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A modern approach to determine the offside law in international football

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Abstract

The outcome of football matches is heavily dependent on referee decisions regarding violations of the offside rule. Football players should decide the outcome of the game rather than the referees. Instead of technology discrediting the ability of referees it should be adopted into the game to increase the accuracy of the offside decision. A system has been proposed that uses player tracking technology to quantify players' positions and runs an algorithm to determine which players are offside. The likelihood of algorithm error is dependent on the accuracy of player tracking technology. It was found that algorithm accuracy is improved by increasing the sampling rate and precision of player tracking technologies. The most suitable technology form for use in the proposed system is camera based player tracking. No device is required to be worn by players and body segment positions can be determined to ensure the offside law is completely adhered to. Before this proposed system could fully function a series of improvements must be made to the proof of concept model.

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1. Introduction

Offside is one of the most critical decisions football referees make during the match. Attacking players who are involved in the offside decision are often part of a goal scoring opportunity. The offside law is specified by FIFA. The law states that if a player is in an offside position when the ball is played by a teammate, he/she may not become actively involved in the play. An offside position is taken when the player is nearer to the goal line than

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both the ball and the second to last member of the defensive team. The preceding statement only applies when in the opposition half of the field. FIFA (2013) states that being “nearer to an opponents’ goal line” refers to “any part of the player’s head, body or feet”, however the “arms are not included in the definition.” To become actively involved a player can touch the ball, obstruct opponents, intrude opponents’ line of vision or gain advantage from being in the offside position. Advantage can be gained if the ball rebounds off the goal frame or a player (FIFA, 2013).

Previous studies have revealed failure rates for offside decisions of 12% at the 2009 Confederation Cup, Mallo et al. (2012), 10% at the 2006 World Cup and 26% at the 2002 World Cup, Catteeuw et al. (2010b). Debate occurs whether technology should be used to assist referees in their decision making process. As of the 2013/14 season the English Premier League will implement goal line technology to ascertain whether the ball has fully crossed the goal line. This decision proves that governing bodies believe technology can be used to enhance game officiating. This shift is vital to the perception of referee integrity.

Video replay technology has long been used to verify the calls and performance of referees. Rather than shame referee capabilities, video replay technology has been suggested to aid the offside decision process. This method dictates a time delay before the decision is made. Players, fans and FIFA oppose time delays. To overcome these issues a new system has been developed to enhance the offside decision process.

Player tracking technology has vastly improved analysis of players’ physical capabilities as well as technical data relating to tactical positioning. Camera tracking, GPS and radio frequency (RF) methods are used to ascertain player positions. Camera tracking involves complex algorithms deciphering visual information to identify where players are on the field. GPS units are traditionally located on players’ chest or neck and use triangulation methods from satellites to locate players. RF systems use a signal strength analysis tool to measure the distance a player’s beacon is away from fixed points around the stadium. These reference positions allow players’ positions to be identified on the field by triangulating the distance from each fixed marker. The proposed system will utilize these quantified player positions to determine offside.

2. The System

2.1. Hardware

A prototype watch been developed to prove the systems concept. It houses: a lithium ion battery, Xbee wireless transceiver, LCD display and two buttons to select the team in question. The Xbee module is configured in transparent mode to allow any wireless data packet received to be directly transferred to the serial LCD monitor. Another Xbee is located in the ‘base station’ on the side of the field. Here a computer is fed with the wireless Xbee data as well as player positions. Team selection is achieved by pressing one of two buttons located on the watch’s top surface. These buttons determine the states of two Xbee pins. The corresponding pins of the Xbee located on the sideline are directly governed by the state of the watch’s Xbee pins in a configuration known as I/O line passing. When a button is pressed on the watch the base station can immediately begin to run the algorithm.

2.2. The Algorithm

To determine which players are offside at a given time an algorithm is run to firstly find the second last defender and then compare every player from the attacking team against this reference. Players are identified by their jersey numbers and by their team. The reference is created using a bubble method in which the largest of a series of values rises to the top. The second largest is then taken for comparison. Each player from the attacking team is compared against the defending team’s reference. Those players who exceed the reference position have their jersey number added to an array. Once all players have been compared, the jersey numbers of offside players are sent as a wireless data packet back to the referee’s watch to be displayed on the LCD monitor.

2.3. Use of System

System functionality is dependent on the referee pressing the applicable button at the appropriate time. As a player passes the ball forward or shoots the referee must press the button related to that player's team. Once this has occurred the players in an offside position have their jersey numbers printed to the LCD. At this time the referee must decide whether these players are involved in play. If he deems they are he signals for the free kick.

3. Simulation

To determine the accuracy of the system for offside decision making a series of simulations were completed in MATLAB. The first simulation was used to ensure perfect accuracy was achieved when optimal conditions were present. This ideal scenario entails player locations completely specified with no error. To prove algorithm functionality the results from computer simulations were manually compared to the expected results. Having verified the algorithm works under ideal conditions, simulations involving error in player position were completed.

Each player tracking technology has a degree of error associated with the player positions. Any input error the algorithm accepts is likely to produce error in the output. To quantify the influence of positional error on the accuracy of the system another MATLAB simulation was completed. The independent variable in this experiment was the maximum magnitude of the error from the tracking technology. The dependent variable was the accuracy of the algorithm over 10,000 randomly generated player positions.

Another source of error produced by the tracking technologies occurs due to the sample rate. The time delay between samples produces error as the players continue to move between samples. The third simulation was completed to determine the influence sample rate has on the accuracy of the algorithm. The independent variables were the sample rate of the tracking technology and the velocity of players, while the dependent variable was the accuracy of the system over 10,000 trials.

A final simulation was completed to determine the influence of all independent variables on the common dependent variable. The combination of player velocity, tracking technology precision and sample rate was trialed simultaneously to reflect their influence during normal play. The values used were representative of current tracking technologies.

During the simulations the outcome of two trials were compared. One trial involved no player error, while the other had position error present. If the offside decision was different between the two trials a counter was increased. Algorithm error was found by dividing this accumulated counter by the 10,000 trials.

4. Results

4.1. Initial Algorithm Verification

After extensive manual verification the algorithm was deemed to work perfectly when presented with ideal player positions. Fig. 1a. reveals how manual verifications were made. The result of the algorithm is displayed on the screen, as the text; 'OFFSIDE' or blank for not offside. This result was compared by the researchers against the location of the players also presented in this image. Only slight alterations to the algorithm were required to obtain ideal outcomes.

4.2. Influence of Error in Player Positions

Fig. 1b. affirms the notion that as player position error increases the likelihood of error in the algorithm increases also. This relationship is a linear one. The range of error used for simulation reflects the range of typical error values associated with various player tracking technologies. Camera tracking typically has error values in the order of centimetres, while GPS based tracking has errors of multiple metres.

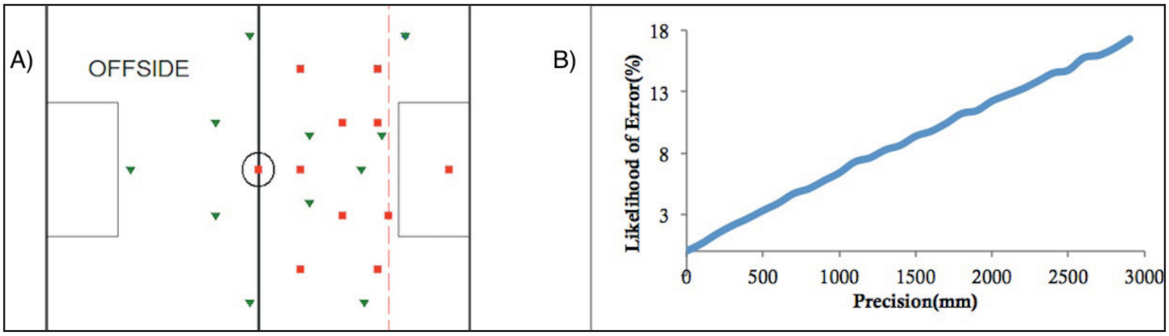
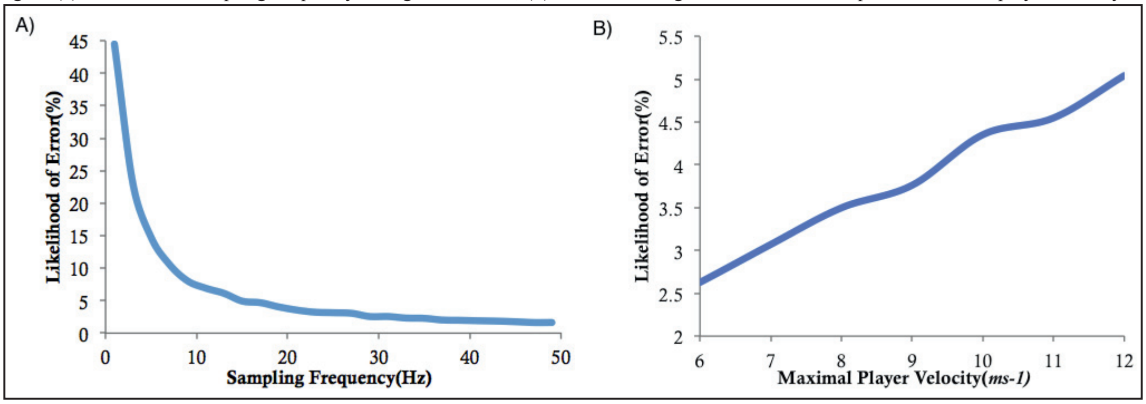


Fig. 1. (a) Manual Verification Plot; (b) Relationship between player position precision and algorithm accuracy

4.3. Influence of Velocity Vector

As players move across the field of play they are tracked in discrete intervals rather than continuously. The difference between these discrete intervals is proportional to the sampling frequency of the tracking technology and the velocity of player movement. Fig. 2a. suggests that an increase in sample frequency directly results in a lower likelihood of error. The influence of player velocity is shown in Fig. 2b. with a fixed sampling frequency. A player moving with a higher velocity is more likely to produce an error in the algorithm.

Fig. 2. (a) Influence of sampling frequency on algorithm error; (b) Variance of algorithm error with respect to maximal player velocity



4.4. Real Tracking Technology Characteristics

Table 1 contains the results of simulations completed in MATLAB when values quintessential of various tracking technologies were used. Rather than using a range of input values to identify their influence on system accuracy, real values from tracking technologies were used to outline how various technologies produce different algorithm error rates for the given system. The player velocity used for these simulations was 12 metres per second. All tracking technologies would have lower practical algorithm error, as players do not always move at full speed. However for theoretical purposes the maximal error was calculated. The single hertz frequency of GPS units produced very large errors, as players were able to move multiple metres between samples. Much more acceptable errors were produced by the RF and camera technologies. This was accredited to the higher sampling frequency.

Table 1. Simulation results using typical values of various tracking technologies

Tracking Technology		Sample Rate(Hz)	Precision(m)	Algorithm Error(%)
GPSports SPI-Elite	Coutts and Duffield (2008)	1	2.0	47.68
GPSports WiSPI	Coutts and Duffield (2008)	1	0.7	45.95
LPM	Frencken et al. (2010)	45	0.03	1.90
Optimeye T5	Catapult Innovation, Melbourne, Australia	10	0.2	8.73
Hawk-Eye	Hawk-Eye Innovations, Basingstoke, England	60	0.03	1.53
VICON	Duffield et al. (2010)	100	0.3	2.71

5. Discussion

The theoretical accuracy of the algorithm was extremely important during algorithm development. However the practical applications of the algorithm are far more relevant for implementation. All player positions presented to the algorithm have a degree of error. For this proposed solution to be considered an enhancement of the current human based system the algorithm error must be lower than current referee inaccuracies. These errors are associated with limitations of the human visual system as outlined by Maruenda (2004). The error values found by Mallo et al. (2012) and Catteeuw et al. (2010b) provide the basis for comparison.

The results of numerous simulations suggest that the proposed system would greatly enhance the offside decision. For example if Hawk-Eye were to be implemented the chances of an offside decision being incorrect are drastically reduced from 12%, Mallo et al. (2012), to as little as 1.53%. This elevated offside decision accuracy is the result of technology being used to assist the referee. With less of the referee's attention required along the offside line the quality of other refereeing decisions should also improve as less of the 'on ball' action is missed.

However not all tracking technologies are of sufficient accuracy to be implemented in the proposed system. Any combination of frequency and precision that produces an algorithm error less than the error rates specified by Mallo et al. (2012) and Catteeuw et al. (2010b) are considered to assist referees make more accurate decisions. Those with sampling rates above 40Hz and precisions below 0.3m have been deemed acceptable for use. Systems with these characteristics are either camera based or involve radio frequency positioning techniques.

The role of player tracking is not limited to player position. Velocity, work rate and distance covered are an example of the data player tracking was originally designed to identify. However these technologies have far greater implications on the games outcome if player positions can be used to aid the offside law.

For this system to be deployed into international football matches a wide range of practical considerations are required. Football associations from countries such as England and Germany use these types of tracking technologies in their top divisions. Each stadium in these leagues, and others, are fitted with technology adequate for use with the proposed system.

6. Implementation

Paramount to the realisation of this system is the interaction it holds with the main referee. A prototype watch has been developed that houses all the necessary components to allow the system to work during real match situations. This watch features an LCD display, lithium polymer battery, Xbee wireless transceiver and two buttons. When the referee observes a forward pass played, he/she presses the button corresponding to the passing team. At this point the wireless transceiver relays the signal to the 'base station' for the algorithm to begin. If any players are in an offside position their jersey numbers are sent back to the watch to be displayed on the LCD. It is then up to the referee to determine if the specified players are actively involved in play. The referee then signals for an offside infringement if this is the case.

Video replay methods have been suggested to solve the issue of incorrect offside decisions. The fundamental flaw of this system is the delay in the match as the referee waits to hear if the player was offside. FIFA and fans alike fiercely oppose this delay. Thus smooth game flow must occur with the proposed system. Improvements to the proposed system include redesigning the referee's whistle to have the two buttons on each side. This feature would allow the referee to have quick access to the buttons, as the whistle will remain in his hand at all times. A second enhancement would incorporate a speaker into the watch to alert the referee if any players are offside. This alert would negate the need for the referee to constantly monitor the watch.

The unique situations that can occur during a football match mandate that a technician monitor and interact with the base station. One example of this requirement is the need to alter players in the algorithm when substitutions occur.

7. Conclusion

The veracity of this system is directly proportional to the accuracy of the player tracking technology. Having verified the algorithm with no positional error, a series of simulations were completed to define the relationships that sampling rate, player velocity and precision each have on algorithm accuracy. Increasing the sampling rate drastically increases accuracy of the algorithm as changes to player positions are more frequently updated. Maximal player velocity had less influence on algorithm accuracy than the sampling rate and precision of tracking technology. In all simulations not studying velocity, the player velocity value implemented was 12 metres per second. Such a high velocity represents a worst case scenario for simulations.

Algorithm accuracy is also increased when the tracking technology can more precisely locate the players to their actual position. The characteristics of real tracking technologies were used to identify what type of tracking technology can be implemented to increase the accuracy of offside ruling. It is concluded that camera tracking is the optimal source of player position data as the high sampling rate and precision values produce desirable algorithm outcomes. Camera tracking also mitigates the need for players to wear any devices to monitor their location. Although still in its infancy stages the proposed system is theoretically capable of providing more accurate offside decisions. Alterations are required before real game use can occur however the hypothetical implications of the system have been established.

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