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# Analysis of Goal Line Technology from the perspective of an electromagnetic field based approach

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**Abstract**

The aim of this work is to analyze Goal Line Technologies with focus on the electromagnetic field based approach GoalRef™. This paper will give an overview of the requirements that must be fulfilled by to get approved by FIFA. The existing solution approaches will be described and possible environmental influences like occlusion or deformation of the ball that can affect the system's performance will be discussed. Afterwards, GoalRef™ will be presented in detail.

Finally measurement results for one test scenario in the lab will be presented to validate the system approach and to determine the potential accuracy range of the system.


Selection and peer-review under responsibility of the Centre for Sports Engineering Research, Sheffield Hallam University

Keywords: Goal Line Technology, GoalRef, Football, Tracking

**Nomenclature**

| | |
|---|---|
| FIFA | Fédération Internationale de Football Association |
| IFAB | International Football Association Board |
| RFID | Radio Frequency Identification |
| GLT | Goal Line Technology |


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## 1. Introduction

The ‘Wembley Goal’ in the World Cup final 1966 between England and Germany is probably the most famous goal in the history of football. The question whether it was a goal or not has been an open problem for decades. In 2012, after a long period of evaluation of different technologies, the International Football Association Board (IFAB) approved the use of Goal Line Technology (GLT) in official football matches. The objective of a GLT system is to provide a clear indication to the referee –typically on a special watch- whether the ball has fully crossed the line. Fraunhofer IIS conducted research work on the electromagnetic field based solution GoalRef, which is one of the currently licensed GLT systems.

## 2. Requirements

There are several requirements a GLT system has to fulfill before it is allowed to be used in official matches. These are stated in the FIFA testing manual (FIFA, 2012) and they range from material tests in the lab to system tests under real game conditions and aim to guarantee a fully functional GLT system. There are three stages on the way to the pitch that have to be passed. First of all, in order to get licensed by FIFA, a system check guarantees the system to work even under adverse conditions. This has to be checked in a slightly modified manner for every stadium during the final installation test. This is usually done by an independent test institute and guarantees the installed system to work like the system tested during the system check. Finally, before kick-off the referee performs some short tests to ensure that the system is working properly.

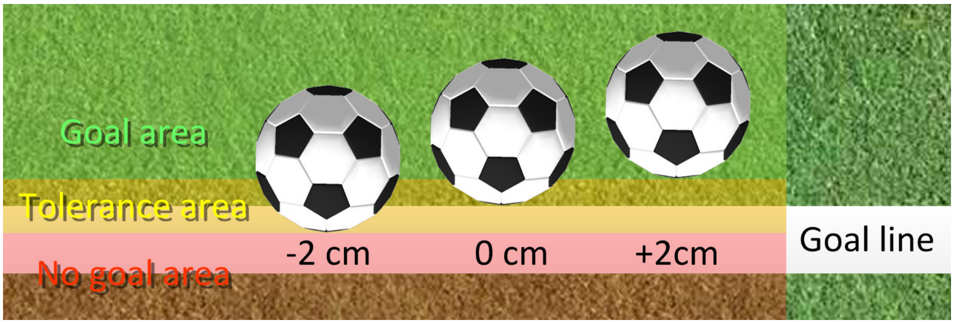


Fig. 1. Goal decision areas.

The present paper focusses on the accuracy of a GLT system. These are based on dynamic tests with a target wall that has to be passed with an accuracy of ±3cm and a slider test that allows to determine the offset where a goal is triggered (±2cm). Fig. 1 shows the areas relevant to the slider test. Balls in the no goal/goal areas always have be detected as no goal/goal. The area in between (±2cm from the back side of the goal line) is a tolerance area, in which a goal and no goal decision will be accepted.

## 3. Solution Approaches & Influencing Factor

### *3.1. Solution approaches*

Today there are two approaches for realising a GLT system. One is a video-based approach and the other is an electromagnetic field based approach.

The video-based approach generally consists of several (e.g. 2×7) high-speed cameras with fast lenses mounted nearby each of the goals (Hawkeye, 2013, Goalcontrol, 2013) and an infrastructure to connect all cameras to a high performance computer cluster. To guarantee best view the cameras are mounted on different positions above the field at the catwalk or other construction elements of the stadium roof. The data of all 14 cameras is streamed to the computer cluster, where sophisticated image processing algorithms detect the relevant ball (as well as to distinguish it from similar objects) and decide whether the ball has fully crossed the line.

In an electromagnetic field based system the ball may be equipped with electronic circuitry for transmitting and/or receiving and/or reflecting electromagnetic signals and therefore require electronic components inside the ball, wherein the size of the electronics may differ depending on its functionality and the used frequency range. The electronic may be installed within the ball's center or for systems using magnetic fields in the sub-MHz range, the required loop antennas and/or the further electronic components may be installed on the circumference of the ball. Additionally an electromagnetic receiving and transmitting element is required, which is normally installed on or close to the goal frame or buried in the ground.

All of these approaches are able to detect a goal under perfect conditions without any external influences. In practice there are several adverse environmental conditions, which could degrade the precision of the system. Under all these conditions a GLT system has to keep its precision within the required tolerance.

### *3.2. Influencing factors*

#### *3.2.1. Ball speed*

The most influencing factor is the movement of the ball itself. Typical ball speeds during a game are 50-80 km/h, but can sometimes reach speeds up to 140 km/h. Fig. 2 shows the relation between speed and displacement of the ball for different frame rates. The figures can also be used for the measuring rate of electromagnetic field based approaches. At high speeds of 140 km/h the ball travels app. 4 cm within a period of 1 ms, which is the time between two frames at a frame rate of 1000 Hz. A resolution of 1 cm requires a frame rate of app. 4000 Hz. In practice additional positions between two frames can be calculated using algorithms to determine the trajectory of the ball, so that lower frame rates are possible.

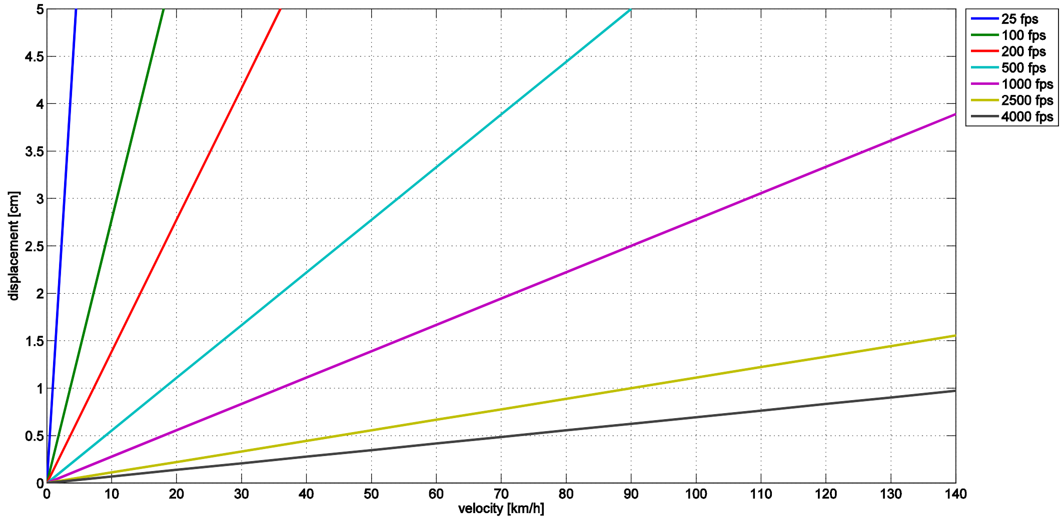


Fig. 2. Relation between displacement and ball velocity for different frame rates.

#### *3.2.2. Ball Compression*

Depending on its speed, the ball will be compressed when hitting against an obstacle like a player's leg or the goalpost. The rule of the game define that a goal is given, when the ball has completely crossed the goal line. Hence when a ball is compressed, its diameter decreases, which has to be taken into account. This is a challenge for both approaches.

*3.2.3. Light conditions*

Obviously light conditions as sun, shadow, rain or snow do not have any influence for any kind of electromagnetic field based system but have to been taken carefully into account for all kind of video based systems. The illumination of the scene strongly influences the choice of cameras and lenses.

Relatively slow changes of light conditions (e.g., cloudy sky) will easily be balanced by the signal processing, whereas rapid changes as snow fall or heavy rain will be a real challenge for the processing unit – as well as sharp edges of bright light and shadow nearby the goal or even between both goalposts.

*3.2.4. Occlusion of the ball*

In football games the ball is often hidden by players. It can seem that the ball is completely occluded, but in most cases, the ball can partly be seen from other perspectives. Hence video based systems have to use several cameras to generate different perspectives of the goal to ensure to detect parts of the ball even under heavy masking effects.

Electromagnetic field approaches do not have this problem since the low frequencies used are immune against human bodies and environmental conditions like rain or snow. As a result, the detection accuracy is not affected by obstacles and the system works even under full occlusion.

## 4. GoalRef System

The electromagnetic field based solution GoalRef is based on a RFID approach. It consists of a reader generating an exciter signal at a low frequency of 119 kHz, the exciter loop, which is a current-carrying conductor embracing the goal frame, loop antennas in the ball, one or more receiving antennas around the goal frame and a receiving unit inside the reader.

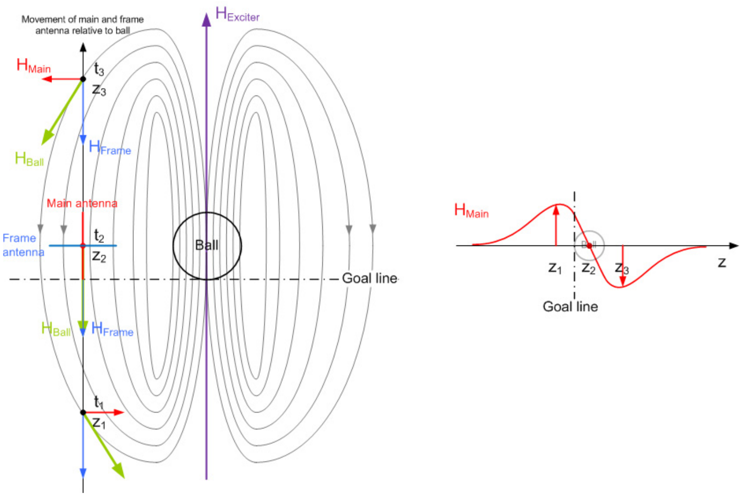


Fig. 3. (a) Working principle of the GoalRef system; (b) Amplitude of magnetic field main antenna component over z.

Fig. 3 (a) shows the working principle of the GoalRef system. It shows a top view on a ball within the systems range. The reader with the exciter loop antenna creates an electromagnetic field ($H_{Exciter}$) perpendicular to the goal frame. This field vector stimulates the purely passive loop antenna in the ball, which reflects back a part of the exciter field ($H_{Ball}$) which is received by antennas attached to the goal frame. One receiving antenna consists of two orthogonally arranged loop antennas, the so called main- and the frame-antenna ($H_{Main}$, $H_{Frame}$). These receiving antennas are symmetrically arranged around the exciter loop wire, with the loop conductor placed exactly in the middle of the receiving antennas. With this antenna construction it is possible to determine the orientation of the incident magnetic field vector ($H_{Ball}$) of the backscatter signal of the ball.

The exciter loop antenna, together with the receiving antennas, are mounted exactly at a distance equal to the radius of the ball ($z_2$) behind the goal line. Hence when the ball completely crosses the goal line ($z_2$, $t_2$), the loop antenna in the ball is exactly in line with the exciter loop and the receiving antennas. The magnetic field vector $H_{Ball}$ is then exactly perpendicular to the frame-antenna, which means that the frame-antenna component $H_{Frame}$ is getting its maximum and the main-antenna component $H_{Main}$ is getting zero. In other words, a ball crossing the goal line is resulting in a zero crossing of the amplitude of the main-antenna magnetic field component as shown in Fig. 3 (b). Note that for reasons of clarity only the envelope signal $H_{Main}$ is shown in Fig. 3 (b), omitting the carrier signal. The purpose of the frame-antenna is to decide whether the ball crosses the line inside the goal frame or outside the goal frame. The signal amplitude of the frame-antenna is inverted, when the ball passes outside the goal frame.

The receiver stage in the reader converts the modulated carrier signal, which corresponds to the amplitude of the magnetic field. The antenna signal is amplified, sampled by an Analog-to-Digital-Converter at a sampling frequency of 1 Mbit/s, digitally down-converted to baseband and low-pass filtered to increase signal to noise ratio. At the output of the receiver the signal is available at a sample rate of 2500 Hz. The receiver output signal is analyzed by detection logic in the server software. The signals from several antennas are combined to get a more reliable result. The software algorithm is detecting the zero crossing in the signals and triggers a wireless communication link to the referee watch, which indicates the detected goal to the referees.

Fig. 4. Three orthogonal coils inside the ball.

This approach needs to integrate passive loop antennas into the balls but allows on the other hand a clear identification of the ball. No algorithms are necessary to distinguish the ball from other objects like players in a camera picture. This reduces system complexity. For achieving detection properties which are rotationally invariant, three orthogonally loop-antennas are placed inside the ball (Fig. 4).

## 5. Test setup

In order to determine the accuracy of the electromagnetic field based approach a static test at one goal in the lab has been performed which is based on the slider test as stated in the FIFA testing manual. The exact point at which the GLT system triggers and indicates a goal is measured. The goal frame is equipped with an exciter wire and several receiving antennas mounted around the goal frame. The signals of the antennas are recorded by the reader and analysed to derive the goal decision. The goal decision is generated in the PC and the information is sent to the referee watch. During the test, the referee watch has been observed.

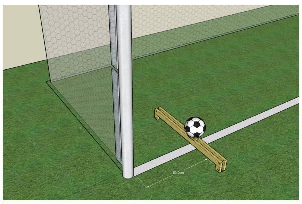

Fig. 5. Test setup.

The test has been performed with a test ball with a single effective coil perpendicular to the exciter field. The intention of the test is to determine the system performance limit without any influencing factors.

Therefore a slider is placed on the goal line to slowly move the ball (approx. 1cm/s) across the line. A precise measurement of the location of the coil when the system is triggered is possible in this test.

The frame of the slider is positioned over the goal line at 0.8 m from the left post and aligned to it. With the ball on the bars, the position of the goal event is assessed using a plumb line (orthogonal to the pitch and the inner edge of the goal line). To start the measurement, the ball is taken from a position where it is clearly outside the goal and placed on the outer end of the slider. The operator is working from the goal mouth and moves the ball continuously across the goal line until the GLT system indicates a goal on the referee watch. At the point, where the system has detected a goal, the movement is stopped and the offset of this position to the geometrical goal line is measured. The test is repeated with the slider positioned in the centre of the goal at 3.6 m. The ball is moved at a height of about 50 cm above ground perpendicular to the goal frame as depicted in Fig. 5. This was done five times for each of the two positions.

## 6. Results

The results are shown in Table 1.

Table 1. Goal detection positions compared to the geometrical goal line.

| Measurement | 1 | 2 | 3 | 4 | 5 | Mean Value | Standard Deviation. |
|---|---|---|---|---|---|---|---|
| Difference to real goal line @ 0.8 m | 1.7 mm | 2.3 mm | 3.5 mm | 3.3 mm | 4.0 mm | 3.0 mm | 0.9 mm |
| Difference to real goal line @ 3.6 m | 1.4 mm | 0.7 mm | -1.0 mm | -0.6 mm | -3.6 mm | -0.6 mm | 1.9 mm |

Negative values indicate that the system detects a goal before the goal line whereas positive values indicate that the detection was behind the goal line. The mean values are +3.0 mm at 0.8 m distance and -0.6 mm at 3.6 m distance from the goal post. Since the measurement has been done manually, there could be some reaction time between observing the goal decision on the watch and the stop of the movement of the ball. Taking this into account the system detection threshold is pretty close to the real zero point. The standard deviation is below 2 mm for both positions.

## 7. Conclusion

This paper has tried to give an overview to the actual status of GLT for football, to the different solution approaches and the influencing factors in real operation. The presented electromagnetic field based solution GoalRef offers some advantages over video based systems. It can detect the ball even under full occlusion, since no line of sight is necessary and it offers simple detection of the ball with an update rate of 2500 Hz. Finally the lab measurement results show the potential precision of this system approach, which could be down to a few millimeters.

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