A Boxing Interface for a Games Console

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A dissertation submitted to the University of Dublin,

in partial fulfilment of the requirements for the degree of

Master of Science in Computer Science

2006

DECLARATION

I, the undersigned, declare that this work has not previously been submitted as an exercise for a degree at this or any other University, and that, unless otherwise stated, it is entirely my own work.

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ACKNOWLEDGEMENTS

Firstly, I would like to thank Mads Haahr for supervising me and helping me with any problems I had throughout this dissertation. Thanks also to Paul Noone and Cormac Driver for providing me with everything I needed for the project.

Thanks to the whole Ubicom class for making it a great and memorable two years. Special thanks to Joe McKnight for answering any questions I had with the MT9's and for working with me on getting the infrared working. That IR Dongle was nearly the death of us both Joe, but we got it going in the end.

I would like to dedicate this dissertation to my parents, Peter and Cathy, for all their support over the years and for putting me through six years of college.

ABSTRACT

Obesity is a serious health problem globally and it is on the increase. Half of the adult US population is expected to be obese by 2025 if current trends continue. A major cause of obesity is inactivity and it has also been linked to playing computer games. As a result, fitness games and peripherals for games consoles are becoming increasingly popular as a method of exercise and as a way to help motivate people to exercise. A wide range of these fitness gaming products exist and state of the art of these along with research in this area are discussed in this document.

This paper introduces a gesture recognition system for playing boxing games on gaming consoles. The aim of this interface is to provide a method for exercising and to provide the user with a more intuitive and realistic way of playing boxing games. This document describes how the users movements and a variety of different punches are recognized by the boxing interface. This is achieved by analyzing the acceleration and Euler angle data from Xsens MT9 sensors placed in gloves and on the users chest. The boxing interface is connected to the games console via infrared. This is done by storing the infrared signals from the buttons of game controllers as sound files. These sound files are then played on a computer through a sound to infrared converter to control the game console.

User testing was carried out showing that the interface helps to motivate the user and that it is effective and enjoyable means of exercise.

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LIST OF ABBREVIATIONS

PS2 – Sony Playstation 2

EA – Electronic Arts, Games Company

IR – infrared

RF – Radio Frequency

BPM – Beats per Minute

Chapter 1: Introduction

1.1 Overview

Obesity is on the rise globally and in particular the US. One of the main causes of obesity is due to inactivity. This inactivity has been linked to television watching and computer game playing especially in children. With a large number of homes today owning a gaming console, introducing fitness products for these consoles offers people a great opportunity to get more active. People are far more likely to exercise if they are motivated and are having fun while doing so. Computer fitness products help to immerse the user so that they are less aware that they are performing exercise which helps to motivate them. Many fitness games are competitive which pushes the user to exercise harder to achieve a better result in the game. Fitness games are particularly important for children who see the benefits of staying healthy as less important than adults do and would be more happy to play games.

Using games for fitness and health is a growing area of research. Numerous fitness gaming products have been released by companies in recent years in response to growing need for people to get more active. These products are wide and varied, and range from devices to practice your golf swing to body building interfaces which allow the user to play racing games.

This paper introduces a fitness device for modern gaming consoles. This fitness device is a boxing interface which can be used to play boxing games without using the game consoles controller pad. The boxing interface consists of 3D accelerometer/gyroscope sensors attached to gloves and one attached to the chest which are used to recognize the punching gestures and movements performed by the user. The recognized punch or movement is then performed by the user's character in the boxing game. Other boxing or fighting peripherals for game console do not address the needs of modern boxing games, only supporting some of the movements which can be performed in the game. The motivation for making this boxing interface was to provide the user with a more natural and instinctive way of playing games other than using a standard game controller. The aim was to create a boxing interface which benefits the user by making them more physically active in an enjoyable way and would motivate them to exercise using the interface.

A method for connecting the boxing interface to a games console via infrared red is also described in this document. This method involves capturing signals from infrared game controller and storing them as WAV files. When the user performs an action and it is recognized, a WAV file is played through a sound to infrared converter which is directed at a infrared receiver connected to the game console. This method could be used as a quick way of testing other gaming interfaces with a games console..

User testing of the boxing interface was carried which showed that the user receives an intense workout even after short periods of playing. Users who performed the testing were enthusiastic about the interface and felt that it would motivate them to exercise.

Further research is proposed and additional features which could be added to the boxing interface are also noted.

1.2 Background

In this section game console sales statistics will be discussed along with computer game usage statistics. This will be followed by a discussion of obesity, injuries caused as a result of game playing and the benefits of boxing.

1.2.1 Gaming Sales Statistics

Figure 1 below shows the monthly console sales statistics for the United States from November 2005 to April 2006 [1]. These figures show an extraordinary number of sales of games consoles and this is just for a six month period. These sales trends have been continuing for many years with most homes that can afford a games console having at least one or more. Therefore there is a large number of people that could potentially be reached by introducing fitness games and peripherals for these consoles.

Month	PS2	Xbox	GameCube	Xbox 360
November 2005	531,000	197,000	272,000	326,000
December 2005	1,500,000	415,000	606,423	281,441
January 2006	272,000	89,000	66,000	249,000
February 2006	299,000	88,000	67,000	161,000
March 2006	273,000	83,000	63,000	192,000
April 2006	206,995	38,987	38,028	295,381

Figure 1 – Monthly console sales statistics in the US, November 2005 to April 2006

All of the consoles represented in the chart above have EA's Fight Night boxing games available to them, making the boxing interface described in this paper available to millions of homes if released. In March 2006 Fight Night Round 3, the latest incarnation of the Fight Night series showed very high sales in the US. In the top selling console games by units [2], Fight Night Round 3 on the PS2 came 6th with 180,000 sold, 9th with 149,000 sold on the Xbox 360 and 18th with the Xbox version. The revenue generated by this game for March 2006 was 6th, 8th and 19th overall for the Xbox 260, PS2 and Xbox respectively. These statistics show a great interest in boxing games by game players and a large potential user base for the boxing interface.

1.2.2 Gaming Usage Statistics

According to a recent study into computer game usage in the United States [3], 35% of game users are under 18 years old, 43% are between the ages of 18 and 49 and the rest are all over 50 years of age. The average age of the game player is 30 and the adult gamer on average has been playing games for over 10 years. This is down to the fact that these adults will have started playing games as a child and have continued to do so ever since. Gamers on average play games for 6.8 hours per week with 8 to 18 year olds playing an average of just under 50 minutes per day [4]. The survey reported that 79% of game users of all ages played sports for an average of 20 hours per month. This study showed that of the console games purchased in 2004, 17.8 % were sports games and 5.4 % were fighting games. That is over 20% of games purchased that a fitness peripheral such as the boxing interface could potentially be applied to.

1.2.3 Obesity and Gaming

Taking advantage of the popularity of console games and in particular the Fight Night series, Burger King have found their way into latest release of Fight Night, Round 3 on the Xbox 360. This is as a result of Burger King pays to advertise in the game. As part of Burger Kings addition to the game, it is possible to hire the Burger King character as the trainer for your fighter. Using the Burger King character as a trainer gives the users fighter increased stamina in the form of a "heart boost" and makes it easier for the fighter to get up after being knocked out [5]. This is the complete opposite of what fast food such as Burger King gives a person. A recent 15 yearlong study has shown that eating fast food more than twice a week has strong links to obesity and diabetes [6]. This confirms the finding of the popular film Super Size Me by Morgan Spurlock where the director went on a McDonald's only diet for a month and suffered from health problems and weight gain. This sort of advertising in games surely gives the wrong impression to users many of which are young and impressionable.

Obesity is a disease that has become a worldwide epidemic. A person is considered medically obese if their Body Mass Index (BMI) is greater than 30. The BMI is a measure of a person's body fat based on their height and weight. The primary causes for obesity are excessive calorie consumption and a lack of physical exercise. In a press release by the Department of Health and Children in May 2005 [7], the following facts were released. The total number of people that were obese worldwide in 2000 was 300 million and it is predicted that as much as half of the US population will be obese by 2025 if trends continue. The current prevalence of Obesity in the US is that 39.8 million adults (1 in 6 people) are obese and 57% of the adult populations are overweight. Statistics show that 18% of Irish adults are obese with 39% being overweight. Estimates by the Worldwide Health Organization stated that physical inactivity resulted in 2 million deaths worldwide each year. Across Europe the most prevalent childhood disease is being overweight. Obesity causes some very serious health risks such as heart attacks, strokes, respiratory diseases, diabetes to name but a few. The recommended solution to obesity is a healthy diet and exercise but it is harder to treat once it has become established and so obesity prevention especially during childhood is recommended. Television and computer games have been widely blamed for years as a contribution to the increasing obesity problems worldwide. A recent research paper from Canada [8] showed that TV watching and computer game usage cause an increased risk of becoming overweight of 17-44%, while there is an increased risk of 10-61% of becoming obese. It is claimed that they encourage people to stay inactive and stay sitting for long periods of time. There are an increasing number of companies in the games industry bringing out games and peripherals to encourage people to get more active and get off the couch. Some of these games and peripherals are discussed in the next chapter of this paper, state of the art.

1.2.4 Gaming Related Injuries

There are some relatively common problems associated with repeated game playing. A medical paper from Trinity College Dublin [9] discusses some of these problems. Users playing games excessively can suffer from repetitive strain injuries as well as wrist and neck pain. Neck pain can occur when the user sits hunched over a control pad for hours at a time. Long repeated gaming affects people differently as they have different tolerances for the injuries and the users' posture during game playing varies also. Problems incurred by vibration feedback systems are also discussed whereby the user suffers from locomotor problems of the hand similar to those found in people using power tools giving such as pneumatic drills. According to an article on repetitive strain injuries [10] due to gaming, wrist injuries are the most common form of repetitive injuries. Carpal tunnel syndrome, one of the more serious forms of repetitive strain injuries occurs when the median nerve in the wrist is compressed and results in problems for the wrist and hand such as tingling, pain, coldness and weakness in parts of the hand [10]. Studies into this syndrome have shown that 10% of frequent computer users suffer from this, and 3.5% suffer from nerve damage. Other problems referred to in this article called computer related injuries are also a concern for gamers. Problems such as tendonitis, musculoskeletal problems and overuse injuries such as back and finger pain are examples of this. All these problems introduced from gaming are due to the use of a game controller and the user's posture during game playing. The boxing interface takes away these problems as the interface allows the user to play games in a more natural way.

1.2.5 Benefits of Boxing

Boxing is one of the world's oldest sports which provide many benefits to people and it results in a great fitness workout. Boxing is one of the best ways for relieving stress and pent up aggression. It has the benefit of keeping people relaxed and may help to control one's life more efficiently [11]. Shadow boxing is a long used method for boxing training and is the method for fitness training of which the Boxing Interface is based on. Shadow boxing is essentially a form of sparring practice carried out solo without a punch bag or an opponent; instead the boxer just punches air. Shadow boxing provides many benefits with little or no side effects. Coordination is improved after just a few rounds of shadow boxing and most importantly in terms of fitness is that a cardio vascular workout is given as a result of extended rounds of shadow boxing [12].

Chapter 2: State of the Art

In this section previous research in the area of fitness in gaming is discussed and fitness products currently available for gaming consoles are discussed also.

2.1 Related Research

Research in the area of fitness in gaming and “virtual” fitness is an active area of research. The general aim of this research is to motivate people to exercise through the use of computer games.

Only one example was found of research in the area of boxing being used for exercise during a game. Shadow Boxer [13] was developed by the University of Tampere, Finland. It is a prototype for a physically interactive fitness game that is controlled by detecting body movements using a webcam. The researchers of this project studied the effectiveness and playability of the game as a form of exercise. Results showed that the game increased the user’s heart rate to the optimal exercise level in most test cases, which shows that it is an effective method of fitness training. Tests were carried for 5 minutes and 11 users took part. Playing the game was also found to be enjoyable experience also. The game used in Shadow Boxer is limited. Only straight, hook and uppercut punches are available to the user and these are performed when prompted by the game to perform a task in the game. As the Boxing Interface can be used with the latest boxing games available for gaming consoles, it provides the user with a richer experience and more freedom during game playing . Future work discussed in this paper involved connecting a heart rate monitor to the system so that data from it could be used in the game. The benefit of this would be that the game could adapt based on users heart rate. The rate at which the user needs to punch could then be changed so that their heart rate stays at their optimal exercise level.

Most other areas of research use cycling or jogging to demonstrate fitness with computer games. *Fitness Computer Game with a Bodily User Interface* [14] was a project intended to merge aspects of gaming and exercising to motivate the user and give them a "sense of presence" while exercising. The bodily interface in the paper consists of an exercise bicycle which is steerable using buttons and a virtual environment which was generated based on map data. The bicycle was placed in front of a screen on which the environment was projected. The terrain in the environment affected the amount of effort needed to pedal e.g. when the terrain is uphill pedalling was harder. The aim of the game was to cycle around the virtual course against the clock. Heart rate data from the user as well as their elapsed time was displayed on the screen. User tests were carried out using a mix of personal trainers and students who exercise regularly and have little experience with games. Results showed that the test users were more aware that they were exercising then playing a game due to the physical exertion needed to play the game. The users found it to be an enjoyable experience and they also found themselves immersed in the environment while playing the game.

The paper *Ubiquitous Computing on the Run: Motivating Fitness by Computing Technology* [15] discusses the current use of technology in relation to fitness and how it does not motivate the user enough. Equipment such as exercise bikes for example, require the user to enter information such as weight and age which due to the size of the display means people nearby can see this information. This leads to the motivation of the user being reduced. The author aims to develop new fitness applications which would be tested in real world conditions as well as researching how technology in current equipment could be improved.

Games for health are a community of researchers, medical professionals and game designers which work together to develop a "best practices platform for the numerous games being built for health care applications" [16]. It was founded by the Serious Games Initiative [17] which coordinates work done in the game industry and work done in the area of games for education, training, health, and public policy

2.2 Gaming Fitness Products

The area of fitness in gaming has become very popular of late and there are an increasing number of companies within the gaming industry releasing various products aimed at promoting fitness. The following is a description of a variety of gaming products promoting fitness.

2.2.1 Peripherals for Fighting Games

The first three I will mention are similar products to the Boxing Interface but they are a more general solution and are used for all types of fighting games. There is a fourth device by Xavix specifically for boxing which is mentioned later in this chapter. The first example is the BodyPad [18]. The BodyPad is a fighting simulator for use with the Playstation 2 and the Xbox. It works with most fighting games and also some sports games such as track and field games. The BodyPad uses pressure sensors on the knees and elbows to detect punches and kick. When the knee is fully bent or the elbow is straightened a kick or punch is detected. It also has handles for the hands which have buttons and a directional control cursor for movement and other functions. The BodyPad cannot recognize individual punches like the Boxing Interface. The triggering of a pressure sensor on the knee or elbow simply acts as a single button on a game controller. The BodyPad will not work with games where the analogue sticks of the controller are used, unlike the Boxing Interface. This would be a problem especially in the more recent boxing games such as Fight Night as they are heavily reliant on the analogue sticks. It is also probable that if using boxing games with the BodyPad that kicks would have to be performed to do some punches which takes away from the gaming experience. Punches like uppercuts would have to be performed like a straight punch, further taking away from the realism. From this it can be seen that the BodyPad, while good from a fitness point of view is not really suitable for boxing games. The price of the BodyPad is around $80.

Another peripheral device with a similar function to the BodyPad is the Thrustmaster Fighting Arena [19] which was released in 2001 for the Playstation. Like the BodyPad it can detect both punches and kicks. Player movements are detected using a mat with pressure sensors in it and four infrared beams passed between two vertical posts. Each infrared beam corresponds to a button in the game, which are triggered when a beam is broken. Like the BodyPad this peripheral doesn't actual recognize the type of punch performed e.g. jab or hook, and it cannot be used for games needing the analogue sticks such as the newer boxing games. *Figures 2 and 3* below are pictures of the BodyPad and Thrustmaster fighting arena.

Figure 2 - The BodyPad Fighting System

Figure 3 – The Thrustmaster Fighting Arena

The third of the fighting systems is the BodyForce by ArcadeMX [20] which was unveiled at the Consumer Electronics Show at the in January 2006, see *figure 4* below. It is used for playing fighting games on the PS2, Xbox and PC such as Tekken or Streetfighter. Like the other two fighting systems it can be used to detect punches and kicks. The system has four sensors [21] which are strapped to the hands and feet and are used to detect the body's movements. Each sensor maps to one button on the control pad eg X, Circle, Triangle and Square on the PS2. A pressure sensing mat is used to perform the other movements and functions in the game. Like the other fighting systems already mentioned it is not ideally suited for boxing games. This is because the system does provide for the functionality of analogue sticks from regular control pads. As the newer boxing games are heavily reliant on the analogue stick for punching and movement, this system cannot be used with them. The slightly older boxing games such as knockout kings 2002 could be partially used. The user would not be able to move due to having no left analogue stick though and would have to perform half of the punches by kicking.

Figure 4 - The BodyForce Fighting System

2.2.2 Sony Eyetoy

The Eyetoy Play for the Playstation 2 is one of the popular fitness devices for gaming consoles selling over 2.5 million copies in Europe since its launch in July 2003 [22]. The Eyetoy is the hardware part consisting of a camera that sits on top of the television and the Play is the game part consisting of 12 mini games. The user is displayed on the television using the Eyetoy camera and vision detection is used to detect when the user performs an action in the game. Depending on the game being played the user's action usually involves punching or slapping objects on the screen to play the game. This provides some physical activity for the user as they do not spend their time sitting down while they are playing the game. Of the games included with Play is a boxing game called Boxing Chump. In this game the user faces a computer controlled opponent on the opposing side of the screen. The user can move around to avoid punches and punch towards the screen to hit the opponent. This sort of game is aimed towards the younger gamer and the user is limited to only simple punch types. Other games have been released for the Eyetoy since Play and support for the Eyetoy has been built into other games such as Harry Potter and games using a Dance Mat. *Figure 5* below is a screenshot of the Eyetoy with the Boxing Chump game.

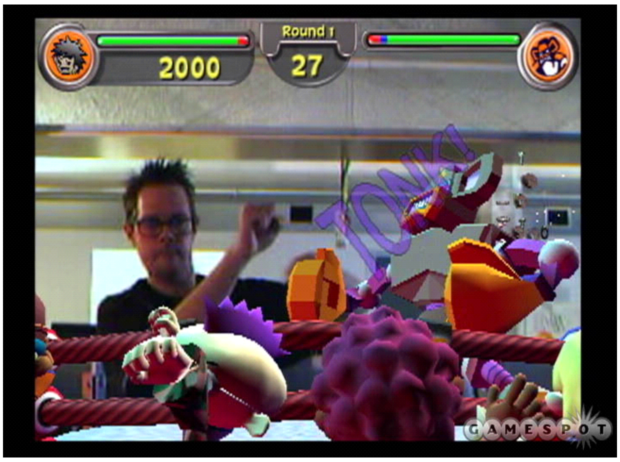

Figure 5 - The Eyetoy in action with the Boxing Chump game

2.2.3 Games using Dance Mats

Another very popular type of game promoting exercise is dance games such as Dance Dance Revolution where a dance mat is used. This type of game has sold millions of copies and dance mats over the past few years. A dance mat is a game controller that consists of pressure sensors which the user steps on to control the game. Usually a dance game involves stepping on certain pads in time with music. Some of the more advanced dance games allow the Eyetoy to be used with it so that users can perform dance moves with their hands as well as their feet. Some other games have an exercise or work out mode which provides more exerting game playing than the normal game modes. There have been numerous reports of significant weight loss after regular use of dancing games. They have even been introduced to fight obesity in some schools in the US where it hard to get students to partake in sports and other physical activities [23].

2.2.4 Game Bike

Another fitness promoting device built around cycling is the Game Bike [24]. The Game Bike is a essentially a regular bike machine that can be found in a gym which has been adapted so that it can be used as a game controller for the PS2, Xbox or Gamecube. It was designed to be used mainly in places like gyms as a means of motivation during exercise. Up to four can be used simultaneously for playing racing games. The faster the user cycles the faster the car or other vehicle being controlled will go and the fact that the user could be competing against other players would motivate them to pedal quicker. Moveable handlebars allow for steering and the Game Bike also provides feedback of statistics such as heart rate data and distance travelled.

2.2.5 Kilowatt Fitness System

Kilowatt [25] is a product similar to the Game bike but it is used for muscle fitness in comparison to the aerobic fitness achieved using the Game Bike. It works with any major games console, PC or Mac and is best used with driving, flying or first person shooting games. The system (see *figure 6* below) is essentially an alloy steel tube which connects a controller on the top to a mat at the bottom and has a back stabilizer. Technology in the tube determines how hard the user is pushing on or pulling on the controller (no part of the machine actually moves though). By pushing and pulling the controller in certain directions the users can control their character or vehicle in the game they are playing. The harder they push or pull the faster their character or vehicle will move. This method of movement mimics the functionality of the analogue stick of a game controller. The technology used in the system is called ISOCOR and is the result of three years and millions of dollars of research involving physiologists, materials scientists, electronics engineers, industrial designers, and video gamers. It uses four semiconductor strain gauges in the steel tube to assess the energy put into pushing and pulling in the X and Y axis. Two microprocessors are used to convert the data from the strain gauges into an input recognized by game consoles. The system allows the user to set the level of effort required and it is displayed on an LCD screen which also displays the total workout time and the weight lifted. The system provides a mainly upper body workout with the quads and gluts also being work out. The system has won many awards including the innovation of the year award 2006 at the consumer electronics show and has received excellent endorsements by many leading newspapers and magazines.

Figure 6 - The Kilowatt exercise machine

Figure 7 – Qmotions Golf Game Controller

2.2.6 Qmotions Gaming Peripherals

The company Qmotions [26] produces a range of interesting peripherals to play sports games on the PS2 and Xbox. Of their range of peripherals they have a device similar to the game bike called the "Fun-Fitness" which is being released in May 2006 and can be used for playing driving games by pedalling. The second of the peripherals made by this company and the most advanced is their golf interface (see *figure 7* above). It is used for playing golfing console games and replaces the consoles joypad. This system consists of a golf ball attached to a sensitive electronic swing arm that converts the user's golf swing and the directional impact of a golf club on the ball into the balls flight, speed and direction. Precise calculations are carried out by algorithms used by the system to give very accurate results from the users swing. Real golf clubs can be used with this peripheral which increases the realism of the system and allows the user to practice with their own clubs. The system is also sensitive to the head speeds of the golf clubs used, allowing for different types of clubs to be used. The system also includes an online statistics tracker which monitors the user's swings and can be used to improve swing consistency and precision. User data is represented online in the form of graphs showing swing speed and accuracy.

The next of their systems is the Xboard (see *figure 9* below) which is a board used for playing snowboarding and skateboarding games. Sensors in the board measure the users shifting in weight and their foot movements while they are standing on the board. The board detects the users movements by the measuring the tilt of the board. These measurements are then translated into movements in the game. A control pad is still needs to be used in conjunction with the board to perform the more complicated moves and trick moves in the games. A review of the board [27] talked of the benefits of the Xboard as providing an increase in balance and strength in the legs.

The last of their systems is the Qmotions-Baseball system (see *figure 10* below) used for playing baseball games. The system has 2 parts to it. The first part is a sleeve which can be placed on any 27" baseball bat. This sleeve contains a motion sensor which is used to accurately measure the batting swings performed by the user and map it to the swing performed by the user's character in the game. Therefore, the users own swing determines how well their character performs in the game. The second part of the system is a home plate which the user controls with their feet. It is essentially joypad buttons on a hard mat used to control the functions in the game other than swinging the bat, such as running and swing selection.

These different peripherals represent some of the more advanced peripherals promoting user activity available for game consoles. The cost of these systems is relatively cheap considering a gamer spends on average $700 a year on games and gaming hardware, according to an IGN survey. The Fun Fitness and the Xboard are available for under $100 while the Qmotions-Baseball system costs $150 and the Qmotions-Golf system costs $250. The latter two are for the more serious user which is reflected by the price.

Figure 9 - Qmotions Xboard **Figure 10 - Baseball system**

2.2.7 Xavix Fitness Gaming Console

Xavix Port [28] is a console that is basic by modern standards but it was designed as a console solely for playing exercise games. It connects to a TV and monitors the calories burned by the user after they enter their age, sex, weight etc. An infrared receiver on the front of the Port is used to receive signals from the games peripherals. Six games are available for this machine all of which come with their own peripheral to play the game. These games are golf, baseball, bowling, tennis, Boxing and J-Mat, an aerobic workout game. The golf game uses a motion sensor placed on the ground to detect the user's swing when it passes over the sensor. It is similar idea to the Qmotions Golf but seems to be less accurate and generally more basic. The baseball game has both a bat and a ball peripheral allowing the user to both bat and pitch. Buttons on the bat and ball allow the user to change options like pitch type. The bat has an accelerometer in it which detects the swing speed and there is an infrared transmitter on it which sends the data to the Xavix Port. The ball is held in the hand and the user goes through the motions of throwing the ball, an accelerometer in the ball measures pitch speed and sends it to the Port via an infrared transmitter in the ball. The golf clubs and baseball bat are made specifically for the games and are plastic unlike the Qmotions peripherals which are used with real bats and clubs. Their bowling game peripheral (see *figure 11* below) works in a similar way to their golf peripheral. The user swings the bowling ball over a motion sensing device placed on the floor and this is related into a swinging of the ball in the game. The tennis game comes with two wireless tennis racquets which are used to play the game. The speed of a users swing is detected by sensors in the racket which is then sent to the console. There is an infrared transmitter in the head of the racket, which presumably sends the swing data when it is pointing at the console during part of the swing.

The last two games were unveiled in January 2006 at the Consumer Electronics Show in Las Vegas and have Jackie Chan in the games as part of a marketing strategy. The J-Mat, an aerobics style game, is the most exercise orientated of the games. It comes with a wired mat with four pressure sensors in it and hand weights. There are two different modes in this game. The first is a workout whereby the user steps on certain pads on the mat and moves there arms to copy the instructor (Jackie Chan) in the game. This mode can be set to different difficulties. The second mode is an action game where the user controls a character in the game. The user must jog on the spot to run, jump to jump in the game, and step left or right to avoid obstacles.

The last game is a boxing one which is of most relevance to this paper, a screenshot of which can be seen in *figure 12* below. The interface for this boxing game consists of two wireless gloves and the mat from the J-Mat can be used to move also. Sensors in the gloves gather data on the punches and send it to the Xavix Port which determines what movements were made. It is not very clear how this is done or what kind of sensors are in the gloves, but considering the other devices all seemed to use an accelerometer in the peripheral this is most likely. There is also little information on the type of punches that can be detected by the system. Most likely only very basic punches can be used. From a review on the game [29], it is said that the user can dodge to the left or right by leaning in that direction so there may be a basic gyro sensor in the gloves also, or else this is done by standing on the pads of the mat. Blocking is performed while the user is in a guard position, how the system knows the user is a guard position is also unknown. There are three modes in the game, exhibition, training, and championship, with different levels of difficulties. Reviews exercise level achieved of the game are mixed, one review [29] said playing the game was quite physically intense [29] while the another said it adequate enough to get the heart rate up a bit but not enough for a proper workout.

The way the Port Console and its peripherals determine the user's movements is through the use of an accelerometer, which it is not enough to properly measure the user's movements effectively, allowing for only basic movement differentiation. While the games are relatively good for fitness, it involves buying a console that only has 6 games for it. The XavixPort costs $80 and the peripheral devices with games range in price from $50 to $90 and so are reasonably priced. There are similar devices out for the major games consoles though, most of which are better and are similarly priced. Consoles such as the Xbox now only cost around 100 euro, so gamers are far more likely to buy them than the XavixPort. The games themselves are also rather limited both in terms of graphics and functionality compared to the games on the major consoles and will not appeal to core game players.

Figure 11 - Xavix Bowling System

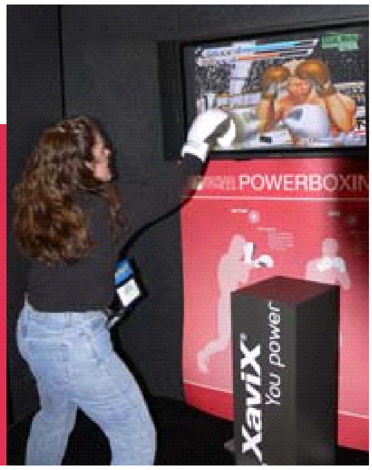

Figure 12 - Xavix Boxing System

2.2.8 Nintendo Wii

The Wii [30] is the latest console from Nintendo which will be released in the final quarter of 2006. The control pad used with the Wii contains a gyroscope and is able to detect acceleration and orientation. This will be used by the new console to provide a much more active and intuitive way of playing games. The unveiling of the Wii at E3 on May 9th 2006 showed the control pad being used to play a tennis game by actually performing the racket swing with the controller. A sword fighting game where the user had to perform the sword swings was also demonstrated amongst other games. This marks a new age in game playing as no mainstream console manufacturer has released a controller anything like this. There will no doubt be a boxing title released soon which can utilize this controller, but it may still be insufficient to differentiate between the number of punches possible in the newer boxing games.

Figure 13: The controller interface for the new Nintendo Wii gaming console

2.2.9 Yourself Fitness Game

Yourself fitness [31] is a virtual fitness trainer for the PS2, Xbox and PC. This game is geared mainly towards women. Yourself fitness has a virtual trainer called Maya who gives the user a training regime after they provide some data about themselves such as age and weight and what goals they hope to achieve during this regime. Maya performs the exercise routine with the user similar to an aerobics video. The game adapts to the user's goals daily, so if the user is unable to perform a full work out one day, it will be taken into account to meet their long term goals. This flexibility of the game would help the user to keep interest as it would allow the routine to fit in better with everyday life. The aim of this fitness aid is to help to motivate the user to exercise by providing dynamic workouts which change each time with music to suit their mood.

Chapter 3: Connection to the Gaming Console

3.1 Introduction

The gaming console used to connect the boxing interface to is the Sony Playstation 2. This choice was made as there are various infrared controllers available for this console. Other methods of connection other than infrared are discussed at the end of the chapter.

The idea to connect to the gaming console via infrared is based on an Engaget article posted in 2004 [32]. The article describes a method of using the iPod as a universal infrared remote control. Infrared signals from remote controls are captured using the Total Remote software with a PDA. The signals are then played through the headphone jack of the PDA and recorded on a PC as sound files which are then stored on the iPod. The sound files are then played out through the Total Remote IR Dongle in the headphone jack of the iPod which converts them back into infrared signals.

To connect to the PS2 infrared signals from an IR control pad are recorded using an iPaq running Griffin Total Remote software. The signals are then recorded from the iPaq to a PC using a 3.5 mm headphone cable and saved as WAV files. The Griffin Total Remote dongle is then placed in the headphone jack of the PC being used. When the WAV files are then played, they are converted back to IR signals by the IR dongle and are sent to an infrared receiver connected to the Playstation 2.

3.2 Hardware and Software Used

3.2.1 Game Consoles

For this project a Sony Playstation 2 (PS2) was used. This choice was made as various infrared control pads and dance mats are available for the PS2 which were needed to connect to the gaming system by the boxing interface. The Microsoft Xbox only uses infrared for its DVD remote control. This remote is of no use since there are no buttons on it which are used for playing games. If there were, the IR signals from the buttons could have been recorded for use with the Boxing Interface. It is possible to use the Boxing Interface with other gaming consoles besides the PS2. A PS2 controller adapter can be used, so that the Boxing Interface can plug into other consoles like the Xbox, Sega Dreamcast or the Nintendo Gamecube.

3.2.2 Game Controllers

A PS2 infrared controller, dance mat or PS2 infrared adapter is needed. Depending on which is used affects the variety of punches, moves and other functionality that can be used in the boxing game. As infrared is pretty much obsolete for use with game consoles, it is very hard to find this equipment. Newer devices all use 2.4GHz RF for wireless connection to the games consoles. Depending on which device is used depends on the game you want to use for the PS2. The older titles such as EA's Knockout Kings for the Playstation One will work with all IR devices as they don't require analogue sticks and use a limited number of buttons. For the newer titles such as EA's Fight Night Series, devices need to have analogue functionality as the control of the game is centered around the use of these analogue sticks. For the project three infrared devices were used. These were an infrared dance mat, infrared remote control which has all the buttons of a control pad bar the analogue sticks and a Go Wireless infrared adapter which allows regular wired PS2 controllers to be converted into infrared controllers. The dance mat allows the use of four action buttons and four directional buttons while the remote allows the use of 10 action buttons and the four directional buttons. The Go Wireless adapter allows the use of the same buttons as the remote but main reason to use it is that it can be used to convert a wired analogue PS2 controller to an infrared controller so that the analogue sticks can be used for the latest boxing games.

A problem with using infrared remote controls is that although they have more buttons than the dance mat, alot of the actions from the boxing games require simultaneous button presses which are not possible using these remote controls. This makes the remote controls only marginally more useful than the dance mat even though there are more individual buttons which can be used from it..

3.2.3 Pocket PC

Two Hewlett Packard iPaq PDA’s were used in the project. A newer iPaq h5500 was used with oscilloscope software to read IR signals so that they could be analyzed and compared to other IR signals. The device could also be used to transmit captured IR signals to test if they were working properly. The second iPaq used is an older model h3970. An older model is needed circa 2002/2003 as the total remote dongle did not work with any of the more recent iPaq models used. The quality of the audio port on the iPaq is also important as the Total Remote will function badly or not at all with iPaqs that have poor quality audio ports. This h3970 iPaq has Griffin Total remote software installed on it and is used to capture the infrared signals from the game controllers which are used.

3.2.4 Laptop Computer

An Acer 5510 laptop is used to run the application. It has 1.73 Mhz Intel Centrino, 1Gb DDR2 Ram, 80Gb Hard Drive, 128mb X700 Radeon Video Card and runs Windows XP professional. This laptop was found to work best when connecting to the console as opposed to other laptops and desktops which were unsuccessful. This was due to the Total Remote which only tends to work with certain devices.

3.2.5 Griffin Total Remote

One of the most important devices used for communications between the laptop and the games console is the Griffin Total Remote. It has been obsolete for the past few years and therefore it has become difficult to acquire. The Total Remote consists of an infrared dongle and software which is used with pocket PC's such as the iPaq. The Total Remote was developed to be a universal remote control that could replace remotes from TV's, VCR's, sound systems etc. Using this software, infrared signals from remote controls or other infrared devices can be captured through the iPaq's IrDA port. The software can then playback these signals through the IrDA port or through the IR dongle which fits in the headphone jack of the iPaq.

The IR dongle is used in older models of pocket PC's to extend the range of the infrared which is limited in these older models. The Total Remote IR Dongle can also be used as a sound to IR converter, which is why it is used in this project. This IR dongle consists of two infrared emitting LED's side by side, with a 3.5 mm headphone jack plug for connecting into the audio port of a PDA or other device (see figure below). The dongle is now discontinued as the adequate range of the IrDA on current models of pocket PC's makes it no longer necessary. The Total Remote was originally designed for use with the Apple iPod but Apple stopped its release and it was adapted for use with PDA's.

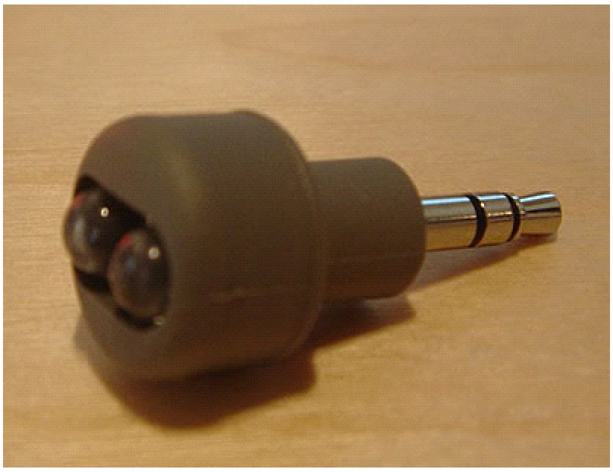

Figure 14 - Griffin Total Remote Sound to IR converter

3.2.6 Other Software

Sony Soundforge 8.0 was used for recording infrared signals played out through the headphone jack of the older iPaq.

The games used are Electronic Arts Knockout kings 2000 for the Playstation One and Fight Night Round 2 for the Playstation 2. Note, that Playstation One games also work on the Playstation 2.

Knockout Kings 2000 has much more limited controls as it was designed for the earlier Playstation One which does not use analogue sticks. There are only four basic types of punches that can be used, left jab, left hook, right cross and right uppercut, with harder "haymaker" and body punch variations possible with each. Blocks and limited bob and weave movements are also possible. This game is used with the dance mat implementation of the boxing interface which is discussed in the Implementations chapter of this paper.

Fight Night is one of EA's most recent boxing releases for the Playstation 2/Xbox. It provides a much greater range of punches and movements than earlier games. Most of the punches and the players' movements are done using the game controller's twin analogue sticks. This game is used with the implementation using the go wireless infrared converter as it allows the use of the analogue sticks. In this game jabs, straights, hooks and uppercuts are possible with either hand. The power of the punch can be also be controlled and more extensive defensive movements are possible than in earlier incarnations of the game.

3.3 How Infrared Devices Work

Before going into how infrared is used to connect the boxing interface to the gaming console, how infrared devices work will be briefly described. An infrared device works by switching an IR light transmitter, such as the LED's on the Total Remote dongle, on and off. This is called modulation [33]. Each time the IR source is turned on it is in fact turned on and off many times very quickly. This is done to make the signal more resistant to noise. The speed at which these rapid on/off's occurs is known as the carrier frequency. The carrier frequency for infrared devices is in the

36 KHz to 40 KHz range. Each IR device's receiver must be set to the same carrier frequency as the transmitting IR device in order for it to successfully read the IR beam. Data is sent through infrared by turning the IR transmitter on and off in a particular pattern which corresponds to binary numbers. On receiving the IR signal the IR receiver can then retrieve the binary signal sent. This signal could be used to perform a particular button press with an infrared game controller for example.

3.4 How the Griffin Total Remote Dongle Works

The total remote dongle is placed in the audio port of a device, such as the iPaq in this case. The signal passing through most audio ports is only up to 20 KHz [34]. As the audio port is in stereo, two 20 KHz signals for the left and right channels are passed through the audio port. The carrier frequency needed for infrared is between 36 KHz and 40 KHz. The two audio channels are sent, one through each LED of the IR Dongle. When this is done one channel is sent out of phase with the other [34]. This produces the 40 KHz needed for the infrared carrier signal.

3.5 Capturing the IR Signals

The infrared signal for each button on the game controller is captured and stored using the Griffin Total Remote Software. To do this the software is started and one shot sampling is chosen. A button on the total remote software (e.g. TV channel 1) is selected to store a particular button captured from the game controller. The older iPaq is then placed with its irDA port facing the infrared transmitter of the game controller. The total remote software captures and stores the signal of the game controller button when it is pressed. This is repeated to store all the infrared signals of buttons from the controller.

3.6 Recording IR Signals on the PC

The infrared signals from the controller must now be taken from the older iPaq and the total remote software and onto the laptop. It is very important that an iPaq circa

2002/2003 is used otherwise the following will not work. This is done by connecting one end of a 3.5 mm stereo cable to the headphone jack of the iPaq and the other end to the line-in of the laptop. The Total Remote software is set to send infrared signals through the Total Remote IR Dongle which is usually inserted in the iPaq's headphone jack. This is done so that signals from the Total Remote software are sent through the headphone jack instead of the IrDA port on the iPaq.

Audio recording software is used to record the signals sent from the iPaq. Sony Soundforge 8 was used to do this. A sound file is created with a sampling rate of 44,100 Hz, 16 bit depth and stereo channels. The signal sent from the Total Remote software on the iPaq after a button press is recorded onto this sound file and it is saved as a WAV file. The resulting sound file can be seen in *figure 15* below. This WAV sound file represents the infrared signal sent by the triangle button from an infrared Playstation 2 controller. The start of the signal is the preamble. The preamble of the signal is a 500 MHz wave that is out of phase across the left and right channels [2]. The preamble is used to increase the range of the signal from the headphone jack by boosting the power to it. After the preamble there are four repeated signals. Each of these signals is made up of a sequence of on and off pulses, which represents the infrared signal sent out by a particular button of the game controller. A close up of one of these sequences of on and off pulses can be seen in *figure 16*.

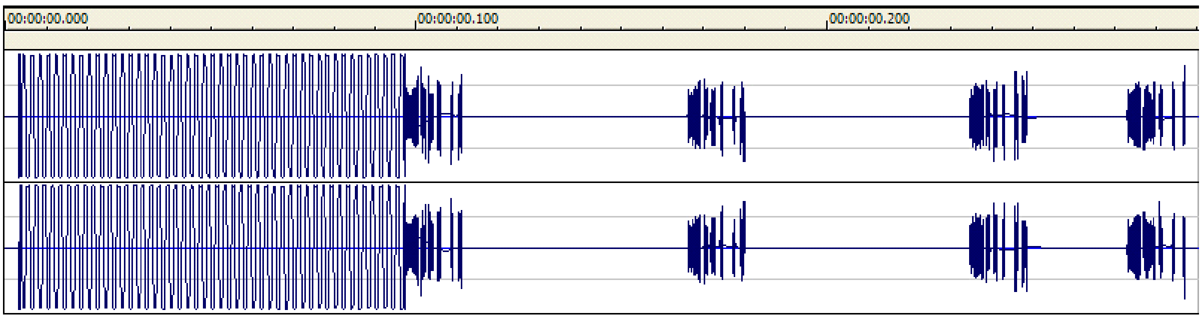

Figure 15 - A raw infrared signal recorded as a WAV file from the iPaq.

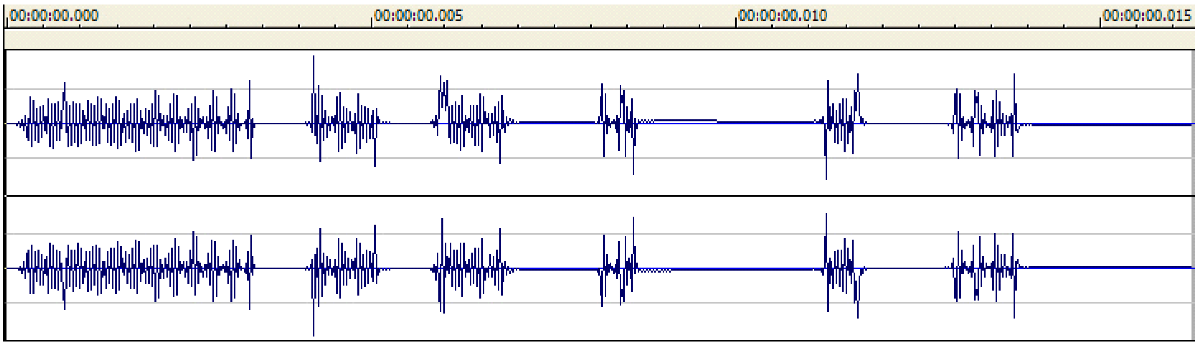

Figure 16 - A WAV file representing the on/off pulses of an infrared signal.

The raw WAV file recorded from the iPaq needs to be cleaned up before it can be used. The resulting infrared signal after this WAV file is played through the audio port of the laptop using the IR Dongle will not work. This is obvious when this resulting signal is looked at with an oscilloscope running on an iPaq. The signal, if it is even picked up by the oscilloscope, is nonsensical at best. The reason for this is that quality of the signal is somewhat reduced when it is recorded onto the laptop from the iPaq. A few different computers with different standards of sound cards used to try and improve the quality of the signal recordings. MP3 players such as the iRiver and the Philips HDD120 were also used to try and record a useable signal from the iPaq. The results were mixed, the MP3 players did not record any signal at all and desktop computers gave similar if not worse results than the laptop.

By looking at the infrared signal given out directly by the infrared game controller on an oscilloscope we can see the desired signal. To try and achieve this desired signal, processing of the signal in the WAV file must be carried out in Soundforge. Processing was done in an ad-hoc fashion with the resulting WAV file signal being compared to the desired signal using an oscilloscope. On comparing the two signals in the oscilloscope, it is obvious which parts of the signal need to be further processed or less processed. The types of processing used were mix of normalization, increasing the gain and enhancement. While some useable results were achieved using normalization followed by a gain increase up to the maximum, this would not work for every signal that needed to be processed. It was discovered that a level 3 enhancement to the parts of the signals with the sequences of on/off pulses was most effective. The result of a level 3 enhancement to the WAV file in *figure 15* can be seen in *figure 17.* It is obvious that the signal is must clearer compared to the unprocessed signal. *Figure 18* shows the sequence of on/off pulses from *figure 16* after processing has occurred. The level 3 enhancement only works for signals from certain devices. The signals from an infrared dance mat worked very well using this technique as did the signals from various Sony TV's. Enhancement on signals from a Gamerz PS2 remote gave mixed results with some signals not working when played back as WAV files and other signals working sporadically.

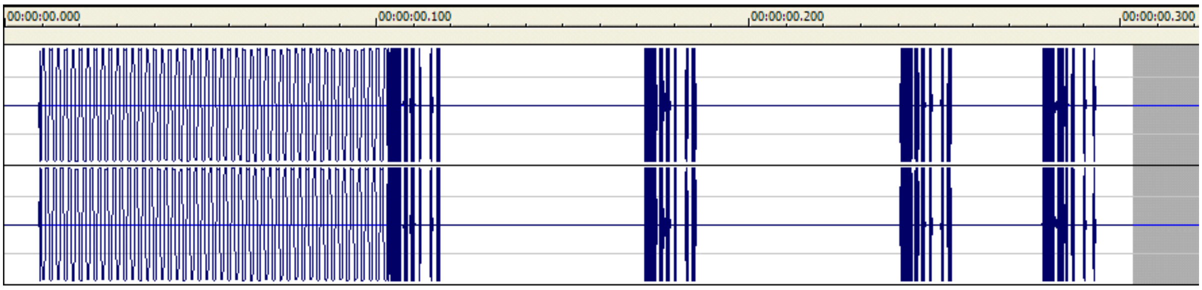

Figure 17 - The same signal as figure 15 after a level 3 enhancement using Soundforge.

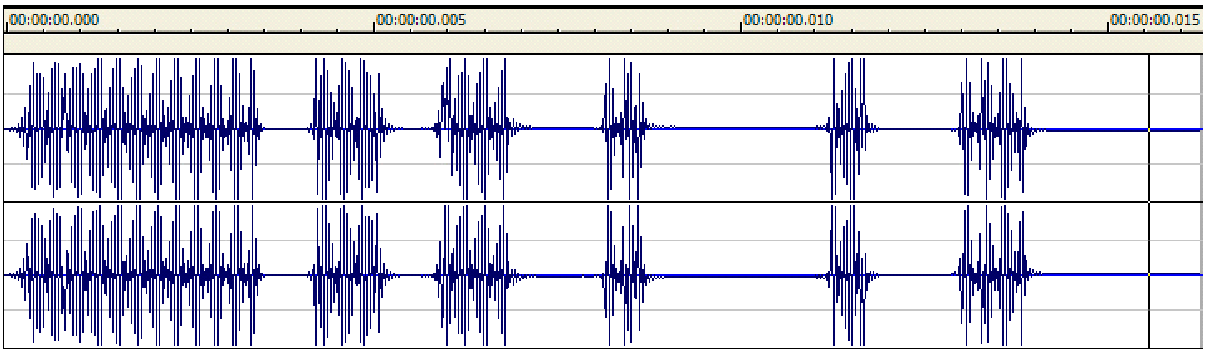

Figure 18 - The same signal as figure 16 after a level 3 enhancement using Soundforge.

3.7 Making the signals shorter

As the boxing interface is used in real time, the lag between the actual punch by the user and the punch by the users character in the game must be keep to the absolute minimum. With this in mind, ways were looked into to reduce the lag. It was discovered when looking at the WAV file that the only part of the whole signal was needed for it to work. The preamble could be removed and all but one of the sequences of on/off pulses were removed. One of the first two sequences is used as the quality of the later ones is lower. By reducing the signals down to one sequence of on/off pulses, this reduces the lag greatly. *Figure 17* shows the whole signal in the WAV file and *figure 18* shows the same WAV file after all but on sequence of on/off pulses are removed. This results in the potential lag of the signal being sent from 0.3 seconds to under 0.015 seconds. This is a very substantial reduction since most punches are under 0.3 seconds and there is an overhead involved in calculating when a punch is thrown also. There are some negative effects of removing a large part of the signal. The effective range of the signal given by the WAV file is reduced significantly. Its effective range is now only 10 - 20 cms, instead of metres. It will still work at a greater range but the receiver will pick up fewer signals the further away it is from the IR Dongle sending the signals. The reduced range is not a concern as the IR Dongle connected to the laptop can be placed right beside the IR receiver of the game controller. Reducing the length of the signal also leads to reliability issues. Signals would occasionally not work even when at close range. It was therefore decided to use the full length signals in the implementations to make sure the signals went through each time. The actual lag introduced is actually much less than the length of the WAV file. The lag is only as long as the time it takes for the receiver to successfully take in one signal of the repeated on/off signals in the WAV file.

3.8 Using the WAV Files to Connect to the Console

After processing the WAV files they can now be used. Before they are used, it must be ensured that the volume is at maximum on the laptop or whatever other device is being used. The Total Remote IR Dongle is placed in the audio port (headphone port) of the laptop and is pointed in the direction of the IR receiver of the game controller. As mentioned in the previous section, the distance between the IR Dongle and the IR controller receiver must be closer than 20 cms, to avoid the risk of the receiver losing any of the IR signals sent to it. This is done whether or not the shorter WAV files are to ensure reliability. When a WAV file is played on the laptop the IR Dongle converts it back to infrared and the IR receiver picks it up and thinks it has come from the game controller IR transmitter e.g. a dance mat. The laptop can now act as the game controller, so whenever a punch is detected by the boxing interface program running on the laptop it can sent the corresponding punch signal to the game controller IR receiver. *Figure 19* below shows the setup of the PS2 and the laptop. An IR receiver can be seen in the controller port in the front of the PS2. The Total Remote IR Dongle can be seen in the audio port on the front of the laptop facing the IR receiver on the PS2.

Figure 19: Connection of the Laptop to the PS2

3.9 Problems Encountered

The Total Remote does not work with the newer iPaq's and so an older model of iPaq (circa 2002/2003) must be used for recording the infrared signals onto the iPaq.

The type of computer for which the signals are recorded from the iPaq also matters. Signals were only successfully recorded as WAV files and played back using an Acer 5510. Attempts to use other laptops or desktop computers to perform the same tasks failed. This does not mean that it is impossible using anything other than this laptop, just the methods described above only worked successfully with this laptop.

The model of PS2 also leads to problems. The very early versions of the PS2 will not work with some infrared peripherals such as Gamerz PS2 remote controls.

The Go Wireless infrared adapter did not successfully work with the PS2, as in the adapter did not work when trying to use it to play games with a regular control pad. As it didn't even work for this no signals could be recorded from it and analogue sticks could not be recorded for use with the latest boxing games. Two of these adapters were purchased and neither worked. At first it was suspected that the first one was faulty but a second was purchased from a different supplier which also didn't work. Replacing the internal 1.5 volt rechargeable batteries with standard batteries was attempted but this did not solve the problem. It was most likely a trivial problem such the adapter would not work with any of the PS2 models used or a problem with charging the adapter. There was insufficient time to further any attempts to get the adapter working.

3.10 Other Connection Methods Researched

Numerous methods to connect the interface to a games console were looked at. The research was mainly directed towards the connection to either a Playstation 2 or an Xbox as they are currently the most widely used games consoles.

Physically hacking the controller was one method looked at. This involves soldering wires to points on the controller's PCB to gain control of the control pad. The downside of this is that it cannot be done for the analogue sticks of the control pad as they are too complicated and there are no points that can be successfully soldered to.

Using Radio frequency signals to mimic those sent by 2.4 Ghz wireless control pads were looked at. It was decided that mimicking the signal was far too complicated due to signals most likely using frequency hopping spread spectrum during transmission. Devices do exist for capturing and playing back RF signals like those from a wireless control pad but the cost of them is around $20,000.

A USB Driver could be written to connect a PC to an Xbox. The Xbox's controller ports are essentially USB port's with an extra pin which it is assumed is for force feedback sent from the Xbox. A posting on an Xbox hack site [35] gives the pin out for the control pad**.** The USB inputs and outputs given out by an Xbox controller are needed for creating this USB driver and are available on the internet [36].

Chapter 4: Detection of Punches and Movements

4.1 Introduction

The boxing interface is a gesture recognition system which is used to determine the punches and movements a user performs while boxing. Each of these movements and punches map to a button on a control pad which is used to perform a movement or punch in a boxing game. An MT9 sensor is placed in each of two gloves for recognizing punches and blocks and a third is placed on the user's chest for recognizing the user's body movements. The MT9 software is used to collect Euler angle orientation and acceleration data which is stored in log files. This data is gathered for multiple repetitions of each punch type and movements such as leaning that the boxing interface is capable of detecting. To differentiate between the different actions that are possible by the user, the data files are analyzed to identify traits that are unique to each user action. After analyzing the data and the user's movement matches the criteria for a particular punch or other action possible in the game then an infrared signal is sent to the gaming console.

4.2 Xsens MT9

The Xsens MT9-B sensor (see *figure 20* below) is a 3D accelerometer, 3D gyroscope and 3D magnetometer which provide real-time data which is used for gesture recognition of the punches and movements performed by the user. The MT9 allows for rapid prototyping of software which needs to use this type of sensor data. The MT9 SDK 2.6.2 was used with the sensor.

MT9 software allows a 3D representation of the sensor to be viewed in real time with its current roll, pitch and yaw Euler angle values. This software can be used to record log data which can be specified. Orientation data can be outputted as Euler, Quaternion or Rotation Matrix log files [37]. Euler orientation data is used in the boxing interface. Euler orientation consists of three values, roll, pitch and yaw measured in degrees. Roll is a measure of rotation around the X axis and is defined from -180° to 180°. Pitch is a measure of rotation around the Y axis and is defined from -90° to 90°. Yaw is a measure of rotation around the Z axis and is defined from -180° to 180°. A calibrated data is also outputted by the MT9 and is used for the boxing interface. The calibrated data consists of acceleration in the X, Y and Z axis measured in m/s^2, gyro rate of change about the X, Y and Z axis measured in radians per second and magnetometer data in the X, Y and Z measured in a.u. Temperature readings are also outputted. For the boxing interface only the acceleration readings are used from the calibrated data. In both the orientation and calibrated data there is a timestamp associated with each set of values outputted. The sample rate for the MT9 is set to read data 100 times per second. The boxing interface uses real-time data from the MT9 rather than the log files.

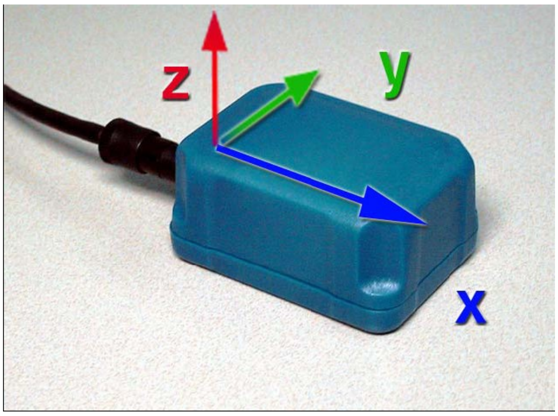

Figure 20 - Xsens MT9-B Sensor

Figure 21 - Boxing Interface Glove with MT9

4.3 Punch and Movement Differentiation

It is simple and straightforward to determine a single punch with either hand. To do this all that really needs to be done is look for acceleration in the X (forward) direction above a certain threshold. This can be calculated very quickly, resulting in almost no lag at all from the time the user performs the punch to the time their character performs it in the game. Most other fighting systems for game consoles can only detect one type of punch with each hand. Some can detect more, but they do this using cameras instead of sensors attached to the hands and it is still a rather limited method. A problem arises when multiple punch types can be performed by each hand. This problem is how to tell which particular punch was thrown and to do so as quickly as possible to reduce lag in the game.

4.3.1 Analyzing Data

For each punch and defensive movement, Euler orientation and acceleration data are outputted to log files using the MT9 and its software. The acceleration in the X direction is of particular interest as this is used to detect the glove going forwards in a punch. Each punch and defensive movement is performed multiple times and a set of logs files are stored for each type of punch and movement. These log files are then physically looked at to identify the punches and movements and any traits that they have which can be used to recognize them.

In the case of the punches, the calibrated data is looked at first to identify areas of the data where the acceleration in the X direction is relatively high for a period of time (at least 5 output readings). This generally represents a punch. Periods of relatively high negative acceleration in the X direction before a period of positive acceleration (above 10 m/s^2) shows the hand moving back for a punch. Most acceleration under 10 m/s^2 was identified as noise due to small meaningless movements by the user. Long accelerations over 10 m/s^2 generally represent a punch. The top acceleration of the punch is identified. For a punch to be outputted by the boxing interface it should have a minimum top acceleration over 15 m/s^2 in the X direction. All the punches in the log files are then identified. As it is known how many punches were performed while outputting data to the log files, it is therefore known how many punches to identify in the log file. Now that all the punches are identified for each type of punch, common traits are found by which each punch type can be distinctly recognized. A trait may be something like a large variation in yaw values at a certain point in the punch which is not present in other punch types. A lot of these traits are present in the quarter of a second (25 sets of Euler and Calibrated data values) after the top acceleration of the punch. The rest of the traits are present during the acceleration of the punch. There are more traits in other parts of the punch data but as will be discussed in the next section, the punch must be determined as quickly as possible. Log files for the punches are in the appendix section at the end of this paper.

Analyzing defensive movements such as blocking and leaning are done in a similar way to the punches. For defensive movements only values at a particular moment in time need to be looked at to determine the movement. This is because the movements are less complex than the punches and it is easier to distinguish one from one another than with punches. When determining defensive movements, the resulting position of the user after the movement is looked for e.g. for a high block, whether or not both gloves are in a blocking position is looked for. The advantage of determining a defensive movement in this way is that its instantaneous so it does not introduce any lag.

4.3.2 Latency vs. Accuracy

When differentiating between punches a compromise has to be struck between the latency introduced by calculating which punch has been thrown and the accuracy of the punch differentiation. The more values over time that are used to calculate the different punches the longer the latency that will be introduced. This latency introduced is between the time the user throws a punch and the time it is thrown in the boxing game used. Using more values to calculate each punch improves the accuracy of the punch calculated. This is because more of the whole punch is looked at. Therefore if only a few values are used, then only a small part of the punch is being analyzed. It is harder to determine the punch if only part of it is being looked at and hence the accuracy will be affected. The part of the punch that is analyzed is from starting acceleration of the punch (over threshold acceleration of 10 m/s) to 25 1/100 second intervals after the top acceleration during the punch. These ranges of values for the punches are looked at as there are a sufficient number of traits within this range to identify each punch type

4.4 Types of Punches

The types of the punches possible using the boxing interface are those used in the Electronic Arts Knockout Kings 2000 game and Fight Night Round 2. These punches are Jabs, Hooks, Straights, Uppercuts and Haymakers both to the head and to the body. The following sections describe each of the punches and the ways in which each individual punch is calculated. The punch calculations work for either left or right hands so there is no problem if the user is left handed.

4.4.1 Jabs

The Jab is the most basic of the punches and is also the most used and most important of the punches. It is a relatively weak quick straight punch, thrown using the leading hand (can be rear hand also) from the guard position. The jab can be used for attack as a build up to a more powerful punch or in defence as a means of keeping the opposing boxer at bay.

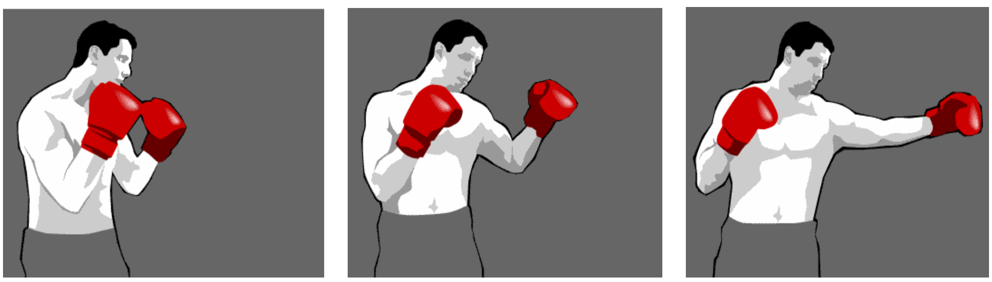

Figure 22 - Performing a Left Jab [38]

4.4.2 Jab Calculation

Jabs are calculated by looking at the difference in yaw (Euler orientation in the x-axis) between the start acceleration and a quarter of a second after the top acceleration of the punch. If the yaw difference value is less than 40 degrees and the top acceleration of the punch is over 15 m/s^2 then the punch is a jab. It must now be established whether the jab is to the head or the body. This is done by calculating the average pitch (Euler orientation in the y-axis) of the jab during its acceleration over the threshold acceleration of 10 m/s^2 in the x - axis. If the average pitch is less than minus 20 degrees then the jab is to the head, if it is greater than minus 20 degrees then the jab is to the body.

To help reduce latency in jabs, they are also looked for early on in the punch when the acceleration is taking place. This reduces the number of values over time that need to be taken in from the sensor. Only the data values during acceleration are needed and not the values (up to 25 timestamps) after the acceleration. This provides a latency reduction of up to a quarter of a second. If the jab is not found early during the acceleration it can still be found later using the method in the previous paragraph. Finding the difference in yaw is only effective when data from the sensor is taken over a longer period of time. To test for a jab during acceleration the average acceleration in the y and z directions is calculated. If the average acceleration in the y and z directions are both greater than -10 m/s^2 and the acceleration lasts for a minimum of 5/100's of a second then the punch is a jab. The acceleration in the x - axis must also be over 15 m/s^2 . Differentiating between a head and body jab is the same as previously described.

Looking solely at the data during the acceleration of the punch is insufficient for any other types of punches other than jabs.

4.4.3 Crosses

A cross or straight is a punch thrown using the rear hand. It is the most powerful of the punches but is the most exerting and leaves the boxer open to a counterattack.

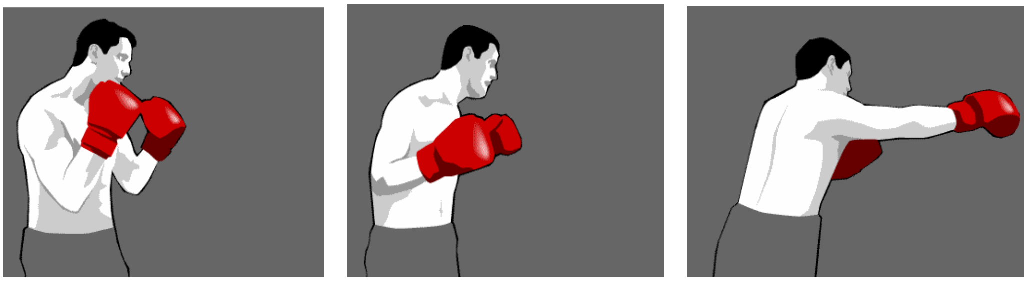

Figure 23 - Performing a Cross [38]

4.4.4 Cross Calculation

A cross is detected in a similar way to a jab using the yaw difference between the start of the punches acceleration over a threshold of 10 m/s^2 in the x-direction and a quarter of a second after the punches top acceleration. It is essentially a strong Jab. If the yaw difference is over 40 degrees and less than 80 degrees then the punch is considered a cross. The head and body punches are differentiated from one another in the same way as jabs. If the average pitch between the top acceleration of the punch and 25 timestamps after the top acceleration is less than minus 20 degrees then the cross is to the head, if it is greater than minus 20 degrees then the cross is to the body.

4.4.5 Hooks

The hook is a punch thrown from the guard stance which travels in a semi circular motion. It has the advantage that it comes from outside the opponent's field of vision.

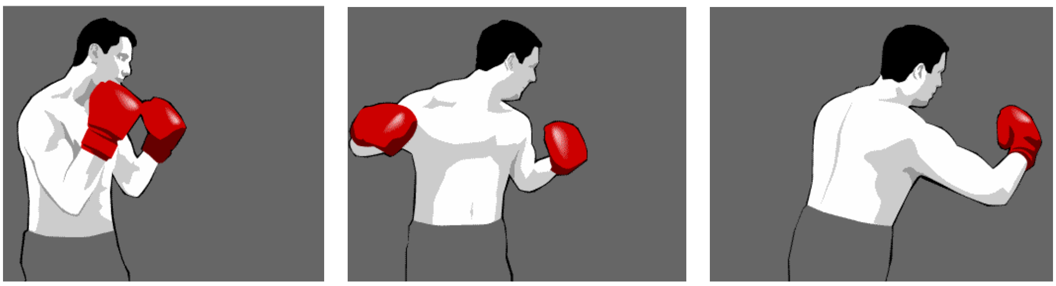

Figure 24 - Performing a Right Hook [38]

4.4.6 Hook Calculation

The difference in yaw is used again in determining if a punch is a hook. If the yaw difference is over 100 degrees then the punch is a hook. To determine whether the hook is to the body or the head the average pitch (Euler orientation about the Y axis) is used. The average is calculated between the pitch at the top acceleration of the punch and the pitch after a quarter of a second after the top acceleration. If the average pitch is positive then it is a hook to the body, if the average is negative then it is a head punch. This technique can be used for left and right hooks.

4.4.7 Uppercuts

The uppercut is vertical rising punch, which like the hook comes out of the opponent's field of vision.

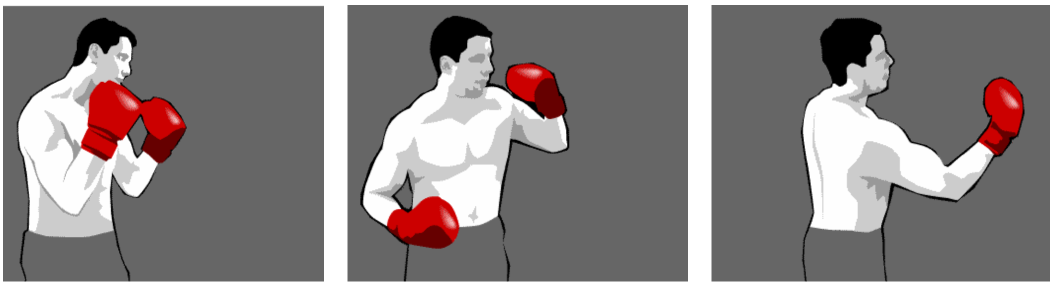

Figure 25 - Performing an Uppercut [38]

4.4.8 Uppercut Calculation

To determine is a punch is an uppercut, the vertical rise of the punch is looked for. This vertical rise during the punch is the main trait of an uppercut. To look for this vertical rise, the lowest pitch orientation during the punch is found. If the pitch is less than -50 degrees between the top acceleration of the punch and a quarter of a second later then the punch is considered to be an uppercut.

4.4.9 Haymakers

A haymaker is a more powerful version of the other types of punches, meant to deliver a knockout blow when playing the game. The speed of the punch does not necessarily show how powerful it is, a jab will be quicker than a hook for example. The boxing interface has no device like a punching bag with pressure sensors to determine the power of a punch. The power of the punch is measured by the "wind up" involved when delivering the punch. To determine the "wind up" of a punch the boxing interface uses the difference in yaw from the start of the punches acceleration to a quarter of a second after the punches top acceleration.

A straight haymaker is found if the yaw difference is between 80 degrees and 100 degrees i.e. if the yaw difference is greater than that of a regular straight punch and less than that of a hook.

4.5 Defensive Movements

The types of the defensive movements possible using the boxing interface are those used in the EA's Knockout Kings 2000 game and Fight Night Round 2. The following sections describe each of these defensive movements and how they are calculated.

4.5.1 Blocking

There are two types of blocks possible, a high block and a low block. The high block is used for protecting the head and the low block is used for protecting the body. A block basically entails moving the gloves in front of the face to protect it (high block) or moving the gloves and arms in front of the torso (body block).

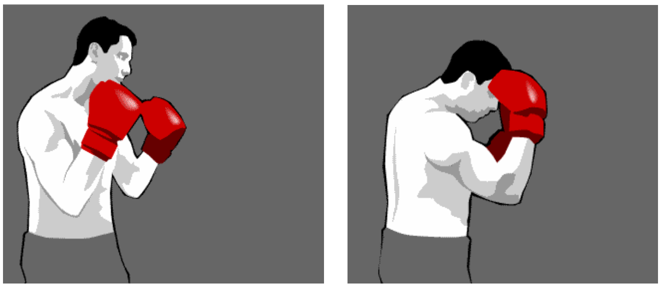

Figure 26 - Performing a high (head) block [38]

During development as only two sensors were available, the determining of blocks had to be done differently than intended. This had more effect on the body block, as is discussed below. With a third sensor on the chest, the body's pitch could be used in conjunction with the pitch of the sensors in the gloves to determine the difference between a head and body block. During a body block the user will have a higher pitch angle than when performing a high block, this can be used to differentiate the two.

A high block is detected by looking at the Euler pitch values of the sensors in both the boxing gloves. If both the gloves are relatively vertical with the user's knuckles pointing towards the sky (i.e. both glove sensors have a pitch of less than minus 65 degrees) then a block has been found. It is also tested that the acceleration of the gloves is below a certain threshold. This is done so the block is not mistaken for an uppercut while one hand is in a high guard position by the head during which both hands will have similar pitch values to a head block.

As data from a third sensor could not be used, the body block is performed in a different fashion to a high block and a "real" body block. The user's gloves are placed with the palms of hands on the stomach and with the knuckles of both hands touching each other. This results in both forearms being parallel to the ground and is similar to the way one would naturally cover their stomach with their hands. To determine if the user is performing a body block, a number of orientation and acceleration data values have to be looked at. First the pitch orientation of each glove has to be looked at. If the pitch of both gloves is between 20 and minus 20 degrees then this shows that the user's knuckles are touching and that the forearms are relatively parallel with the ground. The difference in yaw orientation between the two sensors on the gloves is then looked at also. This is used to check if the user's hands are both flat on the stomach and not at an angle pointing away from the body. As with the high blocks the gloves acceleration in the X direction must be relatively small to prevent mistaking part of a punch as a block. For example, performing a hook while the other hand is low and by the stomach could accidently be mistaken for a low block otherwise.

4.5.2 Leaning

Leaning is a method used by boxers used to get out of the way of punches and involves tilting the upper body in a particular direction. An MT9 sensor on the centre of the user's chest is used to establish which way the user is leaning. Four types of leaning can be distinguished from forward, back, left and right. To be leaning the user must be tilting their torso with a pitch orientation of greater than minus 55 degrees. If the pitch is lower than this it means that the user is still standing relatively upright. The roll orientation value is used to find out what direction the user is leaning in. If the roll value is greater than 150 degrees then the user is leaning forward while a roll value between 12 degrees and minus 15 degrees means the user is leaning back. A roll value between 110 degrees and 70 degrees signifies a left lean and a roll value between minus 90 and minus 130 degrees signifies a right lean.

Leaning was never implemented at the same time as the punches due to a third MT9 sensor for the chest being unavailable. It was also not tested with the game console as there was no infrared controller device for the PS2 for which the lean button signals could successfully be taken off. As a future work leaning could be implemented in the diagonal directions as well as leaning by various degrees extremity. The newer boxing games such as Fight Night allow for this diagonal leaning by different degrees using the analogue stick on the controller.

4.6 Problems with the Punch Differentiation

There are a small few problems with the punch differentiation that there was no time to solve. Firstly there is a bug where if the user punches twice in quick succession, only the first punch will register. This is due to the fact that the program looks at data for a fixed length of time from when the acceleration of the punch starts. If two quick punches occur one after the other then data from the second punch is mistakenly put as part of the first punch. Therefore the acceleration data for the second punch or part of it which is used to identify the start of the punch is missing so it cannot be recognized. A way of solving this problem is to look for two periods of acceleration in the data for each punch and output two punches if there is.

The second problem is that of lag. It was reduced as much as possible but it is still a problem particularly with the very old games such as knockout kings 2000. The lag is due to the time spent differentiating between the types of punches. As the values from the starting acceleration to a quarter of a second after the top acceleration of the punch are looked at, this introduces a fairly large lag. The part of the punch which is analyzed is early on in the punch (when it is just starting). In the newer games the game characters punch speed is very quick, so the punch is able to catch up with the user movements making the lag is less noticeable.

Chapter 5: Implementations

There are three implementation of the boxing interface, increasing in functionality.

The first is based around the buttons from an infrared dance mat. As the dance mat only has four action buttons/pads and four directional buttons it offers limited functionality. Therefore this implementation is used with an older Playstation 1 boxing game, Knockout Kings 2000. This game is relatively limited compared to the more modern boxing games and is playable using the buttons available from the dance mat. As there are only four action buttons available only four different punches can be performed. These are left jab to the head, left hook to the head, right uppercut to the head and right cross to the head. The controller setup in the game allows the up and down directional buttons to be used for high blocks and low blocks which can be performed by the user in this implementation. The dance mat is used in conjunction with the boxing interface in this implementation to allow the user to move in a more natural way. The left and right directional buttons on the dance mat are used to move the user's character forward and back while playing the game.

The second implementation of the boxing interface is for use with the game Knockout Kings 2002 for the PS2. This implementation shows the boxing interface with a newer game which performs much faster than older titles. The advantage of using a newer game is that it takes away most of the lag introduced from determining the punches by the boxing interface. As the punches in the game are performed by the games characters extremely quickly the lag is almost unnoticeable. This is discussed in section 4.6 in relation to problems with lag. As the signals from only four buttons could be captured only left and right hooks and jabs are possible in this version. It is not possible to play against a computer controlled opponent using the boxing interface with this game. This is because the opponents perform punches at an unrealistically fast rate for a human to compete against when they have to perform the punches themselves. This implementation shows that with a little more refinement of the boxing interface, there should be little or no lag associated with using the boxing interface.

Finally there is an implementation of the boxing interface which doesn't have a connection to the game console. This implementation was meant to work with the Go Wireless adapter which converts wired PS2 controllers into infrared controllers. This implementation was aimed to work with the latest boxing game releases such as Fight Night Round 3. The Go Wireless adapter was never got working so the infrared signals could not be captured from it. It would have allowed the infrared signals outputted from the analogue sticks of a controller to be captured and used to play the most recent boxing games. This implementation outputs the punch performed to the screen as text instead of sending the signal to the game console. It was used during the testing of punches during development. All punches and blocks both to the head and body can be performed using this implementation. With a third sensor, this implementation can be used to perform leaning also.

Chapter 6: Evaluation

6.1 User Testing

User testing was carried out to determine if the boxing interface would motivate people to exercise and to see if it is a useful form of exercise. The tests consisted of a user playing six 1 ½ minute rounds against a computer controlled opponent on an easy difficulty setting with a 45 second break in between each round. Before the testing began, the punches and movements that could be performed by the Boxing Interface were explained to the user. Heart rate data was taken from the users before the testing and after each round. The user was also asked to comment on how they felt physically while the tests were being performed. A questionnaire was then completed by users after the testing. The testing was used with the Knockout Kings 2000 implementation of the boxing interface. This implementation was used as more actions could be performed by the user and a dance mat could be used to move the user's boxer in the game. The older game used in this implementation is slower than the newer games such as the Fight Night games so the user could actually fight a computer controlled opponent and have a chance of winning. In the newer boxing games, a computer controlled opponent punches at an unrealistically fast rate making it impossible for a user to win a fight when using the boxing interface.

The expected results of the user testing were that the user would get a relatively hard workout during the six round test. During development of the boxing interface this was obvious as testing of the various punches in the game was quite tiring. It was also expected that the user would find it an enjoyable experience as there was a lot of interest from people in using the boxing interface during its development.

Five users took part in the formal part of the testing all of which were males between the ages of 23 to 30. Only two of the users had their heart rate data taken, the others were observed and asked to comment on how hard a workout they felt they were getting. All the test subjects performed some form of exercise regularly either by going to the gym or cycling for example. The test subjects all owned a gaming console and played games for over 5 hours per week. All the test subjects found the boxing interface to be highly exertive.

The results from two of these test subjects will now be discussed. Test subject A had similar results to the three other test subjects who did not have not have their heart rate taken. Both these test subjects are of similar physical fitness. These subjects both played the game very differently from one another which had different results on their exertion levels during the test.

User A		
Male, Aged 24, No experience with boxing games		
Time	**BPM**	**Comments /Observations**
Resting	70	User Sitting Down Relaxing
Round 1	127	User is tiring, arms starting to get tired
Round 2	144	User complains of being tired, and is sweating
Round 3	125	User tired so is punching less
Round 4	134	User says that they are exhausted – opponent nearly KO'ed
Round 5	125	User's arms are very tired and arms are feeling heavy – opponent nearly KO'ed
Round 6	123	Users shoulders are sore – opponent nearly KO'ed

Figure 26 - Test User A - heart rate and observations/comments of the user

User B		
Male, Aged 24, Experience with boxing games		
Time	**BPM**	**Comments/Observations**
Resting	67	User Sitting Down Relaxing
Round 1	82	User taking it easy, blocking a lot
Round 2	90	User starts sweating, continues to block a lot
Round 3	102	User starting to feel tired
Round 4	105	User's arms are getting tired. User knocks out the opponent twice
Round 5	109	User very tired. User knocks out opponent, opponent does not get up – fight over
Round 6		

Figure 27 - Test User B - heart rate and observations/comments of the user

The two users played the game with very different styles which affected the user's heart rate significantly. User A had a much more attacking style while playing the game and threw many punches and blocked rarely. This can be seen by the user's rapid increase of heart rate in the first round and the fact that the user was already starting to feel fatigue after the first round. The user continued to punch frequently in round 2 as it was having a visible effect on the opponent's health meter. After this round the user is very fatigued and their arms are also feeling more tired. The user also reaches their highest heart rate at the end of the round with 144 beats per minute. In round three the user is visibly fatigued and is sweating a lot. The user starts to punch less due to this fatigue. In round 4 the user is motivated to carry on punching although tired, as they see the opponent's health meter is low and there is a chance of knocking them out. In round 5 the user is feeling even more fatigued but continued to punch as much as possible as the opponent was close to defeat. The users arms were starting to feel “heavy”. In the final round the user was exhausted and was punching less than before but continued to try to knockout the opponent. The user complained of sore shoulders. After the test, the user needed to sit down and was visibly drained by the exercise. It was obvious that the user had received a good workout.

User B played the game in a very different fashion to user A. User B unlike A had experience with playing boxing games like the one used for the test. User B played a far more defensive and tactical game than user A. User B’s heart rate increased gradually over the rounds and never hit the same maximum heart rate that User A achieved. User B only reached 109 BPM by the final round. As the fight progressed, the user’s arms started to get tired towards the end of the fight. User B although not as fatigued as A by the end of the fight, still felt tired at the end of the test particularly in the arms and in the shoulders. User B finished the fight in round 5 after knocking out the opponent 3 times and winning the fight.

User A achieved their target heart rate in round three for a 60% intensity aerobic workout (their target was 145 BPM). User B did not achieve their target heart rate of 149 however. User B did not represent the way other test subjects performed though. The other three test subjects had a very similar experience to User A and were all very fatigued and had sore muscles in their arms and shoulders. Even User B, although their heart rate did not increase significantly, still felt tired after the test and had sore muscles in the arms also. The computer controlled opponent used was on an easy difficulty and so was relatively docile. If a harder difficulty level was set or two human opponents using the Boxing Interface were to play each other, it is believed that User B would have achieved a much higher level of workout. In fact if the difficulty was increased all test subjects would most likely have had an even more intense workout.

Figure 28 - A user during testing of the boxing interface

A further 10 people took part in informal testing whereby they used the Boxing Interface for a few minutes with either the implementation using Knockout Kings 2000 or Knockout Kings 2002. The testers ranged in age from 20 to 56 and were both male and female. All found using the interface quite tiring after just a few minutes, particularly for the arms and they could see the fitness benefits of the interface. The general consensus of the users was that the interface would motivate them to exercise as they were more aware that they were playing a game than exercising.

Chapter 7: Conclusions

7.1 Summary

This paper introduced a fitness peripheral for playing boxing games on gaming consoles. The aim of the Boxing Interface was to provide a method for exercising while motivating the user to do so. The results of the user testing showed that the Boxing Interface is useful as a form of exercise. Most users were very tired after the 9 minute user test. The Boxing Interface would be particularly useful for toning the upper body especially the arms and shoulders. The users who took part in the testing found that using the Boxing Interface would motivate them to exercise as it provided the user with an enjoyable way to exercise. The other aim of the Boxing Interface was to make a gaming peripheral which provided the user with a more intuitive and natural way to play boxing games. This was also successful, although some bugs with the interface such as dropped punches and a lag did take away from the user experience. For this type of system to be completely successful the user should be as unaware as much as possible that they are "wired in" to a machine as it takes away from their experience. With further refinement of the Boxing Interface the system should be able to further improve on this experience given to the user.

The Boxing Interface adds to the state of the art a system unlike other boxing and fighting gaming interfaces. Modern boxing games require a peripheral which can differentiate between the multiple punch types that can be performed by the users. Other systems on the market today which use sensors in gloves can only recognize a single punch type based on the punch performed by the user. The Boxing Interface can successfully differentiate between the different punches needed to play these modern boxing games. It can also use the users body position to perform defensive leaning and blocking movements which no other system provides without using a mat with pressure pads on it.

7.2 Future Work

The following sections introduce further areas for research and additional features which could be added to the boxing interface in the future to improve and expand it.

7.2.1 Future Research

During the implementation of the boxing interface only two MT9 sensors were available so testing could only be carried out using a sensor in each of the two boxing gloves. Testing with a third sensor on the chest along with the two sensors in the gloves would be desirable to add extra functionality to future tests. The third sensor would is used to monitor body movements such as leaning. The Xsens Xbus master kit should be used with the newer MTX sensors as it reduces the number of wires that are attached to the sensors. The Xbus master to the PC being used via Bluetooth and contains its own power source. The MTX sensors connect to the Xbus by a single wire. This would provide the user with much greater freedom while punching and performing other movements. Using the two MT9-B's meant that the user had a wire connecting to the PC from each sensor and a wired power supply connected to those cables also, which made punching difficult at times.

Further refinement of the code is necessary. It should be done to further reduce the lag when calculating punches. It is also necessary to refine the code so that when punches are thrown in quick succession that none are lost. These problems are both discussed in section 4.6.

Further research is needed to show that the boxing interface could be manufactured for a reasonable cost. The price of an MT sensor is around 2000 Euro with the Xbus master being similarly priced. This is an unrealistic price to pay for a peripheral for a gaming console. For a home user to buy the boxing interface it would need to under 150 euro, a gym may be prepared to pay more than this however. A cheaper alternative needs to be found to the Xsens MT sensors. A prototype for a cheaper system for less than 300 euro should be developed to prove that the boxing interface can be commercially viable while performing the same or more functionality.

Further user testing is required to see the long term benefits of using the boxing interface. One fight consisting of six three minute rounds per day for a month should be sufficient for testing for the long term benefits. The users blood should be tested for lactic acid to measure the anaerobic benefits of using the interface as well as using a heart rate monitor for measuring the aerobic benefits.

Testing with two sets of users both using the Boxing Interface would good to see if it could be used as a form of sparring. As Fight Night can be played online using the PS2 version this opens up interesting possibilities of online sparring and an online ranking system.

7.2.2 Additional Features for the Future

The use of infrared for connection to the gaming console is useful for proof of concept and rapid prototyping. It is not viable for releasable solution however. As the infrared signals are recorded as sound files and then converted back into infrared signals, the quality of the signal is reduced. Problems arise when infrared signals are sent too close together and some signals are lost meaning some punches thrown by the user are not carried out in the game. A better solution would be use radio frequency technology in the 2.4 GHz range which is used by most modern wireless controllers. This solution should be used if the Boxing Interface was ever to be manufactured.

The addition of a heart rate monitor to the system would be a valuable feature for gathering data on the users' fitness while using the boxing interface. If game designers allowed for this functionality it could be built into the boxing game to display the heart rate or it could be used to calculate the user's energy level in the game. The game could use the heart rate data gathered over time to adjust the difficulty of the game but giving the user tougher opponents to fight as they get fitter. This would motivate the user to get fitter so that they can advance further in the game. The third sensor for the chest could be built into the heart rate monitor which would be wrapped around the chest. A display for the heart rate could even be built into the wrist strap of the glove.

The addition of pressure pads for the feet is a necessary addition to allow the user to move in the game. A regular dance mat is insufficient as the size of the centre (non functioning rest square) is too small to allow the user to punch without losing their balance or accidentally stepping on another square. Therefore a different mat is needed with a larger centre square and 4 rectangular pads around it for moving forward, back, left and right. The diagonal pad squares on regular dance mats are not needed as they have no function in any of the boxing games. The mat would have to output the same directional signals as the left analogue stick on a control pad in order for it to work with the newer games. With the addition of this mat, the exercise achieved from the Boxing Interface should increase as it will further increase the users activity.

An alternative solution to using the pressure mats for movement is to use an MT9 sensor on each foot to detect gestures made by the feet. For example, lifting the heel on one foot could be used to make the users' character move forward in the game and lifting the toes could be used to move backward etc. The addition of sensors on the feet would mean the Boxing Interface could be extended so that it could be used with all types of fighting games including those with kicks.

The boxing interface could also be extended to work for other sports games. This would give the user greater flexibility in their fitness routine and make people more likely to purchase the interface if it were ever released. It could be used for tennis games where the user's hand movements could be used to hit the ball in the game. Also in rugby or American football games, throwing gestures could be used to throw the ball in the game for example.

A feedback system would be an interesting feature to add to the boxing system and would perform a similar function to the vibrate feature in the PS2 and Xbox controllers. A vibration device could be placed in each glove to perform feedback when a punch is performed. Vibration devices could also be placed on the chest to provide feedback when the user's character in the game has been punched. This could be built in with the sensor and heart rate monitor on the chest. It should be insured that if the interface was to use batteries as a power supply that the feedback system should not use too much power however.

The use of fully wireless sensors on the body would be helpful to prevent snagging of the wires connected to the sensors and would provide the user with a greater range of movement as well as making movements and punches easier to perform. If the sensors were wireless, they could be embedded in boxing gloves and would therefore be unseen to the user. This would add to the realism and hence the experience of the user as it less obvious to them that they are “plugged in”. The connections of wires that are attached to the MT9’s are relatively fragile and are prone to being damaged while throwing punches so the use of wireless sensors would be necessary if the boxing interface were to be released as a commercial product.

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Appendices

Appendix 1 - Sensor Data for the Punches

Sensor data for one punch of each type is included below. Data is from both a calibrated data log file (accelerations only) and Euler orientation data log file which were outputted an Xsens MT9-B Sensor. The data is shown for the timestamp where acceleration started over 10 m/s^2 to 25 timestamps after the top acceleration of the punch. Periods of acceleration are highlighted in bold, and the top acceleration is specified also. Acceleration is measured in m/s^2 and Euler orientation is measured in degrees. See section 4.2 for more information of the MT9 and the data it outputs. Data is shown for left jab head, left jab body, right hook and right uppercut.

Calibrated Data (timestamp and accelerations only) for a Left Jab Head

Timestamp	**accel X**	**accel Y**	**accel Z**
9.8500	**10.238693**	**-15.562315**	**2.700864**
9.8700	**20.120066**	**-13.455112**	**2.176075**
9.8800	**26.381907**	**-10.298846**	**1.809331**
9.8900	**32.712311**	**-4.770669**	**1.375933**
9.9000	**37.084503**	**4.545142**	**1.162654**
9.9100	**39.956074**	**16.530964**	**0.889752 – Top Acceleration**
9.9200	**39.848835**	**28.685617**	**0.181155**
9.9300	**39.061054**	**37.266975**	**-0.963404**
9.9400	**38.498203**	**38.800446**	**-2.549080**
9.9500	**36.366791**	**34.548416**	**-3.924187**
9.9600	**31.290251**	**28.477125**	**-4.382371**
9.9700	**22.888872**	**23.112015**	**-3.523670**

9.9800	**11.157354**	**20.038628**	**-1.664040**
9.9900	-6.949342	17.288677	1.087821
10.0000	-31.924261	13.114442	4.539510
10.0100	-53.765400	6.783757	7.088059
10.0200	-67.955330	-3.565423	8.738418
10.0300	-76.522766	-19.741919	9.298280
10.0400	-63.910965	-30.075945	9.680038
10.0500	-51.669987	-30.557573	10.696499
10.0600	-42.273678	-26.367399	13.026883
10.0700	-37.885887	-21.229916	14.029589
10.0800	-36.356331	-14.746574	12.110026
10.0900	-31.145998	-8.085189	7.766968
10.1000	-23.666611	-4.193079	5.298605
10.1100	-18.338711	-3.669647	5.171402
10.1200	-15.277572	-3.856319	6.055125
10.1300	-12.365053	-2.956323	6.420008
10.1400	-8.604546	-0.999634	5.720747
10.1500	-3.871517	0.300193	4.170279
10.1600	2.102874	0.807413	2.241429

Euler Orientation Data for a Left Jab Head

Timestamp	euler X	euler Y	euler Z
9.8500	**-84.173416**	**-36.483101**	**3.055055**

9.8600	**-82.254227**	**-37.844418**	**3.030198**
9.8700	**-79.782684**	**-39.427383**	**3.079257**
9.8800	**-76.882431**	**-41.303612**	**2.985839**
9.8900	**-73.623375**	**-43.597816**	**2.479458**
9.9000	**-70.127335**	**-46.341576**	**1.423334**
9.9100	**-66.728188**	**-49.276802**	**-0.052671 – Top Acceleration**
9.9200	**-64.254509**	**-51.728874**	**-1.259931**
9.9300	**-63.668392**	**-53.026665**	**-1.155343**
9.9400	**-64.997910**	**-53.006775**	**0.456201**
9.9500	**-67.201401**	**-51.763405**	**2.808413**
9.9600	**-69.116280**	**-49.328499**	**5.025108**
9.9700	**-69.989830**	**-45.678650**	**6.502971**
9.9800	**-69.805344**	**-40.813198**	**7.021328**
9.9900	-68.758591	-34.713100	6.682792
10.0000	-67.494209	-27.928205	7.001786
10.0100	-65.799950	-21.450432	8.231634
10.0200	-63.404541	-15.686936	10.409606
10.0300	-60.073349	-11.025873	13.669878
10.0400	-55.740509	-7.648089	16.843578
10.0500	-51.498898	-5.563380	18.666126
10.0600	-48.625492	-4.614385	18.996574
10.0700	-47.700527	-4.553271	18.437086
10.0800	-48.670712	-5.415824	17.686743
10.0900	-50.997860	-7.283475	16.971470

10.1000	-53.819012	-9.665786	16.113508
10.1100	-56.229107	-11.962992	15.039251
10.1200	-57.720932	-13.993813	13.853285
10.1300	-58.392784	-15.897318	12.660542
10.1400	-58.648869	-17.824062	11.445732
10.1500	-58.846329	-19.737207	10.118700
10.1600	-59.343334	-22.178236	8.625399

Calibrated Data (timestamp and accelerations only) for a Left Jab Body

Timestamp	**accel X**	**accel Y**	**accel Z**
7.7300	**14.048684**	**-4.656004**	**7.491156**
7.7400	**18.025854**	**-4.468086**	**7.657766**
7.7500	**22.159916**	**-4.510180**	**6.523734**
7.7600	**25.964535**	**-2.671839**	**3.269089**
7.7700	**29.492407**	**2.478041**	**-1.363541**
7.7800	**33.859211**	**9.960998**	**-6.519176**
7.7900	**37.725834**	**16.618948**	**-10.852670**
7.8000	**39.062428**	**19.204006**	**-12.027453 – Top Acceleration**
7.8100	**37.219318**	**16.978983**	**-9.779755**
7.8200	**32.687916**	**15.093078**	**-7.301260**
7.8300	**26.669493**	**14.916125**	**-7.092607**
7.8400	**16.113756**	**18.985291**	**-7.869121**
7.8500	-4.151386	26.220856	-6.737772
7.8600	-37.947701	28.742140	-0.118445

7.8700	-79.290977	18.127575	12.088719
7.8800	-111.702560	-5.662910	20.141808
7.8900	-98.787628	-25.044979	21.066664
7.9000	-76.969597	-30.393690	19.652790
7.9100	-54.206341	-27.255154	13.360882
7.9200	-42.138958	-20.089100	7.572430
7.9300	-37.232262	-10.909877	2.284026
7.9400	-31.475887	-0.603361	-2.192394
7.9500	-25.029238	5.356313	-3.352986
7.9600	-20.909561	6.465245	-1.095927
7.9700	-19.694370	4.685217	2.756412
7.9800	-18.783606	2.939274	5.679734
7.9900	-16.359177	2.825375	6.428637
8.0000	-13.650676	2.263558	6.260791
8.0100	-9.742537	0.877898	5.803088
8.0200	-5.526884	-0.791216	5.464248
8.0300	-2.169111	-2.931343	5.753226
8.0400	0.194134	-5.603293	6.361386
8.0500	1.871894	-8.041483	6.972763

Euler Orientation Data for a Left Jab Body

Timestamp	**euler X**	**euler Y**	**euler Z**
7.7300	**-52.808971**	**-11.720325**	**168.775024**

7.7400	**-52.000046**	**-11.951903**	**167.397842**
7.7500	**-51.305149**	**-12.090858**	**166.104324**
7.7600	**-51.089626**	**-12.333014**	**164.936371**
7.7700	**-51.889122**	**-12.901402**	**163.982788**
7.7800	**-54.028023**	**-13.922581**	**163.243698**
7.7900	**-57.374737**	**-15.140458**	**162.684601 – Top Acceleration**
7.8000	**-61.022732**	**-15.788941**	**162.341782**
7.8100	**-63.462410**	**-15.121030**	**162.248016**
7.8200	**-63.389763**	**-12.988444**	**162.277130**
7.8300	**-60.517498**	**-9.684623**	**162.055496**
7.8400	**-55.586632**	**-5.179497**	**161.393326**
7.8500	-50.029869	1.334115	160.988907
7.8600	-45.359806	10.101309	161.175690
7.8700	-41.880756	19.294893	163.009216
7.8800	-38.321758	25.659887	167.111496
7.8900	-34.153191	28.560120	172.240479
7.9000	-30.210648	29.452871	176.220490
7.9100	-27.648455	29.427347	178.367493
7.9200	-27.446543	28.544262	178.462387
7.9300	-29.327719	26.879841	177.148880
7.9400	-32.475685	25.003874	175.273911
7.9500	-36.270153	23.356121	173.160172
7.9600	-39.976089	22.016602	170.890305
7.9700	-42.883133	20.759216	168.809677

7.9800	-44.566986	19.374470	167.233292
7.9900	-45.245243	17.837650	166.225769
8.0000	-45.450394	16.289551	165.673889
8.0100	-45.648224	14.900080	165.481018
8.0200	-46.106857	13.713228	165.517090
8.0300	-46.904583	12.623905	165.690491
8.0400	-48.006145	11.576732	165.371597
8.0500	-49.184799	10.591761	164.692291

Calibrated Data (timestamp and accelerations only) for a Right Hook

Timestamp	**accel X**	**accel Y**	**accel Z**
17.0600	**10.882917**	**8.185740**	**-11.546167**
17.0700	**12.274427**	**7.908532**	**-11.046634**
17.0800	**13.058965**	**7.789848**	**-9.748338**
17.0900	**13.382582**	**7.341694**	**-8.013309**
17.1000	**13.790965**	**7.095876**	**-6.289031**
17.1100	**14.326436**	**7.591911**	**-4.620353**
17.1200	**14.749866**	**8.386516**	**-3.281451**
17.1300	**15.188245**	**9.814802**	**-2.096775**
17.1400	**15.945731**	**10.603971**	**-1.233144**
17.1500	**17.543768**	**9.970349**	**-1.525015**
17.1600	**19.793163**	**8.659615**	**-3.446239**
17.1700	**22.429642**	**7.677369**	**-7.128259**
17.1800	**25.267881**	**7.137708**	**-11.340873**

17.1900	**27.514053**	**7.038294**	**-14.690104**
17.2000	**28.321209**	**7.971263**	**-16.608570 – Top Acceleration**
17.2100	**27.490177**	**10.339669**	**-16.453711**
17.2200	**24.154249**	**14.727767**	**-13.875873**
17.2300	**18.627762**	**21.699297**	**-11.054105**
17.2400	**13.646448**	**27.270473**	**-12.804427**
17.2500	**12.051129**	**29.886776**	**-21.431328**
17.2600	**11.149519**	**29.788511**	**-32.592533**
17.2700	8.078458	26.999327	-41.858879
17.2800	3.036418	23.194122	-47.691730
17.2900	-5.479938	21.809450	-53.897400
17.3000	-12.539548	25.552216	-67.418037
17.3100	-10.886188	25.780025	-87.542221
17.3200	-6.524502	18.477942	-107.402328
17.3300	-9.474300	9.677649	-119.781250
17.3400	-23.625273	4.262375	-120.833435
17.3500	-43.837654	-0.237902	-111.835381
17.3600	-64.346329	-1.343453	-97.247025
17.3700	-74.875267	-2.386549	-82.901649
17.3800	-83.731796	-15.890845	-72.207077
17.3900	-84.421135	-39.670895	-60.777672
17.4000	-89.247665	-26.928631	-35.474953
17.4100	-92.527626	-4.731706	-7.757076
17.4200	-87.305840	-12.524529	7.600847

17.4300	-74.447083	-8.295810	9.209513
17.4400	-63.377136	0.535412	9.156536
17.4500	-60.104771	0.132068	16.200663

Euler Orientation Data for a Right Hook

Timestamp	**euler X**	**euler Y**	**euler Z**
17.0600	**105.400444**	**-29.637966**	**-52.029125**
17.0700	**105.354935**	**-28.224804**	**-52.834492**
17.0800	**105.355469**	**-26.895493**	**-53.240261**
17.0900	**105.521690**	**-25.656288**	**-53.332970**
17.1000	**105.947723**	**-24.469872**	**-53.151871**
17.1100	**106.639862**	**-23.316469**	**-52.778061**
17.1200	**107.547340**	**-22.127579**	**-52.287647**
17.1300	**108.575386**	**-20.906218**	**-51.795826**
17.1400	**109.658600**	**-19.679134**	**-51.462627**
17.1500	**110.856583**	**-18.406713**	**-51.364208**
17.1600	**112.265968**	**-17.087046**	**-51.444023**
17.1700	**113.962196**	**-15.726048**	**-51.542801**
17.1800	**115.893394**	**-14.330432**	**-51.388741**
17.1900	**117.885307**	**-12.932781**	**-50.688480**
17.2000	**119.762695**	**-11.603184**	**-49.317417 - Top Acceleration**
17.2100	**121.276718**	**-10.396392**	**-47.342979**
17.2200	**122.171349**	**-9.296773**	**-45.086079**

17.2300	**121.923340**	**-8.065194**	**-43.199642**
17.2400	**120.194496**	**-6.316159**	**-42.164368**
17.2500	**117.173180**	**-4.165421**	**-42.029224**
17.2600	**113.611160**	**-2.112043**	**-42.353130**
17.2700	110.648537	-0.715380	-42.671307
17.2800	109.192543	-0.225623	-42.706146
17.2900	109.382576	-0.557472	-42.452171
17.3000	110.594078	-1.731495	-42.288857
17.3100	112.081848	-4.076186	-41.794991
17.3200	113.360435	-7.639076	-39.709084
17.3300	113.959579	-12.089565	-35.043915
17.3400	113.070366	-16.863293	-27.791174
17.3500	110.038101	-21.254930	-18.402952
17.3600	104.765572	-24.358221	-7.444775
17.3700	97.811111	-26.023708	4.043716
17.3800	90.740875	-26.560963	15.127999
17.3900	84.737030	-25.918003	26.429697
17.4000	79.920074	-23.001945	37.335651
17.4100	74.975342	-19.654657	46.063602
17.4200	71.014030	-17.453323	52.095600
17.4300	68.972275	-16.330774	56.388855
17.4400	67.527313	-16.192453	60.273468
17.4500	66.597092	-16.590677	63.809643

Calibrated Data (timestamp and accelerations only) for a Right Uppercut

Timestamp	accel X	accel Y	accel Z
11.3900	**14.160524**	**-30.521021**	**-57.939018**
11.4000	**23.031698**	**-27.022636**	**-57.625557**
11.4100	**35.309273**	**-26.558069**	**-60.954178**
11.4200	**42.026039**	**-30.245800**	**-63.559750**
11.4300	**42.806961**	**-35.483154**	**-66.586861 – Top Acceleration**
11.4400	**40.523327**	**-38.885689**	**-69.599152**
11.4500	**35.833427**	**-38.473095**	**-72.441345**
11.4600	**28.549007**	**-35.000412**	**-74.010895**
11.4700	**18.283239**	**-30.248713**	**-72.708595**
11.4800	7.433660	-25.974241	-69.504265
11.4900	-1.387505	-23.525249	-65.465668
11.5000	-8.656628	-22.261520	-61.472515
11.5100	-15.445879	-20.236284	-58.254250
11.5200	-22.032488	-18.548769	-55.367752
11.5300	-28.733635	-15.629355	-53.564526
11.5400	-34.413334	-13.073439	-52.164181
11.5500	-39.977989	-15.987862	-48.802090
11.5600	-43.114487	-20.730301	-45.761337
11.5700	-41.765724	-21.796129	-45.031555
11.5800	-41.384983	-21.029325	-46.619987
11.5900	-41.505016	-21.524021	-48.477089
11.6000	-44.862434	-23.254040	-45.829525

11.6100	-51.311947	-22.712053	-37.371098
11.6200	-55.733082	-19.418644	-26.724997
11.6300	-55.569954	-19.878321	-13.322402
11.6400	-50.965015	-18.576214	-1.369654
11.6500	-45.775269	-12.628171	5.995750
11.6600	-40.798904	-7.554181	11.241612
11.6700	-33.834518	-4.534771	15.575475
11.6800	-28.802744	-3.710554	20.061831

Euler Orientation Data for a Right Uppercut

Timestamp	**euler X**	**euler Y**	**euler Z**
11.3900	**-145.376465**	**28.532478**	**-84.239883**
11.4000	**-144.818939**	**29.524527**	**-84.578804**
11.4100	**-144.480164**	**29.595547**	**-85.513664**
11.4200	**-144.474350**	**28.369442**	**-86.864090**
11.4300	**-144.483353**	**25.960936**	**-88.431572 – Top Acceleration**
11.4400	**-144.257339**	**22.391085**	**-90.098473**
11.4500	**-143.851074**	**17.550449**	**-91.707069**
11.4600	**-143.642303**	**11.499025**	**-93.219513**
11.4700	**-143.804031**	**4.437706**	**-94.523148**
11.4800	-144.332626	-3.167625	-95.608620
11.4900	-144.990234	-10.836676	-97.454613
11.5000	-145.551239	-18.596029	-99.161278

11.5100	-145.972366	-26.292643	-100.713402
11.5200	-146.241196	-33.915859	-102.189438
11.5300	-146.465652	-41.186634	-103.619415
11.5400	-146.577118	-48.323673	-105.463203
11.5500	-146.267242	-54.987049	-107.828308
11.5600	-145.391846	-60.944500	-110.319748
11.5700	-143.803513	-66.343346	-113.231529
11.5800	-141.609909	-71.412422	-116.909065
11.5900	-137.675552	-76.487556	-122.764328
11.6000	-126.089798	-81.594627	-136.547775
11.6100	-84.886513	-85.136490	-179.569321
11.6200	-31.553675	-83.036858	126.091454
11.6300	-14.664877	-78.125984	109.086273
11.6400	-7.271867	-73.202393	103.075439
11.6500	-2.138127	-68.743156	99.058090
11.6600	1.591579	-64.928017	95.698799
11.6700	4.194427	-61.573322	92.732193
11.6800	6.106953	-58.756218	90.099022