Virtual lines for offside situations analysis in football

Karim Ferreira Lima, Rodrigo Marques de Figueiredo, Eduardo Augusto Martins and Jean Schmith
Escola Politécnica
Universidade do Vale do Rio dos Sinos - Unisinos
Av. Unisinos, 950
CEP 93022-00, São Leopoldo, Brasil

***Abstract*—Offside is one of the situations that is analyzed by the Video Assistant Referee (VAR). However, it has caused some controversy due to the delay in the analysis and definition of the irregularity. This work proposes a method that helps in the analysis of offside situations and also makes it available for non-professional matches. Here, image processing algorithms were used to determine offside situations in football matches from TV videos, of course, in accordance with the game regulation. The method includes the image vanishing point identification, camera calibration and the virtual offside line drawing. The method presented good results from 10 videos selected for analysis, with five from the right side of the field and five on from the left side. Among the videos, one was chosen as the basis for explaining the development of the method and demonstrate a situation with a virtual line drawn automatically, therefore determining an offside situation. As a result, the virtual line is identified by the color red when the manually selected player is in offside and green when he is not.**

Keywords: Football Offside, Virtual Offside Lines, VAR, Digital Image Processing.

I. Introduction

Offside is a specific rule in the official football (soccer) regulation and it is responsible for one of the great controversies of the game. There is a certain complexity in determining the infraction during the game and it often generates confusion, or even irritability, between the players, referees and spectators. According to the IFAB [1], the offside is established when a player is in the opponent's defense field, closer to the goal line than the last opposing player, and he touches the ball. In other words, knowing whether or not the athlete is actually in offside is a very complex task, especially when the difference is minimum between players involved. The situation become even worst when the offside is analyzed with naked eyes in extremely fast situations.

Previously, several studies and systems for automatic analysis of offside situations through images were introduced in sport, either academically or even as a form of validation in official championships. An example is the system proposed by Hashimoto and Ozawa [2], they used 16 fixed cameras spread out on both sides of the field and analyzed offside situations based on homographic tracking and classification of players. Another work proposed by D'Orazio et al [3] investigated the feasibility of a system with exactly six cameras, arranged in different places on the field, to perform a real-time detection of the players and the ball due to automatically determine an offside situation.

Since 2018, football has the technology called Video Assistant Referee (VAR) which was included in the official rules of the game. The VAR is a tool that has the task of supporting the referee's decision-making process using video technology. Although, VAR is allowed to interfere in the match only in specific situations. Offside is one of those situations. Offside is an infraction that may lead to a goal and the VAR verifies the irregularity by creating Virtual Offside Lines (VOL), which are graphically superimposed lines on the field helping on determining the infraction. However, the technique used in VOL creation has some manual operations, which presents a delay for the system's response causing a certain degree of irritability and discomfort in players and fans. In addition, another factor that is unfavorable to VAR is that the implementation and use of its technology requires a high investment by clubs for the field calibration. Therefore, many teams or small leagues may not be able to use the VAR benefit.

Hence, this work propose a method that aims to develop a tool to help the analysis of offside situations in selected players, in order to make the system more autonomous, with low implementation investment and also that it can be used in non-professional games. The methods and techniques used are presented in section II. Simulations and analysis of the method results are formalized in section III. Conclusions, future work and a discussion of the proposed method against VAR technology are provided in section IV.

II. Materials and methods

For the proposed method, the Python programming and the library for digital image processing Open Source Computer Vision Library (OpenCV) [4] was used. As example to show the method, the input data is a video extracted from the last match of the 2020 Brazilian Football Championship (Brasileirão), between Sport Club Internacional (red shirt) and Sport Club Corinthians Paulista (white shirt). All the videos are freely available at Globo Esporte[1] website. In Fig. 1, the first frame of the video is shown, where the Internacional team is making an attack and one of its players was in irregular position when received the ball.

[1]ge.globo.com

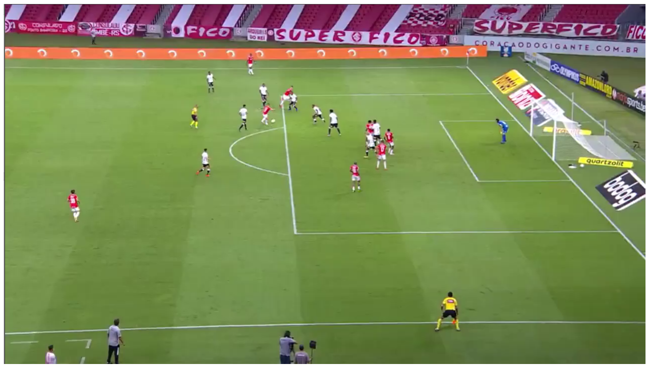

Fig. 1. Example of offside situation. The team with red shirt is in attacking position and the most forward player (except for the goalkeeper) is in offside situation.

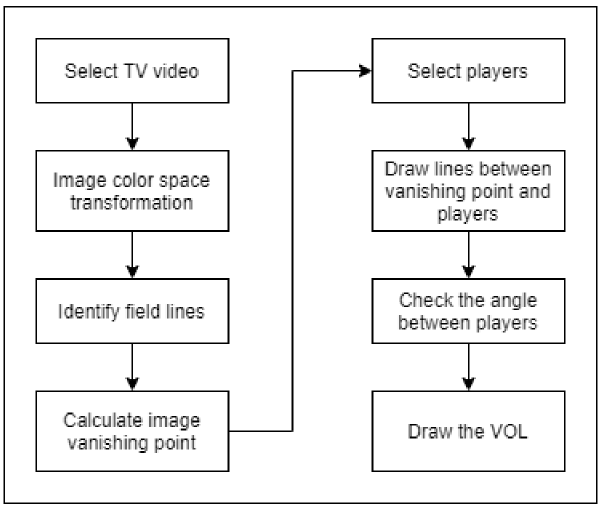

Fig. 2. Diagram of the proposed method.

The method is divided into stages as follows: detection of parallel lines to the goal line, determine the vanishing point of the image, camera calibration and the drawing of virtual lines that defines if the player under analysis is in offside condition. For a more detailed understanding of these steps, a diagram representing the method is shown in Fig. 2.

After the image processing, the players (one from each team) submitted to analysis should be selected. Thus, the lines between the vanishing point of the image and the selected players are drawn. The angle between these lines are calculated and depending on the value, the offside is established. All the algorithms are detailed in the following subsections.

A. Determination of Field Area

All the images used in this method comes from TV videos of official games. As the camera position and the field color may vary from different videos, first it is necessary a calibration for the field area determination. Thus, it is necessary to eliminate information that is not important for the analysis, such as fans and club flags, distinguishing the field area from other regions.

Fig. 3. Result of the field determination.

According to the IFAB [1] regulation, the playing field must be predominantly green.

Then, the color space is converted from RGB (Red, Green and Blue) to HSV (Hue, Saturation and Value). A range of values representing the color band of the green spectrum in the HSV color space is defined. Knowing these values a threshold is calculated to perform the field determination. The result obtained is a binary image, in which the pixels where the field are located are highlighted in white and the other areas in black, thus creating a region mask.

The and operation between the mask and the original image are performed. The result of these calculation is a color image with the field highlighted and other areas marked in black. The Fig. 3 shows the output of this operation.

B. Field Line Detection

In the field image the vertical lines should be detected. The Sobel [5] operator was used to identify the intensity gradient in the horizontal direction in order to highlight the vertical lines of the field. Further, the Canny Edge Detector [6] is applied to find edges in the image. To detect the field lines, a method based on a parallel coordinate system PClines [7], [8] was used. In this way, PClines analyzes each edge point of the image and its collinearity in the parallel coordinate system. The PClines method is more suitable to real time application then the classical Houghlines transform [9]. In Fig. 4 the detection of the field back line and the extreme line of the large area by the PClines method is presented.

C. Image Vanishing Point Identification

Football games broadcasted by TV channels have distortions in images. The parallel lines of the field found by the PClines algorithm connects to each other generating a vanishing point. By equalizing the functions of the lines it is possible to find out the intersection of these lines and the determination of the vanishing point VP. Thus, parameters of the equation $y = ax + b$ from two lines is calculated and, the functions are equaled to find out at which point have the same value for the coordinate x and y in both lines. Therefore, the coordinates of the vanishing point VP (x, y) is determined. In this way, if drawing a straight line at any point in the image that passes

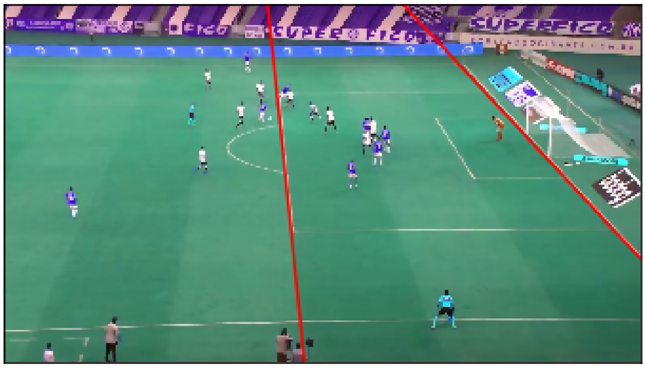

Fig. 4. Result of line detection using PClines.

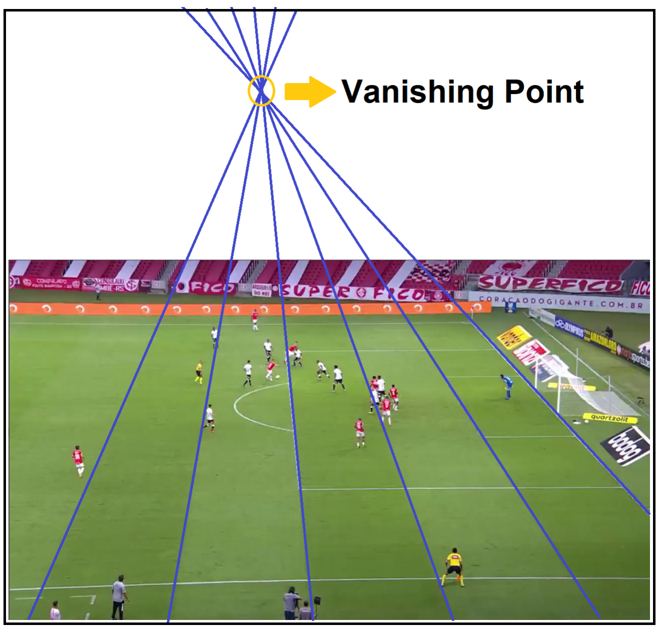

Fig. 5. Vanishing point representation.

through the vanishing point a parallel line to the goal line is obtained. Fig. 5 is a representation of the vanishing point in image.

D. Players Identification

The VAR system needs the identification of the players important to the offside situation. Also, the method proposed in this work demands the same action. The players was manually identified and then tracked. The used tracker algorithm was the Channel and Spatial Reliability Tracking (CSRT) [10]. The players identification was done at the first frame of the video file.

E. Drawing the Virtual Offside Line

The next step of the method is to draw a Virtual Offside Line (VOL). Therefore, to carry out this step, an order is created for marking the players. First, the player in the attack position should be marked, then the defender of the opposing team. In this context, as each mark has coordinates in the image plane,

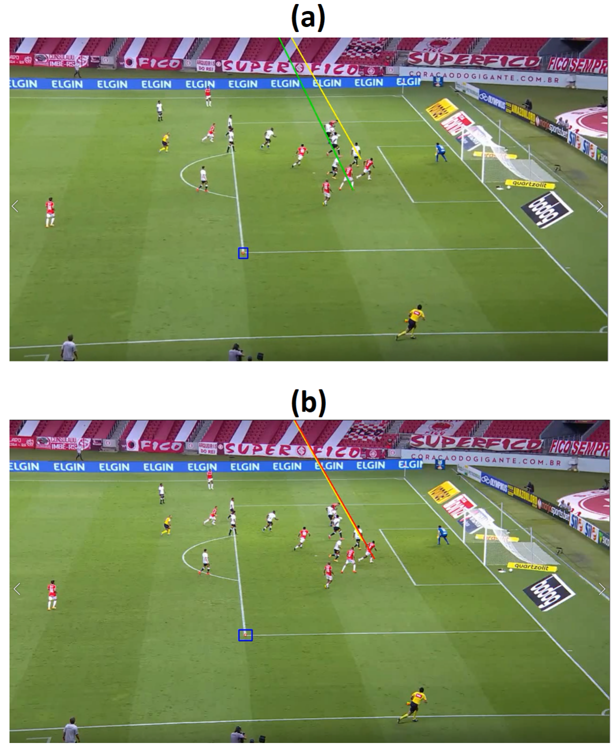

Fig. 6. Example of the virtual offside lines. In a, the selected player in red shirt is not in an irregular position. In b, the player in red shirt is in offside position.

it is possible to drawing a line from the point closest to the goal line of each mark until the calculated vanishing point. In addition, the angle α between these lines is calculated, with the defender's line as the initial axis. If $\alpha > 0$, the player in attack position is in offside position and its line to the vanishing point turns to red. If $\alpha \leq 0$, the forward player is in a legal position and his line color turns to green.

The Fig. 6 shows an example of the drawing lines. In part a the selected player is not in irregular position. In part b, the forward of the team in red shirt is in offside position.

F. Calibration

As the input file is a video transmitted over a television broadcast, it follows the dynamics of the game and the camera is always moving from side to side following the position of the ball. The coordinates x and y of the vanishing point through the parallel lines are identified in the first frame of the video and a fixed point in the plane is obtained. As the camera moves, the original $\mathrm{VP}\,(x, y)$ should also move. Therefore, before choosing the players to be analyzed, the CSRT function is used to track a known position in the field plan with the initial coordinates $\mathrm{FP}\,(x_i, y_i)$, for example, the corner of the penalty area. With the camera movement, the final coordinates of this point are $\mathrm{FP}\,(x_f, y_f)$. The displacement is easily determined resulting in $x_d = x_f - x_i$ and $y_d = y_f - y_i$. The new vanishing points to frame by frame displacement are determined by $\mathrm{VP}_k\,(x + x_d, y + y_d)$, where $k = 0, 1, 2, ..., N$

is the frame number. In other words, the displacement of this known position FP in each frame is analyzed and a new vanishing point is determined with the same displacement.

To verify the effectiveness of the calibration, three fixed points in the field was marked and lines between the vanishing point and those fixed points are drawn resulting in parallel lines. As the camera moves, the parallel lines should stay fixed to the points in the field. The Fig. 7 shows the calibration method. The pink line represents the movement of the camera between the frames and the displacement used to determine the new vanishing point for each frame. Also, the black lines overlaps the white lines of the field, indicating the effectiveness of the calibration method.

III. Results

In order to analyze the performance of the proposed method, several simulations was done in different situations. We selected 10 videos from the A series matches of the Brazilian Football Championship (Brasileirão) in 2020. We selected 5 videos in which the infraction occurs on the right side of the images and 5 on the left side. The method presented a good performance. Although the method requires manual action to identify players, it is still very fast to show the VOL results.

The VOL lines in this proposed method was drawn in all frames of the video, and it do not take into consideration the ball condition. Therefore, as the actual VAR system, the final analysis and interpretation should be taken by the referee. However, as the colored VOL are automatic drawn in all frames, the referee should only choose the frame with the last pass to determine the offside situation. The most relevant results are presented in this section. Also, a video with the main simulations is available[2].

A. Simulations

During the game, players are constantly moving. Therefore, to demonstrate that the presented method obeys the football game rules, different situations were simulated. First, the transition from one state to another is presented in Fig. 8. The Internacional team is in attack situation and the forward player (red shirt) was in an offside position and he moved into a position with no longer irregular situation. The VOL was in red color and changed to green at the moment that the two selected players (red shirt and white shirt) were on the same line. In Fig. 9, the opposite transition situation occurs, where the player in red shirt was in a legal position, with the VOL line in green color, and then he became to offside with the VOL line changed to red color.

The method was also tested in matches from other clubs. Fig. 10 shows the result obtained from a situation in a match between Grêmio Foot-Ball Porto Alegrense (blue shirt) and Esporte Clube Bahia (white shirt). First Grêmio was in attack position in a good condition and the VOL line is in green color, in next frames the same player keeps out of the offside condition and the VOL keeps the green color. Thus, the player marked with the blue shirt keeps in regular condition in all frames analysed.

The analyzes so far were carried out in a sequence of images in which the move takes place by the defender's field in the right side of the video. For this reason, a derivation of the code was also created to the transmissions of matches in which the attacking moves occur in the left side of the video. In Fig. 11, it is possible to observe a situation of the same match between Grêmio and Bahia in which the Bahia team forward player is in a legal condition. Then the forward passes the defender and is closer to the goal line, so the VOL changes to red color indicating an offside condition.

IV. Conclusion and discussion

This work proposes a method to draw virtual lines for offside situations analysis. In all cases the method was able to create an automatic virtual offside line. The players involved in the offside situation was manually selected following a logic in accordance with the official rules of the game. If the selected forward player is closer to the goal line than the last opponent's defender, the result shows a line parallel to the goal line colored in red, validating the athlete's irregular position. Otherwise, the line is green, confirming the legal position. In the analysis of the method output, it is also highlighted that the algorithm works correctly for any side of the playing field, left or right, being able to create a VOL with low processing time. The proposed algorithm became satisfactory, considering that it correctly performs the function of determining offside. The main advantage is the low investment cost, considering that all input data to the algorithm are from television images, without the need for specific equipment. Also, the manual action to identify players is simple and fast.

Nowadays, the VAR system used in official games is available by few companies with a validation with several tests performed by FIFA [11]. This system requires that the playing field undergo a specific calibration of its dimensions. That is, for each field that uses the VAR technology, there is a specific and unique parameterization, which makes the VAR system extremely accurate in relation to the positions of players in the field. However, in conversations with managers of professional football clubs, in particular with representatives of Clube Esportivo Aimoré (RS-Brazil), the calibration of the field for the use of the VAR system costs thousands of dollars and, in addition, the use of the system for each game have a heavy costs for each club, which definitely ends up making the system unfeasible for clubs with smaller budgets.

Comparing the proposed method with the official VAR system, it is possible to analyze two major important relationships between them. The first is that the method presented does not need the field calibration, as it uses TV cameras resulting in a method with lower financial costs. The second, on the other hand, is that the system is not highly accurate. It works for all cases, but for offside situations where the players position is a millimeter difference, or in obstruction of players, it will not get the desired result, which makes the VAR system more accurate and reliable.

[2] https://www.youtube.com/watch?v=1iY5DUG7y-E

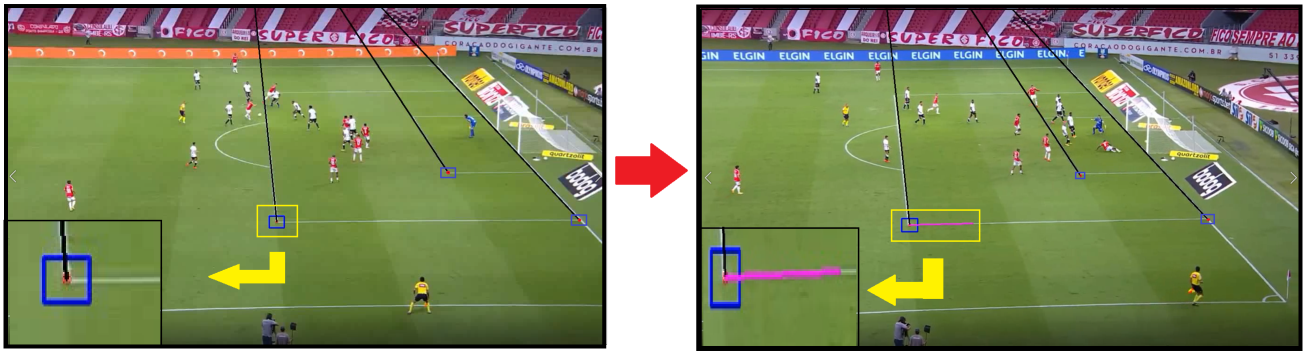

Fig. 7. Calibration method. As the camera moves, a new vanishing point for each frame is determined by the displacement represented in pink line.

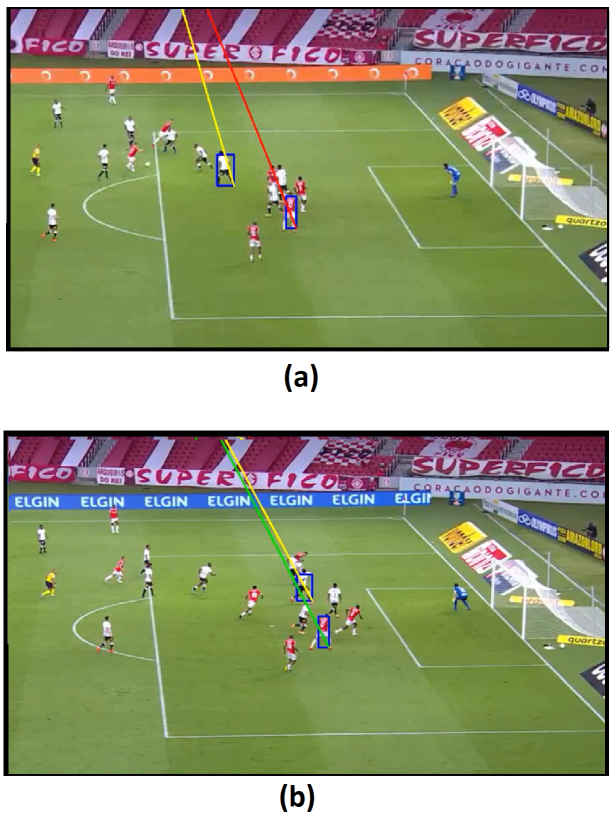

Fig. 8. Example of transition from offside (a) to regular situation (b).

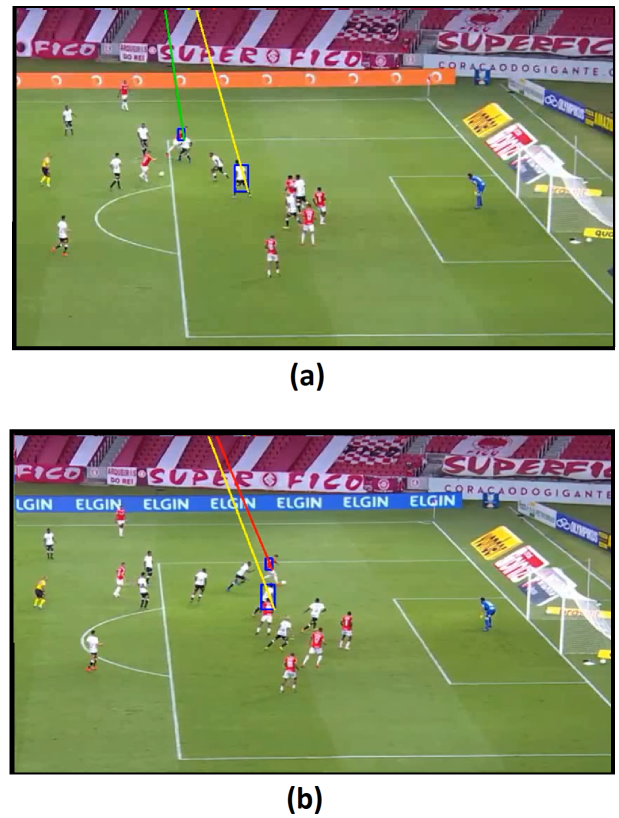

Fig. 9. Example of transition from regular(a) to offside (b) situation.

Therefore, to improve the accuracy of the system and make it more reliable than the VAR some methods should be improved. At this point, the players are identified manually to the tracker with an rectangle resulting in low accuracy of the athlete body. An algorithm to identify the contour of the players body accurately should be implemented. Furthermore, tracking the ball is a challenge even for the VAR system, and must be taken into account. Automatic identification of players should also be implemented.

More complex and expensive implementations should also take place, such the analysis of the field and players in 3 dimensions. Currently, the calculation of the vanishing point and the positions of the selected players are related in terms of x and y, excluding the coordinate z (the height of the objects). If the z variable is analyzed, it is possible to have a better accuracy of the players.

To eliminate the problem of obstruction of players, the use of two or more fixed cameras in specific positions on the field should be taken into consideration. Doing so it would be possible to analyze the shots from other angles. Also an improvement in the tracker algorithm should be taken into account.

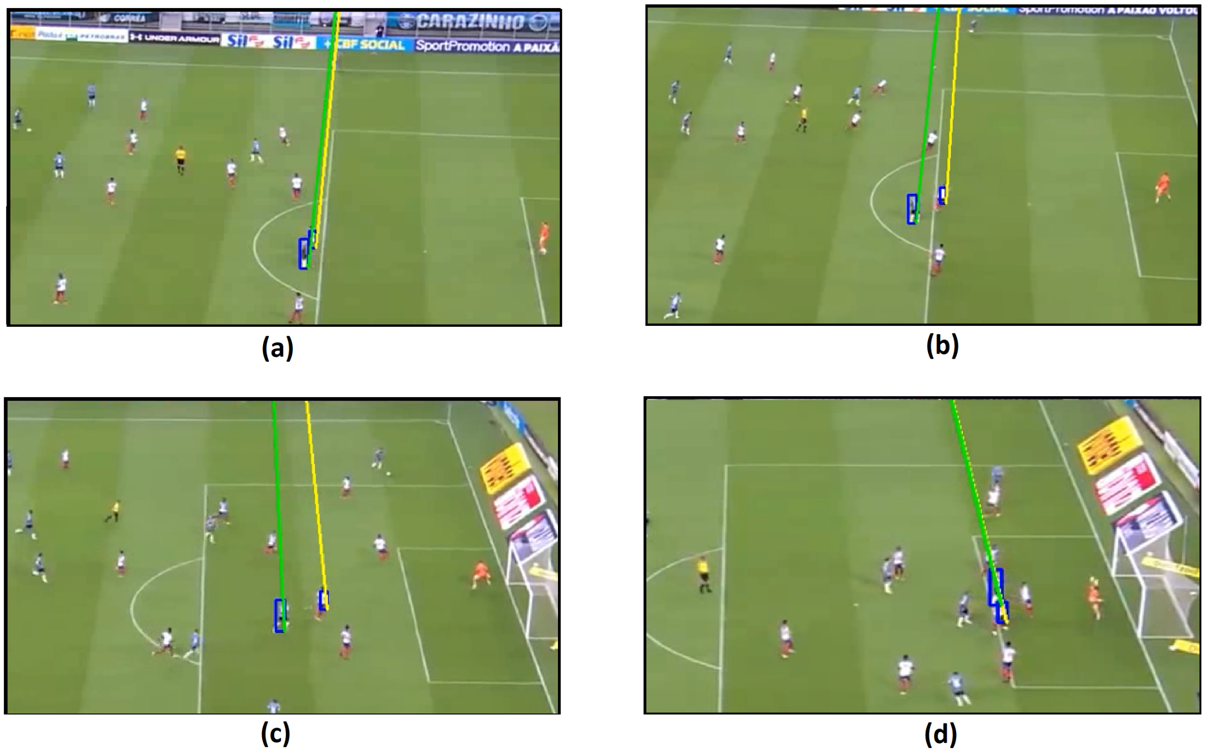

Fig. 10. Example of VOL to always no offside condition in four sequential frames (a to d).

ACKNOWLEDGMENT

The authors would like to thank the leaders of Clube Esportivo Aimoré for the receptivity and support in the development of this work.

REFERENCES

[1] IFAB. The international football association board. laws of the game. football laws, rules and regulations. [Online]. Available: https://www.theifab.com/

[2] S. Hashimoto and S. Ozawa, "A system for automatic judgment of offsides in soccer games," in *2006 IEEE International Conference on Multimedia and Expo*. IEEE, 2006, pp. 1889–1892.

[3] T. D'Orazio, M. Leo, P. Spagnolo, P. L. Mazzeo, N. Mosca, M. Nitti, and A. Distante, "An investigation into the feasibility of real-time soccer offside detection from a multiple camera system," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 19, no. 12, pp. 1804–1818, 2009.

[4] G. Bradski, "The OpenCV Library," *Dr. Dobb's Journal of Software Tools*, 2000.

[5] I. Sobel, "An isotropic 3 $\times$ 3 image gradient operator, machine vision for three-dimensional scenes, 376–379," 1990.

[6] J. Canny, "A computational approach to edge detection," *IEEE Transactions on pattern analysis and machine intelligence*, no. 6, pp. 679–698, 1986.

[7] M. Dubská, A. Herout, and J. Havel, "PClines — Line detection using parallel coordinates," in *CVPR 2011*, 2011.

[8] J. Havel, M. Dubská, A. Herout, and R. Jošth, "Real-time detection of lines using parallel coordinates and CUDA," *Journal of real-time image processing*, vol. 9, no. 1, pp. 205–216, 2014.

[9] P. V. Hough, "Method and means for recognizing complex patterns," Dec. 18 1962, uS Patent 3,069,654.

[10] L. Alan, T. Vojíř, L. Čehovin, J. Matas, and M. Kristan, "Discriminative correlation filter tracker with channel and spatial reliability," *International Journal of Computer Vision*, vol. 126, no. 7, pp. 671–688, 2018.

[11] F. Fédération Internationale de Football Association, *Handbook of test methods for virtual offside line assessment*, 2019.

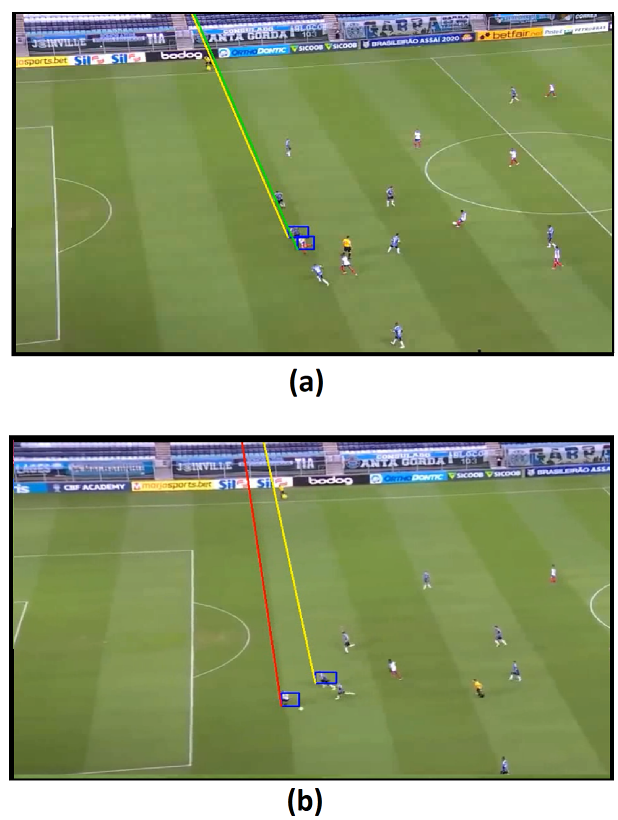

Fig. 11. Example of transition from regular (a) to offside (b) situation in the left side of the field.