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Original Research Article

Hawk Eye Technology Used In Cricket

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Abstract: Game of cricket is improving day by day. Development of the sport technologies is one of the major reasons behind this improvement. Hawk Eye is one such technology which is been used in the game of cricket. Due to numerous amount of assistance given by this technology for the improvement of the quality of the game it has become very popular among the public. But due to a lees number of researches carried out on this topic the public understanding regarding the technology is very much law. Therefore this paper aims to discuss the principal behind the Hawk Eye, multiple uses of it in the game of cricket, accuracy of the system, reliability of the system while suggesting future enhancements to be done.
Keywords: Hawk Eye, DRS, LBW, Wagon wheel, Pitch map, Despin, Beehive.

INTRODUCTION

Television broadcasting has become a very profitable business all around the world. Sport broadcasting is one area where a large amount of audience is available. As a result there is a massive competition among the broadcasting channels to become the pioneer. In order to achieve this channels intend to give a superior experience to their viewers with the help of the latest technologies available. Hawk-eye is one such technology which was used by broadcasting channels to produce various kinds of visualizations including colorful wagon wheels [1].

Hawk-eye technology was created by Dr. Paul Hawkings and it was developed by the engineers of Roke Monor Reseach limited [1]. Although this technology was initially used by the broadcasting channels, with the improvement it has become a decision aid tool for a number of sports including cricket, tennis, snooker, football etc. In the game of cricket this is used to aid the LBW (Leg Before Wicket) decision because it is the first and the only ball tracking system which is available in the game of cricket [2]. Using multiple cameras to feed the system the trajectory of the cricket ball is monitored during the entire duration of the play.

At present the Hawk-eye technology has become a vital part of the context of the game of cricket as it is considered to be the major part of the DRS (Decision Review System) [3]. Earlier there was no such method called DRS. And all the decisions were taken by the on field umpire. But with development of the technology the players gained the ability viewing the replays and slow-motion videos. As a result they were able to pick the incorrect decisions given by the umpires where the final decision of the game would go in the other direction [7]. Therefore it was obvious that when a cricket ball travels exceeding 90mph the accuracy of the umpires' decisions could be reduced. This resulted in evolving the DRS system which allows players to challenge the on field umpires decision.

Although the Hawk-eye technology is widely used in the game of cricket it has not been a topic of research within the public understanding. Therefore the aim of this study is to give a better understanding about Hawk-eye technology.
This study will discuss about what is hawk-eye technology, how it is been used in the game of cricket. Furthermore this paper will focus on the accuracy of the existing system and how much reliable the existing system is while suggesting future enhancements which can be done.

This paper will use existing literature in order to gather information and statistics obtained from the ESPN Cricinfo web site will be used to analyze the impact Hawk-eye in the game of cricket.

EXPERIMENTAL SECTION

Under this section research findings relevant to bellow categories are discussed.

I. Hawk Eye Technology
II. The LBW Decision
III. Wagon Wheel
IV. Pitch Map
V. Despin Graphics
VI. Beehive Graphics
VII. Uncertainty of the Hawkeye System
VIII. Dependability of the Hawk Eye Technology

Hawk Eye Technology

This technology can be considered as an instance of a RTD (Reconstructed Track Device). Visible-light television cameras are used in order to follow the trajectory of the ball [4]. These results are then directed to filter the available pixels in each frame. Then it analyzes those pixels. After the analyzing phase certain pixels are selected for various kinds of representations. Such representations include representation of the position of the cricket ball, representation of the position of the line and to represent some other features relevant to the playing area [2]. Figure 1 will give a better understanding regarding the above mentioned procedure.

Fig-1

The coordinates of the pixels (time coordinates and space coordinates) are presented numerically. Meanwhile statistical algorithm is been used to reconstruct the flight of the cricket ball, impact point of the cricket ball and also some of the very important stats about the playing area. And these facts will also consider the details regarding different pixels available in different frames while considering the stats related to the size of the cricket ball, the physics related to its distortion and the width of the line (the blue line in Figure 2). After performing the above mentioned calculations the system will then decide the decision to be given [2].

Fig-2

Almost all the technological systems are based on some sort of principle. This Hawk Eye technology is based on the “TRIANGULATION” principle. This principal is used to determine the exact location of a point. In order to determine the location two known points (besides any end of a fixed baseline) are been used. With the help of those two points the angle to the point which needs to find the location is been measured without measuring the direct distance to that point [3]. Figure 3 will give a better understanding regarding this principal.

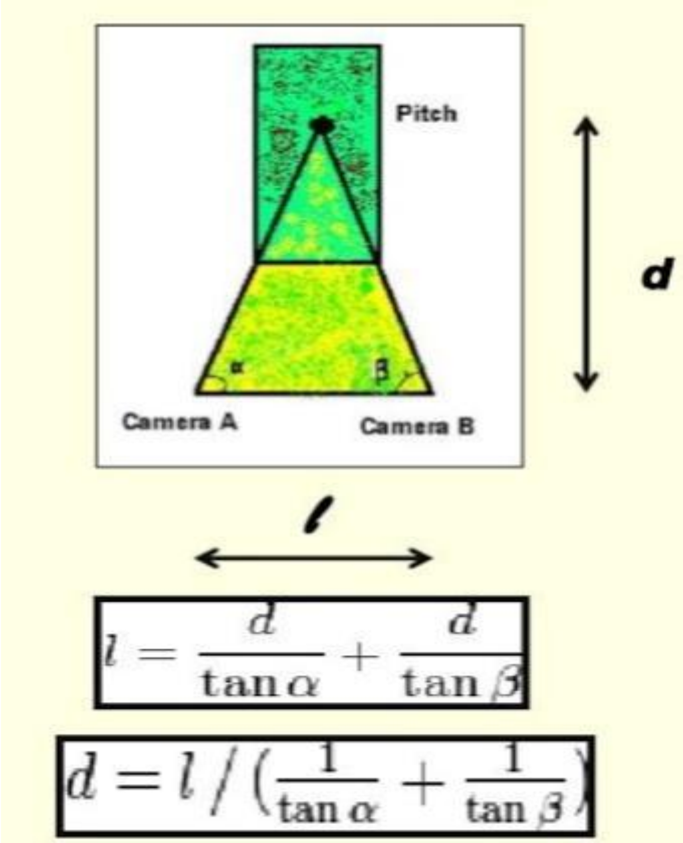

Figure 1

The Hawk Eye system takes two types of inputs

1. The video which is provided by the six cameras at six different locations.
2. The speed of the moving cricket ball.

The frame rate of the cameras which are been used in this system is 120MHz. Therefore these cameras will help to track the entire trajectory of the cricket ball starting from the bowlers release point. Figure 4 and Figure 5 will help to get a good understanding about the placement of the cameras in a cricket ground. There is a high speed video processor. With the help of it the video feed which is provided by the cameras are been rapidly processed [3].

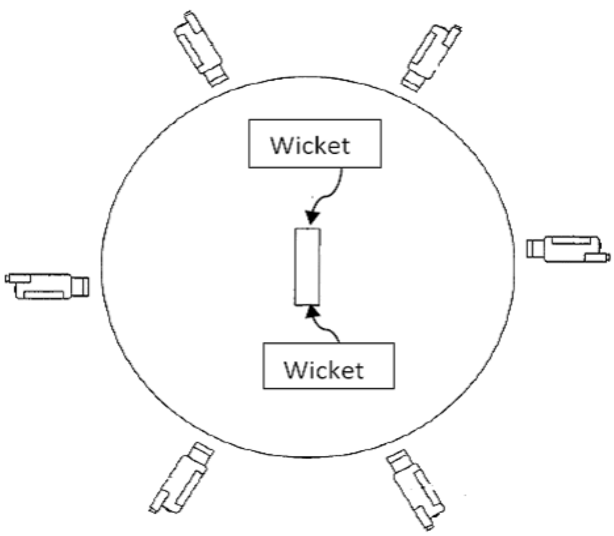

Fig-4

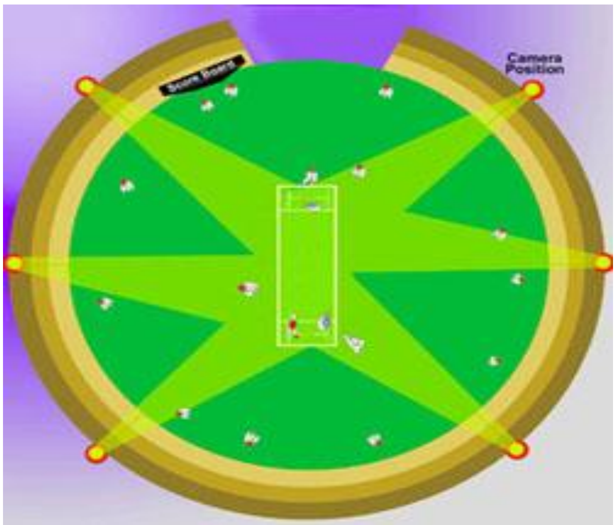

Fig-5

The cameras we use in the Hawk Eye system are having a limited frame rate. There is a slight gap between the frames. As a result of this the position of the ball within that gap can't get detected using the video. Hence the position of the ball has to be predicted. In order to do so, software has been implemented with the system. This software will interpolate the trajectory of the ball in between the frames. Then the final trajectory of the ball is detected while considering both the predicted trajectory and the actual trajectory [4].

The software uses a statistical algorithm in order to predict the trajectory of the cricket ball. The trajectory of the ball consists with "data points". A data point can be considered as a three-dimensional remodeling of the cricket ball. This will always consider information gathered from two or more cameras. Each frame of the video will provide a single data point. As a result of using more than one camera in the process of modeling the data points the frame rate related to one data point should be higher than the frame rate provided by a single camera. Therefore the frame rate related to a data point is referred as the "effective frame rate". As a result more accurate prediction for the trajectory of the cricket ball can be taken. When the system detects more data points it will allow the system to detect complex curves with regard to the balls' trajectory [4]. Figure 6 will help to get an overall idea about the entire functionality of the Hawk Eye system.

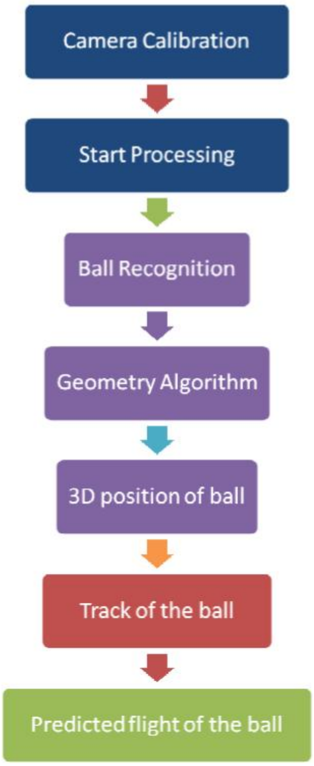

Fig-6

The LBW Decision

In the game of cricket an umpire plays an important role. All the decisions are taken by the umpire. Cricket is a game where the ball moves nearly 90Mph in most cases. Therefore we have to accept that it is very difficult to make judgments during a cricket mach. One of the most critical decisions made by the on field umpire is the LBW decision. This rule declares a batsman as out when a batsman intentionally or unintentionally try to stop the ball only using pads where the ball would hit the stumps if not [4]. Figure 7 will provide a clear idea about this rule. Before giving his judgment for a LBW appeal by the fielding team umpire has to consider several important points including whether the ball is pitched in line with the stumps, whether the ball makes an impact with the batsman while being along the line of the stump and finally the ball is hitting the stumps or not. Therefore it is clear that an on field umpire has to make the decision within a very short period of time. Hence there is a possibility of making a wrong decision which would affect the final decision of the game. As a solution for this DRS (Decision Review System) was introduced. Hawk Eye system is also a major part of the DRS system [6].

When the Hawk Eye system is been involved in the DRS system for a LBW decision it has to predict the entire trajectory of the cricket ball from the point it makes an impact with the body of the batsman up to the stumps. Therefore the trajectory of the cricket ball has to be extended beyond its last data point. The trajectory is displayed in figure 8.This extended trajectory will be displayed in screen showing what would happen if the ball passed the batsman without hitting him [4].

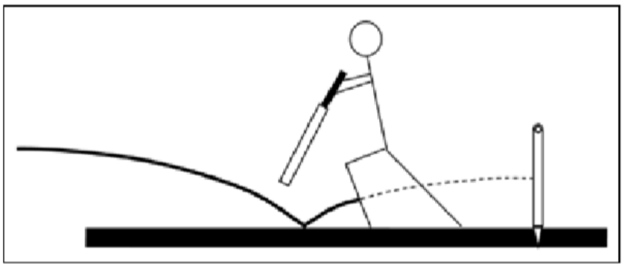

Fig-7

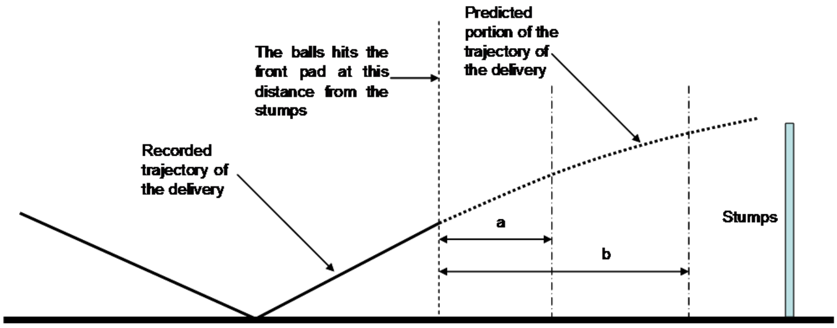

Fig-8

Now it is clear that this system is able detect the trajectory of the ball while predicting the path of the cricket ball assuming that the batsman is not present in the way. As a result of this it will help to detect the lateral position of the cricket ball with regard to the stumps and also the height of the cricket ball when it is in line with the stumps. With Figure 9 it demonstrates how the trajectory of the cricket ball is detected with regards to the facts mentioned above. This Figure clearly shows how the batsman is been removed in order to give a complete picture of the trajectory of the ball starting from the point where it left the bowlers hand [9].

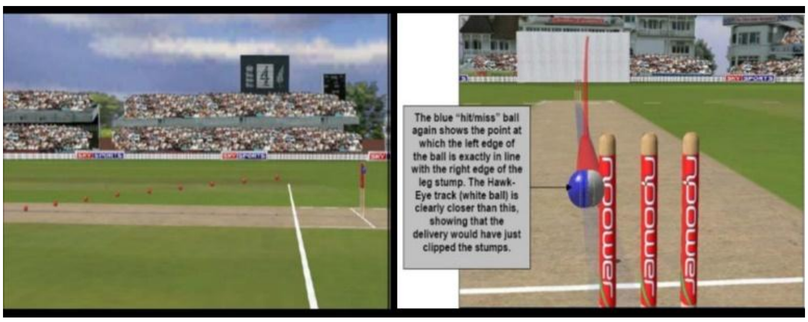

Fig-9

The LBW decision is associated with several rules. All the rules have to be considered before giving the decision. Therefore the Hawk Eye system has to be fully equipped with all the rules relevant to that decision. With the advancement of the system it has reached up to a level where it has the ability of handling almost all the rule relevant to the LBW decision. Hence the system has the ability of identifying whether the ball has pitched out side of the batsman's leg-stump. When the case is this, the decision is granted as NOT OUT even the trajectory of the cricket ball is shown as hitting the stumps as in Figure 10. Meanwhile it is important to detect whether a batsman is right handed or left handed. In order to do so the system uses the videos taken from the front view cameras. When the ball hits the batsman while being outside the line of the off-stump and he is also trying to play a shot, the batsman is not declared as OUT. If this is the situation the system has to track two things. First it has to track the point at which the ball hits the batsman and then it has to detect whether the batsman is offering a shot. This procedure is clearly shown in Figure 11. The system is not having the capability of detecting whether the batsman has offered a shot. Therefore that part has to be done manually [9].

Fig-10

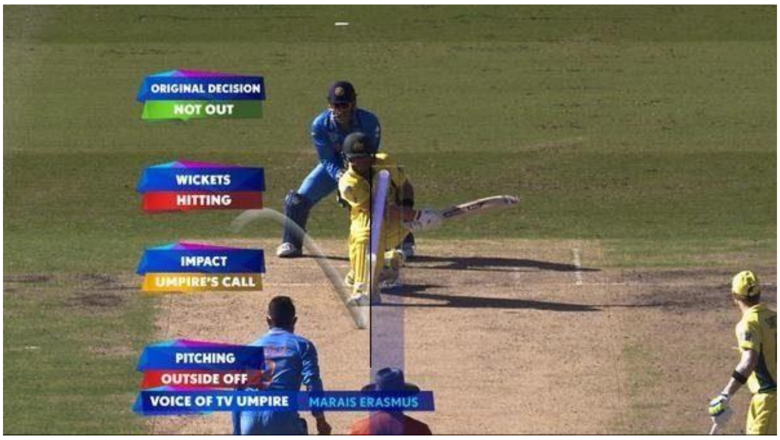

Fig-11

As a result of the uncertainty there is some amount of error associated with the Hawk Eye system. It will be discussed under the "Accuracy of the system".

Wagon Wheel

Another use of Hawk-eye technology in the game of cricket is producing different kinds of wagon wheels [1]. These wagon wheels demonstrate various statistics with regard to the shots played by a batsman. In order to perform this, the Hawk Eye system tracks the trajectories of the cricket ball after it is been played by the batsman [3]. By combining the relevant information the system has the ability of generating a graphic which demonstrate 6s, 4s, 3s, 2s and 1s scored by a batsman, entire team or in any other relevant way as shown in Figure 12. These information are been largely used by the broadcasting channels in order to improve the viewer's experience. By using these graphics commentators make their view point with regard to the shot selection [9]. Most often this information are used by the players in order to improve their skills, identify their weaknesses as a result this Hawk Eye system can be also considered as a practicing aid in the game of cricket.

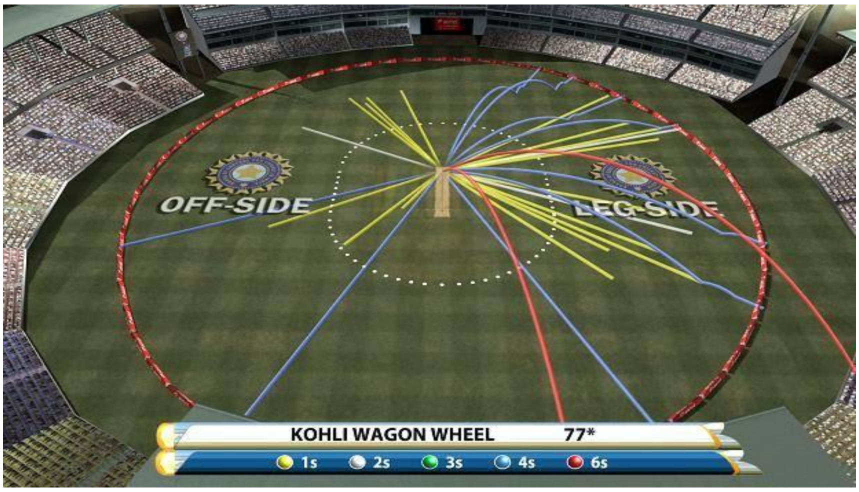

Fig-12

Pitch Map

This is also one of the very common uses of the Hawk Eye technology in the game of cricket. Here system tracks the location of the cricket ball where it bounces on the cricket pitch. By observing the Figure 13 it can be clearly seen that the cricket pitch is been divided in to different zones. These zones are divided based on the distance from the batsman. By using this graphic it enables to detect the exact places where the bowler pitches the cricket ball during the play. By analyzing these graphics it enables to get to know various strategies used by various bowlers according to different opponents they play, according to the type of pitch (slow tracks, fast tracks), according to various environmental factors (wind, humidity, sun light) and many such conditions. This also allows the batsman to assess their performance with regard to different types of bowlers and different length deliveries offered by the bowlers. Therefor these kinds of graphics can be also considered as a training aid for the cricketers while it was first implemented as a technique used in the field of broadcasting. This has resulted a lot for the vast improvement in the game of cricket during the past decade [9].

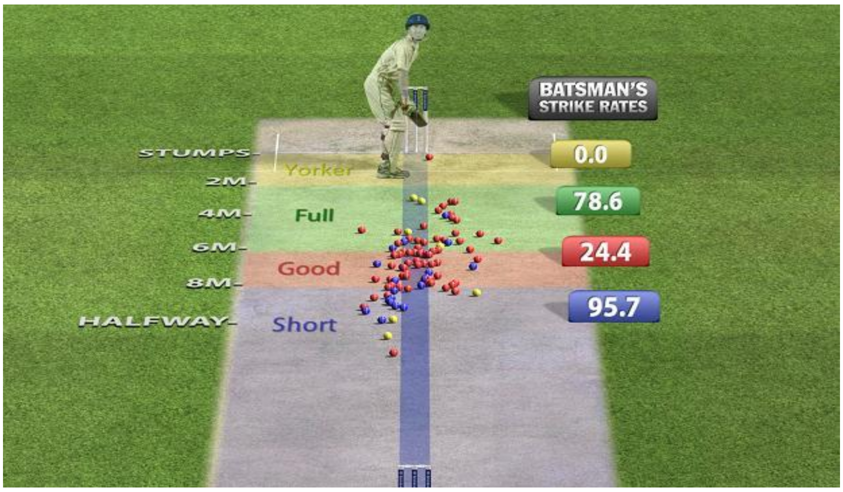

Fig-13

Despin Graphics

Despin is a very common type of graphic which can be seen while watching a cricket match. This is also a type of graphic which is been produced with the help of the Hawk Eye technology. The main idea behind this is to track the movement of the cricket ball after pitching on the surface. Most often this is used to track the movement of the balls bowled by the spinners. With the use of this graphic it will help to detect the plight produced by a spinner and the amount of spin that he is able to get from the particular surface. By analyzing these graphics a batsman is able to identify the tricks used by different bowlers in order to improve his game while not been beaten by the bowlers. Not only the types of deliveries (flippers, googlies, doostras) bowled by the spinners but also the types of deliveries (in-swings, out-swings, off-cutters) bowled by the fast bowlers also can be tracked with the help of these graphics [9]. More clear understanding about the despin graphics can be gained by observing Figure 14.

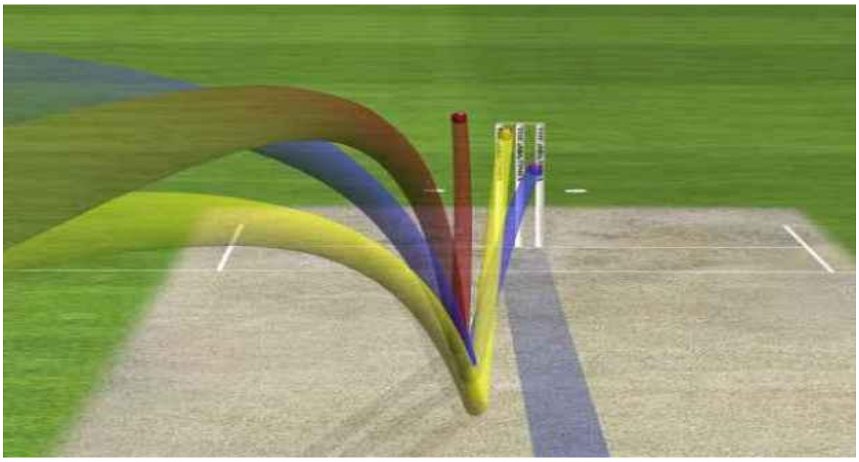

Fig-14

Beehive Graphics

Most commonly used type of graphic in the game of cricket which is used to depict the position of the cricket ball. The position is determined with respect to the plane belongs to the batsman. With the use of information regarding the trajectory of the cricket ball the system demonstrate a mark. This mark which is placed on the batsman's plane will demonstrate the points where the cricket ball has gone beyond or would have gone beyond the batsman. The system also has the capability of showing an analyzed version while demonstrating the deliveries where the batsman has scored in one color and the deliveries missed by the batsman in another color. As a result of this it has become very much easy to understand all the strengths as well as the weaknesses related to a batsman. While concentrating on these graphics a bowler can aim certain weak areas of a batsman to get rid of him without making much impact to the scoreboard [9]. Behavior of beehive graphics is shown in Figure 15.

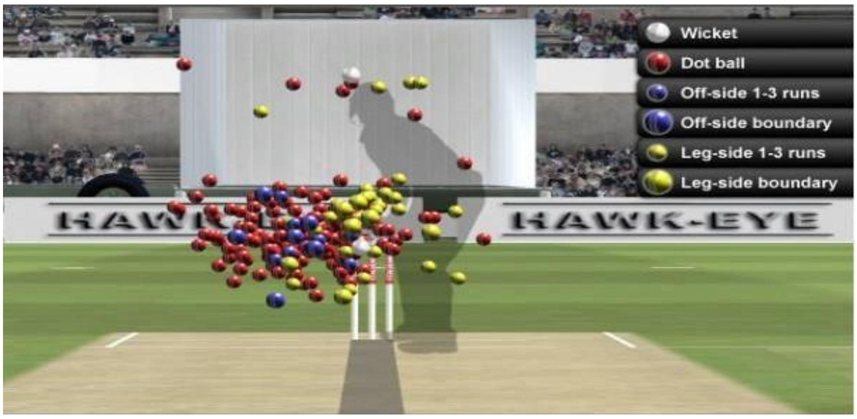

Fig-15

Uncertainty of the Hawkeye System

Almost all the systems in the world do not work 100% accurately. There is a tiny amount of error associated to most of the technological systems. Hawk Eye system will tend to make errors at certain instances. This happens as a result of not considering some factors which could make an impact to the trajectory of the cricket ball. The Hawk Eye system does not consider factors such as the amount of spin provided by a bowler, factors related to the environment (speed of the wind, condition of the pitch, flight made by the ball) [6]. As the decisions given in the game of cricket will directly effects the context of the game it is important to reduce the impact of the error of the Hawk Eye system to the final decision. As a solution to this two rules have been implemented with respect to the DRS system. Those are the "uncertainty range" and "250cm rule".

With regard to the LBW decision in the game of cricket, sometimes the on-field umpire is not sure whether the ball would have hit the stump or not. Hence there is a doubt. The benefit of the doubt is most often given in favor of the batsman. In order to aid this hawk eye was implemented. Even we use hawk eye in order to assist the on-field umpires decision there is a critical area which is known as the "zone of uncertainty". This area is located around the corner or the edge of the stumps which is about 55 millimeters (half of the width of a stump + half of the width of the cricket ball). When the ball is around this area the system is not in a position to over-rule the decision of the on-field umpire. In case where an umpire declares a batsman as not out and the fielding team reviews for it, the system will first track the trajectory of the cricket ball. Then the trajectory will be displayed. Even though the displayed trajectory is showing that the ball hits the stump in order to over-rule the original decision given by the on-field umpire the ball should hit the stumps 55mm inside to the outer edge of the stump otherwise the original decision given by the on-field umpire prevails. As such if the umpire declares the batsman as out, the decision by the on-field umpire will be over-turned only if no part of the ball is inside the zone of uncertainty. Figure 16 will help to get a better understanding about the zone of uncertainty [2].

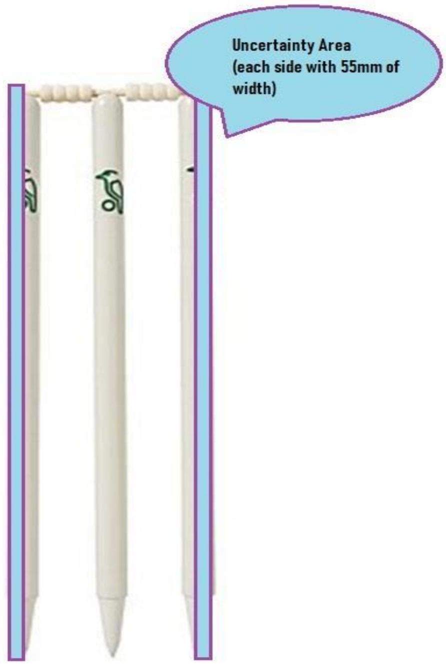

Fig-16

Other than the zone of uncertainty there is another consideration with respect to the LBW decision. Here the distance from the stumps to the impact point is measured. If the measured distance in greater than 250cm DRS will not be used. Instead the decision will be made by the on-field umpire with the use of normal cricketing principals. With the use of two rules (zone of uncertainty, 250mm rule) it will make a high accuracy to the decisions taken by the DRS system with the aid of Hawk Eye technology

Dependability of the Hawk Eye Technology

In order to find out the dependability of the Hawk Eye system which is used to aid the DRS system statistics regarding DRS decisions made during the cricket matches were gathered from the ESPNcricinfo website. ESPNcricinfo website is considered as the most popular cricketing website over two decades among the cricket fans all around the world. Hence the statistics gathered from this website is reliable.

The DRS Year By Year

Year	Matches	% overturned	Referrals/match	Overturns/match
2009	23	27	9.0	2.4
2010	18	30	7.4	2.2
2011	29	25	9.7	2.4
2012	23	28	9.3	2.7
2013	25	24	10.4	2.5
2014	34	21	9.2	1.9
2015	31	24	9.7	2.3
2016	32	32	12.6	4.0

Fig-17

Figure 17 demonstrates some statistics with regard to DRS decisions made during test matches played from year 2009 to year 2016. It is important to note that these statistics do not include the occasions where a team or a player should have revived or it is necessary to review but the allowed number of revives are over.

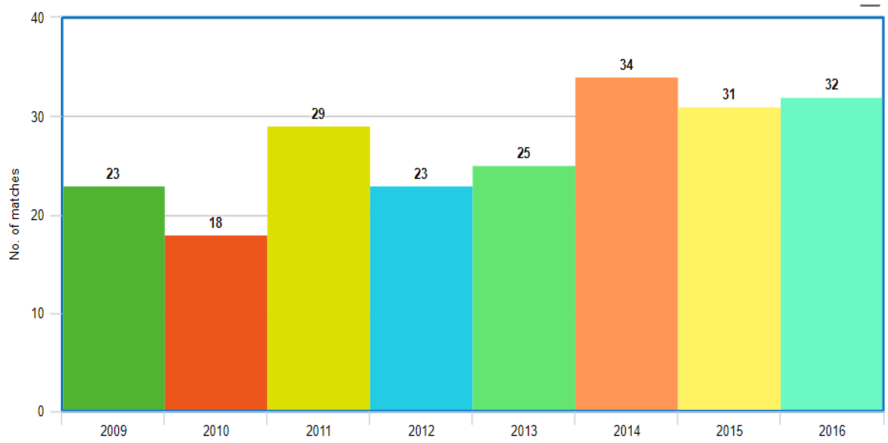

Fig-18

When this technology was initially introduced it was only used if the teams ask it to be implemented. Hence only few matches were played using DRS at the beginning. Figure 18 – Histogram will demonstrate the number of matches played while using DRS while using the statistics obtained from Figure 17. This histogram shows an upward trending pattern with respect to the years. Therefore it can be concluded that the dependability of the system forced the game to adapt this system. As a result at present all most all the cricket matches are been played while using DRS.

When a decision is overturned by the DRS system, it means that an on-field umpire has done a mistake. When we analyze the data regarding the decision over-turned percentage in figure 19 it shows that average of 26% of the decisions were over-turned. This means that for every 100 decisions which are been challenged by the players 26 decisions will change the decision made by the on-field umpire. This will result for changing the entire result of a cricket match. Hence it proves that how much dependable the DRS system in the context of the game of cricket.

DRS Success Rates (% Of Umpires Decisions Overturned) 2009-2017

Team	Success	Batting	Bowling
Zimbabwe*	34%	37%	29%
India*	30%	60%	18%
Australia	29%	36%	24%
South Africa	28%	36%	23%
England	27%	34%	23%
Bangladesh*	27%	43%	16%
Sri Lanka	25%	36%	19%
New Zealand	25%	36%	19%
Pakistan	23%	29%	19%
West Indies	23%	30%	17%

Fig-19

Figure 19 demonstrates some statistics with regard to DRS decisions made during test matches played from year 2009 to year 2017. The statistics include data regarding the success rates achieved by the test playing cricket teams with respect to their reviews. Meanwhile it will also provide data about the bowling and batting success rates with respect to each team.

When the data is analyzed it shows that in average 38% of the batting decisions are successful while only 21% of the bowling decisions are successful. This can be looked in another angle where it shows that 38% of the "out" decisions are been overturned when they are reviewed while only 21% of the reviewed "not out" decisions get changed.

Figure 20 – pie chart will demonstrate these averages clearly. It shows a reasonable gap between the success rates of batting decisions over the bowling decisions.

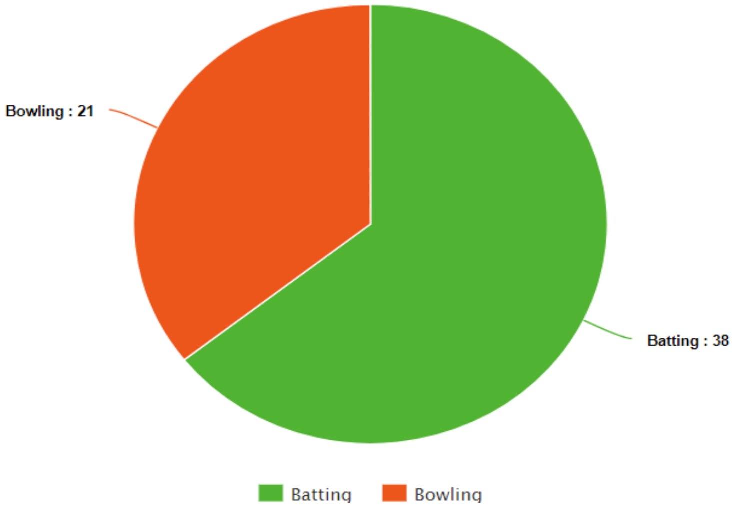

Fig-20

With all the above mentioned analysis it demonstrates the evolution of the DRS system with the Hawk Eye technology and how it has influenced to improve the complex of the game with respect to time while improving the dependability of the system.

DISCUSSION

Over a decade the term Hawk Eye is cohesively bounded with the game of cricket. Although it was not a lively part of the game it became so much popular among the cricketing world within a very short period of time. Even though it was popular, public understanding regarding the Hawk Eye technology is very much low. Hence this entire study was done in order to improve the public understanding about the technology while discussing about the technology behind the Hawk Eye, different types of uses of it in the game of cricket, uncertainty of the system and the adopted techniques to improve the accuracy of the decisions given while avoiding the uncertainties, how much dependable the technology for the game of cricket and the suggested future enhancements.

The main idea behind the technology is to track the trajectory of the cricket ball. In the process of tracking the trajectory first the video input from cameras are collected. Meanwhile the video input will be processed while considering about the speed of the cricket ball. Then the ball is recognized by the Hawk Eye system. With the help of the "Triangulation" principal 3D position of the cricket ball is determined. Software which uses statistical algorithms will be used to determine final trajectory of the ball while considering the trajectory determined by the video inputs and predicted trajectory.

Data gathered regarding the trajectory of the cricket ball is used in generating valuable information. One of the most important use of this technology is the assisting the DRS system while making the LBW decision. Here Hawk Eye tracks the path of the cricket ball from release point of the bowler while moving through the batsman up to the line of the stumps. This will help to determine whether the ball has hit the stumps. The most critical assumption is determining the path of the ball from the point at which the ball hits with the batsman up to the stumps. "Wagon Wheels" which demonstrate the shots played by a batsman, "Pitch Maps" where the bouncing points of the deliveries bowled by a bowler are visualized, "Despin Graphics" of the paths of the deliveries bowled and "Beehive Graphics" where the points at which the cricket ball passes a batsman are visualized with respect to the plane belongs to the batsman are the most common uses of Hawk Eye technology in the game of cricket.

The most critical decision made with the use of Hawk Eye technology is the LBW decision. It is because this decision affects the final result of the game directly. Therefore when DRS system is used to assist the LBW decision, the predicted trajectory has to be accurate. Hence Hawk Eye technology should be able to work exactly. When determining the trajectory of the cricket ball the system has to predict the path to determine whether the ball is going to hit with the stumps. This prediction might make a little error. In order to reduce the effect of this uncertainty the system use two strategies "uncertainty range" and "250cm rule". With all these implementations the system has achieved 99% accuracy.
This study analyzed data regarding the DRS decisions from year 2009 to year 2016 in order to determine whether the Hawk Eye technology is dependable. With that study it was identified that with the years the number of cricket matches

which were using Hawk Eye has been increased. And it was also found that 26% of the decisions made by the on-field umpire were over-turned. In the process of making referrals 38% of the reviews by the batting team were successful while only 21% of the bawling reviews were successful. This shows that Batting teams are more successful with regard to making positive reviews.

In the process of determining the trajectory Hawk Eye system do no not consider about the amount of spin provided by a bowler, factors related to the environment such as speed of the wind, condition of the pitch, flight made by the bowler. As a result of this there is an uncertainty about the predicted trajectory by the Hawk Eye system. As a remedy for this it was suggested to use physical stimulations which will consider the environmental factors. Therefore it will be able to maintain a high accuracy. This process will be supported by the GPU while allowing parallel architecture.

With the study it can be seen that since this technology was introduced to the game it has made a positive impact for the betterment of the game. This technology becomes more critical when it works with the DRS system in the process of making the LBW decision. During this process it can be observed that the benefit of doubt has been shifted in favor of the umpire. Earlier it was given in favor of the batsman. At the point of making a review by the fielding team, wicket keeper is mostly involved in taking the decision to take a review. Therefore he is under immense pressure. At the same time when the batting team makes a review batsman in the non-striking end is under pressure as he has to assist the striker in appealing for the review. When considering about the above factors it can conclude that the nature of the game is changing with the technology. Therefore it is important to improve the quality of the game with the new technology while conserving the original nature of the game.

The benefit of the doubt has shifted in favor of the umpire as Hawk-Eye technology is not pin point accurate. In order to reduce the effect of that uncertainty on the decision given benefit of the doubt has shifted toward the on-field umpire. If it is possible to make improve the accuracy of the system then it will again shift the benefit of the doubt towards the batsman. In the process improving the quality if the frame rate of the cameras used in the Hawk-Eye can be increased then the gap between the frames can be reduced. As a result it will give a more accurate trajectory. Meanwhile in the process of predicting the trajectory beyond the batsmen’s point of intersection, if it is possible to consider all the environmental factors which affects the movements of the ball it will give more accurate prediction. It is better to use physical stimulations as mentioned above with the existing technology.

CONCLUSION

The study discussed about the technology, different uses, dependability, and uncertainty and suggested future enhancements with regard to the Hawk Eye technology in order to give a better understanding to the public. It can be observed that this technology is highly bounded with the game of cricket in many aspects. There for the technology should be developed in such a way that it will not make a negative impact on the nature of this beautiful game.

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