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Video Signal Processing in Volleyball Video-check System: Examination and Analysis

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ABSTRACT

Video images of sporting events have come to play a pivotal role in sports refereeing. However, owing to the potential for error of the system's referee when reviewing video images, the user and the referees are at times faced with great challenges to make the right call, while the often-long interruptions for reviewing images may disrupt the flow of the game. As such, the purpose of this study was to propose a real-time algorithm for processing the images of video-check systems using image processing techniques to accurately and quickly detect whether the ball is landed inside or outside the court.

This 9-step algorithm detects whether the ball has landed inside or outside the volleyball court, which includes: preprocessing on the input frames, separating the background image, line detection, determining the coordinates of the court, detecting and tracking the ball, determining the direction of movement of the ball when contact with the ground, removing the shadow under the ball, determining the coordinates of the ball in contact with the ground and, last but not least, determining, based on the previous step, whether the ball has landed inside or outside the court. The proposed algorithm is implemented, and the evaluation results revealed 98% accuracy, 100% Specificity and 96% true positive rate (i.e., sensitivity), an average detection time of 0.26 seconds, indicating the optimal performance of the proposed algorithm with a low error rate and latencies.

Key words: Video check system, ball path, line review system, video image processing, line detection, volleyball, ball detection, video signal processing

INTRODUCTION

Volleyball is rightfully deemed an extremely fast-paced and competitive sport, and hence the accuracy umpiring is of paramount significance to the outcome of competitions [1,20-21]. The effects of a refereeing error may range from a small point for a team to large effects, including a decision to eliminate or keep a team in the competition. Furthermore, a refereeing error may reduce the referee's performance, leading to heightened stress levels in referees and tension brewing in matches. In contrast, high refereeing performance has been shown to enhance the performance and focus of the players and coaches, hence maintaining the attractiveness of games [2].

Volleyball referees can make mistakes for various reasons, including reduced focus, ball speed and eye error, and as such, having the capacity to review an incident in the match at any level of competition can prove to be pivotal. A line detection system to help detect whether the ball has landed inside or outside the volleyball court can benefit both the teams and the referees. High-ranking volleyball executives also emphasize that at some levels of the competition, the speed of the ball is so high (i.e., more than 100 kilometers per hour) for line judges and referees that they cannot make an informed judgment. Nevertheless, some coaches and referees argue that errors in judging the line is a minor issue in volleyball and that good, professional players must accept refereeing mistakes. Nevertheless, the majority of volleyball coaches, players and officials agree that errors of this nature may bear important consequences on the outcome of a match, to the extent of turning around the outcome of a match and hence the tournament/cup which the match corresponds to, hence the necessity of assisting referees using state-of-the-art technologies.

Sports review systems have been implemented slowly over the past few years. A line-checking system, such as a video check, has proven effective in other sports. In matches where the video check system is employed, a distinct referee is assigned for reviewing purposes, which has the discretion to review the following items and present the result to the first and second referees at the request of the team captain or coach [1]:

- Contact of the ball with the antenna
- Contact of the ball with the opponent
- Contact of the player with the antenna
- Contact of the player with the net
- Contact of the serving player's foot with the court line
- Contact of the backcourt player's foot with the frontcourt line before serving

- Crossing the attacking player's foot from the net line, after an action on the ball
- Determining whether the ball has landed inside or outside the court

Also, according to the Fédération Internationale de Volleyball (FIVB) rules, in case of an error, the coaching staff must immediately request a review, and any challenges after five seconds from the decision are not accepted. If the challenge is valid, one point is awarded to the challenging side, and otherwise, a point is awarded to the opponent. Teams will keep the right to call another "Challenge" if their claim is correct, up to the maximum of two unsuccessful Challenges per set [1].

A plethora of research has been conducted on mapping and tracking of players, balls and field lines in videos of sports including tennis, football, cricket, badminton and volleyball, among others. Hsu et al. [3] used player identification technique and jump pattern for volleyball. Cheng et al. [4] examined the tracking of players through prediction and particle filter-based post-sharing in images of volleyball incidents. Takahashi et al. [5] developed a powerful multi-camera tracking system using a ball tracking technique, a background subtraction algorithm and multiple cameras to determine the position of the ball. Gomes et al. [6] studied the methods for tracking balls and players in beach volleyball videos. Vijiakomar et al. [7] developed the hawk-eye algorithm for cricket. Sein et al. [8] similarly proposed the goal-line and hawk-eye technologies for soccer matches.

Regarding the processing of sports videos, there have been no conclusive studies in reviewing the scenes in competitions that may be plagued with refereeing human errors. Nevertheless, a significant portion of these competitions have the applicability of image processing techniques, and this technology can be used to reduce costs and human error in refereeing tasks.

In recent years, In and Out Line Monitoring systems have been used to help detect game errors and the position of the ball on and off the field. This system seeks the function of 8 cameras from different angles around the volleyball field, and two cameras are for each line installed for simultaneous display of playground lines. Each camera is tasked with processing the images of a particular line and the area therearound, using which the position of the ball inside or outside the playing field is determined. From there, video images are sent to the central computer and are hence reviewed [39].

In official volleyball matches, the coaches can call for a challenge: a request from the judges to review the video images from the recording system to decide on game fouls [1]. Owing to the probable visual error of the user system when reviewing video images, detecting fouls may prove to be challenging even with the reviewing system. On the other hand, reviewing images often causes long interruptions during the match, reducing game speed and excitement. In volleyball, even a few seconds are important for the flow of the game, and in some cases, the coaches challenge the calls only to seek to pause the game and buy some time for their team to rest, at times proving to be detrimental to the opposing team.

This study seeks to propose a novel algorithm for processing video images from the video challenge system using image processing techniques to automatically and instantly detect whether the ball has landed inside or outside the court. The system automatically and instantly detects whether the ball has landed inside or outside the playing field by receiving video images and processing video images based on the proposed algorithm. This eliminates the need for calling challenges and refereeing errors, as it does not require referring to videos from video challenge systems. Results indicated that the proposed algorithm could determine the final position of the ball on the ground with exceptionally high precision and extremely low error rate, effectively mitigating umpiring and line-keeping errors. The steps of the proposed algorithm are described as follows:

Steps of the proposed algorithm

Figure 1 shows the diagram of the proposed algorithm. Each step consists of processing tasks that should be implemented before proceeding to the later stages:

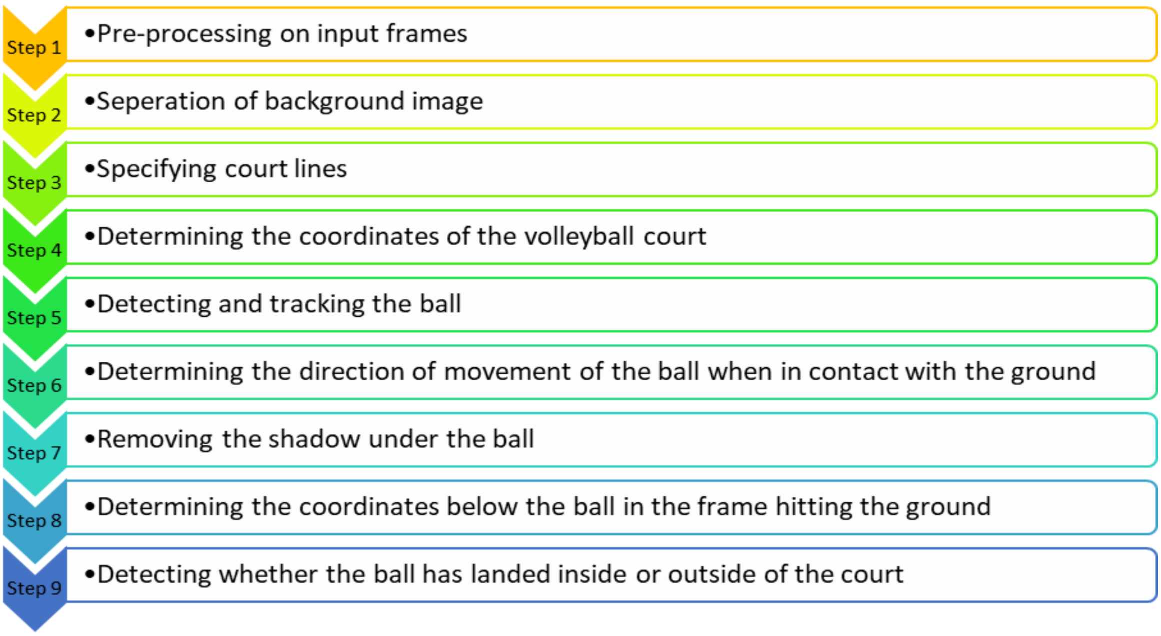

Figure 1: Diagram of the proposed algorithm

Preprocessing on input frames

The cameras of the video challenge system can provide the required input images for the proposed algorithm, and the frames of the incoming video images are stored in order. Each frame is an RGB color image and with an M × N × 3 matrices of color pixels, each color pixel representing a trio corresponding to the red (R), green (G), and blue (R) components of the RGB image.

Feature standardization involves adjusting each data size to achieve a mean of zero and a variance of one. To this end, the average of each frame is first calculated, and then each pixel is subtracted from the calculated average. In the next step, the standard deviation of the frame is calculated, and each of the pixels is divided by it, the results of which would be a standard deviation of one [10].

Because the color of the ball is of paramount importance in the ability to detect and track the ball, normalizing the frames enhances the performance of the algorithm. Figure 2 reveals the results of the standardization functions on the system input frames.

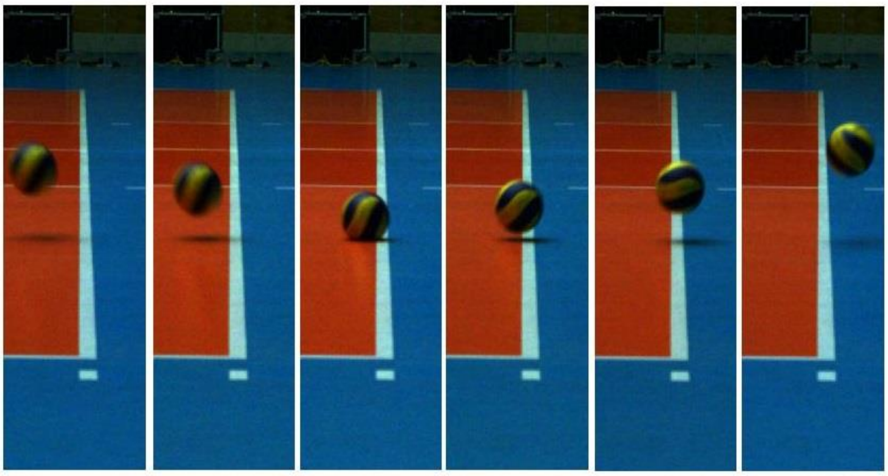

Figure 2: Frames resulting from frame standardization

Separation of the background image

Considering that the installed cameras of the challenge system are fixed in terms of motion, the algorithm seeks use of this advantage to separate the background image from the input frames to detect the ball and the playing court lines. Hence, the median filter is applied separately on all three RGB components of the extracted frames, as Figure 3 plots the three background images with the corresponding filter applied. These three components make up the RGB image of the background. Using the median filter in the direction of the third dimension on the images of the frame components eliminates the presence of noise in the input frames. As a result, only one RGB background image is separated from the input frames.

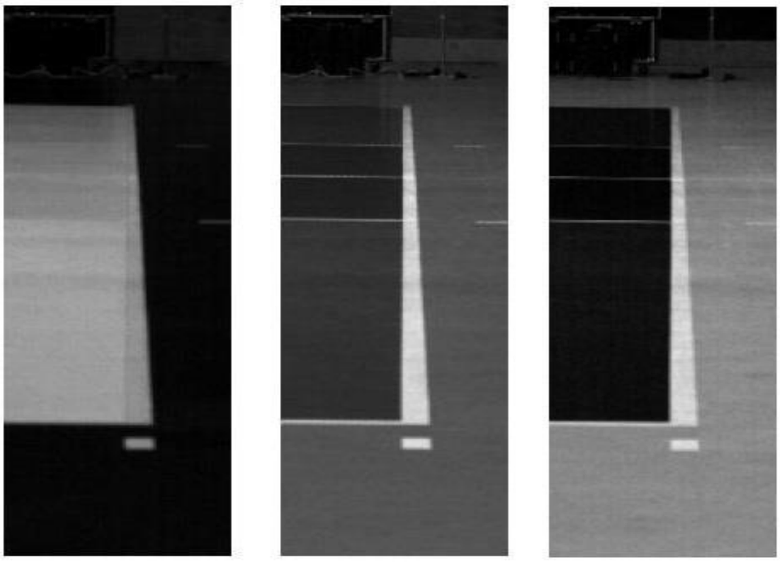

Figure 3: Results obtained by applying the median filter, (a) background image with the R component, (b) background image with the G component, (c) background image with the B component

Detection of court lines

The FIVB requires that the white color be used for all official competitions and matches to paint the lines [1]. Having the capacity to detect the court lines enables the extraction of the playing area [11]. The background image, an RGB image, is first converted to a grayscale image to detect the line. The court lines are outlined by limiting the RGB coefficients of the background grayscale images in the range of 0.7 to 0.9 and performing morphological operations. In such a way that each threshold of the lines are obtained.

The opening of set A with the structural element B, denoted by A ∘ B in Equation (1), is defined as [12,13,14]:

$$A \circ B = (A \ominus B) \oplus B$$

Which states that the opening A by B is obtained by the expansion of A by B, and then the expansion of the resulting set by B. Equation (2) represents the closing of set A with the structural element B [33, 34, 35].

$$A \cdot B = (A \oplus B) \ominus B$$

Considering the discussion above, the outcome of this operation is the connection of the lines and the omission of extra parts. Evidence has shown that the ratio of the area of the line to the total image is significant. The image is scaled down such that the aforementioned ratio would be less than 0.08, from which the line is distinguishable. To remove noise and objects other than the line, a line size filter is employed, such that the lines that are greater than 500 are detected as such.

Determining the coordinates of the court area

The outer edges of the court must first be identified to visualize the area of the court. The most common method of derivation in image processing applications is the gradient, which is defined for the function f (x, y) as follows [12,13]:

$$\nabla f = \left[\frac{\delta f}{\delta x}, \frac{\delta f}{\delta y} \right]$$

The magnitude of this vector [12,13],

$$\nabla f = mag\,(\nabla f) = [(\frac{\delta f}{\delta x})2 + (\frac{\delta f}{\delta y})2\,]1/2$$

Applying gradient derivative filters and Equations (3) and (4) enhances the contrast of important edges while leaving the other features of the image unchanged [12,13]. As such, the outer edge of the court is recognized, and the position of the playing field is determined from the outer edge of the line to the left of the vertical line.

It is worth noting that due to the fixed position of challenge system cameras, the steps corresponding to the separation of the background image, detection of court lines and determining the coordinates of the ground area of the proposed algorithm can be performed only once before the deployment of the algorithm and there is no need to repeat these three steps when the algorithm is called. As such, the actual process of the algorithm starts from the stage of detection and tracking of the ball.

Detection and tracking of the ball

According to the rules of FIVB, all balls used must be the same in terms of color (yellow and blue), size and weight [1,15]. In the proposed algorithm, fuzzy logic detects and tracks the ball in the input frames.

In the proposed algorithm, Gaussian Membership Function is used for fuzzification of input variables at a distance of [0,1]. The fuzzy inference engine combines fuzzy (If-Then) rules using the fuzzy logic intersection to calculate the output. Ultimately, the outputs are defuzzied using alpha cutting and thresholding operations. The curve of the Gaussian membership function used in the proposed algorithm is an exponential function that can be calculated according to Equation (5). The degree of membership indicates the degree of membership of the element to the fuzzy set. If the membership of an element of the set is zero, that member is perceived to be completely out of the set, yet if the membership of an element is equal to one, that member is completely in the set. If the membership value of an element is between zero and one, the element is considered to have a gradual membership degree or relative affiliation.

Equation (5) outlines the Gaussian membership equation [16].

$$\mu\,(X) = \exp\,[-\frac{1}{2}\left(\frac{x-m}{\sigma}\right)^2]$$

The complement of a membership function is defined in Equation (6) [16]:

(A (X) = 1- μA (X)

To detect and track the ball in the input frames, the following three criteria are checked and calculated:

- The relative affiliation of each frame to the background image
- The relative affiliation of the values of the three components of the blue color of the ball with the color components of each input frame

- The relative affiliation of the values of the three components of the yellow ball with the color components of each input frame

Equation (6) calculates the relative affiliation of each frame with the background image, and Equations (7) and (8) determine the relative affiliation of the RGB values of the color components of the ball (blue and yellow) with each frame. That is:

$$\mu imb\,(f) = 1 - e^{-\left|\frac{imb - imm}{\sigma}\right|} \quad (6)$$

$$\mu imbl\,(f) = e^{-\left|\frac{imbl - imm}{\sigma}\right|} \quad (7)$$

$$\mu imye\,(f) = 1 - e^{-\left|\frac{imye - imm}{\sigma}\right|} \quad (8)$$

Where μ (x) is the Membership function imm denoted the input frames, imb represents the background image, imbl represents values of the three components of the blue color of the ball, and imye denotes the values of the three components of the yellow color of the ball.

In Figure 4, each area of the image that resembles the background image is marked with darker contrasts, while areas less or relatively similar to the background image are marked with lighter contrast. As a result, the difference between each input frame and the background image is obtained, and moving objects in the image are extracted.

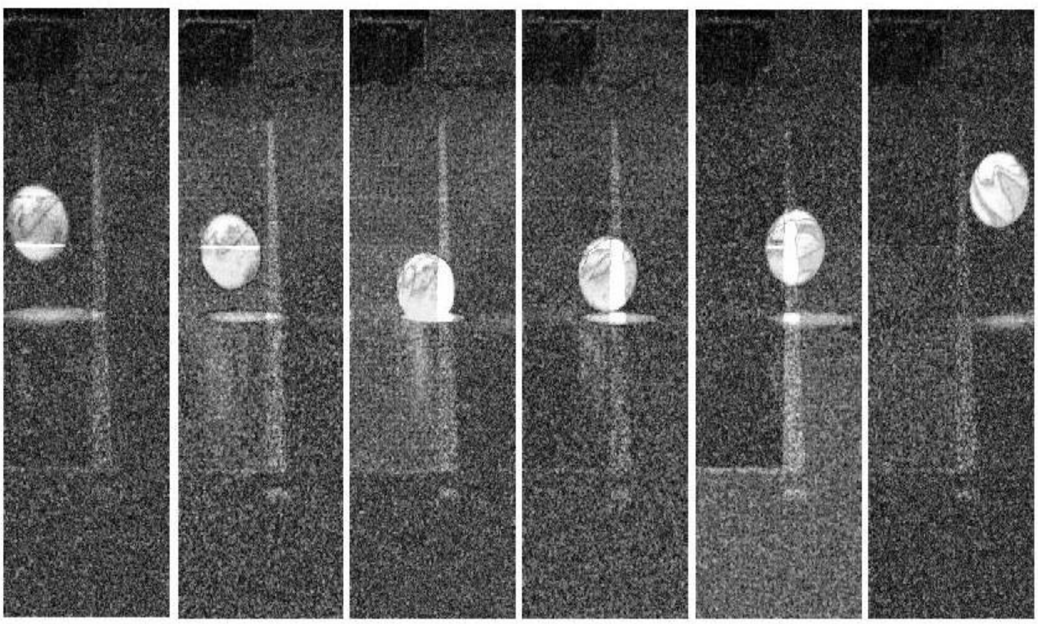

Figure 4: The result of the difference between each frame and the background image

The fuzzy intersection of the two sets A and B represented by A ∩ B and is as follows:

$$\mu A\cap B\,(X) = \min\,[\mu A\,(X), \mu B\,(X)] \quad (9)$$

According to Equation (9), the fuzzy intersection of Equations 6 to 9 is defined as Equations (10) and (11):

$$\mu_{ball}\,(f) = \mu_{imb}(f) \cap \mu_{imbl}(f) \cap \mu_{imye}(f)$$

$$\mu imb\cap imbl\cap imye(f) = \min\,[\mu imb(f), \mu imbl(f), \mu imye(f)]$$

With these assumptions, the fuzzy inference engine combines and calculates the output of the input using the logical function of the fuzzy intersection equation (10). Hence, the arrays are arranged in the third dimension to identify the balls in each frame. In other words, any area of the input frames that differ from the background image and at the same time has dots resembling the yellow and blue colors of the ball are considered as ball candidates, and that area is marked with a bright light. Finally, the output of the inference motor is defuzzied by using the alpha cutting operation. By performing the alpha cut operation, the fuzzy space becomes logical. In each frame, large and small areas are produced as ball candidates, where non-ball objects must be separated from the frames and removed. Figure 9 shows the frames in which the ball candidates are produced as small and large bright spots, many of which are non-ball objects. To detect and track the ball in each frame, these objects must be removed. For this purpose, two morphological operations of opening and closing are used to remove non-ball objects in each input frame, and small, and large points produced as ball candidates are removed.

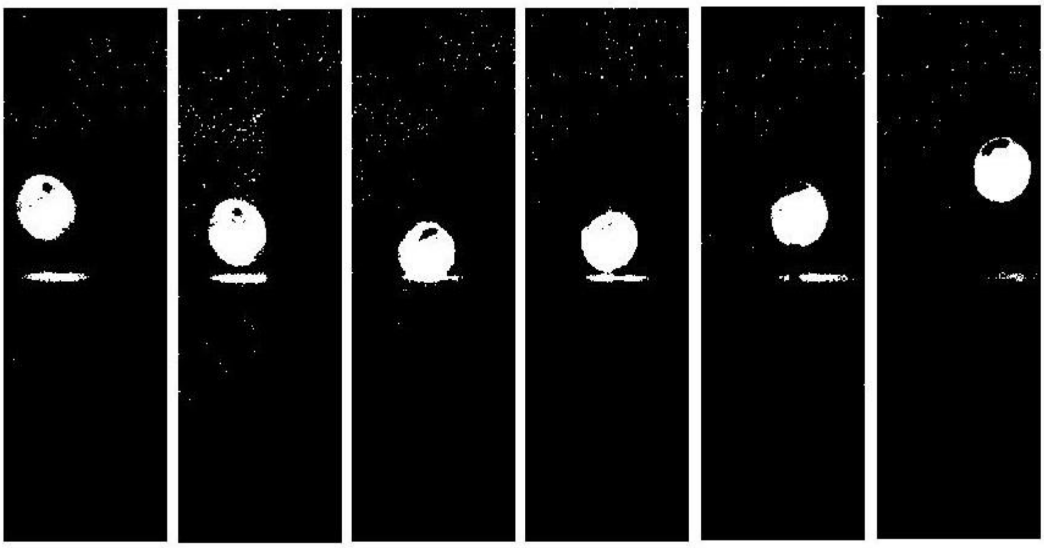

Figure 9: Ball candidates in each input frame

In order to eliminate the effect of the reflection of the image of the ball on the ground in the input frames, two filters are used, namely (1) ball size filter and (2) filter for the position of the ball and the reflection of the image of the ball on the ground relative to the Y-axis

The remaining ball candidates in the input frames, among which are the ball and the ball reflection, are marked as bright areas in the image. Each of these ball candidates has different sizes, all labeled. The size of each bright area in each frame is assigned to a 2x2 vector and is sorted using descending sizes. In the first row, there is the size of the ball, and in the second row, there is the size of the ball reflection or vice versa, and the rest of the rows are removed due to the presence of small dots. If the area of the first row is greater than one and the ratio of the area of the second row to the area of the first row is greater than 0.6 (experimental value), then we have the ball and the reflection of the ball. Otherwise, we have the ball. Then the coordinates of the ball and the reflection of the ball are calculated. Since the reflection position of the ball is always lower than the ball, the coordinates of the area higher than the y-axis are considered the ball, and its coordinates are stored. Sometimes the size of the ball reflection is larger than the ball, so the size of the ball alone cannot be considered. Using the coordinates of the ball and the reflection of the image of the ball relative to the y-axis is often deemed a proper method for delineating the ball from the reflection of the image of the ball on the ground. Figure 10 shows the removal of ball reflections and other objects in the input frames.

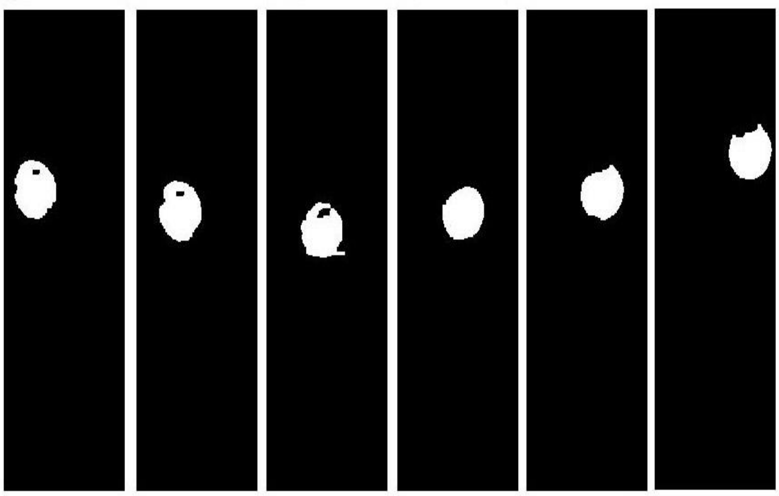

Figure 10: Recognition of the ball and elimination of the reflection of the image of the ball on the ground

Determining the direction of movement of the ball in contact with the ground

Obtaining the coordinates of the first contact of the ball with the ground is of utmost significance, as it can be used to determine whether the ball has landed inside or outside the court. Determining these coordinates is obtained by determining the direction of movement of the ball in the input frames. To find the trajectory of the ball in the input frames inspired by [17,18,5,6,19], the position and coordinates of the resulting ball in each frame are arranged consecutively, and the trajectory of the ball is obtained from the position of the balls. Using the path of the ball and the position of the ball in each frame, the maximum and minimum coordinates of the ball in each frame relative to the Y-axis are extracted. The lowest coordinates of the ball relative to the Y-axis reflects best the moment the ball first hits the ground. Figure 1 shows the extraction of the frame that has the lowest coordinates of the ball concerning the Y-axis, that is, the moment the ball first hits the ground.

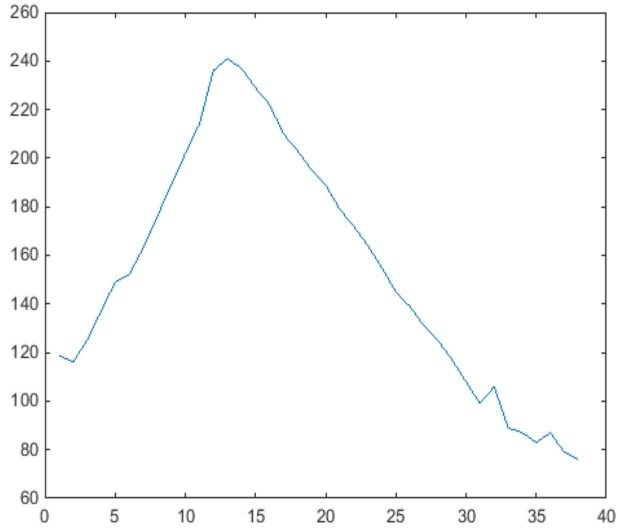

Figure 1: Curve corresponding to the ball hitting the ground

Eliminating the shadow under the ball

Figure 2 plots the curve of the ball size, in which the horizontal axis corresponds to the y-intercept and the vertical axis represents the ball size. As can be seen in the image, a relative minimum value is obtained, and from this point, the presence of shadow is determined due to the increase in the size of the ball and from this point, the shadow is removed from the ball.

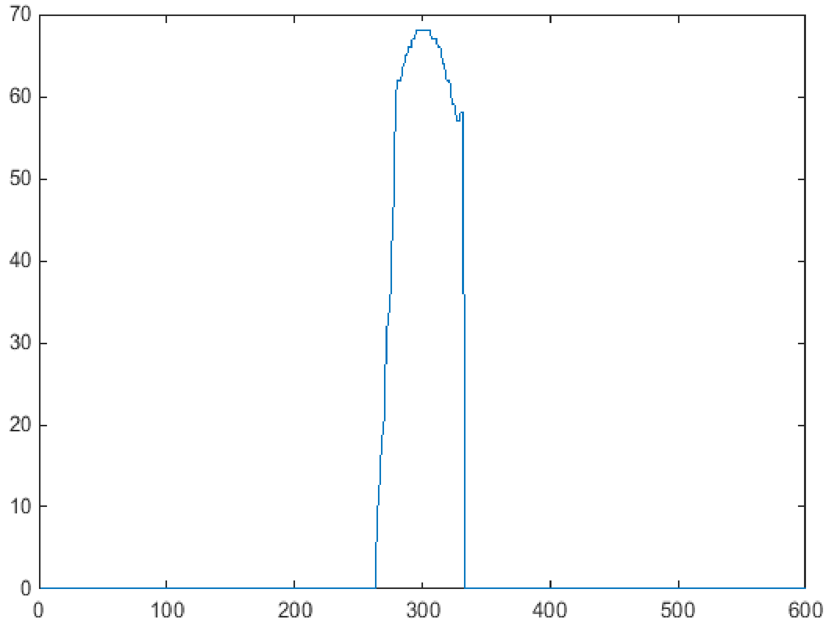

Figure 2: The curve plotting the ball size

Determine the coordinates below the ball in corresponding to the contact of the ball with the ground

Identifying the frame at which the ball first hits the ground and the coordinates below the ball that make contact with the ground is of paramount importance, as it can be used to determine whether the ball is on or off the court, effectively rendering this frame as the most important one. When the ball hits the ground, only the surface under the ball comes in contact with the ground, through which it can be determined whether the ball has landed inside or outside the playing court. A gradient derivative filter, the equations of which have already been described, is used to find the edge of the ball and the point of contact of the ball below the ground [33,34].

By applying morphological operations, small and discontinuous pixels are omitted, and hence large and continuous pixels remain. Finally, the opening morphological operation is performed to detect the edge under the ball in contact with the ground. Figure 11 shows the steps for detecting the contact edge of the ball with the ground using the edge finder filter and morphological operations.

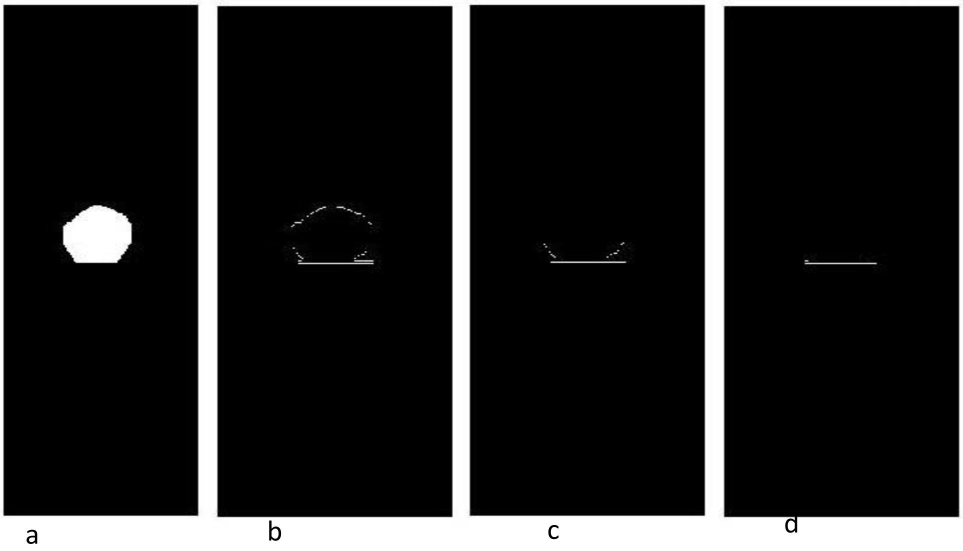

Figure 11: (a) Image of the ball hitting the ground (b) Applying a filter to detect the edge of the ball (c) Applying morphological operations to remove discontinuous pixels (d) Applying an opening morphological operation to detect the edge under the ball in contact with the playing field.

Detecting whether the ball has landed In or Out

The In or Out status of the ball is determined based on the following coordinates of the ball, the line and the area of the playing field obtained in the previous steps, according to the following condition:

If the sum of the product coordinates below the ball and the playing field area is greater than zero, then according to Equation (12), the ball is declared to have landed inside the field of play; otherwise, the ball is declared to have landed outside the court

$$\sum_{i=0}^{n}(\text{Under Ball} * \text{Court}) > 0 \quad (12)$$

Figure 12 depicts the frame showing the position of the ball, the line and the area of the playing field. The In or Out status is detected using the aforementioned procedures, according to which the ball is detected inside the playing field.

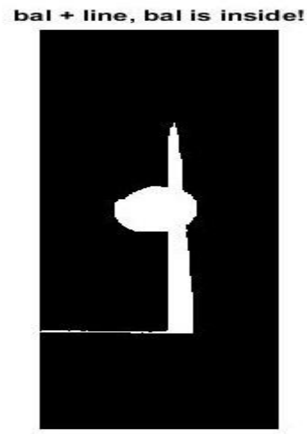

Figure 12: Determining whether the ball has landed inside or outside the court

RESEARCH FINDINGS

The accuracy of the algorithm compared to the opinion of referees and the duration required for checking the final position of the ball (i.e., being inside or outside the playing court). The proposed algorithm was simulated on 54 samples of video images from the volleyball challenge systems (22 samples corresponding to side line images of the field and 32 samples corresponding to back line images of the volleyball court) at a frame rate of 200 FPS. To implement the proposed algorithm, MATLAB 2014 on a computer with an Intel i7 CPU, and 16GBs of Ram was employed. The testing of this algorithm and its evaluation is based on three indicators, namely, accuracy, specificity and sensitivity.

The following parameters were used to calculate the three indicators of the proposed algorithm:

- True positive / TP: Right call on the ball landing inside the court;
- True negative / TN: Right call on the ball landing outside the court;
- False-positive / FP: The ball has landed inside the court, but the algorithm has called it outside;
- False-negative / FN: The ball has landed outside the court, but the algorithm has called it inside;
- P: The ball has landed inside;
- N: The ball has landed outside;

Equations for calculating three indicators:

$$Accuracy(ACC) = \frac{TP + TN}{P + N}$$

$$Specificity(spc) = \frac{TN}{FP + TN}$$

$$Sensitivity(TPR) = \frac{TP}{TP + FN}$$

The values of Table 1 were obtained according to the definitions and the performance of the proposed algorithm on 54 samples of video images of the system considering for detecting the final position of the ball. The results of the simulation of the proposed algorithm reveal an accuracy of 98%, specificity of 100% and sensitivity of 96%, hence indicating the optimality of the proposed algorithm.

Table 1: Performance test analysis of video checks sample video images

	call
True positive/TP	29
True negative/TN	24
False positive/FP	0
False negative/FN	1

Table 2: Simulation result

Parameter	**TPR**	**SPC**	**ACC**
In or Out detection	0.96	1	0.98

Another important analysis performed on the proposed algorithm is the duration of In or Out detection time. Evidence has revealed that every video challenge requires 30-45 seconds before deciding whether the ball has landed inside or outside the court. The algorithm above can announce the corresponding results in a meagre 0.261 seconds. Table 3 compares the results of the analysis of the detection time for the proposed algorithm against the video challenge system. The proposed method detects the final position of the ball in a very short time, so there is no need to review the video images of the challenge system.

Table 3: Duration required for awarding a point using the proposed algorithm against the traditional challenge system

Duration of detection of the ball inside or outside the field of play	Video challenge system (s)	Proposed algorithm (s)
Duration of detection from the moment of challenge	30-45	0
Detection time from the moment the ball first hits the ground	-	0.261

In the proposed algorithm, a novel method for tracking and detecting the ball in video images using fuzzy logic was proposed. The simulation results indicate the optimal performance of the ball detection algorithm in input frames.

Conclusion

In the proposed method, the position of the ball in each frame was determined by presenting a new method of detecting and tracking the ball using fuzzy logic and also deciding on the frame in which the first contact of the ball with the ground was established. Using the area of the volleyball court, per the white lines that demarcate the court, the algorithm determines the first contact of the ball with the field relative to the field of play, based on which it then specifies whether the ball has landed inside or outside the playing field.

The proposed algorithm was simulated on 54 samples of video images from the volleyball challenge systems (22 samples corresponding to side line images of the field and 32 samples corresponding to back line images of the volleyball court) at a frame rate of 200 FPS. The results of the simulation show an accuracy of 98%, while the duration of detection, that is, from the time of the first contact of the ball with the ground to declaring the ball to be inside or outside of the court, was 0.261 seconds on average. The efficiency of this algorithm is hence vindicated by the low error rate and a short detection time.

It should be noted that Iran Volleyball Federation is a proper first-hand candidate for employing the proposed algorithm in the volleyball video check systems.

Employing and implementing the proposed algorithm in volleyball video check systems can yield numerous benefits, namely reducing the refereeing human error and detecting the position of the ball entering and leaving the field of play in a fraction of a second. As a result, it eliminates long interruptions, further eliminating the need for line judges in official volleyball matches.

Among the instances on which the future of volleyball video check system can be employed for automatic detection are:

- Contact of the ball with the antenna
- Contact of the ball with the opponent
- Contact of the player with the antenna
- Contact of the player with the net
- Contact of the serving player’s foot with the court line
- Contact of the backcourt player’s foot with the frontcourt line before serving
- Crossing the attacking player's foot from the net line, after an action on the ball.

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