8.1 Ball Game Design

In this application, players would use the system to play a simple game of catch. In this game, players would throw the ball at one another with the intent of hitting the player much like in dodgeball. The goal of the game would be to successfully catch the ball. If the player successfully catches the ball, sound effects would be played to signal a successful catch. If the player drops the ball, then the sound effect would signal that the ball has made contact with the ground and the player that last was in range of the ball would take damage. This application, although very simple in nature was used to demonstrate the functionality of the current prototype. Special sound effects were played for various detected ball events that will be described in the next section.

The application used the current ball system, as well as several additional features such as sound playback. An example of the system can be observed in Figure 8.1.

Figure 8.1: Event flow for Augmented Catch Ball Game: Sound effects on Impact and Player Detection

8.1.1 Application of Augmented Features

There were various features added to the application in the form of sound effects and external displays. As the original nature of passing the ball has not changed, the feature for this application is to demonstrate that the ball is capable to detecting elements mechanically without human assistance. Table 8.1 summarises the effects and features that were added as augmentations to the game.

8.2 Haptic-Auditory Asynchrony

To demonstrate an real-time augmentation, we expected the users of our system to experience a near-real-time response and thus latency was a large issue that was initially discovered with our system (as previous hardware improvements suggest).

We had a look at minimum latencies between sound effects and found there existed asynchrony between haptic (ball being caught) and auditory stimuli (sound effect being played). We explored this further by testing for system latency with regards to auditory feedback.

8.2.1 Asynchrony Evaluation: Sound vs. Haptics

To test the asynchrony between the sound effects being heard and the haptic effect, we set up an experiment to evaluate the level of latency that occurs between the sound of impact and sound effect that is triggered by the system. We assume that the sound resulting from the impact occurs at the same time as the haptic

Table 8.1: Augmented application features

Effect Added	Effect Detail
Sound Effects (Impact)	Sound Effects were played on Impact
Sound Effects (Bounce)	Sound Effects were played after Impact if the ball bounces
Sound Effects (Catch)	Sound Effects were played after Impact if the ball is successfully caught
Sound Effects (Freefall)	Sound Effects were played when the ball is in fall motion, usually from a pass or rebounding off a player
Sound Effects (Spin)	Sound Effects were played when the ball experiences a significant level of spin
External Display (Player Identification)	The currently possessing player is shown on the external display
Player Damage via Display (On Impact)	Sound is played, and on impact, 'HP' of the detected player is deducted if in range

sensation that will be felt. The experiment flow is illustrated as follows in Figure 8.2.

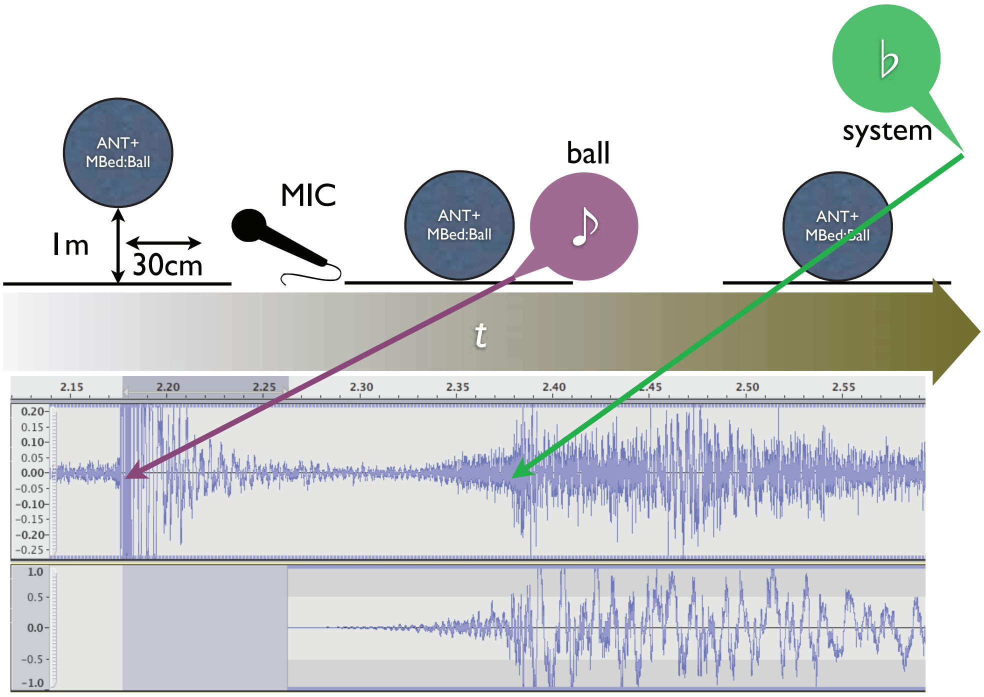


Figure 8.2: Experiment flow for asynchrony evaluation(top); single sample wave sample (below)

The experiment was conducted in a sound-controlled environment. The microphone[1] was placed 30 cm next to the ball. The ball was then be struck by a hand while being fixed in place. The recorded sound from the ball strike (purple), as well as the sound emitted from the system registering a detected strike would sound shortly after (green). The recording was then analysed with respect to the sound source to evaluate the delay with which the playback begins. This was conducted several times to obtain a general insight into asynchrony within the system.

8.2.2 Asynchrony Evaluation: Results

An example of one sound sample obtained from the experiment can be seen in Figure 8.3. In this sample, the ball was struck 10 times as can be seen from the

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[1] TASCAM DR-07mkII LINEAR PCM RECORDER

sudden spike in sound levels. The trailing sound playback from the system can be seen with a very clear period of silence in between.

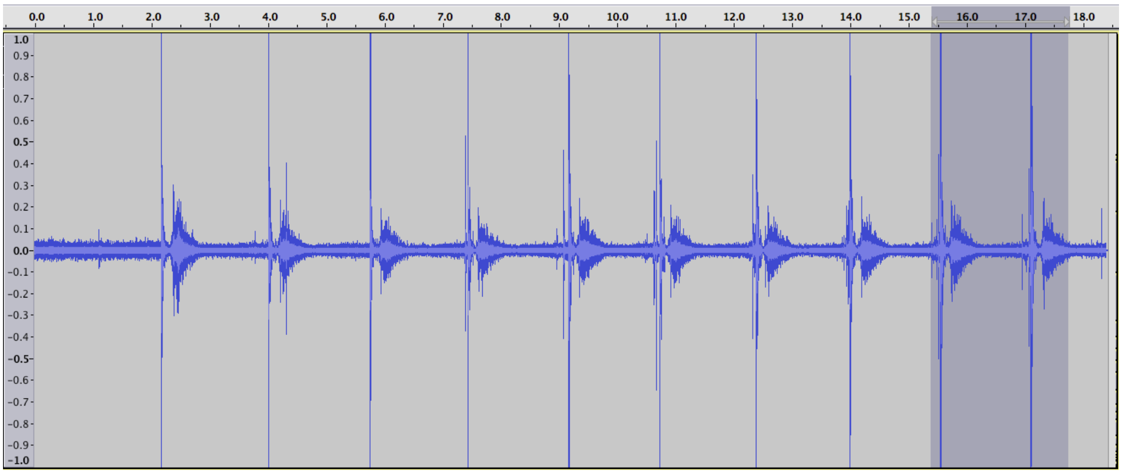
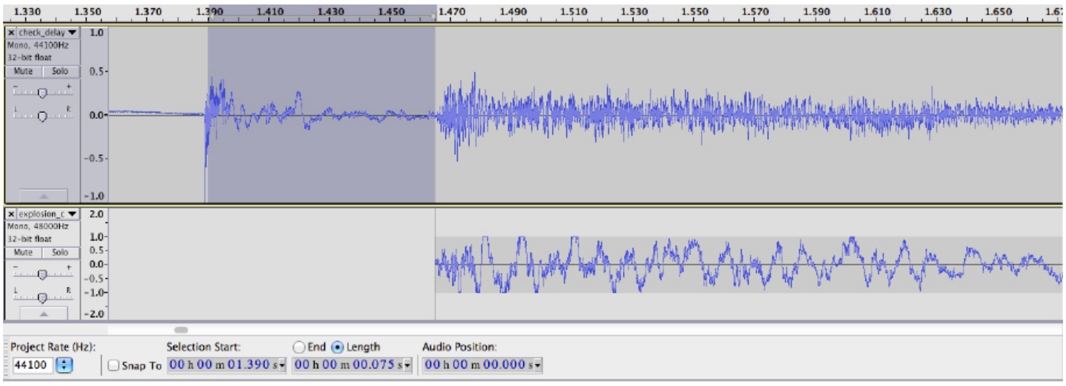


Figure 8.3: A sample recording for striking sound vs. sound playback

On closer inspection (Figure 8.2, lower), it can be seen that there is an initial 200ms delay between the physical strike (haptic feedback) and when the sound effect can fully heard (sound file peak). This can be partially attested to the sound file being used having a period of dead noise (refrain) at the beginning of the sound clipping.

The experiment was conducted once again, this time with the sound clip trimmed of the leading refrain resulting in a sample seen in Figure 8.4.



Project Rate (Hz): 44100
☐ Snap To
Selection Start: 00 h 00 m 01.390 s
○ End ● Length: 00 h 00 m 00.075 s
Audio Position: 00 h 00 m 00.000 s

Figure 8.4: Single strike sample comparision with cropped sound source

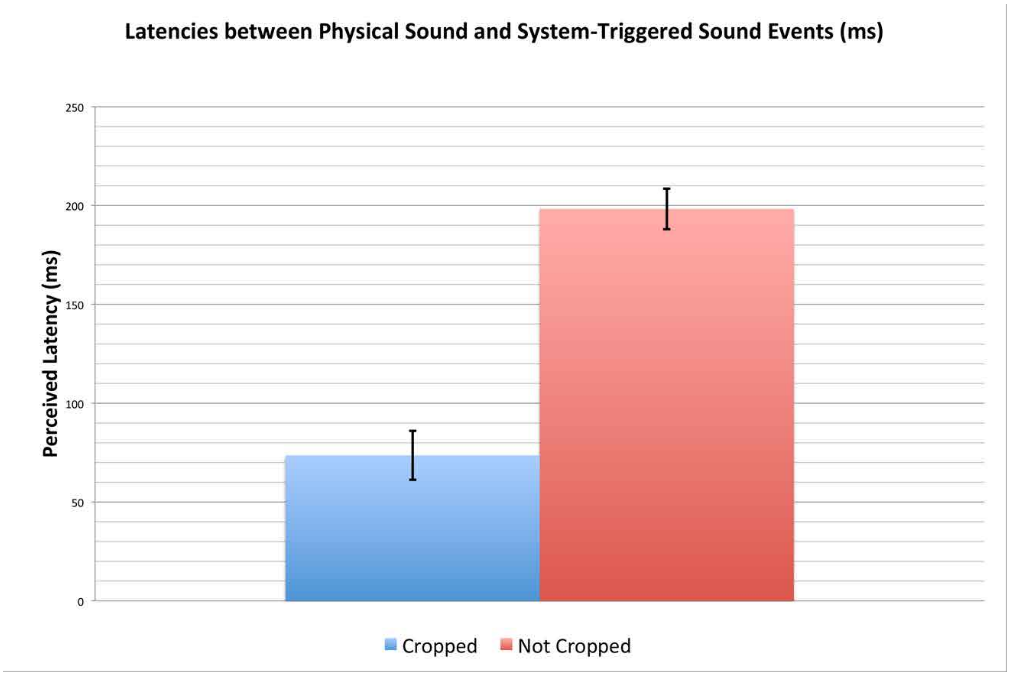


Figure 8.5: Average latencies for cropped and non-cropped sound sources

Figure 8.5 summarises latencies resulting from 10 repeated strikes. The latency in this system was found to be an average of 72ms ($\sigma = 12$ms) an improvement from 198ms ($\sigma = 10$ms). Although a large fraction of the improvement was from cropping the sound source, the remaining latency (60-80ms) is produced by the system. This can be the sum of the time between sensor reading, to data transmission, to host PC processing and sound playback.

8.2.3 User Questionnaire

This application was demonstrated at an open laboratory as a part of research showcase. Users of this system were requested to participate in filling out a simple questionnaire that aims to answer the following questions:

1. Is it worth add bonus rules and features to Dodgeball

2. Is player balancing important to the enjoyment of Dodgeball

3. Does the addition of digital effects increase the appeal of Dodgeball

4. Which digital effect applied to which event appealed the most
5. Is the sound latency of the system noticeable?

Participants were asked to rate on a likert (1-5) scale regarding their opinion on the above after experiencing the demonstration. Questions that were unable to be answered by a scale was given tick boxes. A sample of the questionnaire in Japanese can be found in the Appendix A.1.

Although this user study does not comment on the game application, it does provide insights on elements in the game which can be explored toward the augmentation of sports. Elements such as timing and the use of sound effects are examples of insights toward such augmentations.

A contingency table of the results can be seen in Table 8.2. On first observation, it can be seen that Dodgeball (Japanese variation) can be seen as a very easy to understand sport with a majority strongly agreeing (65%), and that users tend toward feeling that dodgeball is boring if player skill is unbalanced (agree (31%) & strongly agree(47%)). In areas of augmentation, participants found the added sound effects to be very interesting (60% strongly agree). For the current system, given the augmented elements (sound effects), users whom experienced this system had a distribution carding the asynchrony, or latency of the digital effects however there was a slight tendency toward the delay being not obvious (disagree (25%) and strongly disagree (30%)).

There was a tally system where users could vote on the best or more interesting sound effect. This could be for many reasons, one being the application of the sound effect or the atomic event to which that sound effect is applied. The results are summarised in the graph depicted in Figure 8.6. The standard impact sound (sound of an explosion) was voted the most popular with the participants, however there were many surprised comments regarding the ball's ability to differentiate between catch and bounce. Spin also seemed like a very novel addition although it did not receive much attention. The worst of the sound effects was the fall (sound of a whistle).

Table 8.2: User survey for Augmented Dodgeball applications (N=20)

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Dodgeball rules are hard	0 (0%)	0 (0%)	1 (5%)	6 (30%)	**13 (65%)**
Unbalanced teams are boring *(N=19)*	6 (31%)	9 (47%)	3 (16%)	1 (5%)	0 (0%)
Adding SFX is interesting	**12 (60%)**	6 (30%)	1 (5%)	1 (5%)	0 (0%)
Asynchrony is noticeable	3 (15%)	3 (15%)	3 (15%)	6 (30%)	5 (25%)

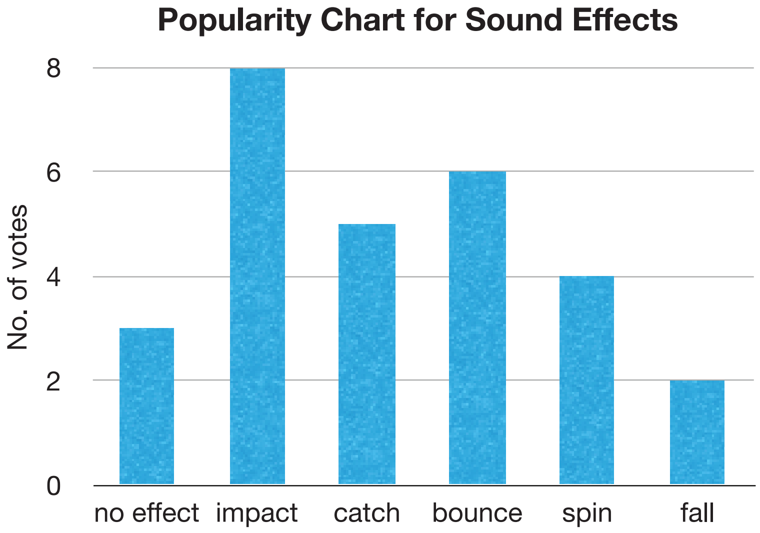


Figure 8.6: Voting tally for each individual sound effects (and its use)

8.3 Summary

In this chapter we developed an application to demonstrate the functionalities of our system. Since our system was capable to classify several atomic events in Dodgeball, we restricted the play to a catch ball type setting and assigned several different effects for these atomic events while adding indicators of changes in ball extrinsic information.

One issue with this system was the haptic-audio asynchrony that was experienced during play, where players would hear sound effects that were delayed after the interacted with the ball. There was a clearly noticeable delay between observed events and sound effects and thus we investigated this latency. Our experiment showed that using sound files with an apparent lead in refrain increased the asynchrony to obvious levels and thus trimming these files reduced the latency greatly, improving the synchronisation. The overall system latency was found to be an average of 72ms from event to sound playback.

We had the opportunity to gather user comments at an open laboratory held where this system was demonstrated. A total of 20 participants assisted in evaluating the idea of augmenting dodgeball as well as the idea of using sound effects to supplement dodgeball events. The sound latency of our system was also commented on. We found that the users think that Dodgeball rules are easy to comprehend, and can become boring when the player skill is not balanced. They also thought that adding sound effects is very appealing, and that the current system lag was not that noticeable.

Chapter 9

Discussion

This chapter opens the discussion of results that were found throughout the paper. It will cover the main issues found during development that can be open to discussion including areas of:

1. Hardware Prototyping
2. Player Recognition
3. Data Analysis
4. Design Approaches

while suggesting alternatives or areas of improvement for said issues. The direction of future iterations that can be made to achieve the goals defined in Section 3.1.

9.1 Hardware Prototyping

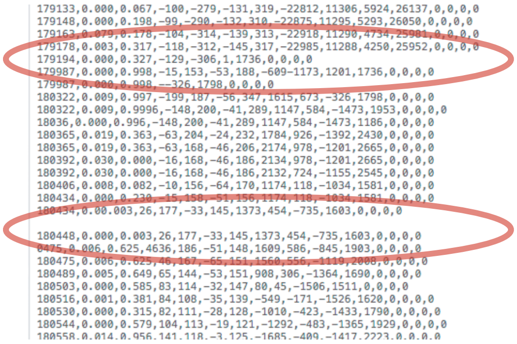
During the process of prototyping, there were many issues within the development of the system as well as technical difficulties that occurred during use. These can be generalised into three sections: Streaming, Sensor and Durability.

9.1.1 Streaming Limitations

During early prototyping, there were issues found within the XBee modules that limit the transmission range of the devices. There was a limitation using the

XBee (chip-antennas) while XBee (external-antennas) proved to be a much better alternative(Figure 9.2). Although for close range communications (2-3m), chip antennas fared very well, external antennas allowed for a longer distance (10m) for stable communication. However, even with the antenna, there was a dead z-axesone of transmission found during the field test where the out-field players were positioned (Figure 5.12). The resulting collected data would have inconsistencies that would need to be manually cleaned (Figure 9.1) as a method of noise reduction. As the antennas are not completely in line of sight, then a drop in range is not surprising considering that the device is encased in sponge and in an wide open area.

At the current moment, streaming is done via unsigned character arrays, this should be improved due to the large volume of data being moved over the wire. We suggest using an encoded byte or multi-byte character for each piece of data transmission in order to keep the packet load minimal regardless of the data contents.



```
179133,0.000,0.067,-100,-279,-131,319,-22812,11306,5924,26137,0,0,0,0
179148,0.000,0.198,-99,-290,-132,310,-22875,11295,5293,26050,0,0,0,0
179163,0.079,0.178,-104,-314,-139,313,-22918,11290,4734,25981,0,0,0,0
179178,0.003,0.317,-118,-312,-145,317,-22985,11288,4250,25952,0,0,0,0
179194,0.000,0.327,-129,-306,1,1736,0,0,0,0
179987,0.000,0.998,-15,153,-53,188,-609-1173,1201,1736,0,0,0,0
179987,0.000,0.998,--326,1798,0,0,0,0
180322,0.009,0.997,-199,187,-56,347,1615,673,-326,1798,0,0,0,0
180322,0.009,0.9996,-148,200,-41,289,1147,584,-1473,1953,0,0,0,0
18036,0.000,0.996,-148,200,-41,289,1147,584,-1473,1186,0,0,0,0
180365,0.019,0.363,-63,204,-24,232,1784,926,-1392,2430,0,0,0,0
180365,0.019,0.363,-63,168,-46,206,2174,978,-1201,2665,0,0,0,0
180392,0.030,0.000,-16,168,-46,186,2134,978,-1201,2665,0,0,0,0
180392,0.030,0.000,-16,168,-46,186,2132,724,-1155,2545,0,0,0,0
180406,0.008,0.082,-10,156,-64,170,1174,118,-1034,1581,0,0,0,0
180434,0.000,0.230,-15,158,-51,156,1174,118,-1034,1581,0,0,0,0
180434,0.00.003,26,177,-33,145,1373,454,-735,1603,0,0,0,0

180448,0.000,0.003,26,177,-33,145,1373,454,-735,1603,0,0,0,0
0475,0.006,0.625,4636,186,-51,148,1609,586,-845,1903,0,0,0,0
180475,0.006,0.625,46,167,-65,151,1560,556,-1119,2008,0,0,0,0
180489,0.005,0.649,65,144,-53,151,908,306,-1364,1690,0,0,0,0
180503,0.000,0.585,83,114,-32,147,80,45,-1506,1511,0,0,0,0
180516,0.001,0.381,84,108,-35,139,-549,-171,-1526,1620,0,0,0,0
180530,0.000,0.315,82,111,-28,128,-1010,-423,-1433,1790,0,0,0,0
180544,0.000,0.579,104,113,-19,121,-1292,-483,-1365,1929,0,0,0,0
180558,0.014,0.956,141,118,-3,125,-1685,-409,-1417,2223,0,0,0,0
```

Figure 9.1: Discrepancies in the sensor streaming data on transmission errors

The latencies for transmission were also one point to be considered. Our application produced a system latency of ≈72ms and the device-side latency of sensor readings was found to be 11ms and 14ms for the data to reach the host PC (Prototype (Rev.3): Table 5.5), we can assume that approximately 50-60ms or so is used for processing the data on the host side.

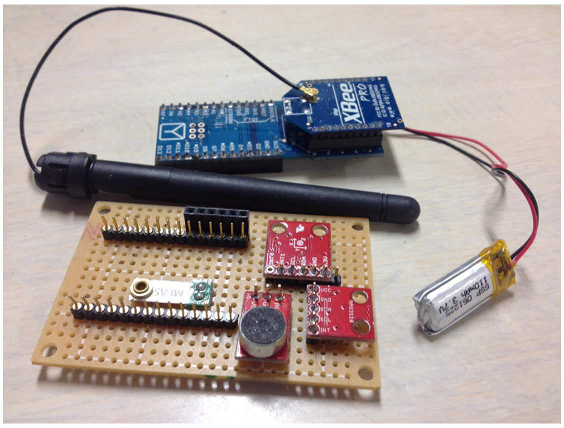


Figure 9.2: Installation of a XBee Antenna to Prototype Rev.1

9.1.2 Sensor Range Limitations

Within the streaming data visualisation, there were several sensors that experienced plateauing due to over ranging of the value with respect to the available data structures or hardware limitations. One example is that of the gyroscopes and accelerometers. 16-bit values for the gyroscope are easily overflowed by the spinning of the ball (which can spin at speeds of more than 600 revolutions per minute ($3600°/s$)(american football standard [33]) and up to 2000 ($12000°/s$) (baseball average pitch spin[30]). This can be seen in Figure 9.3 where the gyroscope (reds) and accelerometer (blues) max out at their respective bit limits.

Although there were range limitations, the sensor values can still be considered meaningful in the context of impact classification as the deterministic classification system was able to produce feasible results.

9.1.3 Hardware Durability

As we are considering the augmentation of a sport that deals with rough treatment of the device, we first had to keep in mind the durability and longevity of the system. Over the several prototype versions the hardware has iterated through, the casing and fixture have been improved. Figure 9.4 shows the previous casing, which used a sewed mouth to fix the unprotected device within the ball. This

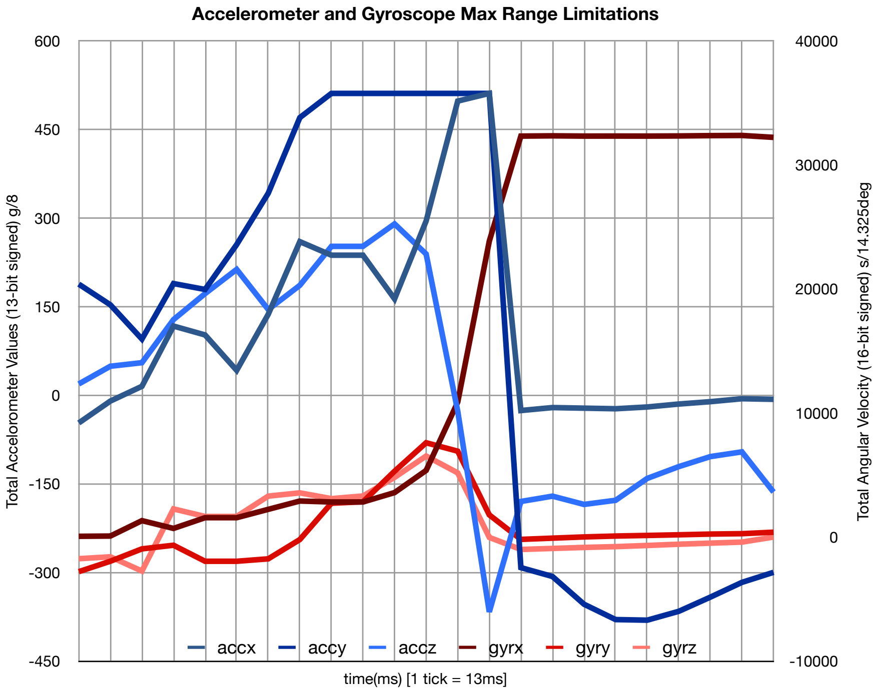


Figure 9.3: Sensor range limitations for IMU sensors (±16g @ 13-bit & ±2000°/s @ 16-bit

resulted in damage to the device hardware board and needed to be remedied. The new split case version uses a plastic shell to cover as well as a flush seating in the centre of the ball core.

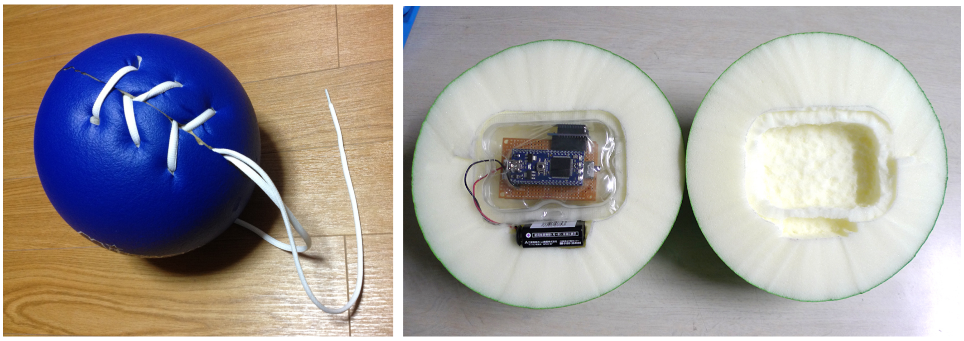


Figure 9.4: Evolution of the sponge casing, sewed mouth (left) vs. split case (right)

9.2 Player Detection

As the player detection system was built upon a fairly complex ANT protocol, and as demonstrated in the previous chapters there existed a strong tendency toward unstable results. The system is still in early development, however can be improved in many areas such as beacon responses; and range finding.

9.2.1 Beacon Responses

The beacon responses were established over a period of 10ms, responses were also expected to come in at this rate. However, due to the nature of RF communication there was instability when the ball device was not in complete range or the antenna positioning was not in favour of the communication direction. A result of this would be the fluctuation between detection and non detection. A solution was to set a timer or a count (soft timeout) that would allow the player change to occur after a certain number of failed or successful acknowledgements (Figure 9.5). The ball-player communication would then need to sustain reliable communication (more than 3-5 consecutive detections) before players would be detected.

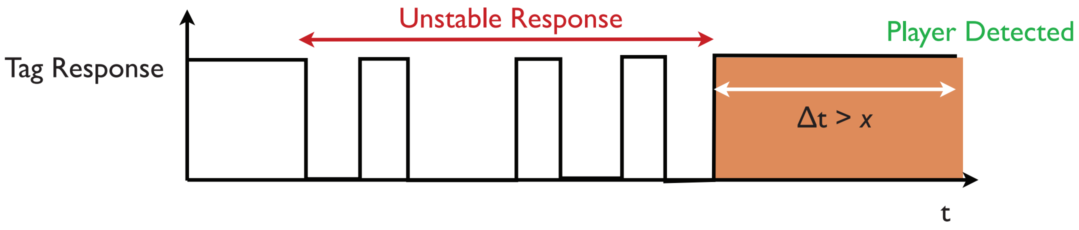


Figure 9.5: Timing filter for stabilising of player tag responses

However this would result in an additional latency between the ball coming into physical range and the detected player changing to the correct value. This can be an area of future work as it deals with ANT protocol manipulation and RF wireless communications/environments.

9.2.2 Timing Limitations

Given the results in Section 6.5.2, there was a very large variance observed for the detection timings for player detection. Although the standard mean time was 820ms after entering player range, the large standard deviation showed that (at P=0.95) the system would need up to 2 seconds until the player would successfully and reliably detect. This system instability was also seen with the first correct detections, having 44% of the detections being correct the first time with a mean time to detect at 450ms ($\sigma = 220$).

As a player detection system, since dodgeball will be a very fast paced, dynamic game, the current system is not completely capable of accurately withstanding real-time conditions. Thus, there needs to be further consideration into short range, low latency protocols or systems that allow for accurate player detection without the use of cameras. One system is similar to that of Catapult Sports [6], which uses GPS systems for high resolution player tracking that can also be used as player detection with respect to the ball.

9.2.3 Range Limitations

Similarly to the timing limitations mentioned in the previous section, the range measurements of the player detection is very unstable and is highly dependent on the environment. For example, the orientation of the player tag, as well as the orientation of the ball (i.e. the relative positioning of the antenna with respect to the receiving antenna) is a very big factor for range detection. Instead of losing connection with player nodes, it may be possible to sustain the connection and base communications on a different variable to determine the closest player (or possessing player). This solution would then implement a different approach instead of a single channel, proximity-based communication solution. For example, using the RSSI (Received Signal Strength Indicator) functionality of ANT, or any wireless module (Figure 9.6) it is possible to determine the proximity of a node with respect to the another node. Thus it is possible to develop a proximity prioritised system without needing to disconnect nodes/players (all the white channels remain open).

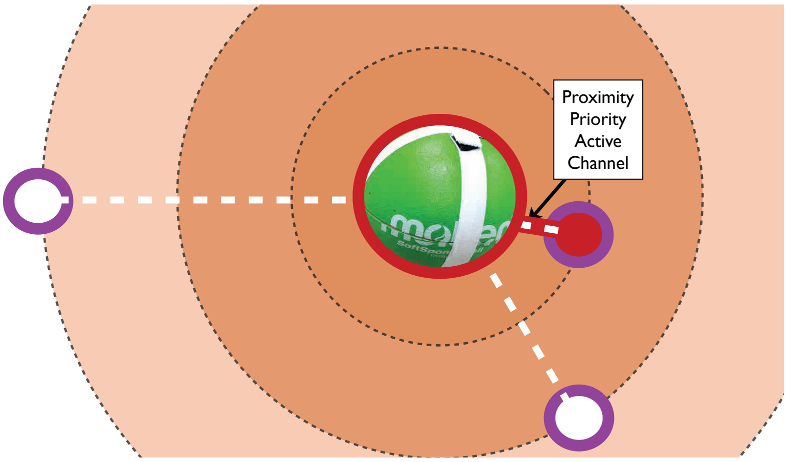


Figure 9.6: RSSI-based proximity priority system where all nodes are in sync

9.3 Data Analysis

9.3.1 Deterministic Methods

The deterministic method was derived from a heuristic study of sensor responses from various experiments done on the field and in controlled environments using the prototype ball (Rev.3). This resulted in a large volume of data (6 minutes x 13ms per recording x 1 line per recording x 60-100 chars$\approx$ 2 Megabytes of string streaming over 6 minutes) to be analysed for trends and possible relationships toward events. The process of this method is very tedious, and may have to be repeated for every particular atomic event that can be considered an element of a sport.

9.3.2 Deterministic Method: Merits

As the system uses very simple techniques to differentiate between atomic events, it is very easy to implement and responsive to a degree. However, prior knowledge of the sensor responses is required given the nature of the heuristic approach to developing this solution. There is no requirement for complex techniques however the scalability and portability of this solution may be questionable.

In terms of hardware, the system would only require an accelerometer to be able to differentiate between Throw and Impact, and classify different types of Impacts. The system can be further enhanced by factoring in gyroscope activity (Section 7.2.1).

Although it has not yet been proven, extended analysis on the vibration sensor may be effective in increasing the system's accuracy.

9.3.3 Deterministic Method: Limitations

The main limitation for this system is that it uses a very simple deterministic method, based of heuristics taken from experiments in both controlled and non-controlled environments. This alone will effect the accuracy in varying environments. For example, Figure 9.7 shows uncommon example for the response for a *Bounce* event that may cause the system to give a false negative (Output: *Catch*) due to the accelerometer value not settling down before the t_0 has elapsed.

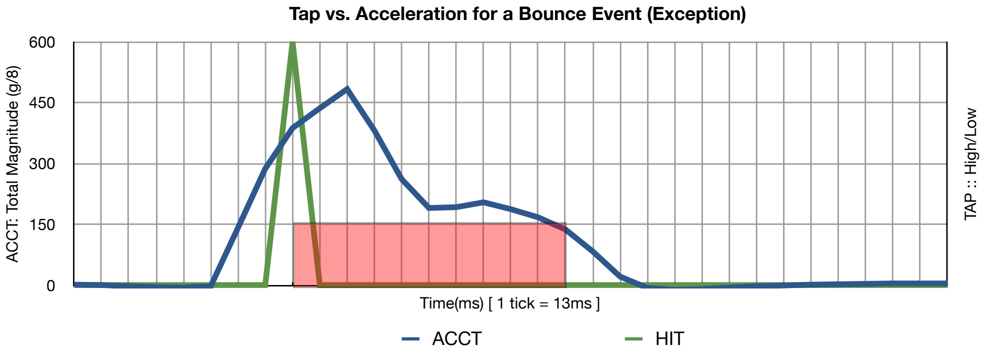


Figure 9.7: Exception Bounce sensor response sample that will result in false negative

There are also many other exceptions to the classification system. The nature of the deterministic system is that one value at a particular time after impact would determine the state of the system – in dodgeball, there is no guarantee that this is always the case. For example, if the ball is thrown at great speeds, and then upon impact the acceleration would continue to rise (due to the ball ricocheting) even after the threshold timing (t_0) has been reached. Another example is when a player catches the ball without controlling it's rebound trajectory (i.e The player bounces the ball of their body to catch the ball) – this can also be falsely classified as a bounce. Due to this discovery, it may be feasible to consider other methods that are able to classify sensor signal responses without the requirement of declarative steps (which can limit the vocabulary of the system).

Also, if the ball is in player possession; the system cannot the determine the difference between the ball bouncing off a player, or bouncing off the ground. Here is a very big determining factor for decision making; thus making it a very large area of improvement.

9.3.4 Deterministic Method: Timing

As there is a timing requirement for classification between *Bounce* and *Catch* events, there is an additional minimum t_0 latency on top of the base system latency after impact to flag the correct event. In this case, assuming that the processing time is negligible, the system latency would then be in Equation 9.1:

$$\Delta t_{system} = \begin{cases} \Delta t_{sensors} + \Delta t_0 + \Delta t_{transmission} + C, & \text{if } \phi_{tap} = 1 \\ \Delta t_{sensors} + \Delta t_{transmission} + C, & \text{otherwise} \end{cases} \tag{9.1}$$

Suggesting that there would be at least an additional $\approx$ 100ms period after an Impact before the system can determine the event.

9.3.5 Proposal: Machine Learning Approach

As an alternative approach to event classifiers, the idea of Machine Learning was proposed instead of deterministic methods. The merits of machine learning is that there is flexibility of the data and that features from the data are automatically generated rather than heuristic methods for deterministic functions: there is no need to manually analyse sensor responses for the purpose of finding and extracting features to develop a classification method.

9.3.6 Introduction to Gesture Recognition

Gesture recognition is one very popular technique that uses machine learning. By using mathematical models obtained through observations (input data), it is possible to predict either the given or the next state depending on current state or previous observed state.

An application of this is the creation of models from sampled that a represent a certain "gesture". One these gestures are trained, then it is possible to analyse the incoming data for patterns and features that resemble that of the trained gestures. This analysis will result in a likelihood that the current movement is a gesture and can be used for recognising both spatial (ball position) and temporal gestures (ball events). The flow of the process can be seen in the GRT example seen in Figure 9.8.

9.3.7 Application of ML to Event Classifiers for Dodgeball

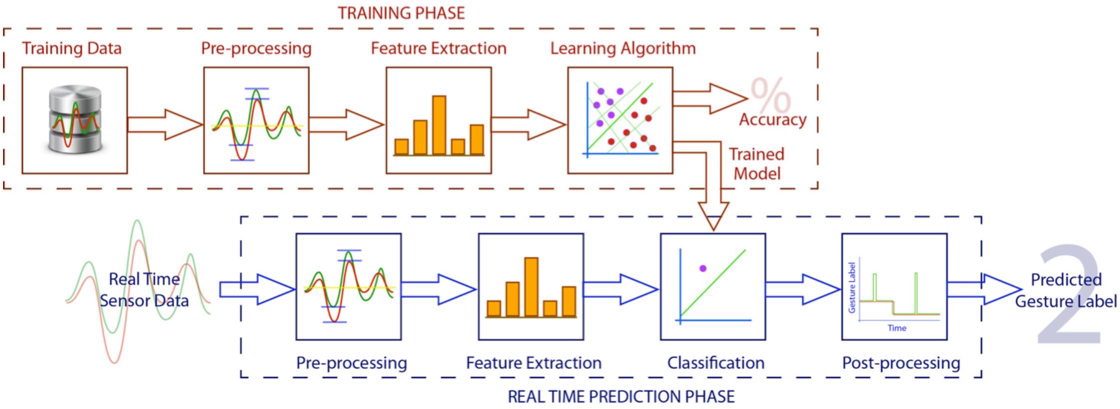


Figure 9.8: Gesture Recognition process (GRT)

9.3.8 Proposal I: Gesture Recognition in Ball Motion

This proposal suggests the use of a Gesture Recognition Toolkit [11] as a means to record, train and predict gestures from raw sensor data found in Dodgeball. These gestures can be assumed to be equivalent to the atomic events that are defined in Section 7.2.1. Given that each event has a specific data representation, it should be theoretically possible for these representations to be modelled via machine learning to a model used to predict similar events given the incoming data.

The process that is suggested can be seen in Figure 9.9. Much like the process described in the previous section, we translate the sensor responses data representations that are used to create a trained model via an algorithm of our choice. We then use this model to classify incoming raw data to predict with a likelihood the particular type of event that data represents.

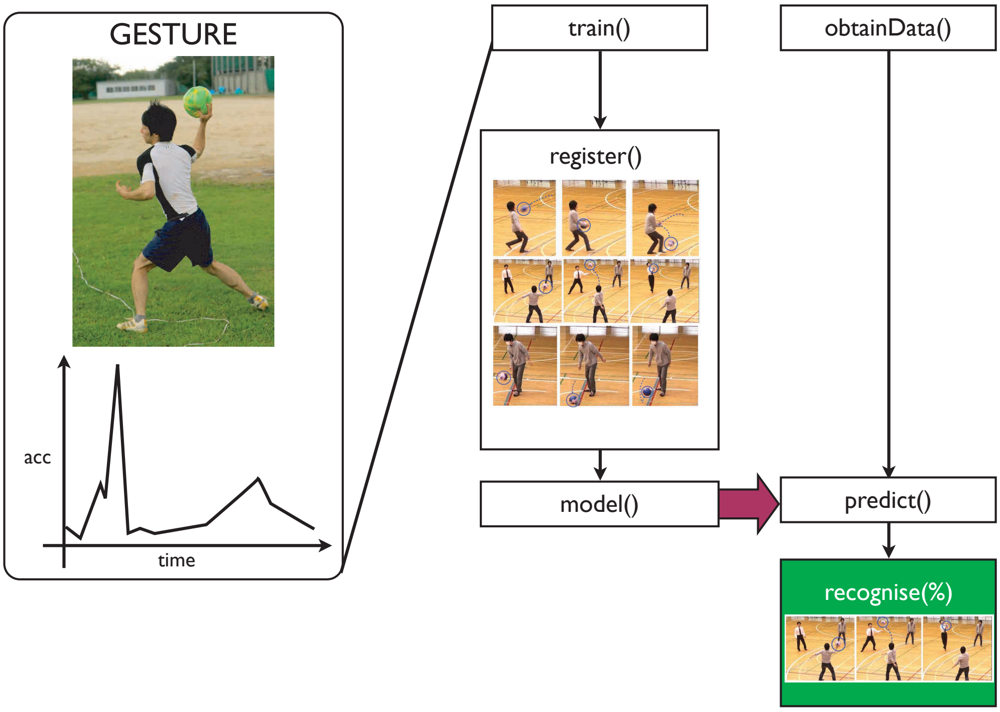


Figure 9.9: Gesture Recognition for Dodgeball Event Classification

Upon first implementation of the system; the classification system was found to be very unstable and did not give fairly meaningful nor accurate responses. It is worth investigation as the process for machine learning is very intricate and the system will require substantial modification before it can be used.

9.4 Design Implications

Over the process of the designing for the augmentation of Dodgeball, there were several points in terms of game design when considering the atomic events. In order to create an Augmented Sport, considerations of environmental issues that will affect gameplay, player centric variables and how they can used in game augmentations.

Environmental Issues

One point that was not covered in the Augmentation possibility is the events based on over-the-line decisions. For example, if the user held the ball and threw this ball while over the line, then the ball would be called a foul. In our system, it is not possible to detect this over line error. This is a key issue for Dodgeball as a sport, and while not addressed in this iteration of research, requires scrutiny before actual application can be considered.

Other environmental issues is the field in which Dodgeball will be played. If heuristic methods are to be used for the design of Dodgeball to be played indoors with the intent of using an inertial measurement system like our prototype, then moving the application field to outdoors will incur unexpected response due to non-controlled environment changes.

Ball-Centric Variables

Given that the sensors were not completely able to cover the full range of ball movement, it was still possible to obtain minute movements and use this information for event classifications. However, as mentioned earlier in Section 9.1.2, this will not be possible for other applications that use high speed spinning balls as it will be almost impossible to able to obtain an accurate measurement using just an internal inertial system alone.

Player-Centric Variables

In this research we discussed the use of player-centric variables that are not physical, for example, hit points and player skill. Although this was not explored in depth in the application, it can be demonstrated by offsetting player health for each player. In this case players were found to attempt to catch the ball without triggering an impact that will result in a loss of health. This was an interesting design implication as players would try to "beat" the system by playing the game in this way.

Game Design

Elements of game design were also discussed on the basis of atomic event classification. For example, if there were automatic event classification; then the game would play like the augmented example defined in Section 4.3.1. Moving away from traditional sporting rules, it is then possible to add game design concepts such as player skills, or team skills where players can activate to assist their team or hinder the opposing team. Although the purpose of this research was to explore the Augmentation of Dodgeball through means that do not modify the sport directly, it is a very interesting area of application.

9.5 Application

Our developed application demonstrated the ability to play sound effects upon successful sensing of various ball-centric movements, as well as player detection via communication with a host PC. Sound effects were played when the ball detected atomic events such as *Throw, Catch, Bounce*, etc.

9.5.1 Haptic-Audio Asynchrony

We found that the sound effects that were played by the system upon successful detection of the event had a level of latency that was noticeable, especially after the user had felt that the ball event occur (e.g Feeling the ball hit you, and then hearing a sound effect).

Upon further investigation via a controlled experiment of a strike test, we found that the latency between the haptic-feedback and system-feedback was found to be initially 200ms. In a detailed analysis of the sound recordings that were extracted by the microphone used in the experiment with a comparison of the original sound source, we found that the sound source had noticeable leading refrain (110 130ms) before an audible sound. Hence, by removing this refrain, the system appeared to respond more promptly, reducing the asynchrony to levels of 70ms.

Research on Haptic-Audio Asynchrony done by Adelstein et. al. [1], where users were asked to hit an object whilst wearing headphones that produced delayed or premptive sound feedback, suggest that users will detect asynchrony between haptic and audio stimuli almost at a 100% at latencies of greater than 50ms. Therefore, a system with an audio lag of less than 50ms after haptic feedback (Impact via the ball) is ideal for unnoticeable delay.

In order to achieve this level of delay reduction, several points can be considered. Each and every source of delay must be investigated: at this point in time the mbed MCU-side processing will result in a 14ms delay per sensor update. Hence, there can only be 35ms between transmission and sound playback before the user will begin to notice the sound lag. One suggestion is to remove the PC host source as an audio playback system and use an xbee based wireless speaker that the ball can directly connect to, here we can eliminate and possible issues of using serial on a PC due to slow serial processing on the PC-side.

9.5.2 User Response

A simple survey of 20 participants to gather insight into the direction of this research also proved useful in determining areas worth investigating. From the responses, it can be easily assumed that there will be very little resistance from users when adding special rules or new additions to the current traditional version of Dodgeball; in fact, if this option helps balances users (For example, Player HP dependent on agility or throwing strength) it would be a welcomed feature.

In terms of the application of Augmented features, we investigated the use of sound effects without visuals to explore the possibility of a semi-augmented reality (non-standard sound effects coming from ball events). The users reacted very well to the use of sound effects with a 60% strongly agree; this implies that it will be worth adding special effects (in particular sound effects) to events in dodgeball such impacts or catching/bouncing. It also might be worth investigating the types of sounds used for each event - this can be a possible area of future work, with the aim to better the user response to this developed system.

9.6 Continuation and Improvements

As this research is still in its early stages; after having investigated the design and implementation of Augmented Dodgeball through a strenuous behaviour, trend and data analysis, there are still several iterations left before this system is capable of providing an Augmented Sport experience to its players.

9.6.1 Hardware Improvements

Given the current generation of hardware, the largest problem that can be observed is the over-ranging of the sensors while the ball system is in active use. As seen in Section 9.1.2, the choice of sensors for this application is not appropriate if accurate extrinsic ball information is required. Therefore a solution would be to use a different sensor system that allows for a wider range suitable for throwable sensors or develop a new method to derive quantitative meaningful data.

Wireless modules may also be replaced with those of low latency, high throughput systems to allow for a stronger real-time feel. Although the current system is hardware independent, it may be feasible to invest in developing a platform that allows for the installation of multiple sensors using a plug-and-play interface. This way, sensors that are appropriate for the application should only be installed. Given the nature of the system is a pure streaming system (and sometimes a classifier depending on application), there is a possibility that the system can support a hub like infrastructure.

9.6.2 Software Improvements and Applications

The classification methods are one key point of what this makes this research unique. As the purpose is to separate atomic events within ball sports - investigation of another method; or improvement of the current method using similar methods (heuristics and deterministic values depending on sensor responses) may be explored even further for future work. Integration of multiple sensors for a sensor fusion type solution would also be an ideal area of improvement.

Development of an Application that is closer to Augmented Dodgeball (as seen in the video game example) would be the next given step provided the hardware allows. At the moment the system only supports 2 players due to the limitation of hardware tags for players.

If this problem is solved (by creating and programming more player tags), then it is possible for multiple tags to be active simultaneously. However, given the current state of the player detection system and algorithm, it will be paramount to develop a stronger, more robust protocol on top of ANT+ to allow for stable player recognition.

As the system currently uses the ANT+ protocol, it is possible to have the player tag to communicate with other slave nodes (personal sensors, pedometers, heartbeat sensors, etc) to extract valuable player information. This information can then be used for the augmentation of Sport the players are currently participating in. (e.g, Dodgeball users can resist more damage from balls if their heart rate is high).

9.6.3 User Studies

Improvements with hardware and software can also be accompanied by independent user studies. Although it was partially attempted once, live play of dodgeball using the ball system (including player detection) has yet to be conducted. Having the data available as well as actual footage of the game will provide for a very strong evaluation method, as well as a data footprint to work toward the improvement of the methods used in this system. Added augmentations to the application used in user studies will also give an insight into how users react to different types of stimuli, as well as in various different contexts (i.e investigation of different sound effects for different events).

9.7 Future Works

Here we discuss future directions of this research, especially within the area of Digital Sports: which can look at many possibilities such as: Spectator-Centric approaches, Augmented Sports (this research), and Exertion Interfaces.

9.7.1 Spectator-centric Feedback for Digital Sports

Allowing feedback to the player is a given in sporting contexts. This allows the player to comprehend interactions with the ball and maybe other players. If the player can feel the ball striking their body, it would mean that they can react accordingly.

However, spectators do not necessarily have the same stimuli. Obtaining the perspective from the spectator is also an area of insightful investigation: spectators make up for a large populace of the sporting community. For example, having an external feedback system where the spectators would experience something similar to what the player is feeling would be a novel way of using real-time quantitative data that is sensed by the system.

It is also worthwhile to investigate spectator-centric devices for interacting with the sport itself or interact with other spectators of the same sport in a social fashion. Although the former seems very unlikely as it may disturb the spectating experience, sharing the same experience with other like-minded individuals will possibly increase the enjoyably of spectating sports.

9.7.2 Exertion Interfaces

As our ball interface already inherits a ball affordance (the ball affords to be picked up, thrown, kicked, etc); it is possible to apply this to the exertion interface repertoire. For example, the ball will not respond unless a very strong force is applied in a particular way – making this an interactive system where the main interaction is exertion.

Applications that explore metaphors that this sensor ball system uses, for example the classification of Impacts (Catch/Bounce), plus the addition of strenuous activity may also be an area for future work. As the concept of Exertion Interfaces is still quite early, however, exercise gaming and fitness-related activities have been growing as of late.

Chapter 10

Conclusion

The contributions of this research can be summarised as follows:

1. Wireless Sensor Ball System capable of real-time sensor data streaming.
2. A proposed method for player detection using a throwable master system with multiple flexible slaves.
3. A method capable to separating classifications of impact-class events (Bounce and Catch)
4. A design process that can be applied to other ball sports of similar nature.

10.1 System

The system developed used several sensors, including that of an 3-axis accelerometer, 3-axis gyroscope, 3-axis magnetometer, vibration sensor and microphone to obtain real-time information about the its own extrinsic state. The sensor values were limited, and thus capturing accurate speed and spin was not possible with the latest prototype; however, minute measurements and interrupt triggers were implemented using the same hardware toward the classification of Dodgeball events.

The system also used an XBee network configuration to relay the sensor data from the system to the host PC at a minimum latency of 14ms. The range managed to cover a standard dodgeball field, but failed to transmit around the areas of the Out-field (10m away from centre line), which is equally as important as the In-field.

10.2 Player Detection

By implementing the ANT+ protocol separately from the XBee network, it was possible to utilise remote player detection where the ANT+ devices beacons the ball to search for player tags in the proximity whilst still able to stream context information (sensor data) to the PC utilising dual network communication.

The system was successful in player detection under controlled conditions, however, the accuracy of the system is in question as well as the timings (approximately 820ms hold for detection, approximately 2 minutes for (P =0.95+) accurate detection) may not be suitable for a fast paced sporting activity like Dodgeball.

10.3 Classification

Using deterministic methods developed by heuristic approaches, the system was able to differentiate impact events that occur in Dodgeball. These events are *Catch* and *Bounce*, which have sensor responses with different features that was used to separate one another from a standard impact. Values of t_0 (time after impact) and a_b (catch threshold) was used to decide the separation between the different events. The system was accurate to 95% in fixed conditions, however was not tested in live conditions.

10.4 Design

A heuristic solution was used for the design of the classifiers used in this system. This would suggest designing around the data that is collected during live play. If this technique would be applied to other sports, it would follow a similar process however is dependent on the sport where sensor responses are involved. Thus it is safe to say that this process will require further engineering to be able to be applied to other ball sports, as the sensor responses are unique for each interaction and context.

10.5 Summary

In this research we look at the augmentation of sport using a dodgeball as a case study. By breaking down the sport into comprehensive atomic events and designing toward the detection of these events, we developed a wireless sensor ball interface that is capable of detecting dodgeball-specific atomic events to a certain accuracy.

The ball uses two wireless solutions to separate channels for: detecting the player via a RF-based sensor network system and the streaming to the host PC via a low latency 802.4.11 specification network. Player recognition was realised using RF-based wireless sensor network solution, ANT+, on the prospect that player-intrinsic information from individual sport sensors (heartbeat, calories, etc) can be used in augmentation.

By using this ball, it was possible to obtain a level of context awareness within the dodgeball sport and thus provide one step toward the digitalisation of sport. Using a deterministic classification allowed the system to evaluate the correct event (given controlled conditions) at a high success rate.

An application to demonstrate this features was developed to gain insight into the feasibility of the system. The application also featured a user survey whose results verified the opportunity of adding features to Dodgeball, as well as utilising sound effects to make the game more interesting (Augmentation).

As the system is still in early stages of development, the requirement for further field testing including the playing of Augmentated Dodgeball as a final application yet to be explored.

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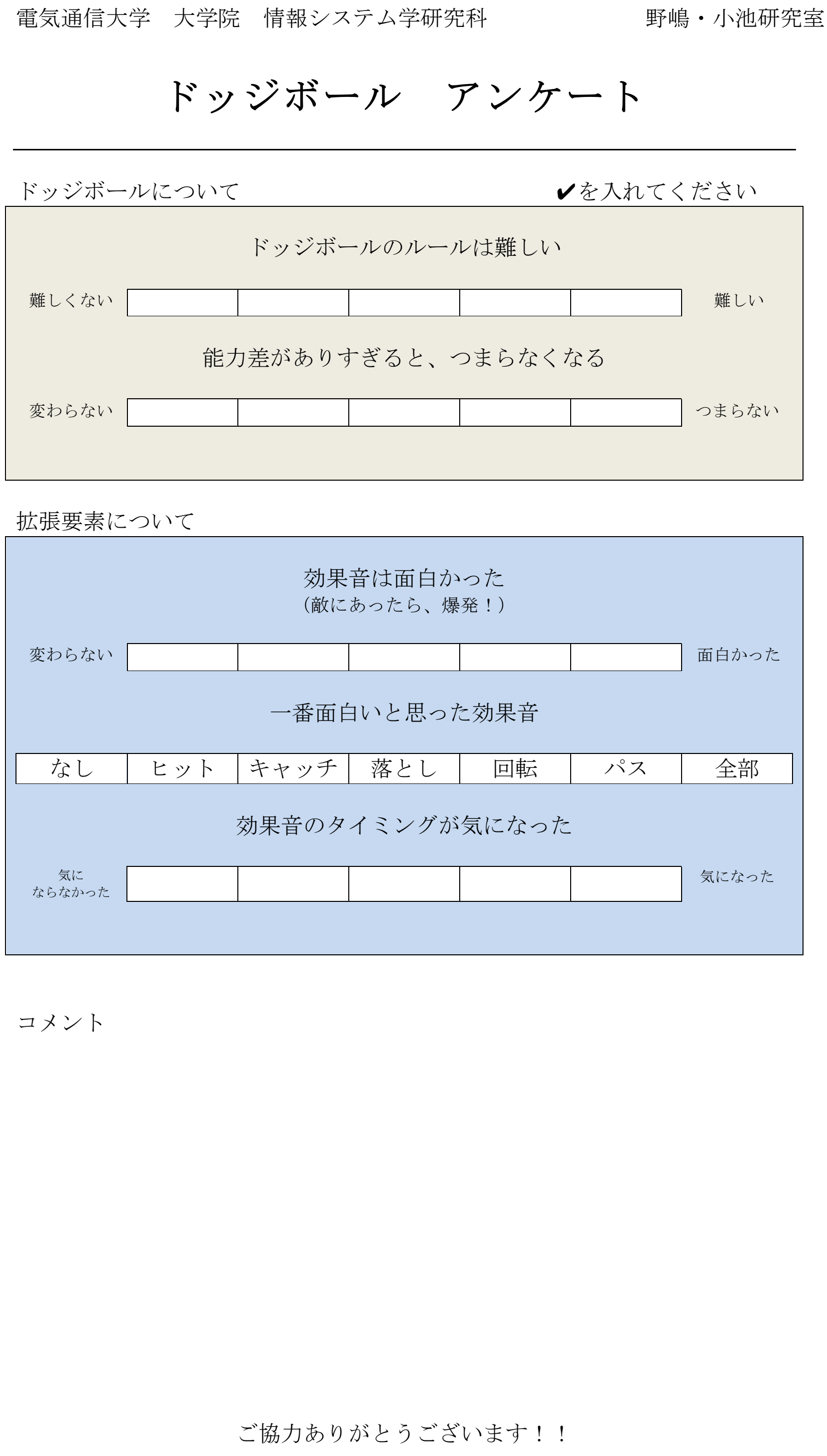
Appendix A



電気通信大学　大学院　情報システム学研究科　　　　　　　野嶋・小池研究室

ドッジボール　アンケート

ドッジボールについて　　　　　　　　　　✔を入れてください

ドッジボールのルールは難しい

難しくない						難しい

能力差がありすぎると、つまらなくなる

変わらない						つまらない

拡張要素について

効果音は面白かった
（敵にあったたら、爆発！）

変わらない						面白かった

一番面白いと思った効果音

なし	ヒット	キャッチ	落とし	回転	パス	全部

効果音のタイミングが気になった

気に ならなかった						気になった

コメント

ご協力ありがとうございます！！

Figure A.1: User Questionnaire for the User Application Demonstration