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HAWK EYE TECHNOLOGY

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Abstract: "Many sports have become very reliant on monitoring systems such as Hawk-Eye in Tennis; this paper has looked into just how accurate the technology is, and assessed the effectiveness of the technological approaches used to implement the system. The level of accuracy is vital for sport monitoring systems, in a number of sports such as Line Calling Decisions in Tennis. Even a small margin of error can affect the decision of whether the ball is called in or out. As many high profile sporting industries have placed a great deal of dependence upon this technology, if it were to prove inaccurate, the sporting world would incur devastating consequences. As governing bodies would then be under a large amount scrutiny, from all over the world. Players, coaches and even spectators would all start to question the decisions made using this technology made in past. And as these were designed to rule out human error in such cases as line calling, any major failings found in the technology would render them useless".

Keywords: Cricket, Hawk eye, Ball, 3-D technology, Cricket, Tennis, Camera Technology.

INTRODUCTION

The game of cricket has attained great commercial importance and popularity over the past few years. As a result, there has been felt a need to make the game more interesting for the spectators and also to try and make it as fair as possible [1]. The component of human error in making judgments of crucial decisions often turns out to be decisive. It is not uncommon to see matches turning from being interesting to being one sided due to a couple of bad umpiring decisions. There is thus a need to bring in technology to try and minimize the chances of human error in such decision making [2].

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 [3]. 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 [4]. 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 lifelike visualizations showing the paths which the ball took [5]. Such data has been used for various purposes, popular uses including the LBW decision making software and colourful wagon wheels showing various statistics. This paper attempts to explain the intricate details of the technology which goes behind the HAWKEYE.

HAWK-EYE: A GENERAL OVERVIEW

Cricket is a ball game played within a predetermined area. A system comprising of video cameras mounted at specific angles can be used to take pictures. These pictures are then used to locate

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the position of the ball. The images are then put together and superimposed on a predetermined model to form a complete visualization of the trajectory of the ball. The model includes, in this case, the pitch, the field, the batsmen and fielders etc. For this to be possible, the images need to be sampled at a very high rate and thus need efficient algorithms which can process data in real time. Such technologies are widely used today in various sports such as Tennis, Billiards which also fall in the category of ball games played within a restricted area. The discussion will mostly contain applications which specific to the game of cricket, however in some cases [6]. There are various issues which crop up when one tries to design and implement such a system. In the game of cricket, the general issues are:

1. The distance at which the cameras see the pitch and the ball are dependent on the dimensions of each ground and can vary greatly [7].
2. Just the individual images don't help too much; for the system to be of practical use, one must ensure that it can track the 3D trajectory of the ball with high precision. In order to get this accuracy, the field of view of each camera should be restricted to a small region – this means one needs more cameras to get the coverage of the entire field.
3. Fielders and spectators might obstruct the camera's view of the ball and the ball might get lost in its flight in one or more of the cameras. The system should be robust enough to handle this, possibly by providing some redundancy. Figure 1 shows the flow chart of the hawk eye technologies [8]

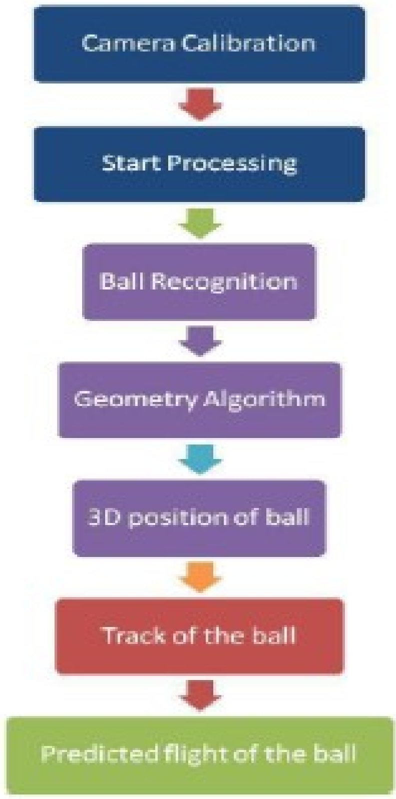

Figure 1. Hawk-Eye flow diagram

The figure above shows precisely the steps that are involved in the computation. The process is started with some calibration of the cameras. This is required to deal with the problem raised in 1 above, about the non-uniform distance of the cameras from the playing area. After this basic calibration is done and the system is up and running, the video input processing is initiated for receiving information from the cameras. In each of the images obtained, the first aim is to find the ball init. Once this is done, a geometric algorithm is used to look at multiple images (which are 2D) and then combine them cleverly to get the co-ordinates of the ball in 3D space. This process is now repeated for multiple times every second (typically at the rate of 100 times per second). Thus, the position of the ball in 3D space at many moments in every second is captured [9]. The final step is to process these multiple positions and find a suitable fitting curve which best describes the flight of the ball. As the positions of the ball are sampled at very short time intervals, the flight of the ball can be very accurately determined. A description of the exact algorithms involved in the entire process will be skipped here.

STEP-BY-STEP DETAILS OF THE HAWKEYE SYSTEM:

In this section, the technical details of the steps involved in the HAWKEYE system. The process, as done before, can be broken down into the following steps:

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 figure 2.

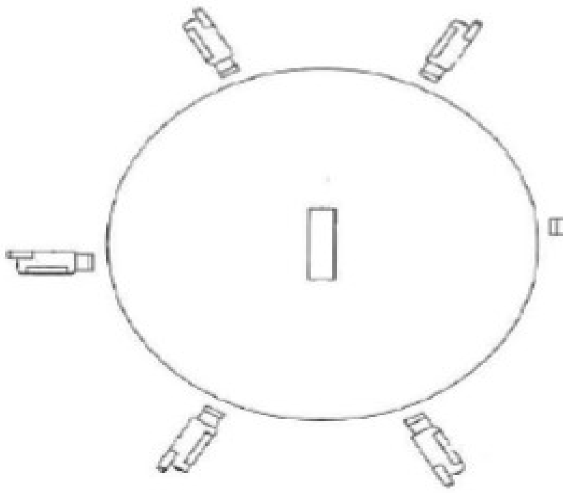

Figure 2. Top view of camera

4. The ball might get confused with other similar objects – for instance, with flying birds or the shadow of the ball itself [10]. The image processing techniques used need to take care of these issues. Luckily, there are techniques which are easy to implement and are well known to the Image Processing community on the whole, to take care of these.
5. To help in judging LBW calls, the system needs to be made aware of the style of the batsman – whether he is right or left handed. This is because the rules of LBW are dependent on the position of the stumps and are not symmetrical about the middle stump. Thus, the system needs to detect whether a particular ball has pitched outside the leg stump of a batsman or not.
6. To determine the points at which the ball makes contact with the pitch, the batsmen or other objects is very hard [11]. This is because spots of ball beforehand are unknown and the model and the real pictures taken by cameras need to be merged to give such a view.

The top-level schematic picture of the system and its various parts is as shown below (each colour represents a block of steps which are related). As one can see, the 6 cameras in use are positioned at roughly 60 degree from each other. They are placed high in the stands, so that there is lesser chance of their view being blocked by the fielders. There are two cameras, one each looking at the wickets directly in sideways fashion [12]. These 6cameras are calibrated according to the distance they are at from the pitch. In order to get good accuracy, one needs to restrict the view of each camera to a smaller region. This means each camera image would show a more prominent picture of the ball and hence the ball will be located more accurately. However, the whole field of play has to be covered with just the 6 cameras which are available. This puts some limitation on how restricted the view of a camera can be. Nevertheless, the accuracy obtained by using 6 cameras is acceptable to the standards prevalent today. Some further setting up is essential for the system to work correctly. The cameras need to be fixed to some frame of reference, which is defined very conveniently in terms of the wickets on the pitch, and the line joining them. This is useful when an automated program is used to merge images from different cameras to form one 3D image.

Also, to avoid unnecessary computation and make the system more efficient, the cameras can be operated in active or passive mode. In the passive mode, no imaging is done and hence the system is more or less completely inactive. The cameras can be triggered into active mode either by detecting some motion in the vicinity of the pitch, or manually by some external trigger. In either case, all the cameras are synchronized and go into active mode simultaneously. The cameras are then designed to stay in the active mode for a fixed time before going off into passive mode. This action of going into passive mode can be manually overridden in exceptional cases. The different modes for the cameras are especially effective for a game like cricket as the game involves significant pauses between phases of actual play. As described in 5 in the list of issues, the system needs to know if the batsman is right or left handed. The front view cameras are used to do this. This information, as previously said is useful in making LBW decisions and formulating other statistics. For instance, the bowler's pitching areas is analysed separately for a left and aright handed batsman. While this is not a very difficult task to do manually every time the batsman on strike changes, the system does provide some way of automating it. Once this setting is done, the cameras are ready to take pictures in their field of view and have them sent to a computer which processes them.

COLOUR IMAGE PROCESSING JOB

This part of the system can be further divided into 3 major parts:

(1) Identifying pixels representing the ball in each image.
(2) Applying some geometric algorithm on the set of images at each instant.
(3) Coming up with the 3D position of the ball in space.

The detailed explanation:

(1) 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. It should be noted that the system does not use the colour of the ball as that is not really same throughout the course of a game, nor is it same across all forms of cricket. A blob detection scheme can be used to detect around object in the image. Knowing the approximate size of the ball, the other round objects are eliminated, such as helmets worn by players. The shadow of the ball also will resemble the ball in shape and size and thus presents itself as a very viable candidate for a blob representing a group of pixels corresponding to the ball itself. The position of the sun at the given instant of time and also information about the position of the ball in previous images is used to make sure this confusion is avoided. Thus, by taking due care, it is sure that the round object which has been located is indeed the cricket ball, which is the object of interest. After this stage, the output as x and y coordinates of the ball in each image. In some cases, it might be the case that the system is unable to determine the exact position in some images. At such times, "Not Found" is returned by that particular camera. One must note at this point that 6 cameras are used to take images. Actually, in the ideal case one can do the job with just 4cameras. Thus, it results in some redundancy and hence, can afford to have a bad result from one of the cameras at some points and still produce a complete picture.

(2) The data x and y co-ordinates from each camera (or a "Not Found" in some cases, which is ignored) is obtained by the Geometric Algorithm which is at work inside the HAWKEYE system. The image taken from each camera is just a 2Dimage and lacks depth. Now, knowing the exact positions of the cameras in space (with respect to the pitch) and the x and y 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 in 3D.

PUTTING FRAMES AT VARIOUS TIMES TOGETHER:

Now the exact position of the ball in 3D space at a given instant of time is found. Next, what needs to be done is putting together this data, collected at various time instants into a single picture which shows the trajectory of the ball. Again, the reader should understand that these parts are very much related so that it is splited in the explanation just to make it easily understandable. The two parts to this computation are:

(1) Tracking the ball at various instants.

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

(1) Tracking the ball at various instants.

Suppose the images are taken by cameras at times t0, t1.....tn during the play of a single ball. Doing the computation as described above at each time instant ti, 0<=i<=n, the n points are found, say (xi, yi, zi) for 0<=I<=0 Now, on the model that is built previously consisting of a picture of the pitch, ground and wickets etc., these n points are plotted. When looked at in their proper sequence, these points tell about the path followed by the ball when it travelled during the last ball that was played. With these points plotted in the 3Dspace, so the next process is continued to move on to the next and final stage in the processing of a single delivery, namely, predicting the flight of the ball.

Predicting the flight or trajectory of the ball:

The n points represent the position of the ball at some particular time instants, which are also known. Now, there is a standard technique, used commonly in the field of Computer Aided Geometric Design which can be invoked here. This allows to draw as good an approximation as required to the original curve, passing through the given points2. This technique gives us a curve which is continuous and differentiable, meaning it is smooth all along, starting at the first point and ending at the last point among the n points. This smooth curve is an approximation to the original curve which the ball would have followed. The more points found on the curve and the higher degree of polynomial basis is selected to use, the better approximations to the original curve is explained. The better approximations obviously come at some additional cost – the added cost of computation of the approximation.

Hence, the system uses some degree such that the computation time is small enough, at the same time the accuracy is acceptable. More can be done with the information about the points. The curve to points also can be extended which is not recorded at all – indeed, it might be the case that the ball struck the batsman and deflected away, but where the ball was headed that point is measured, particularly to help adjudge LBW cases. This extension uses some basic mathematics and ensures that the extended curve is also smooth at all points, particularly at the point from where the extended part starts that is the last point which is recorded among the points. During the flight of the ball, it might go through some points which are of special interest. These include the ball hitting the pitch, the stumps, and the batsman among others. These points are predicted by superimposing the trajectory which is built, onto the model that is fed into the system. It should be noted that there is a possibility that such critical points may not be recorded in any of the images taken by the system and in such cases; the reliance is completely on the predicted flight of the ball. Also, for the particular key-event of the ball striking the batsman, the sideways cameras, which look directly at the wickets at either end of the pitch, are the most reliable sources.

The trajectories which the ball has taken after being hit by the batsman are recorded in the system. This is used to generate a graphic showing 1s, 2s, 3s, 4s, and 6s all indifferent colours for a batsman. These details allow the commentators, spectators and players to analyse the scoring areas of the batsman and also judge if he has played more shots along the turf or in the air. Such information is vital for a

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fielding captain, who might alter his field placement in subsequent matches to adapt to the hitting pattern of a particular batsman.

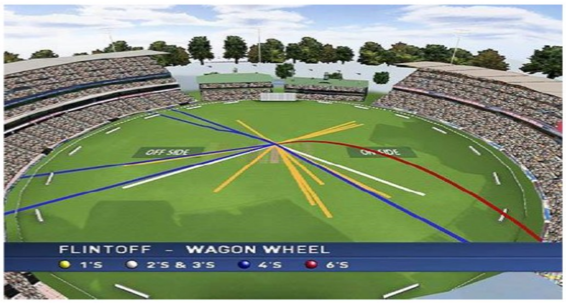

Figure 3. Pitch Maps

As shown in above fig 3, the Pitch Map graphic uses information about the position where the ball bounced on the pitch. The image above clearly shows the pitch being divided into various "zones" which the experts consider in their analysis. It can be very easily seen where the bowler has been pitching the ball primarily. Based on such pitch maps, one can easily see general characteristics of bowlers-for instance, on a particular day a bowler might be taken for a lot of runs. HAWKEYE can show the areas in which the bowler landed the balls and he might be able to find out he was too short on most occasions and hence was being taken for runs. Batsmen also use such graphics to study the general tendency of the bowler and can plan to play him in subsequent games.

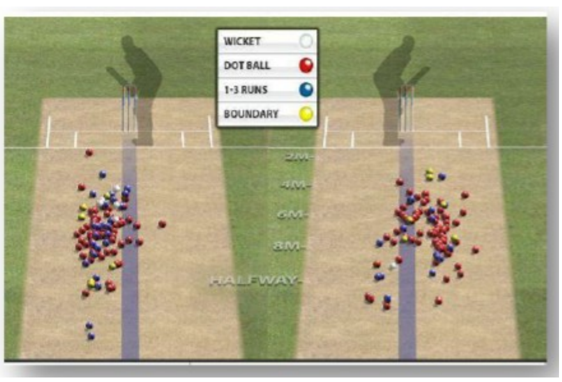

Figure 4. Pitching of balls

CONCLUSION

The various aspects of the HAWKEYE technology are analysed. Initially, the main problems are found which one could encounter while trying to implement such a system for a sport like cricket. Then, the each step of the process finally gives the wonderful looking graphics that is telecast in the TV during cricket analysis shows. With the help of examples, the various types of applications are observed in which the technology finds in modern day sport. The HAWK eye process 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 is 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 analyse previous games and come up with strategies for subsequent ones.

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