FINAL YEAR PROJECT

Intelligent Cricket Ball

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Submission Date: 14th May, 2018

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THESIS

This thesis is submitted in partial fulfillment of the requirements for the final year project of Bachelors of Science in Mechatronics and Control Engineering at University of Engineering and Technology, Lahore, Pakistan.

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ACKNOWLEDGEMENTS

We are thankful to the Almighty Allah Who guided us through the project and empowered us to complete it.

We would like to thank University of Engineering and Technology, Lahore for the opportunity to do this project – in particular our supervisor Dr Abbas Zilqurnain Naqvi. We are also grateful to Dr. Ali Raza and Dr. Ahsan Naeem who were the initial driving force behind this project and provided us with valuable help throughout the project. Thanks should also go to Mr. Misbah Ur Rehman whose enthusiasm for this project was invaluable. We would also like to thank Mr. Dawar Saeed who helped us during the initial stages of the project.

We are grateful to Dr. Awais Mian of LUMS who allowed us to use the cricket biomechanics lab in LUMS to verify the results of our project.

Finally, we would like to thank our families and friends for their support and encouragement.

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ABSTRACT

This project aims at developing a prototype cricket ball with embedded instrumentation. The **intelligent cricket ball** will be able to provide characterization of bowling deliveries. The parameters measured by the instrumentation in ball are the instance of release, the spin rate and the location of spin axis of the ball. The ball is aimed to be used for research purposes, training purposes and practice sessions.

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION AND BRIEF BACKGROUND

The game of cricket is a multi-million dollar sport attracting thousands of live spectators in stadiums, while millions watch on television throughout the world. The fascination of the game is of course the duel between the batsman and the bowler. And while bowlers are often elevated by their supporters to a god-like status due to their exploits in controlling the flight or movement of the ball after bouncing on the pitch, it is doubtful that either they or the bowlers themselves understand the physical principles behind such feats. Two important phases exist in the delivery of a cricket ball. The first is a free flight phase lasting from the time the ball leaves the bowler's hand to when it bounces on the pitch. During this time, the movement of the ball it totally under the control of aerodynamic forces. The second phase is the flight of the ball after bouncing off the pitch, and moving on towards the batsman. This second phase is in the main governed by the orientation of the ball when it hits the pitch, and is outside the control of the bowler. This project is concerned with the data logging and processing of the first free flight phase.

Sports analytics is a thriving industry in which motion patterns of balls, racquets, and players are being analyzed for coaching, strategic insights, and predictions. The data for such analytics are sourced from expensive high-quality cameras installed in stadiums, processed at powerful backend servers and clouds. There is a possibility of significantly lowering this cost barrier by embedding cheap Inertial Measurement Unit (IMU) sensors and ultrawide band (UWB) radios inside balls and players' shoes. If successful, real-time analytics should be possible anytime, anywhere. Aspiring players in local clubs could read out their own performance from their smartphone screens; school coaches could offer quantifiable feedback to their students. Our work follows a growing excitement in sports analytics. Sensor-enabled football helmets, aimed at detecting concussions and head injuries, are already in the market. Nike is prototyping IMU-embedded shoes, while multiple startups are pursuing ideas around camera-embedded jerseys, GPS-enabled soccer balls, and bluetooth frisbees. However, we have not found a serious effort to accurately characterize 3D ball motion, such as trajectory, orientation, revolutions per second, etc. The rapidly advancing MEMS sensor technology opens new scopes for product development in the area of sports technology. The key parameter of MEMS sensors are: size (miniaturization), measurement ranges, and price. A miniature circuit board containing a three-axis accelerometer and one dual-axis and one single-axis angular rate gyro was developed by King, the overall size of which is 19x24 mm and weighs 3 g. Meamarbashi developed a sensor module capable of measuring up to 1750 rad/s, however the module is 230x23x40 mm and weighs 80 g. With the introduction of high speed rate gyros with a range of ±20k deg/s (350 rad/s, 55.56 rps), extendable to ±50k deg/s, in 2011, the high speed revolutions of small sports equipment became measurable for the first time. Before they were introduced recently, gyros had a highest spin rate of ±16.67 rps . This rate would have been too small for measuring the maximal spin rate of wrist spinners (42 rps). So far, the standard method for determining high spin rates was video technology, either with lines drawn on the surface of the ball by determining the number of revolutions per time from the video frames, or with reflective makers attached to the ball, which allows for automated data analysis but disturbs aerodynamics. Cork measured spin rates of pace bowlers between 2 and 25 rps, and rates of spin bowlers between 16 and 37 rps. Spratford and Davison emphasized that the position of the axis of rotation provided a seam stability measure, "but only if the seam position is known". This is difficult to achieve with video technology, but would be simple with a cricket ball, instrumented with high-speed gyros.

High-Tech sports instruments are rapidly increasing in today's global market. One of the reasons is MEMS sensor's technological advancement. For example Analog Devices Inc has developed quad-differential MEMS gyros which combine four separate sensing elements to cancel out the effects of vibration, noise and the influence of linear acceleration. Such sensors provide the opportunity to develop smart ball for performance analysis and research from different angles. The first instrumented cricket ball was developed by Fuss and co-workers for research purposes, consisting of a Logomatic data logger, three high rate gyros (± 50 rps), and a battery. The data sampling frequency of this ball was 500 Hz on each channel, and the data was downloaded via USB port. The ball had to be opened for switching on and off, and for downloading data. The ball was CNC machined of Ureal and the seams were glued onto the ball's surface.

1.2 PROBLEM STATEMENT

Cricket bowling requires high level of skills in many ways (e.g. physically and mentally). The ball delivery technique is one of these important skills which can be optimised with advanced training methods. These training methods hinge on advanced performance parameters. Development of a low cost **intelligent cricket ball** will address the shortcomings of the existing systems and discover and explore cricket bowling kinematics and dynamics. In the past cricket bowling kinematics has not been properly studied using instrumented balls due to technical limitations of sensor system and electronics design. The aim of the project was to develop a highly portable instrumented cricket ball for recording the ball's kinematics and calculating dynamic performance parameters from kinematic data. The ball is designed in such a way that it exactly feels and looks (i.e. mass and material) as a real cricket ball. The ball is constructed from leather hemispheres, a shock damping foam material, and miniaturized electronics circuit.

One of the current method employed in cricket ball kinematics studies uses 14 camera Cortex Motion Analysis System (Version 2.5, Motion Analysis Corporation Ltd., USA) at 200 Hz, and the inbuilt Kintools RT analyser. Bowlers bowl deliveries from their respective over the wicket position to a right-handed batsmen in an indoor laboratory, which extended outdoors to a full-length cricket pitch. The data from the left arm bowlers has to be converted to right arm data. The ball is captured using a system of three reflective, spherical markers attached directly to the ball surface. They aee placed at one hundred and twenty degree intervals around the face, three centimeters from the centre of the face. Markers have to be replaced if any damage or movement occurs.

The ball segment is created using the skeleton builder function of the Kintools RT software to calculate the ball’s angular velocity, which is then separated into components about the horizontal and vertical spin axes. The direction of spin is calculated by projecting the spin axis onto the horizontal and measuring the angle between that and the lateral axis. The elevation of the ball axis is defined as the angle between the axis of spin and the horizontal, with both angles measured in respect to the direction of ball velocity. The centre of mass of the ball is calculated using two additional markers placed on the intersection of the quarter and half seams during a static trial, directly opposite to each other. A virtual dynamic centre of mass is then created with respect to the three dynamic markers from which the linear velocity of the ball is calculated. Marker coordinates are then smoothed using a Butterworth filter at 30 Hz.

Figure 1.2.1: Markers on ball

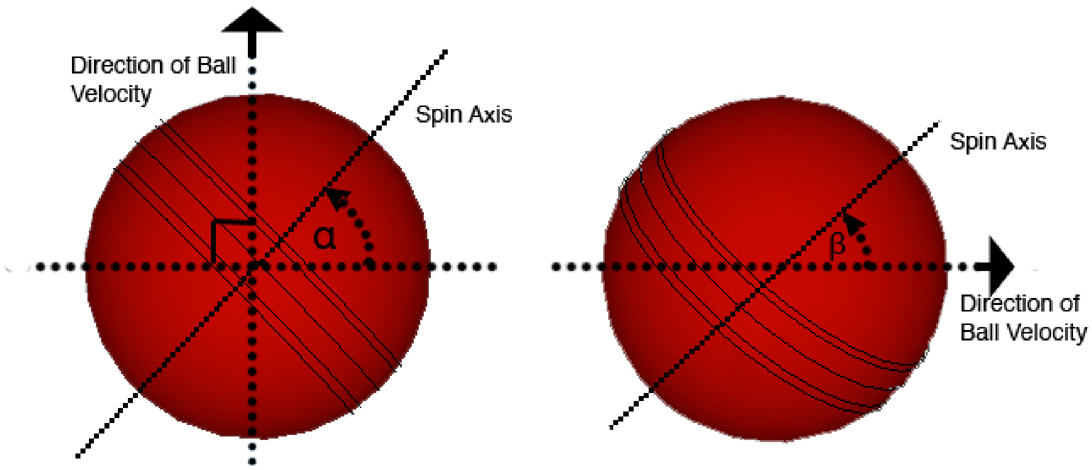

Figure 1.2.2: Top view and lateral view of ball for studying the kinematics

The spin profile of ball is vital for swing and spin. Tracking the ball flight using video technology is expensive and complex. Placing markers on the ball disturbs the aerodynamics of the ball. Real-time data acquisition of bowling has not been done yet. Data for left handed bowlers has to be first converted to that of right handed bowlers in various methods. It is not possible to equip cricket academies on a large scale with modern technology. Intelligent Cricket Ball is aimed at taking these challenges into account and design a product that does not lack these features and is as close to the real cricket ball as possible.

1.3 OBJECTIVE

Assumptions:
Bowling profile is tracked for the ball till the time it hits the pitch.

Objectives to be achieved by the '**Intelligent Cricket Ball**':

1. Measure spin rate of the ball
2. Locate spin axis of the ball
3. Detection of instance of release and instance of impact of the ball

Additional Target:
Wobble information

1.4 PROJECT OUTPUT

It looks like a normal cricket ball, but it's really a computer for bowlers. Intelligent cricket ball will be able to tell bowlers exactly how fast it is spinning and on what axis. It will allow cricketers, both amateur and professional, to discover and improve the style of bowling that is "perfect" for them. Weighing in the normal range of 155.9g – 163.0g, the intelligent cricket ball looks and feels like any other cricket ball. What makes the ball stand out from the crowd is what it has on the inside. In the centre of the smart cricket ball is a circuit board attached to tiny sensors, which measures and records vital aspects of the technique involved in bowling, such as spin rate and spin axis. In the world of spin bowling, 'the faster the spin, better the performance'. Currently, the technology used to measure the spin rate, such as Hawk- Eye, is very expensive and complex and not everyone can use it. However, when it comes to the intelligent cricket ball, anyone can use it and you don't have to be an expert.

The MATLAB interface displays the ball's spin rate in three directions: up or down, left or right and forwards or backwards.

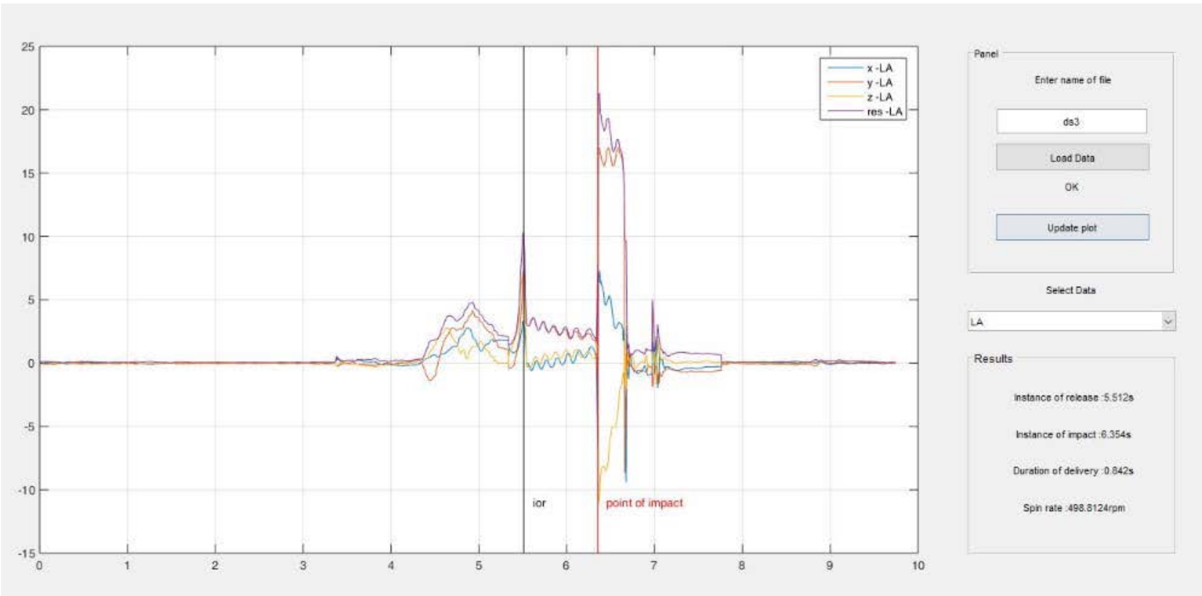

Figure 1.4.1: MATLAB interface showing sample output

The analysis of bowling performance parameters with intelligent cricket ball allows the researcher to quantify the efficacy of coaching interventions, which can take the form of changing technique or teaching new deliveries. The data obtained from the intelligent ball can reveal the various inter-relationships between these performance parameters, which, for the most part of cricket history, have been impossible to determine. For example, the dependency of spin rate on spin torque—an increase in the latter should lead to corresponding increases in angular acceleration and power. In addition, an inverse relationship should exist between precession (speed of the moving spin axis) and efficiency (energy ratio). However, some relationships may be more difficult to assess, such as the relationship between precession and spin rate. Spin bowling performance is improved when spin rate, acceleration, resultant and spin torque, power, and efficiency increase significantly, with concomitant decreases in precession torque, precession, and normalized precession. It would greatly benefit coaches and spin bowlers to know these inter-relationships between the bowling performance parameters, as they may lead to greater insight on the techniques and skills required to improve spin rate, the primary performance outcome in spin bowling.

1.5 IMPORTANCE OF PARAMENTERS

The spin rate of the ball is of particular importance to a spin bowler while the location of spin axis is of great use to both the spin and fast bowlers. The higher the spin rate, the better a spinner can spin the ball and trick the batsman. The location of spin axis would determine where the bowler expects to spin the ball. For a fast bowler, the consistency in the location of spin axis would determine how well he can swing the ball. This can also be utilized to revive the lost art of reverse swing. The following section gives a detailed discussion on how these parameters are important to the game of cricket.

The **spin axis** of sports balls is of particular interest for performance analysis. King investigated and optimized the position of the spin axis in ten-pin bowling for achieving maximal hook potential. The flight path of a baseball is mainly Magnus force dependent. However, precise positioning of a stable spin axis with respect to the seams and smooth leather patches can create different flow regimes on either side of the ball, resulting in a motion similar to the cricket ball swing. In cricket, the spin axis should be perpendicular to the plane of the seam when bowling a swing, in order to avoid seam wobble with reduced swing potential. If the seam wobbles pronouncedly, then the seam advances and recedes once per revolution in the direction of the flight path, thereby changing between rough and smooth surface profiles rapidly. A stable seam, however, with the seam plane at an angle to the flight path, keeps the rough and smooth surface confined to each side of the ball.

While there are many facets that contribute to a successful spin bowler, imparting a high number of revolutions on the ball is seen as critical and the main cause for both the ball’s “drift” in the air and deviation off the pitch. Coupled with the ability to pitch the delivery in advantageous areas, elite finger spin bowlers such as Ashwin play an integral role in the success of teams competing in the international game.

A study on the biomechanics of elite finger spin bowling, at Loughborough University in conjunction with the England and Wales Cricket Board, profiled 30 elite male finger spin bowlers over a four-year period (including the English spinners Graeme Swann, Monty Panesar and James Tredwell). The team of researchers explored the technical factors within a bowling action that influence the rate at which a ball spins. The team observed very strong positive relationships between the orientation of the bowler's pelvis and the rate at which the ball spins during flight, particularly at the instance of front foot contact and ball release. These findings created a compelling argument that highly advanced motions of the pelvis are paramount to producing high spin rates to the ball and therefore that spin bowling should not be solely thought of as an upper arm skill. The movement during the ball's flight is due to its "lift" or Magnus force, which affects the way a ball reacts during motion. This movement occurs because on the side of the ball which is advancing due to the spin motion the air flow is slowed down, creating a high pressure region. On the other, receding side, it creates a low pressure region. The difference in pressure causes a "lateral" force perpendicular to the ground and a lateral movement of the ball during flight. This is known as drift.

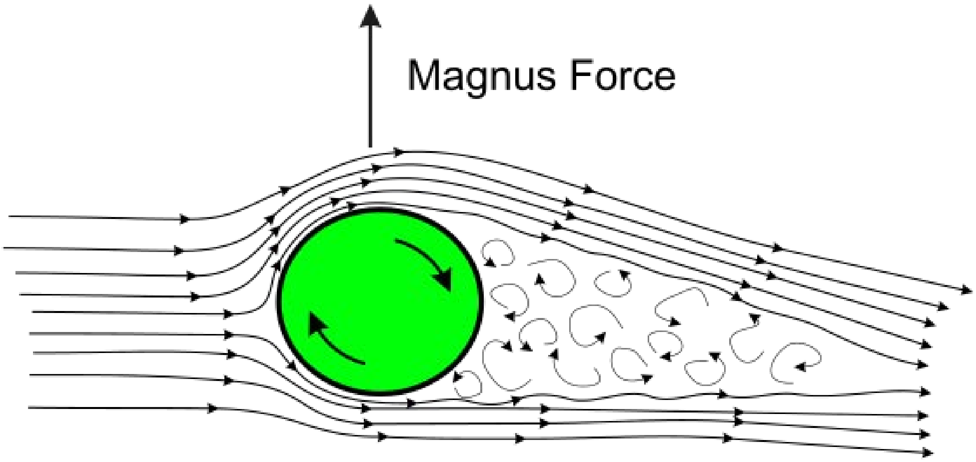

Figure 1.5.1: Magnus Effect

The force of the lift will vary in direction and magnitude and depends on the amount of spin and the axis along which the ball is spinning. In addition, cricket balls have a seam, and spinners commonly apply spin along the line of this seam to help their grip on the ball. This means the spin axis is commonly kept perpendicular to the direction of the seam, promoting a stable seam position and the possibility of the ball deviating off the seam the moment it hits the pitch. When the ball meets the pitch surface, particularly in India (due to drier pitches creating high friction between the ground and the ball), this commonly creates large lateral deviation and a heightened challenge to the opposing batsman.

Coming back to Ashwin, since 2012 he has noticeably made a number of key technical changes to his bowling action to improve alignment and promote a transfer of momentum throughout his delivery stride. In 2016, he bowled with a slightly open pelvis orientation when his front foot hits the ground. This differs to the strictly side-on, or at times closed-off pelvis orientation that he used when releasing the ball back in 2012. He now has the ability to rotate his pelvis effectively and efficiently, promoting the transfer of kinetic energy from the pelvis to the hand as he releases the ball, and so injecting greater spin onto the ball.

The speed at which the ball is released also plays a significant role in the success of an elite spin bowler. When a new, competent batsman enters the crease, they use the idiosyncratic cues provided by the bowler, such as the release velocity, height, and angle of preceding deliveries. This forms a mental template of the ball's trajectory – essentially an attempt to predict the trajectories of the deliveries to follow.

Here, Ashwin's subtle variation of the speed and the axis around which he spins the ball comes into play. He commonly delivers his stock ball with an initial release speed around 54mph. Variations of pace close to this speed may exploit a batsman's mental template and take advantage of the batsman's subtle "blindness" to length and speed. This can create a fatal weakness in judgement, particularly for any new batsman at the crease.

The new batsman's ability to tell what speed and trajectory the ball will arrive is now sub-optimal, meaning vital mistakes are made in deciding whether to come forward or back when playing the ball. This can result in a quick return to the dressing room.

CHAPTER 2
LITERATURE REVIEW

To define our project goals, we had to search and read about the current trends in cricket technologies. This chapter presents our findings and research on the currently employed sports analytics methods, some products that are similar to our 'Intelligent Cricket Ball' and some basics of cricket and ball dynamics. This would eventually help the reader to grasp the importance of this small in size but big in impact project.

2.1 VIDEO TECHNOLOGY

2.1.1 Radar Gun

Measuring the speed of the bowl by a radar is similar to measuring the speed of the moving car. This gun consists of both a receiver and a transmitter. The way it works is that it sends a radio wave that is reflected of by any object that is in the path. In this case it is a cricket ball. The gun gets this echo and then by using the principle of Doppler Shift, calculates the speed of the ball. There are few advantages of this technology: Exact speed is determined with help of a radar gun as it catches the speed of the moving ball the way it is without any error. It is instantaneous and records the speed immediately as the ball passes the radar gun. This is the reason that in any cricket match, as soon as the bowler balls the delivery, the speed is shown on the screen. The gun works efficiently and helps getting the exact possible speed of the bowl.

2.1.2 Hawk Eye

Hawk eye is a computer system that is used officially in various sports like tennis, cricket, football and other sports. A person named Dr Paul Hawkins developed this technology in the UK. The system was initially implemented in the year 2001 for the measuring purposes in cricket. Hawk-Eye is not something that is infallible. It is accurate within the 5 millimeters of its range and is usually considered and trusted as a tool to have a second opinion in the sports. Hawk eye is referred to as a technology that is used to measure the speed of ball as the way it is bowled. This technology was originally made for tracking the missile and brain surgery. This technology gets the data from around six cameras. It then makes use of the data to track the ball path from the time the ball leaves the hand of the bowler until the time the ball goes dead. The technology then presents this information as 3D image. It clearly helps the viewer understand the direction and length at which the ball left the bowlers hand and headed towards the stumps. This also helps in deciding the LBW decision as it allows the 3 umpire to see whether the ball was actually in the line of the stumps when it hit the pads of the batsman.

Advantages of this method are as follows: Accurate speed of the ball as the clear direction is seen in the hawk eye. The direction and the swing of the ball is also measured with this technology clearly states the authenticity of the ball hitting the stumps.

Criticism over the technologies

The technology method to measure the speed has received criticism in the years that have casted doubts on the achievements of some of the top bowlers in the world. For instance in the year 2002, Pakistani Team bowler Shoaib Akhtar was reported to have passed the 100 mph mark in a match against the team New Zealand. However, there were many commentators who expressed their doubts about the accuracy of the radar guns in measuring the speed. There had been many cases like that where there had been doubts raised by the commentators about the bowling speeds of many bowlers in the past. Despite of the criticism, the technology method to measure the bowling speed is still used in the cricket matches and will always be used because nothing is better than technology when measuring the bowling speed in cricket. It is certainly impossible to measure the speed manually.

2.1.3 The Rev Counter

This technology is used to show the rotation speed of the ball. It is used when spinners are bowling, to show viewers the idea how much each ball is spinning. The technology is also able to show the RPM or revolution per minute through a counter, demonstrating how fast the ball is spinning after release.

Figure 2.1.1: Revolution counter

This was first time used by Sky Sports while broadcast of Ashes 2013. However, there was no official word from the broadcasters as to how they measure this rate. Here are two accounts of the most probable methods used for this:

1. A high speed camera focused on the ball, possibly using the same images that are captured for the Hawkeye system. As a starting point, an upper limit of 3000 rpm gives 50 rps. At normal (at least, as normal as cricket-playing countries get) PAL video rates of 50 fps that's a maximum of 1 revolution per frame, so high speed should easily be able to resolve the rotation. And, of course, there's no guarantee that the figures presented in the image are

precise. It is suspected the last two significant digits are bogus. Designing such a system would be quite challenging, but the problem would be in designating the period and exact area of interest, and doing it in a few seconds.

2. The Doppler Radar. Device: X2 Elite. It is a 3D Doppler tracking radar used in tennis and golf, and possibly in cricket. On the (golf) driving range, it was able to get similar readings, but they were from a machine only a few feet away from the tee. There they were even able to determine the rotational axis as well.

Figure 2.1.2: X2 Elite sample output

2.1.4 Vicon Motion Analysis System

Here is an account of how Vicon Motion Analysis System was used for a cricket research study:

A Vicon Motion Analysis System (OMG Plc, Oxford UK) was used to collect synchronous kinematic and kinetic data. Eighteen cameras (M2 MCam), operating at a frequency of 300 Hz, were positioned to cover a volume of approximately 7 x 3 x 3 m. Black fabric was draped along the walls of the bowling facility to reduce glare from the sun; any source of infrared light is seen by the cameras and reduces the accuracy of the data collected. The Vicon Motion

Analysis System’s accuracy is also reduced when cameras can see each other in their field of view. To avoid this, sixteen of the Vicon cameras were mounted on tripods with 1 m extension poles attached, allowing the cameras to be pointed downwards slightly. The two remaining cameras were positioned at a lower height and located at the front of the volume. These cameras were used to reduce the occlusion of markers on the front of the bowlers’ pelvis and thorax as they flexed forwards during the delivery action. The Vicon system was calibrated at the start of each day of data collection using an Ergocal (14 mm markers) static calibration frame, to define the origin and global coordinate system, and a 240 mm calibration wand (14 mm markers). When viewed from behind, the global origin was located at the back-left corner of the force plate; the x-axis pointed from left to right, the y-axis pointed forwards and the z-axis was the upwards vertical.

Two Phantom v4.1 digital high-speed cameras were used to capture all bowling deliveries; this footage was not used directly in this thesis, but provided a useful source of reference. Both cameras recorded at a frequency of 500 Hz and were positioned behind the bowler and to the side. A 50 Hz camera (shutter speed of 1/1000 s) was connected to the Vicon system, providing a visual prompt when viewing or analyzing the data within Vicon. Force data for all bowling trials were recorded as an analogue signal within Vicon (1200 Hz) and also using Kistler’s Bioware v.3.22 software (1008 Hz).

Figure 2.1.3: ViCon data collection environment

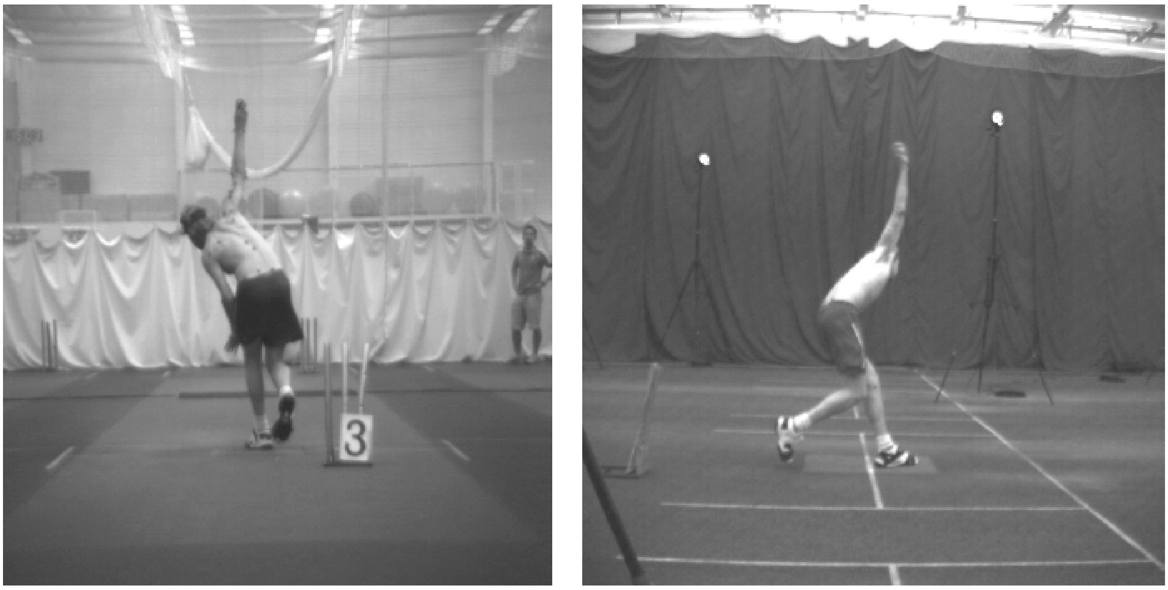

Figure 2.1.4: Images from high-speed cameras

2.1.5 Other Methods

Embedded IMU: IMUs can be embedded in a Cricket ball and is perhaps closest to our work. However, these products report basic features such as angular velocity, time of flight, etc. These features are directly available from the sensors and do not address the actual metrics of interest to the players/coaches. Some other products also embed IMUs but focus mainly on the design and packaging of the ball for high impact. A product explores spin-analytics in the context of a Bowling ball, however, due to low spin-rates and contact with the floor, accelerometers and gyroscopes are readily usable. This simplifies the problem in contrast to Baseball and Cricket.

Wearables, Cameras, and Sports Analytics: Several startups like Zepp, MiCoach, and Ball are extracting motion patterns from wearables. Smart sensor shoes have been proposed for analyzing soccer shots, however, these are essentially classification problems. Hawk-Eye is perhaps the most popular and expensive camera based tracker officially adopted in Cricket, Tennis, etc. Hot Spot is a popular IR technology used to determine contact points between ball and players. Video analytics efforts are processing video feeds to learn/predict game strategies. While creative, the projects are addressing a different set of problems.

Localization and Motion Tracking: Rich literature in indoor localization has mostly focused on human motion. Under sparse WiFi infrastructure and high ball speeds, such techniques are inadequate. UWB based ToF ranging report 10cm accuracy for static objects. Even on this technique but fuse with AoA, motion models, and DoP constraints, to cope with real-world challenges. On a similar note, inertial sensor based tracking have mostly been performed on humans, robots and drones. However, unlike iBall, none of these works address the space of freely falling objects. While work in tracks ballistic missiles, the granularity of tracking is different both in time and space. iBall entails much finer granularities of tracking and appropriately formulates a global optimization problem for better accuracy unlike filtering techniques.

2.2 SIMILAR PRODUCTS

2.2.1 Speedsensor by Kookaburra

The AUD$55 (U.S.45) Speedsensor by Kookaburra is the official size, shape and weight of a standard cricketball, with a small LCD readout on one face. What makes it special is its ability to sense and display the speed the cricketball has been bowled. Radar guns seek a reading in the area between the point the ball leaves the bowler’s hand and strikes the pitch, where the ball is travelling fastest. The Speedsensor measures speed by measuring the time between the bowler’s hand and when it hits something (the pitch or the nets, or that all-purpose, readily-available wicket, the trash can. There’s only one catch – you must program in how far the object is away before you bowl it. This is difficult if you’re aiming at a cricket pitch, because pitching it beyond the target, say 10 metre mark, by one metre will give you a 10% slower speed. The manufacturers claim the ball is very accurate if the distance is exact, but warned against hitting the ball with a bat or anything other than a motionless object. If you’re aiming to measure speed, Kookaburra told us that they recommend bowling in the nets and covering the wire netting with a blanket to avoid damaging the ball. Mark out the point at which you will let go of the ball exactly the distance you program into the ball, and you should be right to get a good reading. The Speedsensor’s operating instructions suggest the ball can monitor up to 190 km/h which is 30 km/h faster than the fastest ball ever recorded.

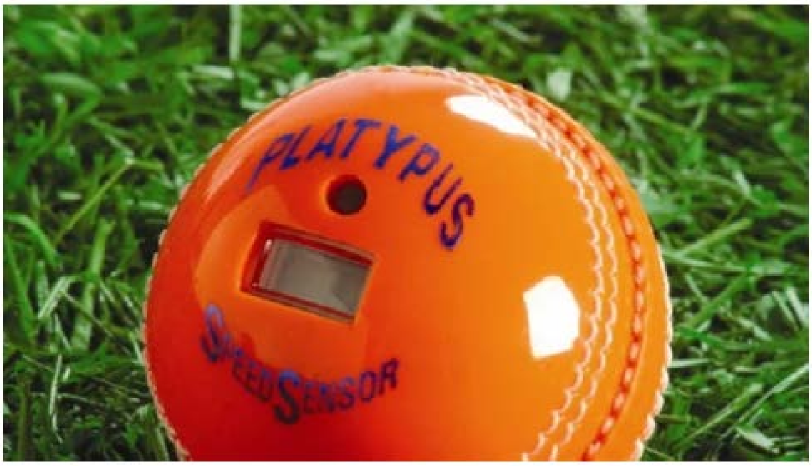

Figure 2.2.1: Speedsensor by Kookaburra

2.2.2 Strike

Strike, the world's first smart baseball can detect and display the speed, spin rate and pitching trajectory of each throw of the ball.

STRIKE MEASURES:

- 3D Trajectory: Our dedicated algorithm tracks the ball's path and generates a 3D replay.
- Spin: Strike measures each pitch's spin rate which is key to curve balls.
- Speed: Strike can instantly detect the ball's velocity.
- Pitch Location: Our strike zone detection technology helps you improve your accuracy.
- Rotation Axis: Strike records the ball's axis of rotation so you can better understand your pitch.

Strike is the best coach to analyze your performance and lead you to the secret for a perfect pitch, for a fraction of the cost of conventional technology.

Strike's App is not only displays trajectory, but also collects and stores the history of each pitch data, and turns them into an info friendly chart for users to refer to any time they need to do so. By doing this, users can find their history record easily and adjust their technique to improve the players' pitch, with each try. Furthermore, coaches and scouts have more options to recruit pitchers as well.

APP FUNCTIONS:

- Activity History: Your pitching stats will automatically be stored in the Strike cloud so that you can review your performance anytime and anywhere! All you need to do is login to your account from any mobile device to view your cloud information.
- Achievements: Strike's unique Achievement System motivates you to keep reaching your goals and to have fun!
- Pitch Comparison: Strike acts as the ultimate personal coach by providing immediate feedback about your pitching performance over time.

Figure 2.2.2: Strike

2.2.3 ADIDAS miCoach Smart Football

Smart football allows user to focus on ability to control, strike and manipulate the football so their on-pitch skills are at their best. The miCoach smart ball's unique built-in sensor can tell you everything you need to know about your kick, while maintaining the weight and feel of a regulation size 5 football. Fine-tune your technique with instant feedback on power, spin, strike and trajectory, along with exclusive tips and guidance to help you get the most from your game.

Integrated sensor inside the ball detects speed, spin, strike and flight path data and instantly relays kick data to the miCoach smart ball app on your devices running iOS 7 or higher, Android 4.3 or higher and Windows 10 via Bluetooth 4.0

Companion app interprets and displays instant feedback on power, spin, strike and trajectory, and includes ball-mastery tutorials with drills, coaching tips and guidance to help improve ball touch and handling

App features: Kick tips and training for power, bend and knuckle balls; Capture video with your kick to help perfect technique; Prove your ability with power and pro challenges; Track and record your stats and measure your improvement over time; Share and compare your best kicks with friends; Comprehensive ball mastery technique videos; Visualize the path of the ball, even if you kick it against a wall

Circumference: 68.6 cm / 27 in; Diameter: 22 cm / 8.66 in; Size 5 regulation weight, quality thermal bonded 32 panel ball with integrated sensor package; Requires inflation

Battery life: approximately 2000 kicks / one week; Charging time: approximately one hour;

Package includes: adidas miCoach smart ball charger base, AC power plug, Quick-start guide

Heat-welded die-cut TPU outer panels; TPU bladder

Figure 2.2.3: Adidas miCoach

2.3 CRICKET TERMINOLOGIES AND BALL DYNAMICS

2.3.1 Cricket Ball Structure

The most commonly used cricket ball is hand manufactured by Kookaburra and has followed essentially the same process since the 1890's. A cricket ball consists of a cork core that is tightly wound with several layers of string and enclosed by two leather hemispheres which are hand stitched together. The ball is used every delivery that takes place as it is bowled at the batsman who then tries to score runs by hitting the ball. This process results in the ball having to repeatedly withstand massive impacts. As such all cricket balls must adhere to British standard 5993 which controls the construction, dimensions and performance of cricket balls.

The ball is designed to last >80 overs (480+ deliveries) in test matches and 50 overs (300 deliveries) in one day internationals (ODI's). A red ball is used in test matches as these are played during the day. A white ball is used in ODI's as they are played into the night since the white ball is more visible at night. The ball is expected to degrade over the course of the match. This affects the ball's behaviour significantly. Several bowling techniques are designed around how the ball changes over time.

There is also a primary 'seam', which is raised about 2 mm above the spherical surface of the ball. On either side of this primary seam and parallel to it around the surface are two rows of 80 to 90 stitches that stand about 1 mm above the spherical surface. Some designs of ball, known as four-piece balls, may also have a secondary seam with internal stitching atright angles to the primary seam.

If a ball has two sub-types: a harder and a softer one, then the ratio of 'same conditions: advantage: disadvantage' when using one ball per innings is 2:1:1, and when using two balls 4:1:1.

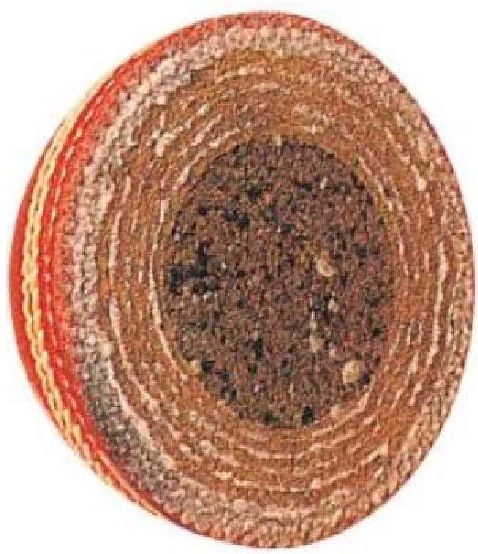

Figure 2.3.1: Cricket ball section

2.3.2 Vertical bounce of a cricket ball

Almost every type of ball used in a sporting event must bounce according to the rules of the game. If the ball bounces too high or too low, the players will complain that something is wrong with it. The standard test for bounce is to drop a ball from a certain height onto a hard surface such as a slab of concrete and then measure how high it bounces. When a tennis ball is dropped from a height of 100 inches (2.54 m) it must bounce to a height between 53 inches (1.35 m) and 58 inches (1.47 m). For official use in major tournaments, tennis balls must be properly tested and approved, for a moderately large fee, but the fee is only a small fraction of the total value of balls sold. Tennis courts themselves vary in hardness, which affects bounce height, so a standard surface such as concrete is used for these tests. There is no such official rule for a cricket ball. There is simply a tradition that is monitored by umpires, and one that is an industry standard. When a cricket ball is dropped from a height of 2.0 m onto a heavy steel plate, it bounces to a height somewhere between 0.56 m and 0.76 m. Cricket balls are a lot less bouncy that tennis balls and the permitted range of possible bounce heights is larger. A useful way of specifying the bounce is to take the ratio of the bounce speed to the incident speed. When a ball is dropped from a height of 2.0 m it lands at a speed of 6.26 m/s, regardless of the type or weight of the ball. A cricket ball bounces to about one third of that height (0.67 m), in which case it rebounds at a speed of 3.61 m/s. The ratio of these two speeds is 3.61/6.26 = 0.58 and is called the coefficient of restitution (COR). The COR of a tennis ball is about 0.75. The COR determines not only the bounce height but also the speed at which a ball comes off the bat. The batted ball speed also depends on the speed of the bat.

2.3.3 Force on a cricket ball

Drop a cricket ball on a cricket pitch and the ball bounces up off the pitch. How long does the ball remain in contact with the pitch and how big is the force on the ball? Cricket balls are relatively stiff compared to say a tennis ball, and the contact time is shorter. A tennis ball spends 0.005 seconds in contact with the court or the strings of a racquet. A cricket ball spends about 0.001 seconds in contact with the pitch or in contact with a bat. The force on the ball has to slow it down to a complete stop and then accelerate it back in the other direction, all in the space of 0.001 seconds. Suppose that a 0.16 kg cricket ball hits a bat at 100 km/hr and then comes off the bat at 100 km/hr in the reverse direction. Imagine a car accelerating from 0 to 100 km/hr in 0.001 seconds. That's a lot of acceleration. A Porshe can do it in 5 seconds, but a cricket ball does it 10,000 times faster. The average force on the ball is 8,800 N, enough to lift a mass of 880 kg off the ground. The peak force on the ball is about double that, enough to lift a 1.76 tonne car off the ground. That's why it hurts to get struck on the head or anywhere else with a cricket ball.

2.3.4 Air resistance

Air plays an important role in cricket. Apart from allowing players to breathe, it causes the ball slow down through the air and it can cause a ball to curve or swing away from the path it would otherwise follow. Air is heavier than you might expect. One cubic metre of air at ground level weighs 1210 gm. A cricket ball weighs 160 gm. A room full of air weighs more than most cricket players. If you drop a cricket ball out of a helicopter hovering 300 m above the ground, it will accelerate up to 123 km/hr in about 5 seconds, having fallen through a distance of about 100 m. It will then fall the remaining 200 m to the ground at 123 km/hr, without gaining any additional speed. At 123 km/hr, the force of gravity pulling the ball down is equal to the drag force of the air pushing it upwards. The total force on the cricket ball is then zero so it falls at constant speed after the first 100 m. A more dramatic effect would be seen if you dropped a cricket ball into a swimming pool. Air has the same basic effect as water in slowing the ball, but it is a smaller effect. A ball bowled horizontally at 123 km/hr experiences a backwards horizontal drag force that is equal to the weight of the ball. At world record bowling speeds around 160 km/hr, the drag force is 1.7 times greater than the weight of the ball. Regardless of the speed of the ball when it leaves the bowler's hand, air resistance causes the ball to slow down by about 12% by the time it lands on the pitch. It slows down by another 30% or 40% when it hits the pitch, depending on the speed of the pitch and the angle of incidence. A ball bowled at 150 km/hr will arrive 0.46 s later at the batter's end, travelling at about 85 km/hr.

2.3.5 Collision between bat and ball

What happens to a ball when it hits a bat? It comes in at around 100 km/hr, reverses direction, and bounces off the bat 0.001 seconds later. But what happens during that 0.001 second it is on the bat? Assuming that the ball is hit in the middle of the bat and heads off straight back to the bowler, all that happens is that the ball squashes, comes to a complete stop, expands back to its original shape and then leaves the bat. If the ball comes off at some other angle, then it hits the bat at an angle and starts to slide across the bat. As it does so, it slows down in a direction perpendicular to the face of the bat and it slows down in a direction across the bat. In addition it will start to rotate if it had no rotation to start with, otherwise the rate of rotation will either decrease or increase depending on the original direction of rotation. The part of the ball in contact with the bat will then grip the bat without any further sliding or rolling, while the rest of the ball continues to rotate. The ball therefore gets twisted out of shape as well as getting severely squashed. As the ball starts to come off the bat it expands back towards its original shape, it releases its grip on the bat, there is a sudden change in the rate of rotation, and the ball slides backwards off the bat. Most likely, the ball will come off the bat spinning much faster than it was before it hit the bat.

2.3.6 Generic bowling types

There are two types of pace bowling in cricket – Fast pace bowler & Medium pace bowler. Medium pace bowler average delivery speed will be within 100 km/h to 130km/h. Pace bowler can seam bowling 'Off cut' and 'Leg cut' in cricket. How to the ball off cut? Rub leg side of the ball and off side should be shining part of the ball. At time of delivery your middle finger should be at center of ball and index finger on Non- shining part of the ball. By applying this trick you will easily beat batsmen with 'Off cut' delivery. The same trick to ball 'Leg Cutter' in cricket, if you have to ball 'leg cut' then rub off side part of the ball and your middle finger must be at center of ball and index finger on Non-shining part of the ball. By applying this trick we can ball 'Leg cutter' in cricket. Fast bowling is not an easy task and there are many fast bowlers, who have more than 140 km/h speed during bowling, e.g. Lasith Malinga, Shoaib Akhtar, Mitchell Starc & Shaun Tait. They have types of deliveries of fast bowling like-

Inswinger – Usually ball comes inside for Right hand Batsmen.

Outswinger – It's like a vice- versa a ball move away from his body part.

Slower ball – A Slower Ball usually delivered to beat the batsman with speed of the ball. To throw ball slower, your ball grip must be like index finger on Outside part of the ball and middle finger on inside part of the ball and thumb finger on center line of the ball. Your hand must be straight, and leave it by a back hand to ball a perfect 'Slower One'.

Yorker – A perfect Yorker delivery, arm legs of batsmen and hit the ball forcefully in that particular area.

Spin bowling means when the ball moves or rotate towards off side or leg side. There are many types of delivery in spin bowling for e.g. Off spin, Googly, Top spin, Leg break, Off cutter.

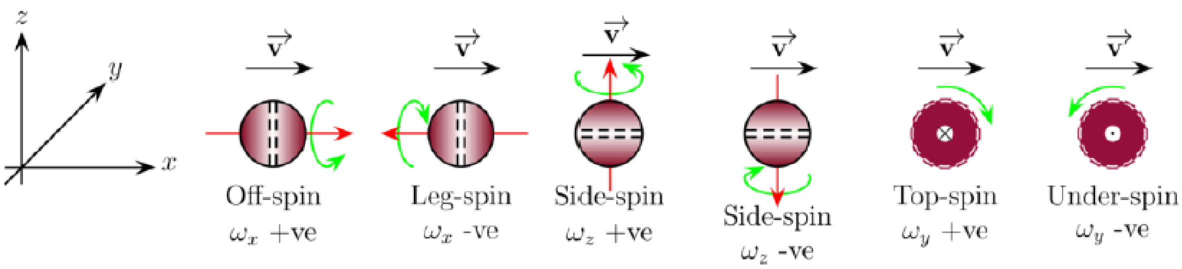

Figure 2.3.2: Spin bowling types

Off Spin - Off spin bowling means when a ball goes inside towards batsmen body part for a Right hand batsman. Your grip toward ball must be perfect to ball off spin for batsmen. A ball must move in the direction from left to right. Your Index finger must be on one side seam and middle finger on opposite seam, distance between two fingers must require. This is technique to ball off spin in cricket.

Googly - When the ball is delivered by off spin bowler, usually he balls a leg spin known as 'Googly'. There are many techniques to ball "Googly" for e.g. we can do it by our wrist, or by fingers. Googly delivery helps bowler to beat the batsman by his swing. A Batsman must be focused on bowler's grip towards his hand to attack him.

Top Spin - When the ball bounces more than its actual delivery. Index finger must be on the seam of ball, thumb and middle finger be on the opposite side of the ball. Top spin bowling is very difficult we must have perfect technique to ball 'Top Spin' in cricket. Not an easy for beginners.

Leg Break - Leg break is a swing bowling delivery, which comes in towards the batsmen's body for left hand batsman and opposite to Right hand batsman goes far from body. If you want to ball leg break, your finger must be on the ball. When you grip it by the fingers and delivered it by using wrist power it will turn quickly. That's a technique to ball a perfect led break to beat batsmen.

Off Cutter - Off cutter is an off break bowling which swings very quickly than off spin. The reason why it swings more than off spin is the grip, your grip in off cutter bowling changes. Your thumb, index, and middle fingers must be on the seam of the ball and rotate your finger to create quick swing. Why it is called "Off Cutter" because of his quick/more swing.

Beside from types of bowling in cricket, there are two spinners in sping bowling in cricket.

1. Finger Spinner – They use fingers to spin a ball.
2. Wrist Spinner – They use wrist power to swing a ball.

2.3.7 Spin bowling dynamics

Spin bowlers have lots of tricks up their sleeve since a ball can be spun in many different ways. A cricket ball, like anything else, has three main axes about which it can spin. Each spin axis has a different effect on the flight of the ball through the air and a different effect on the way the ball bounces. The three axes are perpendicular to each other. The first axis is vertical, pointing to the sky, and the other two are horizontal. The second axis points along the pitch towards the batter. The third axis points across the pitch. A ball can also be spun about an axis that is inclined at an angle to the three main ones, in which case it will have a component of spin about each of the main axes. A ball that spins about a vertical axis will swerve to the left or right through the air (like a golfer's hook or slice shot) depending on the spin direction. There is no kick when it bounces since there is no preferred direction in which it can kick. A ball that spins about the second axis does not swerve at all through the air. However it will kick sharply to the left or right when it bounces, depending on the amount and direction of spin. The ball kicks in the same direction of motion as the top of the ball. Drop a spinning ball vertically onto the pitch and you will see why. Topspin or backspin results when the ball spins about the third axis. A topspin ball dives down towards the pitch faster than a ball without spin, and it bounces at a reduced angle since it kicks forwards when it bounces. A backspin ball tends to float through the air and kicks up when it bounces since it tends to kick backwards, causing the ball to slow down more than a ball without spin. The actual result depends on both the amount of spin and the angle of incidence. If a non-spinning ball is incident at an angle of about 20 degrees to the horizontal, then it will slide along the pitch until it bounces, at about 22 degrees to the horizontal. If the ball has backspin then the trajectory will probably be different. It depends on the ball speed and launch angle or on where the ball lands. In general, a ball with backspin landing at the same spot will be incident at a lower angle, say 18 degrees, and it will bounce up at about 20 degrees. But if the bowler sends down a slower backspin ball and if it lands at an angle of incidence of say 40 degrees, then the ball will start to slide along the pitch for a while and then grip the pitch before it bounces. This will cause the ball to slow down a lot during the bounce, so it will bounce up quite steeply, say at 50 degrees. The formula for the bounce angle is: Slope of bounce angle = (vertical bounce speed) / (horizontal bounce speed) where slope means the same thing as tangent in trigonometry. So, the effect of backspin or topspin depends on whether the ball slides throughout the bounce (as it does at low incident angles) or whether it gets a chance to grip the pitch, as it does at high angles of incidence.

2.3.8 Swing bowling dynamics

A cricket ball can swerve to the left or the right as it moves through the air, either because it spins about a vertical axis or because it spins about an axis perpendicular to the seam. Vertical axis spin is commonly used by spin bowlers by not by fast bowlers. Fast bowlers prefer to swing the ball by making sure the seam is inclined at an angle of about 20 degrees to the direction that the ball is headed, in such a way that about 3/4 of the front of the ball is smooth. That way, the air flows smoothly around the smooth half but it becomes turbulent on the other side since it has to flow past the seam. Turbulent air is at a lower pressure than smooth flowing air, so the ball gets pushed sideways. It is almost impossible to eliminate backspin as the ball leaves the bowler's hand, but if the spin axis is perpendicular to the seam then it will help to keep the seam aligned at a fixed angle. The sideways force on the ball peaks at about 110 km/hr, drops to zero at about 120 km/hr and then reverses direction. Reverse swing arises because the air flow on the smooth side becomes turbulent at sufficiently high ball speeds. The smooth side then becomes the low pressure side so the ball swings in the opposite direction. Normally, this effect is significant only at speeds above about 140 km/hr. However, the effect can occur at lower speeds if the ball has a roughened side and if the roughened side faces forward. Conventional swing bowlers polish the ball so one side is as smooth as possible. Reverse swingers like to make sure the other side is as rough as possible. The best ball to swing is therefore one that stays smooth on one side and roughens up during normal play on the other side. The secret behind swing bowling lies in the way that the thin boundary layer of air near the ball surface can separate from the ball either early or late depending on whether the air flows smoothly over the surface or is tripped into turbulence by the seam or by roughness of the surface, or both. Those boundary layers were revealed many years ago by the marvelous smoke tunnel experiments. Air separates early over the smooth portion, becomes turbulent over the rough portion and separates later, so the air is deflected upward, resulting in an equal and opposite downward force on the ball. That is the secret that lies behind almost all aerodynamic flows, and it is what determines both the lift and drag coefficients acting on an object. Note how air backflows into the low pressure "hole" left behind the ball, forming a turbulent wake.

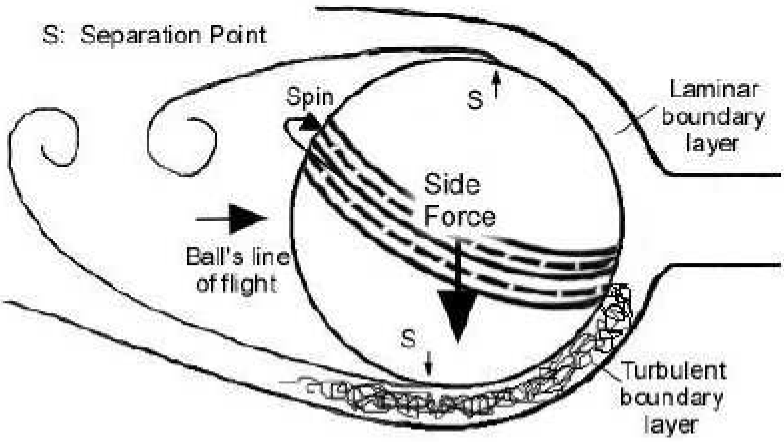

Figure 2.3.4: Conventional swing

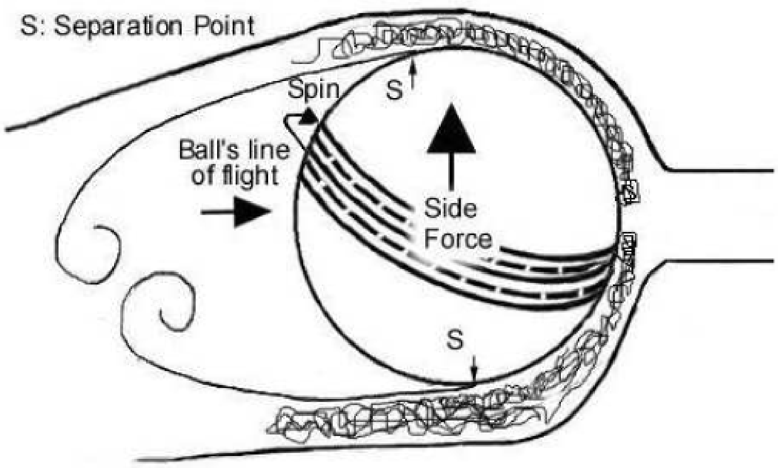

Figure 2.3.5: Reverse swing

CHAPTER 3
METHODOLOGY AND SYSTEM DESIGN

3.1 HARDWARE STUDY

After the literature review, we narrowed down our focus to the hardware we needed for the project. Our main requirements included gyroscope, accelerometer, magnetometer, suitable microcontroller and quick data transfer method. This section presents the findings of the hardware study.

3.1.1 Gyroscope

A **gyroscope** is a device used for measuring or maintaining orientation and angular velocity. It is a spinning wheel or disc in which the axis of rotation is free to assume any orientation by itself. When rotating, the orientation of this axis is unaffected by tilting or rotation of the mounting, according to the conservation of angular momentum.
Gyroscopes based on other operating principles also exist, such as the microchip-packaged MEMS gyroscopes found in electronic devices, solid-state ring lasers, fibre optic gyroscopes, and the extremely sensitive quantum gyroscope.
Applications of gyroscopes include inertial navigation systems, such as in the Hubble telescope, or inside the steel hull of a submerged submarine. Due to their precision, gyroscopes are also used in gyrotheodolites to maintain direction in tunnel mining. Gyroscopes can be used to construct gyrocompasses, which complement or replace magnetic compasses (in ships, aircraft and spacecraft, vehicles in general), to assist in stability (bicycles, motorcycles, and ships) or be used as part of an inertial guidance system.
MEMS gyroscopes are popular in some consumer electronics, such as smartphones.

3.1.2 Accelerometer

An **accelerometer** is a device that measures proper acceleration. Proper acceleration, being the acceleration (or rate of change of velocity) of a body in its own instantaneous rest frame, is not the same as coordinate acceleration, being the acceleration in a fixed coordinate system. For example, an accelerometer at rest on the surface of the Earth will measure an acceleration due to Earth's gravity, straight upwards (by definition) of $g \approx 9.81\ m/s^2$. By contrast, accelerometers in free fall (falling toward the center of the Earth at a rate of about $9.81\ m/s^2$) will measure zero.
Accelerometers have multiple applications in industry and science. Highly sensitive accelerometers are components of inertial navigation systems for aircraft and missiles.

Accelerometers are used to detect and monitor vibration in rotating machinery. Accelerometers are used in tablet computers and digital cameras so that images on screens are always displayed upright. Accelerometers are used in drones for flight stabilisation. Coordinated accelerometers can be used to measure differences in proper acceleration, particularly gravity, over their separation in space; i.e., gradient of the gravitational field. This gravity gradiometry is useful because absolute gravity is a weak effect and depends on local density of the Earth which is quite variable.
Single- and multi-axis models of accelerometer are available to detect magnitude and direction of the proper acceleration, as a vector quantity, and can be used to sense orientation (because direction of weight changes), coordinate acceleration, vibration, shock, and falling in a resistive medium (a case where the proper acceleration changes, since it starts at zero, then increases). Micromachined microelectromechanical systems (MEMS) accelerometers are increasingly present in portable electronic devices and video game controllers, to detect the position of the device or provide for game input.

3.1.3 Magnetometer

Spin estimation poses a different set of challenges. We need to determine the initial orientation of the ball at its release position and then track the 3D rotation through the rest of the flight. With unhelpful accelerometers and gyroscopes, we are left with magnetometers.
A **magnetometer** is an instrument that measures magnetism - either the magnetization of a magnetic material like a ferromagnet, or the direction, strength, or relative change of a magnetic field at a particular location. A compass is a simple type of magnetometer, one that measures the direction of an ambient magnetic field.
The first magnetometer capable of measuring the absolute magnetic intensity was invented by Carl Friedrich Gauss in 1833 and notable developments in the 19th century included the Hall Effect, which is still widely used.
Magnetometers are widely used for measuring the Earth's magnetic field and in geophysical surveys to detect magnetic anomalies of various types. They are also used in the military to detect submarines. Consequently, some countries, such as the United States, Canada and Australia, classify the more sensitive magnetometers as military technology, and control their distribution.
Magnetometers can be used as metal detectors: they can detect only magnetic (ferrous) metals, but can detect such metals at a much larger depth than conventional metal detectors; they are capable of detecting large objects, such as cars, at tens of meters, while a metal detector's range is rarely more than 2 meters.
In recent years, magnetometers have been miniaturized to the extent that they can be incorporated in integrated circuits at very low cost and are finding increasing use as miniaturized compasses (MEMS magnetic field sensor).

3.1.4 Microcontroller

The microcontrollers we searched for this project were:

- Raspberry Pi Zero W
- UAV V3 Development Platform
- TINYTILE – Intel Curie Development Board
- K60 Core Board
- nRF52832 Development Board
- Electric Imp IMP003 Development Board
- HydraBus Board
- RedBearLab Board
- LinkIT Smart Series
- Intel Edison
- Arduino Nano
- MetaMotionC Series

The search was narrowed down to three boards on basis of price, availability and required features such as data transfer, size, sampling rate, etc: Intel Curie Board, Arduino Nano and MetaMotionC.

Intel Curie is a 6 axis board with accelerometer and gyroscope, hence it lacks magnetometer. This board is not available for sale now by Intel so we had to drop this option.

Arduino Nano was the next choice, Nano so it could somehow fit inside the ball. Along with Arduino Nano, we had to use different sensor modules and separate Bluetooth and SD card modules since it lacks all these options. The resulting system was too large in size and had extremely poor frequency. This option was also dropped after some testing.

We finally adopted **MetaMotionC** Board for use in the Intelligent Cricket Ball. The board had all the sensors we needed along with suitable data logging, data storage and data transfer options. And its size was good enough to fit inside a ball.

3.2 METHOD 1 – MPU6050

Initially, we started our project using Arduino Nano in conjunction with InvenSense MPU6050. MPU6050 is a 6 axis IMU sensor (3 axis of accelerometer and 3 axis of gyroscope) and data is logged in SD card. This procedure had few shortcomings. Data transfer to computer was time taking process, MPU6050 had no magnetometer and sampling rate was too low. This method gave us spin rate but within limited range of revolutions per second (2000 dps) due to saturation of gyroscope. To tackle the issues, we did successful live data logging over Bluetooth using HC-05 Bluetooth module in conjunction with TeraTherm software in a laptop with built in Bluetooth adapter. Sampling rate was very low i.e. 10-12 Hz which is not acceptable for our project. Since there was no promise shown by this technique, we dropped the idea after collecting and processing few data sets as it would not benefit us much for the time invested and moved onto finding some other better way.

MPU6050 gave us values of acceleration (accelerometer) and degrees per second (gyroscope) in a .csv file while had to be transferred to computer from SD card. Then the data was processed in MATLAB to get spin rate. The module was tested on drill bit, fan and such revolving devices. Bluetooth module was used when the MPU6050 was placed in ball for experimentation. As the problems described above did not give us reasonable results, we still had some learning outcomes from this method. This experimentation helped us understand the basics of IMU and laid platform for what our next method would be.

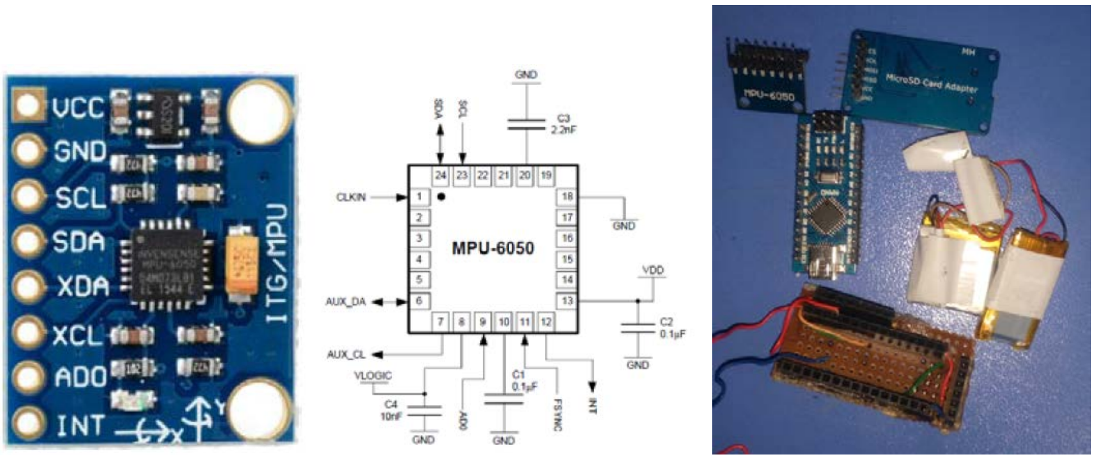

Figure 3.2.1: MPU 6050 and all modules used inside ball

3.3 METHOD 2 – GY80

Gyroscopes saturated at very small values therefore they were not showing any promise. Accelerometer readings became constant due to free fall as it gives data as per reactive forces hence that data was also of not much use to us. Now from our learning during literature review, we had to utilize magnetometer to overcome these challenges put forward by gyroscope and accelerometer. To explore the magnetometer, we changed the sensor from MPU6050 to GY80 while our microcontroller was still Arduino Nano.

GY80 board combines 5 sensors into a single tiny package. It has a 3-axis gyroscope, a 3-axisaccelerometer, a 3-axis magnetometer, a barometer and a thermometer. GY80 is 10 times more costly than MPU6050 but it was more stable as it had inbuilt Barlett window FIR filter. The data from the sensor was logged in a .csv file that was processed in MATLAB. GY80 gave us all three required parameters but it posed two new challenges. Its size was bigger thus we tested it by embedding it in a plastic ball instead of a hard ball of proper dimensions. Secondly, its transmission rate was very low i.e. 10-12 Hz which is not acceptable for our project. Since there was no promise shown by this technique, we dropped the idea after collecting and processing few data sets as it would not benefit us much for the time invested and moved onto finding some other better way.

Figure 3.3.1: GY-80 and all modules used in ball

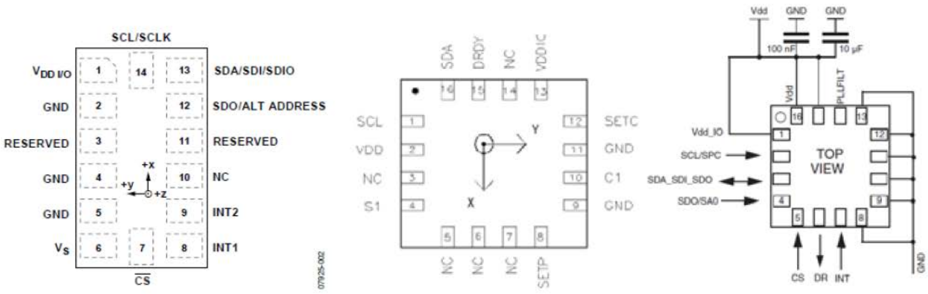

Figure 3.3.2: GY-80 Datasheet (ADXL345, HMC5883L, L3G4200D)

3.4 METHOD 3 – METAMOTION BOARD (ADOPTED METHOD)

After not being able to achieve required results from MPU6050 and GY80, we had to shift our focus to some other sensor/board. Our main requirement was a board containing 3-axis gyroscope, 3-axis accelerometer, 3-axis magnetometer, at least 32-bit microcontroller, on-board memory, wireless transmission of data to computer, easy charging and low cost. The most viable solution to our requirements we achieved was MetaMotion Board.

MetaMotionR is a complete development and production platform for wearable and connected device applications. It features the ultra-low power nRF52832 SoC, providing energy efficient smartphone communication and central processing. MetaMotionR integrates this radio with high value sensors and a rechargeable battery architecture into a miniature form factor. All circuits have been designed from the ground up with energy efficiency in mind.

After extensive literature review and testing using MetaMotionR, we developed two algorithms to find our required parameters of the bowling.

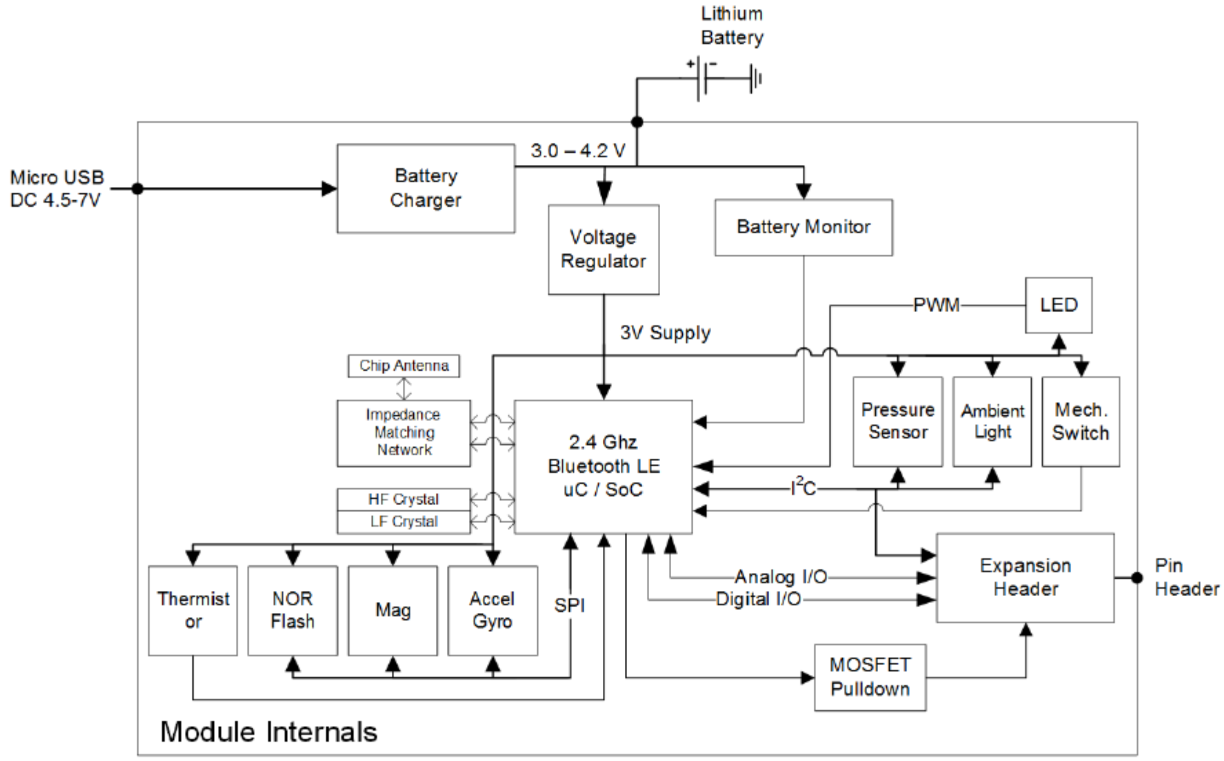

Figure 3.4.1: MetaMotion block diagram

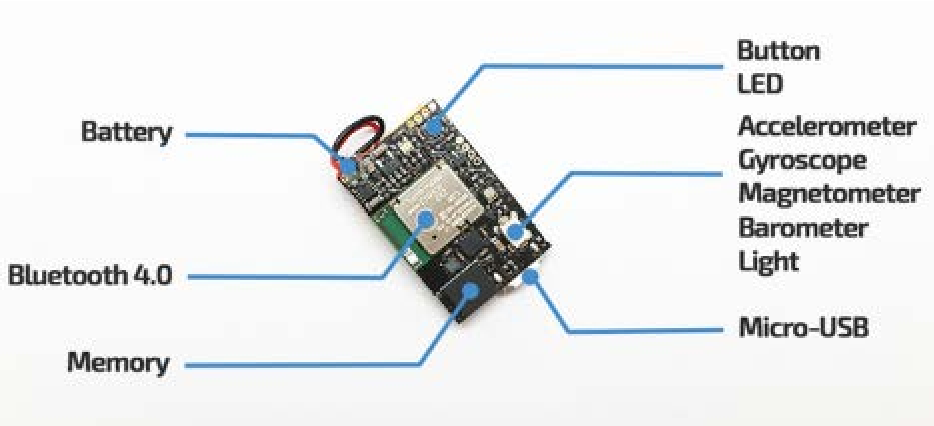

Figure 3.4.2: MetaMotionR

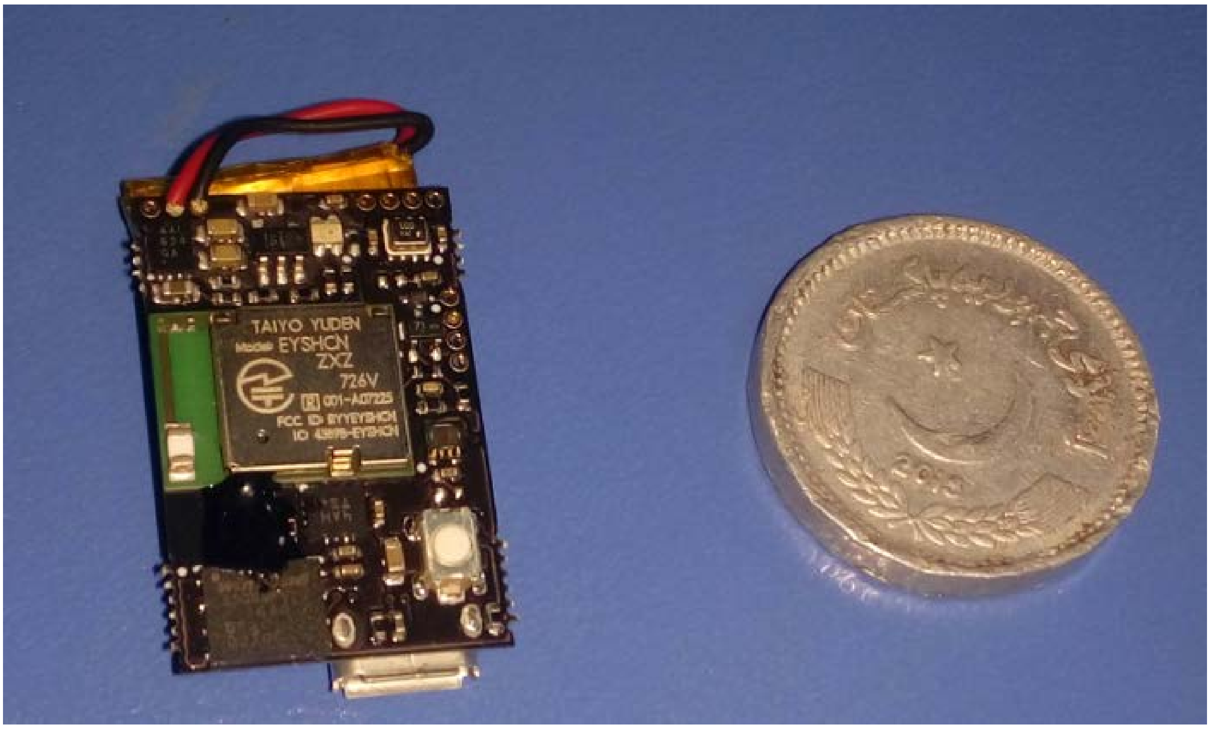

Figure 3.4.3: MetaMotionR vs Rs.2 coin

3.4.1 Algorithm 1 – Linear acceleration using sensor fusion

Sensor fusion intelligently combines data from several sensors for the purpose ofimproving application or system performance. Combining data from multiple sensors corrects for the deficiencies of the individual sensors to calculate accurate position and orientation information.

The linear acceleration measures the acceleration effect of the device movement, excluding the effect of Earth's gravity on the device. It is typically derived from the accelerometer, where other sensors (e.g. the magnetometer and the gyroscope) help to remove linear acceleration from the data. Linear acceleration units are shown in m/s^2 like the accelerometer. A simple method to determine the linear acceleration using only a three-axes accelerometer is to approximate the gravity sensor readings using a low-pass filter on the accelerometer data, and then subtracting the gravity measurements from the accelerometer full measurement. Better linear acceleration measurements are obtained when the gravity measurements are enhanced with sensor-fusion following our discussion of the modern gravity sensor. You can use the experiment below to verify the importance of sensor-fusion in measuring linear acceleration.

Instance of Release and Impact:

The sensor gives 3 components of linear acceleration. Resultant acceleration is calculated which is used for determination of location of spin axis. We calculated the absolute sum of all 3 accelerations, took its derivative and multiplied the 2 quantities. The maximum of the product occurs at instant of impact of ball on the pitch. Time index is found which gives us exact time of impact of ball. To find the instance of release, we scale down data to 3 seconds before the instance of impact. The maximum peak of the resulting data represents the instance of release i.e. maximum acceleration. Time index gives us exact instance of release of the ball. Subtracting the time of instance of release from the time of instance of impact gives us flight time of the delivery.

Spin Rate:

For spin rate calculation, our concerned data is the data between the instance of release and the instance of impact so we scale it down to that. This scaled down data had sinousoids in it so we tried various methods to find the spin rate using it. We tried Fourier Analysis, energy spectrum method and peak count method.

We have 3 data sets as seen on the sample result; 1 each for x,y and z axes. 2 consecutive peaks represent one complete rotation of the ball therefore we divide the number of peaks by time and get the spin rate in revolutions per second. Multiplication by 60 gives spin rate in rpm.

Location of Spin Axis:

Our approach strictly depends on gyroscope for the detection of spin axis location. We use rectangular coordinate approach, where the origin is one point and the second point on the vector is (x_gyro,y_gyro,z_gyro). We then define the angles with respect to planes:

Theta_xy=arctan(x_gyro/y_gyro)

Theta_yz=arctan(y_gyro/z_gyro)

Theta_zx=arctan(x_gyro/z_gyro)

We plot a line in 3D space using the above calculated 3 angles and the resulting line is the location of spin axis of the ball for that particular delivery.

Sample Output and GUI:

We developed MATLAB interface for the data representation using the guide tool. Here is a sample output of linear acceleration for a delivery bowled, on our GUI:

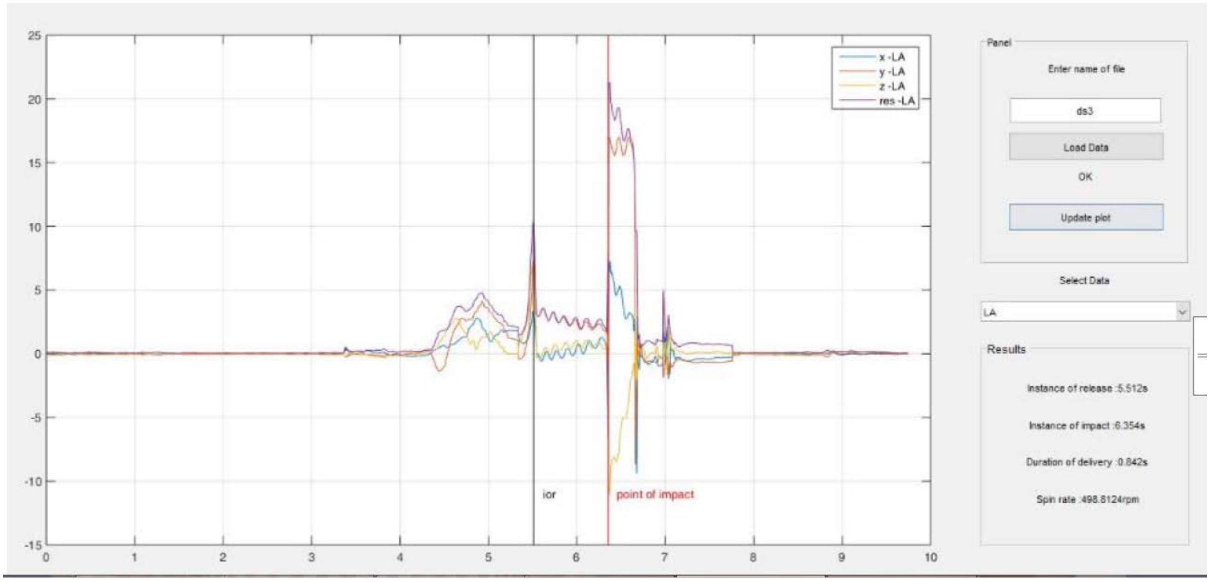

Figure 3.4.4: Sample MATLAB output

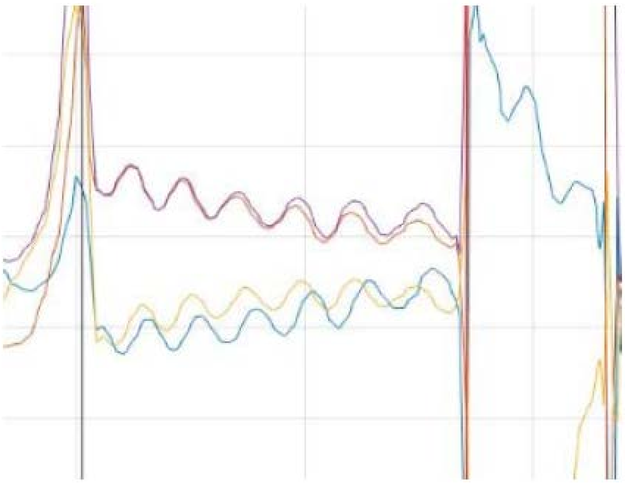

Figure 3.4.5: Scaled down data

3.4.2 Algorithm 2 – Gyroscope, Accelerometer, Magnetometer data

Spin estimation poses a different set of challenges. We need to determine the initial orientation of the ball at its release position and then track the 3D rotation through the rest of the flight. With unhelpful accelerometers and gyroscopes, we are left with magnetometers. While magnetometers do not capture all the dimensions of rotation, we recognize that the uncertainty in the ball's spin is somewhat limited since air-drag is the only source of torque.

We mathematically express the orientation of the ball at time t as a rotation matrix, $R_O(t)$. This matrix is a function of the globally fixed vectors (i.e., rotation axis and magnetic North) and their locally measured counterparts.

$$R_{O(t)} = \left[R^G \quad N^G \quad R^G \times N^G\right] \left[R^L_{(t)} \quad N^L_{(t)} \quad R^L_{(t)} \times N^L_{(t)}\right]^{-1}$$

R^G and N^G are the rotation axis and the magnetic North vectors respectively – both are in the global framework and are constant during flight. The third column vector, (R^G x N^G), is a cross product necessary to equalize the matrix dimensions on both sides. $N^L_{(t)}$ is the local magnetic vector measured by the magnetometer, $[m_x\ m_y\ m_z]^T$. $R^L_{(t)}$ is the local rotation axis which is slowly changing during the flight of the ball.

3 consecutive measurements of $N^L_{(t-1)}$, $N^L_{(t)}$ and $N^L_{(t+1)}$ are taken. 3 values of $N^L_{(t)}$ local magnetic vector are taken from magnetometer. Then we calculate the plane on which all these 3 vectors are coplanar. Then we found vector normal to that plane: $R^L_{(t)}$.

$$R^L_{(t)} = \begin{bmatrix} \cos(\theta_t)\cos(\varphi_t) \\ \cos(\theta_t)\sin(\varphi_t) \\ \sin(\theta_t) \end{bmatrix}$$

$$\text{Elevation } \theta_t = A_{el}t^2 + B_{el}t + C_{el}$$

$$\text{Azimuth } \varphi_t = A_{az}t^2 + B_{az}t + C_{az}$$

$$\underset{6\text{paras}}{\operatorname{argmin}} \operatorname{Var}\left[\angle\left(R^L_{(T)}, N^L_{(T)}\right), \angle\left(R^L_{(T+1)}, N^L_{(T+1)}\right), \cdots\right]$$

We focus on sensor measurements in phase 1 (pre-flight). Since this is not free-fall, and the ball is not spinning fast, the gyroscope and accelerometer are both useful. Our aim is to identify a stationary time point to compute the initial orientation of the ball, and use the gyroscope thereafter to integrate rotation until the point of release, T. Once we obtain orientation at T, denoted $R_{O(T)}$, we simply use the following equation to solve for the global rotation axis $R^G_{(T)} = R_{O(T)} R^L_{(T)}$

Here is the summary of the algorithm implemented:

1. Get coarse $R^{L}_{(t)}$ by combining 3 consecutive magnetometer measurements.
2. Use them as the initial starting point to search for parameters that minimize variance of $N^{L}_{(t).}$
3. Then we calculate the plane on which all these 3 vectors are coplanar. Then we found vector normal to that plane: $R^{L}_{(t)}$.
4. Use gyroscope to tracking ball's orientation at the release time, $R_{O(T)}$
5. Get global rotation axis during flight: $R^{G}_{(T)} = R_{O(T)} R^{L}_{(T)}$
6. Use Equation 1 to compute ball's orientation at any time t during flight
7. Complete derivation of $R_{O(T)}$ using equation 1 to find spin rate.

The following MATLAB plot shows a sample output of a delivery bowled. The spin rate is given and the location of spin axis is scattered on the ball at different time points during the flight.

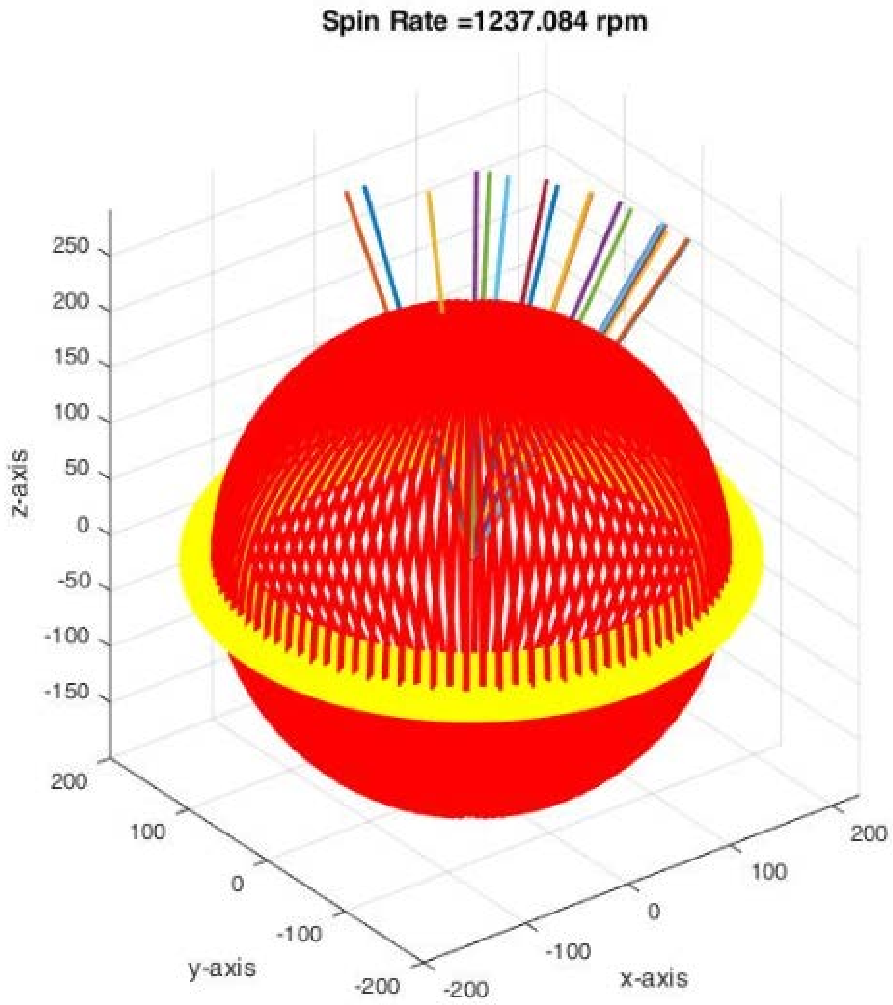

Figure 3.4.6: Sample output of algorithm 2

3.5 MECHANICAL DESIGN

3.5.1 Ball Dimensions

Men's cricket: weight between 5.5 and 5.75 ounces (155.9g to 163g), circumference between 8.8125 and 9 inches (22.4cm to 22.9cm).

At the heart of the ball there is a cork core made from the bark of a Portuguese cork tree. Cork has a high compressive stress resistance axially and uniaxially and very small Poisson's ratio nearing the zero mark. Cork has a low density and is hyper- or viscoelastic. The nature of the fibres found in cork make it largely malleable and the material will retain new shapes required from it. This means cork will remain the sphere it is required to be in a cricket ball. Hyper- or viscoelasticity means that cork will readily bounce under an applied force, this characteristic of cork is responsible for the reason a cricket ball bounces. The cork core size is kept minimal to prevent the ball from having bounce similar to that of a tennis ball, this means that cork has a bouncing limit directly proportional to the amount of cork used and the hardness if its surroundings.

A ball gauge is an instrument used by the umpires in cricket to check whether the size of a cricket ball meets the standard measurements mandated by the Laws of Cricket. It is usually in a form somewhat like a pair of handcuffs with two connected rings: one ring has the minimum acceptable diameter, through which the ball should not pass; the other ring has the maximum acceptable diameter, through which the ball should pass. The gauge that accepts the maximum size is called 'GO gauge', and the gauge doesn't allow the dimension beyond a certain value is called ' NOGO gauge'. If the ball cannot pass through the maximum diameter, or passes through the minimum diameter, or becomes mis-shapen then it is changed.

Figure 3.5.1: Ball gauge

3.5.2 3D Modeling

3D model of the cricket ball was made using Solid Works. This proved helpful in the force analysis and design for imbedding sensor in the ball.

Figure 3.5.2: 3D model of cricket ball

3.5.3 Force Analysis and Protection Measure

Vibration isolation is a procedure by which the undesirable effects of vibration are reduced. Basically, it involves the insertion of a resilient member (or isolator) between the vibrating mass (or equipment or payload) and the source of vibration so that a reduction in the dynamic response of the system is achieved under specified conditions of vibration excitation. An isolation system is said to be active or passive depending on whether or not external power is required for the isolator to perform its function. A passive isolator consists of a resilient member (stiffness) and an energy dissipator (damping). An active isolator is comprised of a servomechanism with a sensor, signal processor, and actuator.
Vibration isolation can be used in two types of situations. In the first type, the foundation or base of a vibrating machine is protected against large unbalanced forces. In the second type, the system is protected against the motion of its foundation or base.

In some applications, the base of the system is subjected to a **vibratory motion**. In the absence of a suitably designed isolation system, the motion of the base transmitted to the mass might cause damage. Similarly, a delicate instrument (mass) may have to be protected from a force or shock when the package containing the instrument is dropped from a height accidentally. In this case, proper isolation is to be used to protect the instrument against excessive displacement or force transmitted from the base motion.

Rattle space is the space left between the main body and secondary body due to which vibrations are transmitted. Transmibility ratio would define in what proportion does mass one delivers force to mass two.

To overcome the issues of vibration isolation, vibratory motion and rattle space, we had various options. We could have used soft springs/dampers such as elastomers, rubber or cotton in between our sensor and the ball. The most viable solution we choose was to use protection case IP 40. The sensor was put in the protection case and the grooves in ball were made as per the dimensions of protection case. This diminished the issue of rattle space.
The IP Code (or **International Protection Rating)** consists of the letters IP followed by two digits and an optional letter. The first digit indicates the level of protection that the enclosure provides against access to hazardous parts (e.g., electrical conductors, moving parts) and the ingress of solid foreign objects. The second digit indicates protection of the equipment inside the enclosure against harmful ingress of water.
IP 40 meant a protection of more than 1mm against most wires, screws, etc while giving no protection against water.

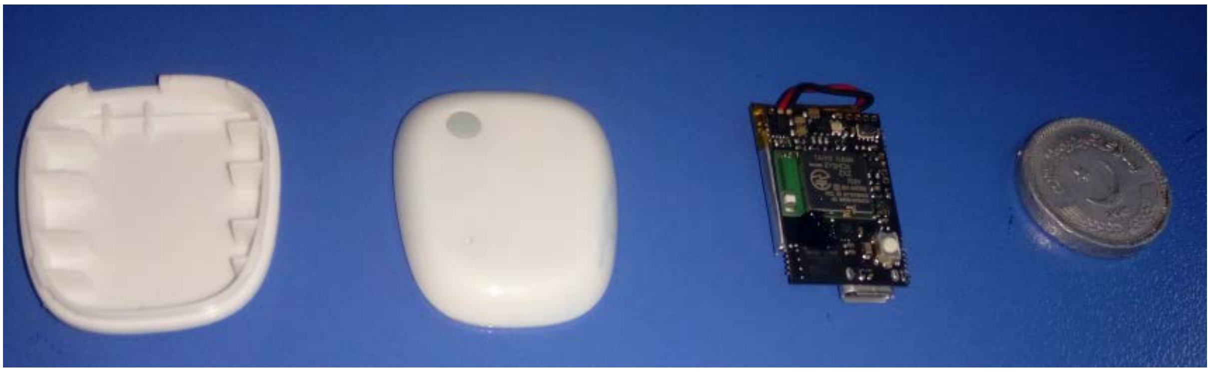

Figure 3.5.3: IP 40 protection case against MetaMotionR and Rs.2 coin

Force analysis was also performed on IP 40 protection case.

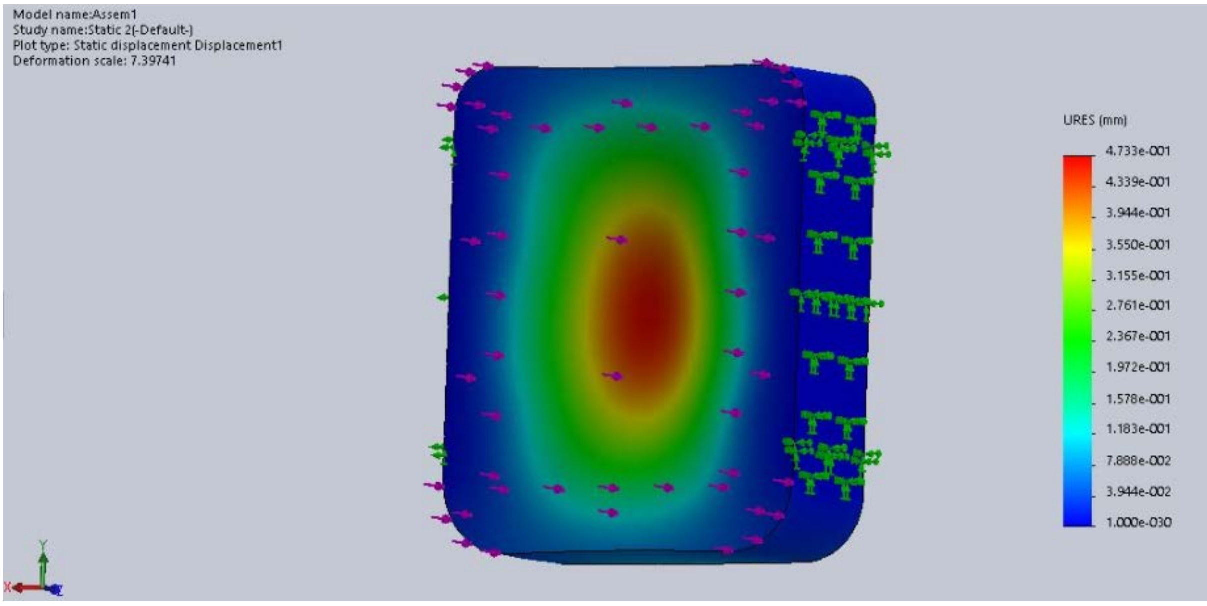

Figure 3.5.4: Force analysis of protection case

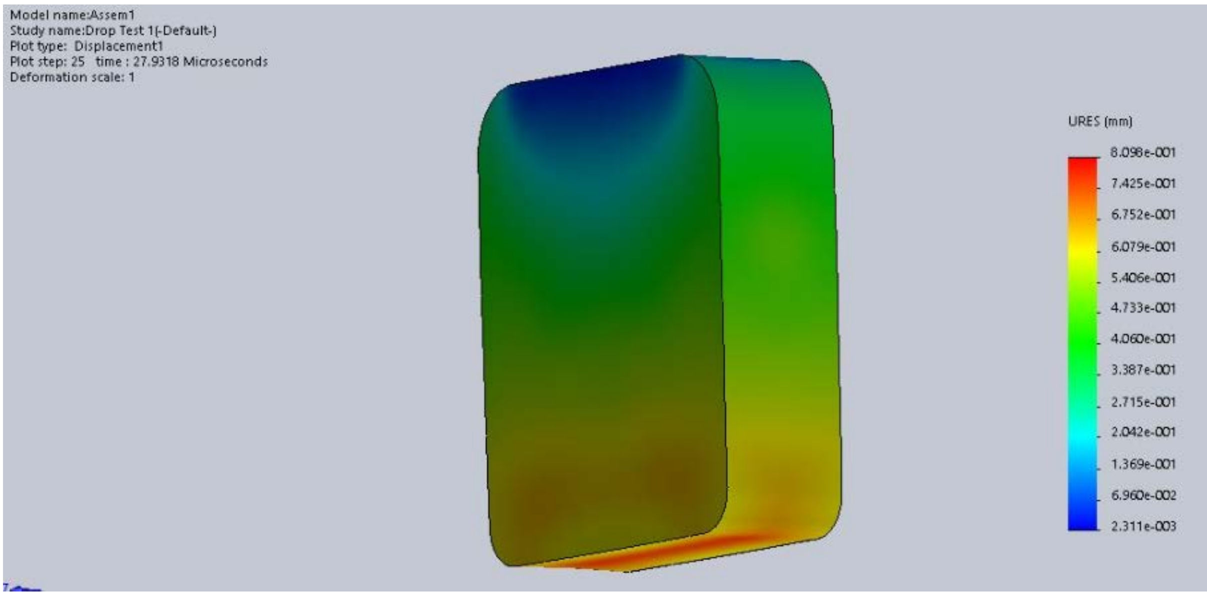

Figure 3.5.5: Force analysis of protection case

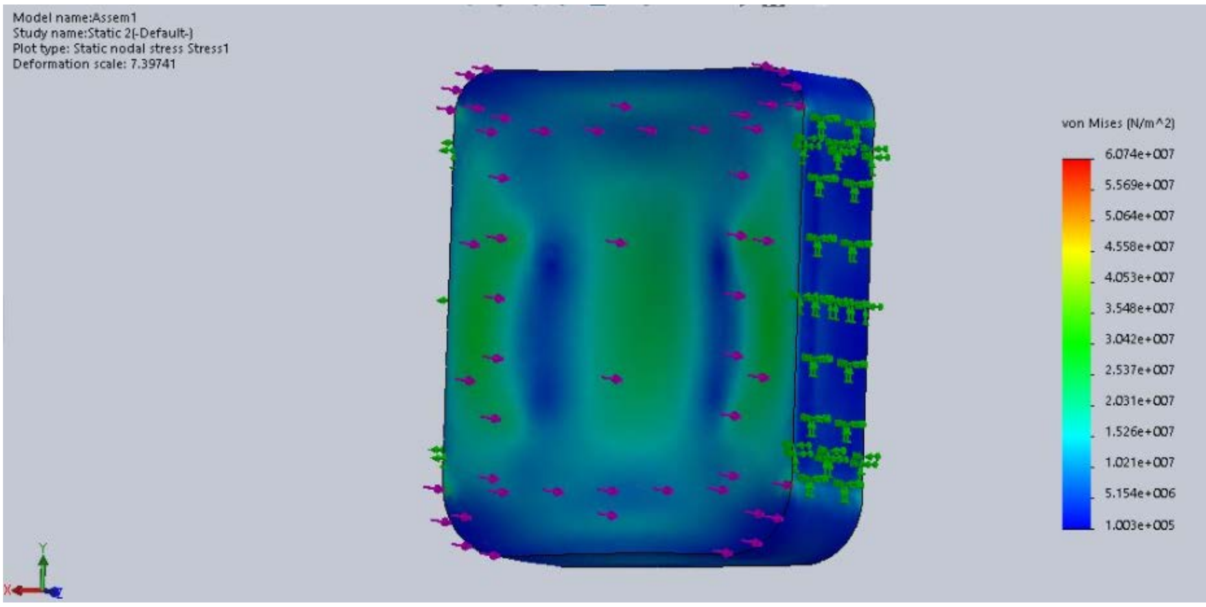

Figure 3.5.6: Force analysis of protection case

Figure 3.5.7: Sensor in the grooved cricket ball

Ball was sewed back to original dimensions after placing sensor and it passed the gauge test. Our choice to embed electronics in the ball, although cumbersome, proved practical for accuracy and coverage in the field. In testing, we gained confidence that embedding should be feasible even under impact.

CHAPTER 4
EXPERIMENTATION AND RESULT DISCUSSION

4.1 CAMERA VERIFICATION

To verify the spin rate from our sensor, we carried out various tests in the lab. But before that, data collection was done and the ball's strength was tested. Different bowlers bowled with their unique styles and data logging was successful and satisfactory output was achieved. A 15mm soft mattress was used to mimic the pitch during lab tests. Our main lab verification was completed using mobile camera. Verification on proper bowling deliveries was not possible at this stage due to camera limitations

Figure 4.1.1: Lab bowling data logging

<u>Test 1: Rolling down a slope</u>

We rolled the ball down a slope from various elevations and recorded the video. Rotations were analysed by replaying the video and spin rate was calculated and compared with the spin rate given by the sensor. The comparison showed promising results.

Figure 4.1.2: Roll down experiment

Table 4.1.1: Roll down experiment

Angle of Ramp (degrees)	Spin Rate by Camera (RPM)	Sensor Value (RPM)	Error (%)
15	295	273	8.058608059
18	310	298	4.026845638
20	318	305	4.262295082

The tabulated data shows two promising results. Firstly, there is very small error which is mainly human error encountered while measuring spin rate from video. Secondly, as the elevation of the ramp increases, the spin rate increase which agrees with the hypothesis. The spin axis location was not verified in this test.

<u>Test 2: Throwing ball in air</u>
We tossed the ball in air along different axis each time.

Table 4.1.2: Air throw experiment

Throw Type	Spin Rate by Camera (RPM)	Sensor Value (RPM)	Error (%)
Along Seam	285	257	10.89494
Across Seam	193	215	10.23256
Random	245	222	10.36036

The results for spin rate show a very small error which is mainly due to our incapability to access exact time points from video due to limited frame rate.
This test was also used to test our hypothesis on the location of spin axis. The first delivery was bowled along the seam so the spin axis should have been perpendicular to the seam. The resulting MATLAB image below also confirms this fact as the spin axis location is scattered around the plane perpendicular to seam. The hypothesis for other deliveries was also verified from MATLAB results.

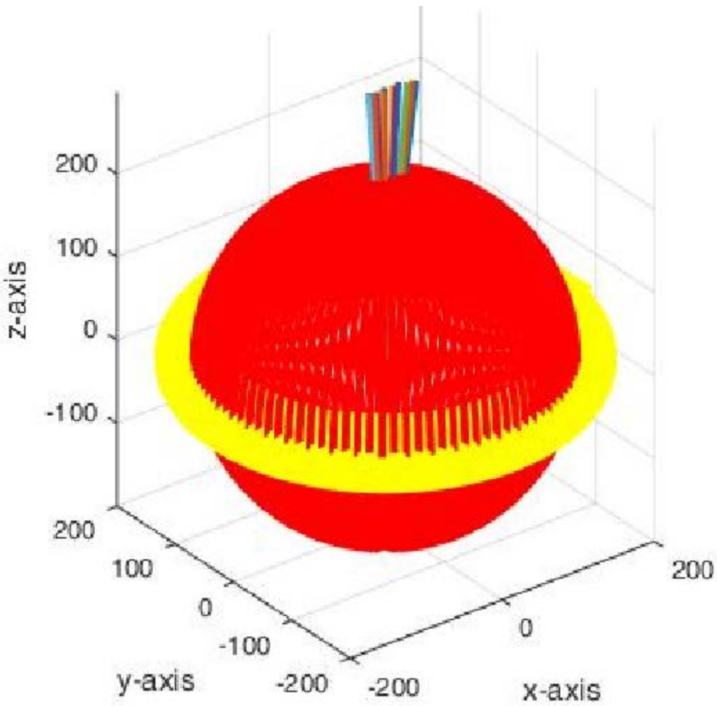

Figure 4.1.3: Ball tossed along seam

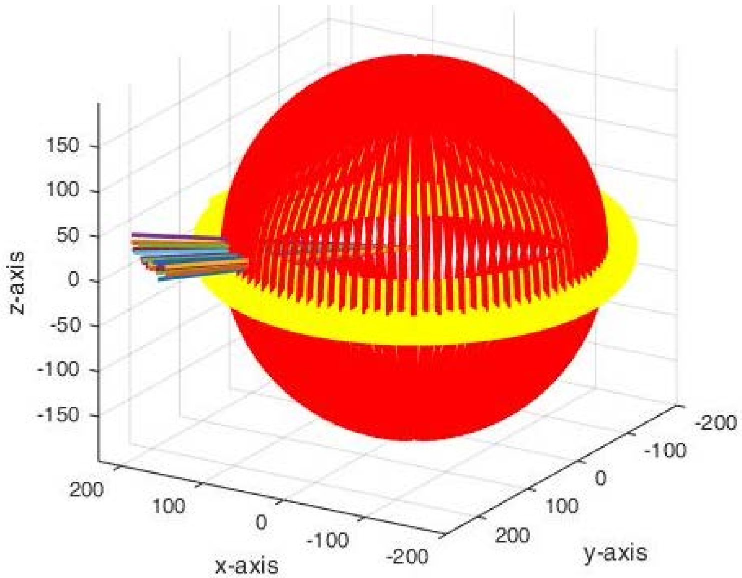

Figure 4.1.4: Ball tossed across seam

4.2 BIOMECHANICS LABORATORY VERIFICATION

In order to verify the results of our algorithm, we visited Pakistan Cricket Board's (PCB's) Biomechanics Lab that is located in LUMS. The lab had ViCon motion camera facility. The detail of ViCon is already discussed in the introduction section and literature review. ViCon cameras work by detecting infrared rays that are reflected back by the ball to the cameras. Reflection is due to placement of infrared markers on the ball. The track is feedback to the computer where the ViCon software locates the points in a 3D space. The model of ball is then fitted to the points for further calculations and analysis.

We performed various kinds of tests on the intelligent cricket ball in the biomechanics lab so we could compare our sensor's data to that of the ViCon.

Figure 4.2.1: PCB – LUMS Biomechanics Lab

Test 1: Rolling ball in hand and rolling ball on floor

The ball was rolled in hand and the cameras detected the ball and three trials were recorded. The ball was then rolled on floor and the cameras detected the ball and three trials were recorded. This test could not prove to be fruitful as our algorithm is based on detection of instance of release and instance of impact and none of them were related to this experiment.

Test 2: Tossing the ball in air

The ball was tossed in air and the cameras detected the ball. Three trials were recorded by throwing the ball in air in a different orientation each time. The results are shown in the table:

Table 4.2.1: Air throw in biomech lab

Throw Type	Sensor Value (RPM)	VICON Value (RPM)
Along seam	172	
Across seam	158	
Random orientation	241	

Test 3: Bowling in the normal way

Two university level bowlers joined the study and aided us in verifying our results. Important data about the bowlers is recorded in the table below:

Table 4.2.2: Bowlers' info

Bowler No.	Name	Age (Years)	Mass (kg)	Height (in)	BMI	Bowling Arm	Bowling Style
1	Umer Farooq	19	65	68	21.79	Right	Off spin
2	Kussum Priyadarshan	21	63	65	23.11	Right	Medium pace

Bowler No. 1 was asked to ball three off spin deliveries and gradually impart more spin on the ball. The sensor values verify the fact that he did increase the spin imparted on ball after each delivery.

Table 4.2.3: Bowler No. 1 data

Delivery Type	Sensor Value (RPM)	VICON Value (RPM)
Low rev off spin	700	
Medium rev off spin	855	
High rev off spin	1034	

Bowler No. 2 bowled three medium pace deliveries and the spin rate affirms to the fact that they were medium pace as the spin rate is low compared to that of off spinner bowler 1.

Table 4.2.4: Bowler No. 2 data

Delivery Type	Sensor Value (RPM)	VICON Value (RPM)
Medium pace	468	
Medium pace	526	
Medium pace	572	

Limitations and issues with ViCon

The system took some time to stabilize as the infrared cameras were highly sensitive. Due to the sensitivity issue, the experimentation was carried out at night to avoid any chance of sunlight disturbing the results. Infrared deflector markers were placed on the ball that would eventually disturb ball's dynamics. Even though the location of markers was tracked by the system, a mathematical model of the ball had to be incorporated in the system and that had to be followed up with an algorithm to find the required parameters as there was no inbuilt mechanism for this. This means that the results won't be as per a standard as the method would probably included estimation due to presence of several grey areas. We could not get the results from the lab in time as the lab's schedule was very tight. Once we get suitable results from the lab and draw conclusions, further experiments can be designed and carried out to verify the algorithm of the ball on a bigger scale.

4.3 SAMPLE RESULTS AND DISCUSSION

Our objectives of this project were to detect the instance of release of ball, calculate the spin rate of the ball and locate the spin axis throughout the flight till the ball hits the pitch. All three objectives were successfully fully achieved.

The following MATLAB plot of accelerometer, gyroscope and magnetometer data shows two large peaks. The first one is instance of release of ball from bowler's hand while the second one is the instance of impact when the ball hits the pitch. This is vital as it gives us time of flight of ball and helps us filter the necessary data for further processing.

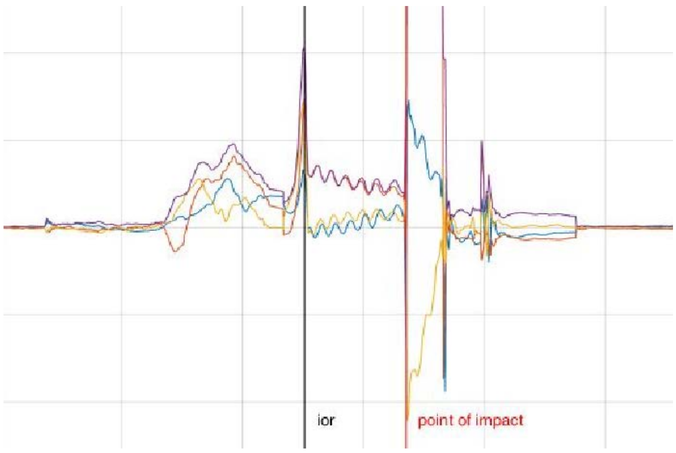

Figure 4.3.1: Instance of release and instance of impact detection

The next two outputs from the MATLAB show us the spin rate of the ball along with the location of spin axis throughout the flight. The straight lines emerging from the ball are the spin axis.

Quantitative measure of the spin rate allows coaches to track a bowler's performance (specially a spinner's) and suggest him improvements to increase it.

The scatter of the spin axis tells the coach about bowler's wobble. After tuning, the wobble can be reduced and tracked from the intelligent cricket ball.

The ball spun along the seam shows scatter of spin axis perpendicular to the seam while the ball spun across the seam shows scatter of spin axis along the seam which tells how well the bowler oriented the ball while releasing it.

Intelligent Cricket Ball would prove to be a great tool for coaching, training and research purposes.

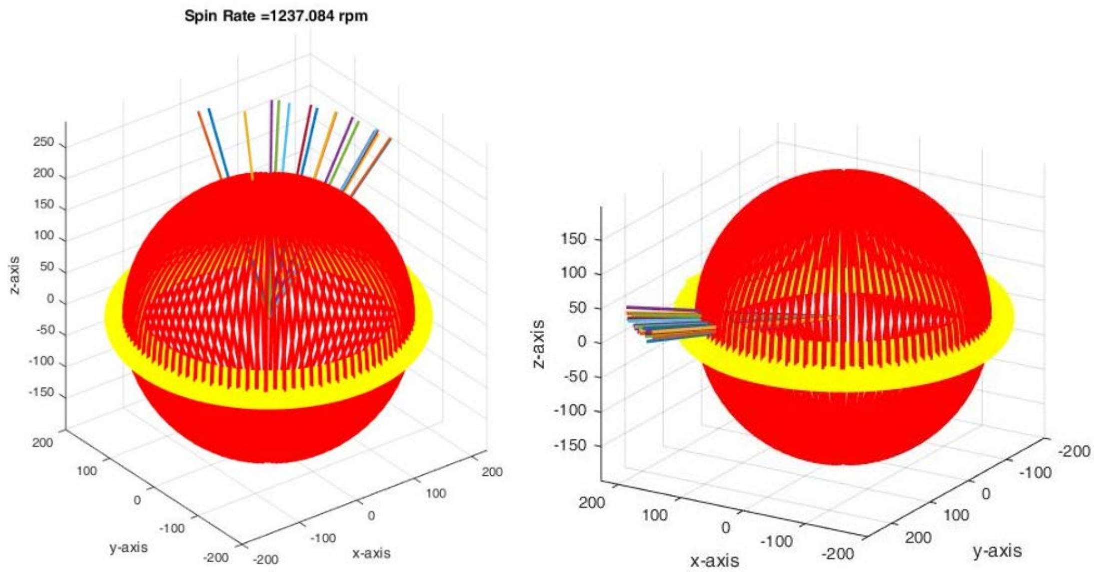

Figure 4.3.2: Balls bowled along seam and across seam respectively

CHAPTER 5
CONCLUSIONS, IMPLICATIONS AND OUTCOMES

5.1 LIMITATIONS

Even though this project was small in size, but it was not easy by any way. Several issues were encountered throughout the project at almost every stage and method we tried to use. Firstly, using MPU6050 and GY80 with Arduino Nano posed the problems of low memory on board and very low data logging frequency and low transmission frequency. Secondly, the gyroscopes saturated at very low values specific to this application. So we wanted to use high speed gyros but they were extremely costly. A single axis high speed gyro costs around $100. However, choosing MetaMotion R eliminated most of the above problems.

A great limitation in this project was the unavailability of suitable experimentation apparatus that would verify the results. Even though the results have been verified at lower rates with very small errors, there still remains a gap that is to be filled by testing it at high rates.

Lastly, there remains some uncertainty regarding the mechanical design of the ball. Since there is a delicate sensor embedded in the ball, computerized force analysis is not enough to ensure safety. We lacked mechanical stress measuring devices to test the ball for different forces in the lab.

Despite all the limitations mentioned above, we are very confident that our project meets all the required objectives and is very durable.

5.2 CONCLUSIONS

An instrumented cricket ball was developed with a nine axis IMU sensor. The sensor was incorporated into a cricket ball. The data were collected and downloaded via the logger's Bluetooth to the computer. The instances of release and impact, the resultant spin rate and the position of the spin axis were calculated. The axis was displayed as the axis point, the intersection of the axis with the surface of the ball, as well as 3D visualization of the ball and the spin axis surface (movement of the axis with time). The intelligent cricket ball will be used to determine the characteristics of different bowling deliveries in terms of spin rate, spin decay, and axis location and movement.

The technology presented herein provides a low cost, highly portable and minimally intrusive measurement system to support cricket bowing training and coaching. The IMU-embedded cricket ball faithfully reproduces the results of the ball to within 10% relative to that measured by camera. This quick visual, quantitative feedback will enable cricket coaches to accurately evaluate and thereby improve bowling performance.

MATLAB was programmed to provide prompt feedback to the bowler, a property that is important for skill acquisition, giving bowlers the opportunity to modify their deliveries under the instruction of a qualified coach.

5.3 OUTCOMES

The **Intelligent Cricket Ball** has a number of advantages over existing performance analysis instruments (e.g. motion analysis and Doppler radar system): the ball kinematics can be determined outdoors and the aerodynamics of the ball is not disturbed by markers. Furthermore, the ball is portable, inexpensive, easy to use as trained operators are not required, and provides more accurate data.

Our objectives of this project were to detect the instance of release of ball, calculate the spin rate of the ball and locate the spin axis throughout the flight till the ball hits the pitch. All three objectives were successfully fully achieved.

The following MATLAB plot of accelerometer, gyroscope and magnetometer data shows two large peaks. The first one is instance of release of ball from bowler's hand while the second one is the instance of impact when the ball hits the pitch. This is vital as it gives us time of flight of ball and helps us filter the necessary data for further processing.
The next two outputs from the MATLAB show us the spin rate of the ball along with the location of spin axis throughout the flight. The straight lines emerging from the ball are the spin axis.

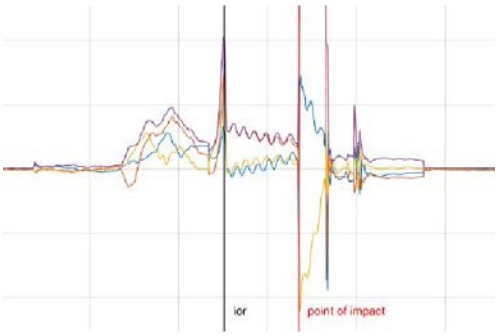

Figure 5.3.1: Instance of release and instance of impact detection

Quantitative measure of the spin rate allows coaches to track a bowler's performance (specially a spinner's) and suggest him improvements to increase it.
The scatter of the spin axis tells the coach about bowler's wobble. After tuning, the wobble can be reduced and tracked from the intelligent cricket ball.
The ball spun along the seam shows scatter of spin axis perpendicular to the seam while the ball spun across the seam shows scatter of spin axis along the seam which tells how well the bowler oriented the ball while releasing it.
Intelligent Cricket Ball would prove to be a great tool for coaching, training and research purposes.

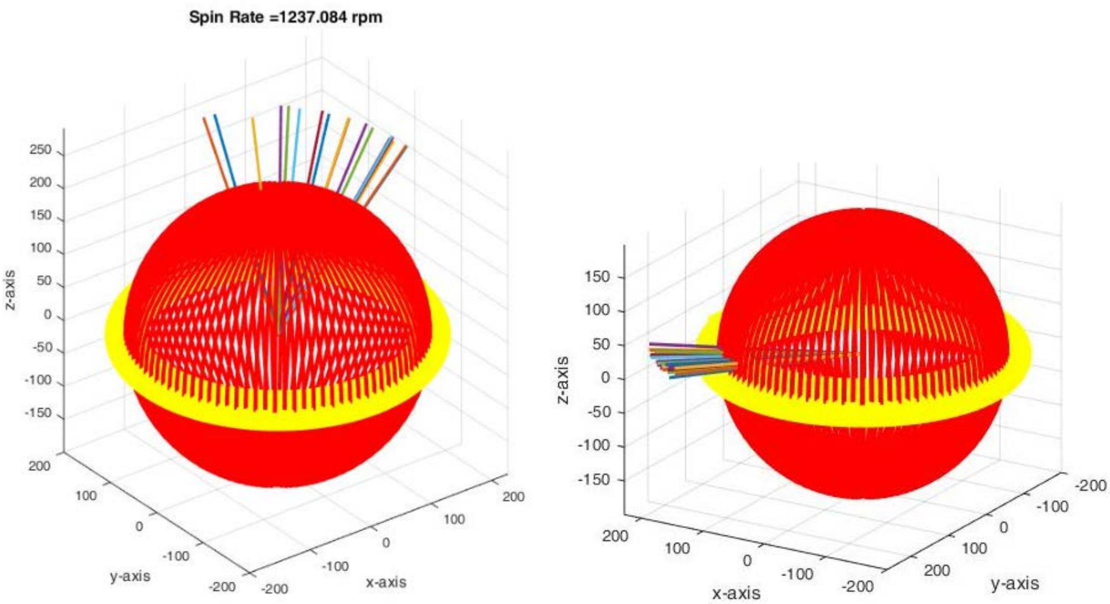

Figure 5.3.2: Balls bowled along seam and across seam respectively

5.4 SUGGESTIONS

Intelligent Cricket Ball is a very promising product. Here are a few suggestions that what could be improved in the future to enhance the scope of this project.

Needless to say, our ball prototype is not ready for real use – the embedded sensor is not optimized to preserve the homogeneous mass distribution inside the ball. This may have led to some biases in the trajectory and spin results, although we believe it is marginal. In the longer run, mechanical engineering experts need to calculate a near ideal weight distribution with feasible impact tolerance. The opportunities arise from smaller spatial footprint of the device, eliminating the battery (by harvesting energy from the ball's spin), and combining the IMU and the radio in a single smaller chip. Validating our results on such a professionally manufactured ball remains a part of future work.

Generalizing to other sports, we believe **Intelligent Cricket Ball's** techniques can be extended to other sports with domain specific modifications. For example, stitches on a baseball induce different aerodynamic effects, however, these differences can be modeled and incorporated into Ball. Such models are also available for golf and tennis balls, allowing them to be suitably "plugged" into our framework. Finally, **Intelligent Cricket Ball's** techniques may extend to hollow balls like soccer and basketball.

Intelligent Cricket Ball can improved to be used for the following applications:

1. Delivery classification
2. 3D tracking
3. Chucking detection

A personal coaching guide can be made by clustering and studying various known bowling patterns.

As far as mechanical design of the ball is considered, we would suggest trying machining a ball with CNC using suitable material with density and other mechanical properties similar to cork e.g. Ureol. A suggested alternative design is shown below:

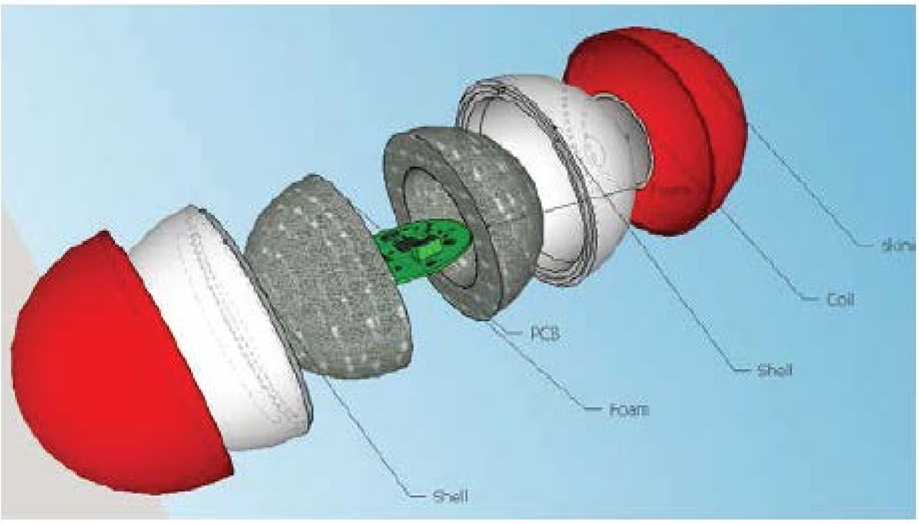

Figure 5.4.1: Exploded view of an alternative design

There is still a lot of room for improvement in the IMU sensor and we would suggest to design and implement a student made IMU sensor. Here is a sample scheme of how it might look like:

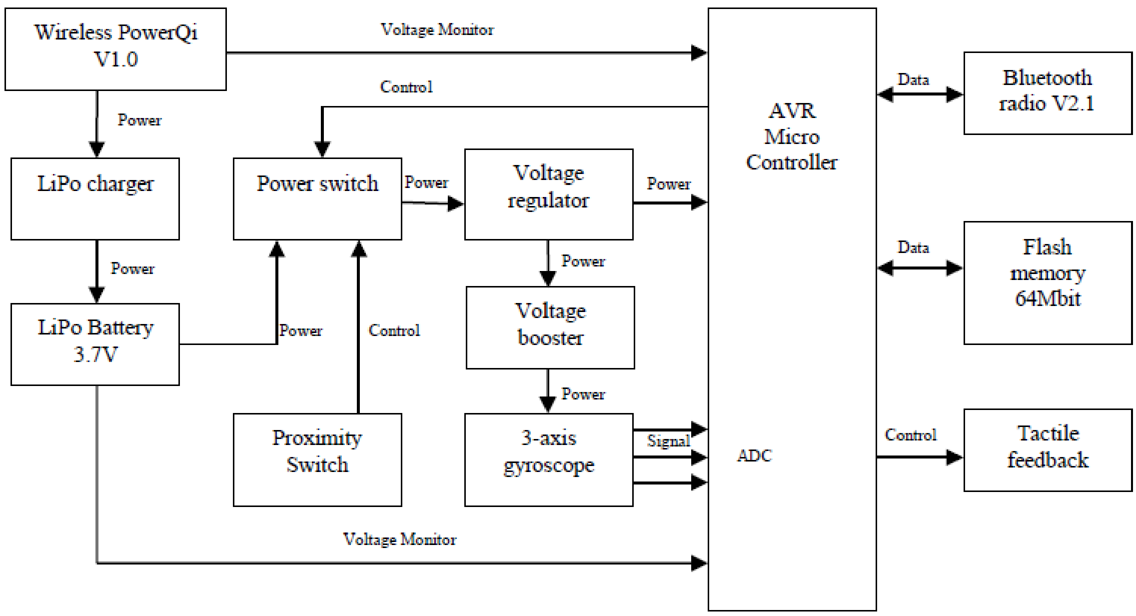

Figure 5.4.2: Block diagram of a suggested IMU sensor

5.5 RESEARCH STUDIES

The Intelligent Cricket Ball is a valuable research tool when it comes to studying various methods and hypothesis in cricket. A list of possible studies that can be benefitted using this project is given:

- Dynamics of spin bowling: the normalized precession of the spin axis
- Effect of Ball Weight on Speed, Accuracy, and Mechanics in Cricket Fast Bowling
- Effect of the Grip Angle on Off-Spin Bowling Performance Parameters
- Relationships Between Fast Bowling Technique and Ball Release Speed in Cricket
- Fluid Mechanics of Cricket Ball Swing
- Analysis of segmental kinetic energy in cricket bowling
- MEASURING SPIN CHARACTERISTICS OF A CRICKET BALL
- Effect on Bowling Performance Parameters when Intentionally Increasing the Spin Rate
- Study of the centre of pressure between hand and ball in off-spin bowling

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