Introduction

Teams across the world are becoming more and more professional with the way they play the game. Teams now have official strategists and technical support staff which help players to study their past games and improve. Devising strategies against opponent teams or specific players is also very common in modern day cricket. All this has become possible due to the advent of technology. Technological developments have been harnessed to collect various data very precisely and use it for various purposes.

The HAWKEYE is one such technology which is considered to be really top notch in cricket. The basic idea is to monitor the trajectory of the cricket ball during the entire duration of play. This data is then processed to produce life like visualizations showing the paths which the ball took. Such data has been used for various purposes, popular uses including the LBW decision making software and colorful wagon wheels showing various statistics. This paper attempts to explain the intricate details of the technology which goes behind the HAWKEYE. We first start off with a general overview of the system and an outline of the challenges that we might face, then move on to the details of the technology and end with various applications where one sees this technology being put to use.
HAWKEYE - a general overview

Hawk-Eye is a complex computer system used in cricket, tennis and other sports to visually track the path of the ball and display a record of its most statistically likely path as a moving image. In some sports, like tennis, it is now part of the adjudication process. It is also used in some instances to predict the future path of a ball in cricket. Hawk-Eye uses six or more computer-linked television cameras situated around the cricket field of play. The computer reads in the video in real time, and tracks the path of the cricket ball on each camera. These six separate views are then combined together to produce an accurate 3D representation of the path of the ball.

Hawk-eye is able to track the ball from the point of release from the bowler to the point at which the ball is in line with the stumps. Further prediction is achieved through use of a parametric model. The output is where the ball pitched and the direction in which it is headed.

- **Hawk-eye can track any type of bounce, spin, swing and seam movement of the ball.**
- **Give a prediction as accurate as 99.99 percent**
- **Hawk-Eye was used for referring decisions to the third umpire in LBW.**
In tennis Hawk-Eye generates the impact of the ball whether the ball is “IN” or “OUT”

HAWKEYE technology successfully treats each of the issues and provides a robust system to be used in practice. The top-level schematic picture of the system and its various parts is as shown below (each color represents a block of steps which are related):

Figure1: Top Level view of the Hawk Eye System
The figure above shows precisely the steps that are involved in the computation.

History

The Hawk-eye technology, as with many recent developments, initially came about from a military application. Initially Hawk-eye was used to track the movement and flight path of missiles, it was though soon realised that it could be used to track any independently moving projectile. Thus it was that Dr Paul Hawkins and his colleagues sought to adapt the military version of Hawk-eye to one that could be used in sports, and in particular cricket.

It was developed by engineers at Roke Manor Research Limited of Romsey, Hampshire in the UK, in 2001. A UK patent was submitted by Dr Paul Hawkins and David Sherry. Later, the technology was spun off into a separate company, Hawk-Eye Innovations Ltd., as a joint venture with television production company Sunset + Vine.

After intensive development the new Hawk-eye system was able to track the flight of a cricket ball with a great deal of accuracy. The Hawkeye system was launched in 2001. The system was first used during a Test match between Pakistan and England at Lord's Cricket Ground, on 21 April 2001, in the TV coverage by Channel 4. It was first used in television coverage of sporting events such as Test cricket, and has now reached the stage of being used by
officials in tennis to assist in adjudicating close line calls. The Nasdaq-100 Open in Miami was the first tour event to officially use the technology. The 2006 US Open was the first Grand Slam event to feature the system, followed by the 2007 Australian Open.

**How does Hawk-Eye work?**

For most sports fans it is not important to know how Hawk-eye works, but there is a lot of interesting science and technology behind the images that appear on the TV screen. In cricket matches Hawk-eye technology is based upon the images captured by six cameras, three on each side to the wicket. Through these six cameras, all round and 3D images can be captured, which allows for the path of the ball to be tracked. The prediction side comes about through the use of logarithms based on known laws of physics and trajectories.

Hawk-Eye uses 6 high speed specialist vision processing cameras which are positioned around the ground and calibrated. In addition the system uses the two “Mat” broadcast cameras and calibrates them so that the graphic is always overlaid in the right place. All cameras have “anti wobble” software to deal with camera movement. When a ball is bowled, the system is able to automatically find the ball within each frame of video from each camera. By combining the positions of the ball in each of the cameras, the 3d position of the ball is measured through-out the delivery. By measuring the position of the ball at multiple frames post bounce, the speed, direction of travel, swing
and dip can be calculated for that specific delivery. Using these measured characteristics of the ball’s flight up to impact, the future path is predicted.

**Principle**

All Hawk-Eye systems are based on the principles of triangulation using the visual images and timing data provided by at least six high-speed video cameras located at different locations and angles around the area of play.

**Triangulation**: Triangulation is a process of determining the location of a point by measuring angles to it from known points from the fixed baseline.
\[ d = \frac{l}{\left(\frac{1}{\tan \alpha} + \frac{1}{\tan \beta}\right)} \]

\[ l = \frac{d}{\tan \alpha} + \frac{d}{\tan \beta} \]

Figure – Triangulation

Technology
In this section, we go into the technical details of the steps involved in the HAWKEYE system. The process, as done before, can be broken down into the following steps (we will divide the process into these seemingly disjoint steps so that it is easy to explain the details, however many of the steps are overlapping):

1. **The cameras:**

   Typically, for a cricket field, 6 cameras are used. These cameras are placed around the field at roughly the places as indicated in the diagram below:

   The cameras need to be fixed to some frame of reference, which defined very conveniently in terms of the wickets on the pitch, and the line joining them. This is useful when we want to use an automated program to merge images from different cameras to form one 3D image.

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2. **Core Image Processing Job:**

   Hawk-Eye takes 2 inputs
1. Video provided by 6 different cameras placed at 6 different places.
2. The speed of the ball.

The system rapidly processes the video feeds by a high speed video processor.

This part of the system can be further divided into major parts:

a) To identify the pixels representing the cricket ball in every image taken by each of the video cameras: An algorithm is used to find the pixels corresponding to the ball in the image obtained. The information which is used in order to achieve this is the size and shape of the ball. After this stage, we have as output the x and y co-ordinates of the ball in each image.

b) Geometric Algorithm: The data of and co-ordinates from each camera is obtained by the Geometric Algorithm which is at work inside the HAWKEYE system. Now, knowing the exact positions of the cameras in space, and the and co-ordinates of the ball in more than one of the images taken by these cameras, one can determine accurately the position of the ball.
3. Putting frames at various times together:

Now we have the exact position of the ball in 3D space at a given instant of time. Next, what needs to be done is putting together this data, collected at various time instants into a single picture which shows us the trajectory of the ball. We can split this part of the process into two parts.

(1) Tracking the ball at various instants: Suppose the images are taken by cameras at times during the play of a single ball. Doing the computation as described above at each time \( t_i :0\leq i\leq n \) instant, we will get \( n \) points, say for \( (x_i, y_i, z_i) \) for \( 0\leq i\leq n \). With these points plotted in the 3D space, when looked at in their proper sequence, these points tell us about the path followed by the ball.

(2) Predicting the flight or trajectory of the ball:

We have points in space which we know represent the position of the ball at some particular time instants, which are also known. Now, there is a standard technique, used in Computer Aided Geometric Design which can be invoked here. This allows us to draw as good an approximation as required to the original curve, passing through the given points. This technique gives us a curve which is continuous and
differentiable, meaning it is smooth all along, starting at the first point ending at the last point among our points. This predicts the trajectory or flight of ball.

**Hawkeye innovations**

**Cricket**

Hawk-Eye has become a resident feature of cricket broadcasts across the globe. Although now familiar to cricket fans from all around the world, Hawk-Eye continually expands its arsenal of statistical features and seeks to incorporate slick new aspects to complement the mainstays of its television output.

**Examples of Hawk-Eye statistics include:**

1. **Wagon Wheels:**

   The singles, 2s, 3s, 4s and 6s that make up quick-fire 50s or vital centuries are represented by the different colours of the Wagon Wheel, which shows the areas of the field that the batsman has been targeting. Hawk-Eye now has the ability to display wagon wheels over photo realistic or virtual realistic backgrounds, giving broadcasters even more scope to tailor the Hawk-Eye 'look' towards the style of their production.

2. **Pitch Maps:**

   Simple yet effective; Pitch Maps make a useful pause for reflection after the frenetic exchanges of the opening overs and highlight a bowler’s consistency or expensiveness, line and length. Hawk-Eye can now display comparative Pitch
Maps in a split screen format, as shown in the example to the right.

3. despin:

Hawk-Eye DeSpin Graphics demonstrate how far a delivery has deviated after pitching. Whilst the blue trajectory below represents a ball that does not spin or seam, the red ‘actual delivery’ shows just how much turn the spinner has achieved.

4. Railcam:

The ‘RailCam’ (side view) shot of the VR World can be used to represent differences in speed, bounce and delivery. The trajectories are animated, whilst the speeds provide further evidence of a bowler’s variation or a telling comparison between athletes.

5. Beehives:

Beehives show where the ball has passed the batsman. As with the Pitch Map, the coloured balls correspond to the number of runs that the batsman has achieved from that delivery. Hawk-Eye Beehives can now be shown against a photo realistic or virtual realistic world, as with the Wagon Wheel feature.
**Tennis**

The Hawk-Eye Officiating System is the first and only ball-tracking system to have passed stringent ITF testing measures. It is accurate, reliable and practical. Not only is the Hawk-Eye Officiating System vital for ensuring that high pressure points do not fall prey to umpiring mistakes, it brings the fans closer to the action. Spectators watch alongside their heroes and heroines on court as Hawk-Eye shows whether a ball was ‘in’ or out’ on stadia big.

**Snooker:**

Hawk-Eye’s most recent development has brought the company into the world of snooker.

  Animated shots

  Blue dot
Applications

Cricket:

HAWKEYE has had far-reaching consequences in many sports. Its major use in cricket broadcasting is in analysing leg before wicket decisions, where the likely path of the ball can be projected forward, through the batsman's legs, see if it would have hit the stumps.

Due to its realtime coverage of bowling speed, the systems are also used to show delivery patterns of bowler's behaviour such as line and length, or swing/turn information. At the end of an over, all six deliveries are often shown simultaneously to show a bowler's variations, such as slower deliveries, bouncers and leg-cutters. A complete record of a bowler can also be
Batsmen also benefit from the analysis of Hawk-Eye, as a record can be brought up of the deliveries batsmen scored from. These are often shown as a 2-D silhouetted figure of a batter and colour-coded dots of the balls faced by the batsman. Information such as the exact spot where the ball pitches or speed of the ball from the bowler's hand (to gauge batsman reaction time) can also help in post-match analysis.

**Tennis:**
In tennis Hawk-Eye generates the impact of the ball whether the ball is “IN” or “OUT”. A great deal of software expertise had been expended on improving our Virtual Reality ‘look’ in 2007, meaning Hawk-Eye can tell even more of the statistical stories relevant to the match in hand.

**Snooker:**

This technology is useful in cases where the cue ball touches the specified ball first or any other ball.

The Hawk-Eye Snooker Software offers a wide range of options to enhance the TV spectator’s viewing experience.

**Doubts**

Hawkeye is now familiar to sport fans around the world for the views
it brings into sports like cricket and tennis. Although this new technology has for the most part been embraced, it has been recently criticised by some, particularly some specific, high profile calls. Some commentators have criticized the system's 3.6mm statistical margin of error as too large. Others have noted that while 3.6mm is extraordinarily accurate, this margin of error is only for the witnessed trajectory of the ball. Its use in broadcasts to predict the trajectory of a ball had it not hit a batsman is less certain, especially in situations where the conditions of the turf would affect its future trajectory, i.e. where the ball is headed to the ground or has only a short hop before hitting the batsman. Currently, the system is not used officially in such circumstances, though it is used in television broadcasts and analysis.

Everyone thought that this LBW was NOT OUT despite it just hitting the stumps

Further developments
On June 14, 2006, the **Wisden Group** bought the Hawk-Eye technology. The acquisition is intended to strengthen Wisden's presence in cricket, and allow it to enter tennis and other international sports. Hawk-Eye is already working on implementing a system for **basketball**.

The **Football Association** has declared the system as "ready for inspection by FIFA", after tests suggested that the results of a goal-line incident could be relayed to the match referee within half-a-second (**IFAB**, the governing body for the **Laws of the game**, insists on goals being signalled immediately e.g. within five seconds).

The use of the Hawk-Eye brand and simulation has been licensed to **Codemasters** for use in the video game **Brian Lara International Cricket 2005** to make the game appear more like television coverage, and subsequently in **Brian Lara International Cricket 2007**, **Ashes Cricket 2009** and **International Cricket 2010**. A similar version of the system has since been incorporated into the **Xbox 360** version of **Smash Court Tennis 3**, but it is not present in the **PSP** version of the game, although it does feature a normal challenge of the ball which does not use the Hawk-Eye feature.
Conclusion

We have looked at various aspects of the HAWKEYE technology. Initially, we outlined the main problems which one could encounter while trying to implement such a system for a sportlike cricket. Then, we looked into the details of each step of the process which finally gives us the wonderful looking graphics that we see on TV during cricket analysis shows. We got a fair understanding of the algorithms and mathematics which goes into the system. With the help of examples, we looked at the applications which the technology finds in modern day sport, with cricket being our main focus. We got an understanding of how the graphics can be produced, using the setup, which also was described in detail.

We have thus seen that the HAWKEYE is a great innovation, which puts technology to good use in the field of sports. The technology is used widely these days, in sports such as Tennis and Cricket. The accuracy which can be achieved with the use of the system is making the authorities think seriously about reducing the human error component involved in important decisions. As the system runs in real time, there is no extra time required to see the visualizations and graphics.

The system is also a great tool which can be used by players, statisticians, tacticians, coaches to analyze previous games and come up with strategies for subsequent ones.
Bibliography

- www.hawkeyeinnovations.co.uk
- www.therulesofcricket.co.uk
- How the hawk-eye works in cricket by Tim Harry
- www.topendsports.com
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Seminar Report

on

HAWK EYE

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