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Original Research Article

Smart Line Judgement System: A Novel Technology in Volleyball Arbitration

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ABSTRACT

Within previous decade, sensitivity to arbitration systems in sports such as soccer, tennis and volleyball has been sharply increased and technicians turned to new technologies to fulfill the demands for a reliable judgement. The main purpose of this study was to address a new method in judgement of presence of ball in the volleyball field in the shortest possible time by manipulation of lines surrounded the field and the ball layer's structure. A carbon semi- conducting fabric layer designed ball was thrown to the printed circuit board (PCB), which have replaced the surrounded field lines. The ball was thrown in six different angles of 15, 30, 45, 60, 75, and 90 degrees and with 20 and 40 $m.s^{-1}$ speed. As soon as the semiconducting ball hits the PCB lines, the LED, which embedded under the PCB, turns on and announce the presence of the ball in the field. In 20 $m.s^{-1}$ speed, the PCB detected 97.1% of ball presence in the field per 1500 trials six angles. Almost similar, in 40 $m.s^{-1}$ speed, the accuracy of PCB in hit detection was 97.6% per 1500 trails. Additionally, regardless of ball speed, the more perpendicular the ball hit the PCB line, the accurate detection was made. The smart line judgment system could be a reliable, efficient, and affordable technology that provide referees with an accurate decision and athletes with a faster game flow.

KEYWORDS: Volleyball, Arbitration, Printed Circuit Board, Carbon Semiconducting Fabric, Smart Line Judgment System

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1. Introduction

Annually, numbers of spectators attend volleyball stadiums in order to observe national and international matches, which has attained an extensive popularity among societies. A fair and clear arbitration team could increase the quality of competition worldwide and assure the spectators, coaches and players that no misjudgment happens. To this effect, the International Federation of Volleyball (FIVB) tries to hire the most experienced and expert referees for a correct and precise judgement.

Within previous decade, new technologies such as Goal-Line, and Hawk-Eye systems has been widely used in various sports as a means of better judgment and analysis [1-8]. In volleyball competitions, the Video-Check system was used former than Hawk-Eye technology. Financially compared, the Video-Check is more economical; however, the Hawk-Eye technology provides the audience with a precise and more beautiful visual scene. Concurrently, a rapid development could be seen among coaches and sport analyzers in usage of modern applications that work with data gathered by high-tech cameras. From this point of view, the camera recording systems might come in handy from both arbitration and analyzing aspects. Yet, diversity of opinions exists on usage of such technologies [4,5,9-11]. It is generally believed that new technologies in sports' arbitration could increase the reliance on judgement team [12]. Other opinions, additionally, discuss about the quality of the competitions, which could definitely increase after utilization of the Hawk-Eye technology. In spite of all that, controversial opinions rigorously challenge the high-tech systems from different aspects [9, 10].

First of all, the time it takes for decisions to be reached can disrupt the flow of the match. Every coach, with the possibility of two mistakes in each set, can ask for reviewing the scene. Individual video referral takes at least 30 seconds to make the right decision. Considering that every coach can ask for at least two video referrals per a set, although if both will be false, two minutes will be wasted in each set. Two 30-second of individual team time out requests, plus two 1-minute of technical time out and 12 possibilities for substitution could waste more than eight minutes per a set.

The average time that each set lasts in international matches is 24-27 minutes. It means that more than 40 minutes could be wasted in a five-set game, and for a volleyball match, that lasts more than 90 minutes, these 40 minutes could accelerate the flow of the match. Fans, in addition, would like to spend more time watching the games, not the video referral or time outs. To this end, the FIVB diminished the technical time outs in 2016 Rio de Janeiro summer Olympic Games in order to speed up the competitions flow.

Based on reviews performed on 2016 Olympic Games, over than one-third of video referral requests concerned the existence of the ball inside the field, which portrays the importance of line judgement in the games. That is the main reason that the FIVB employs four-line referees and Hawk-Eye technology in the competitions to increase the accuracy of arbitration. Furthermore, the coaches, after using their time out chances, with the knowledge of being mistaken request for video referral, make a request just to spend the time in favor of their team. The process of video referral in case of presence of ball in the field and the approximate time for the reviewing is shown in **Figure 1.** For this reason, a simple precise fast technology is required to speed up the volleyball competition to keep the flow of the games and, in addition, let the spectators have a joyful moment.

2. Materials and methods

Within previous two decades, the FIVB shows that is interested in changing the regulations and game tools, such as ball, for the favor of a joyful, exciting and attractive competition. In this study, the smart line judgement system (SLJS) manipulates the ball and the lines surrounded the court floor.

2.1 The ball

The ball that is used in world competition is MI- KASA® MVA200, and its upper layer is a leather that is made of soft micro-fiber and a nylon center. In the ball production steps, what is placed a premium is the 8-panel engineered design of the ball, which aerodynamically keeps it stable in the high-intensity gameplay. Therefore, a simple change in the materials of the ball's upper layer would not highly deteriorate the quality of the ball.

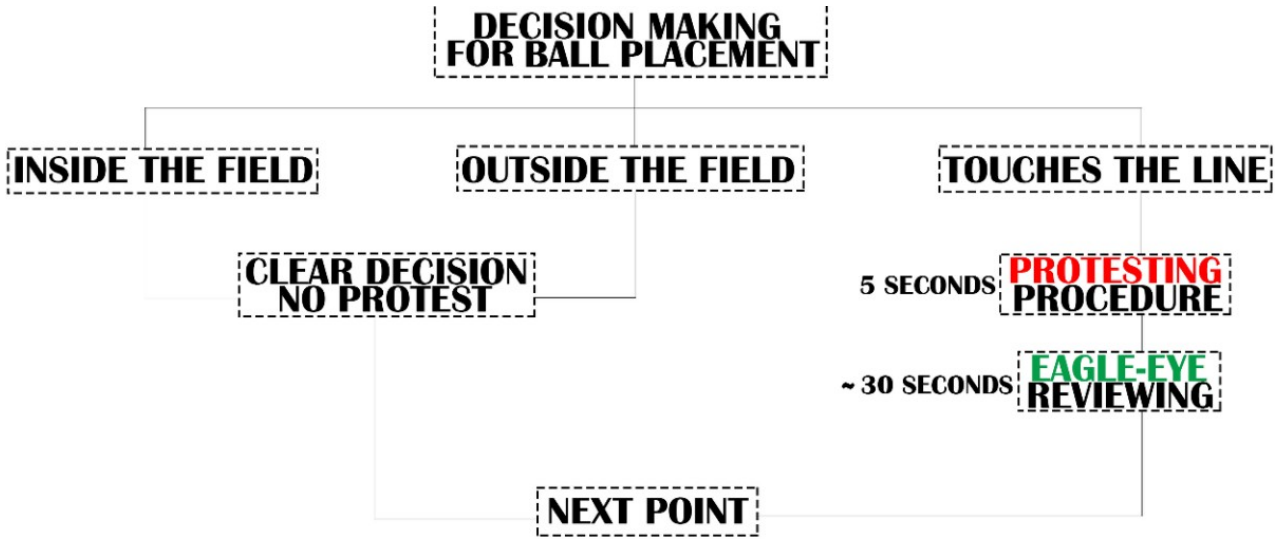

Figure 1. Video referral procedure for the presence of ball in the field

In this research, a carbon semiconducting fabric is designed and used as an upper layer of the ball [13]. The fabric is cut and placed on the bladder similar as the design used in MIKASA® MVA200 (**Figure 2**). Prior to the experimental usage, the ball was used and its quality approved by ten expert players. In addition, no skin disorders happened for the players after one hour of usage.

2.2 The mat

The mat that covered volleyball court floor is made of Polyurethane (PU) and have the capability of producing in variety of colors. The width of lines surrounded the field is 5 centimeters and considered as a part of field range. Thickness of PU floors is between 3 to 12 centimeters. Considering the thickness of the PU floors, a small change in the lines surrounded the field happened in this study. The lines dumped and a transparent Printed Circuit Board (PCB) replaced in the same level as the floor and the same width as lines (**Figure 3**).

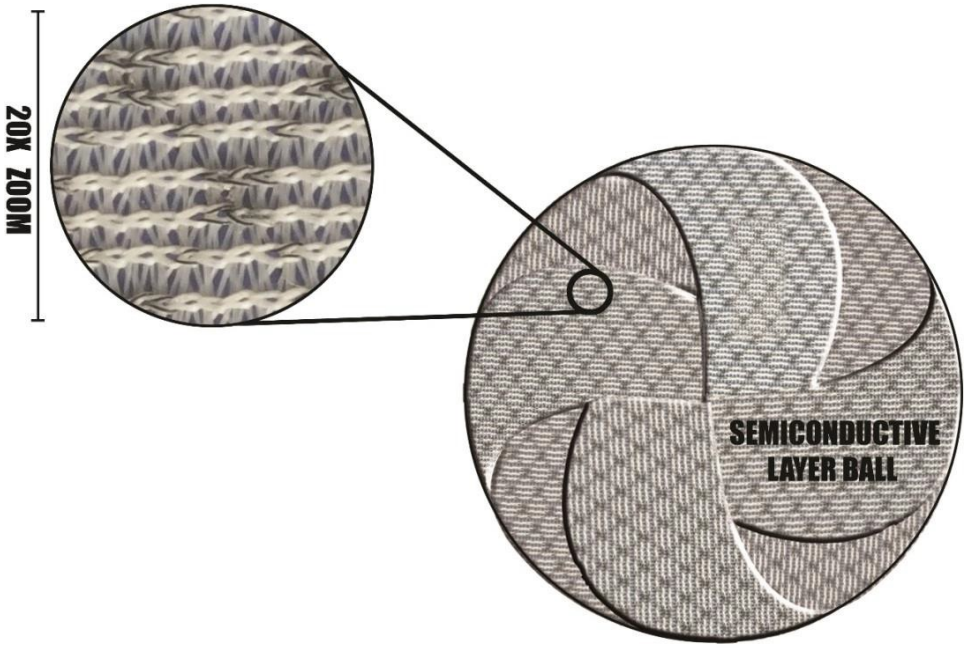

Figure 2. The experimental ball covered by a semiconducting fabric

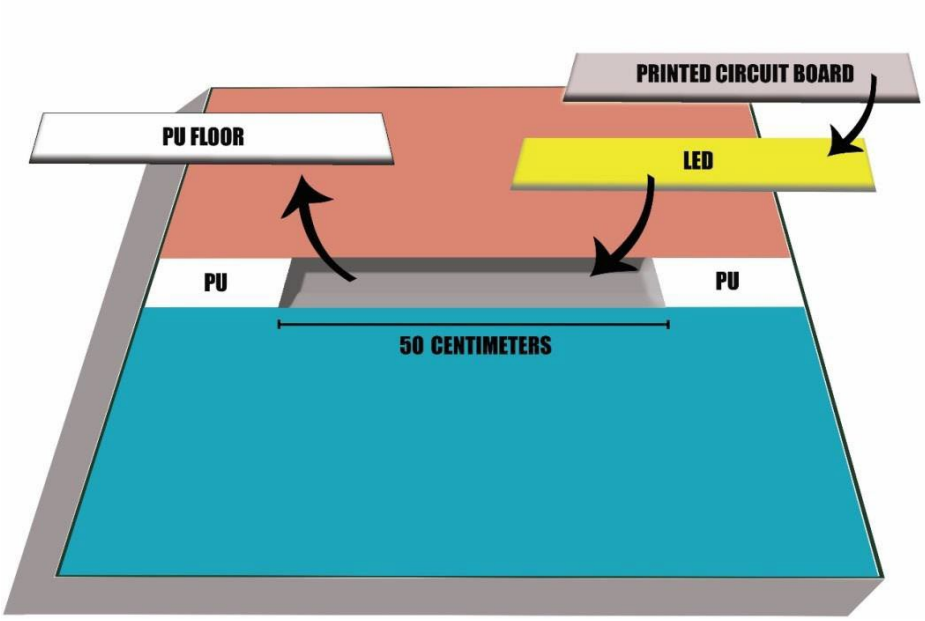

Figure 3. The Printed Circuit Board and LED embedded in the floor

2.3 The board

Every PCB has the length of 50 centimeters and width of five centimeters to increase the accuracy of sensitivity and ease of replacement in case of damage. The boards divide into 50 centimeters pieces to precisely show the ball placement on the line. Therefore, touching other boards does not affect the judgement. Behind each PCB, one LED embedded that turns on when the ball touches the line and clearly shows the exact place of ball.

2.4 Test setup

In order to quantify the accuracy of SLJS, a 5×50 centimeters PCB embedded in the PU floor of a volleyball field. Two carbon semiconducting fabric layer designed ball was thrown with two different speeds of 20 and 40 $m.s^{-1}$ using Total Attack Volleyball Machine. In volleyball competitions, the ball hits the line with various angles. To this end, six 15, 30, 45, 60, 75, and 90 degrees' angles were investigated in this study.

Each condition was recorded 250 times with GoPro Hero 5 Black Edition camera (GoPro, Inc., San Mateo, California, USA) with the framerate of 240fps. Given that sometimes the ball does not touch the line, but is very close to it, the ball was thrown to the line as following conditions:

- Total-Touch: The ball's cross-section covers entire 5 centimeters of the line width.
- Semi-Touch: The ball's cross-section covers 2 centimeters of the line width.
- Non-Touch: The ball's cross-section touches the filed 2 centimeters away from the line.

Once the ball hits the PCB line, the semiconducting fabric layer causes a connection between the electrical circuits of PCB and the LED embedded below the board turns on (**Figure 4**). This procedure announces the presence of the ball in less than one second.

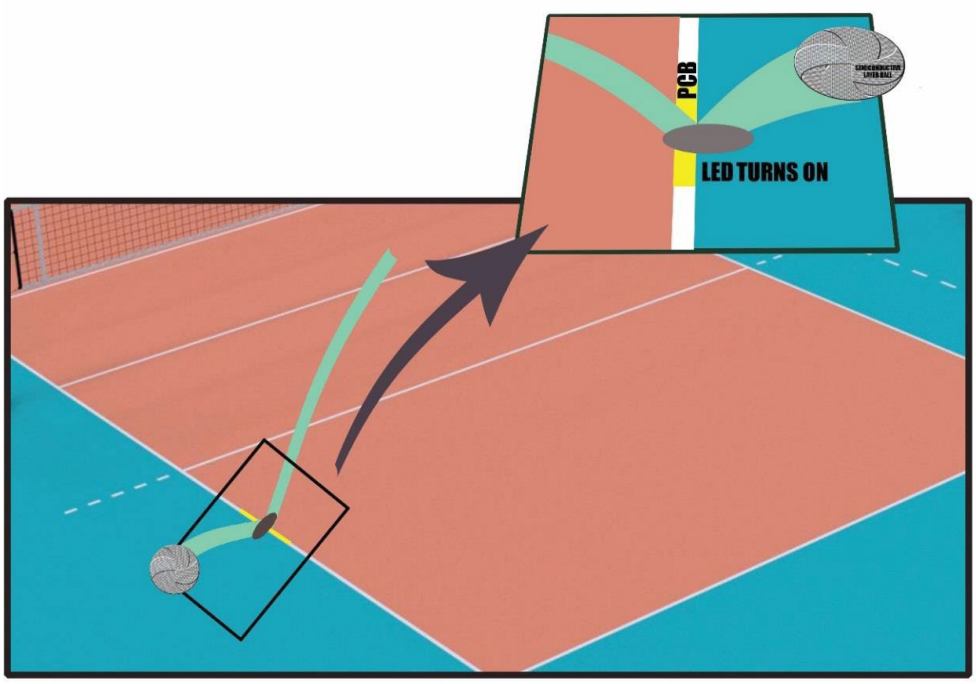

Figure 4. The LED turns on when the ball touches the line

3. Results

With 97.4% accuracy per 3000 trials in six different angles, the SLJS portrays an outstanding performance in the first experiment of ball detection. As could be seen in **Table 1**, more precise ball detection recorded in perpendicular impacts of the ball, which seems rational for the case that greater cross-section of the ball is in touch with ground. Therefore, less accuracy is observed when the contact angle decreases to 30 and 15 degrees, even in case of higher speed. In terms of speed, the faster the ball touches the line, the accurate detection is made by the SLJS. In 40 $m.s^{-1}$ speed, the system detected ball presence with the accuracy of 97.6%, while in 20 $m.s^{-1}$ speed, 97.1% of ball presence detected. All false detections happened in the cases that the ball touches 2 centimeters of the PCB line. Overall, the SLJS accuracy increases whenever the ball touches the line perpendicularly and with higher speed (**Figure 5**).

Table 1. Accuracy of printed circuit board in distinction of presence of ball in different angles and speeds

Angle (Degree)	Speed ($m.s^{-1}$)	Numbers of Trials	True Detections	False Detections	Accuracy Percentage (%)
90	20	250	246	4	98.4%
	40	250	248	2	99.2%
75	20	250	245	5	98.0%
	40	250	246	4	98.4%
60	20	250	242	8	96.8%
	40	250	246	4	98.4%
45	20	250	244	6	97.6%
	40	250	244	6	97.6%
30	20	250	241	9	96.4%
	40	250	240	10	96.0%
15	20	250	239	11	95.6%
	40	250	240	10	96.0%
Total		3000	2921	79	97.4%

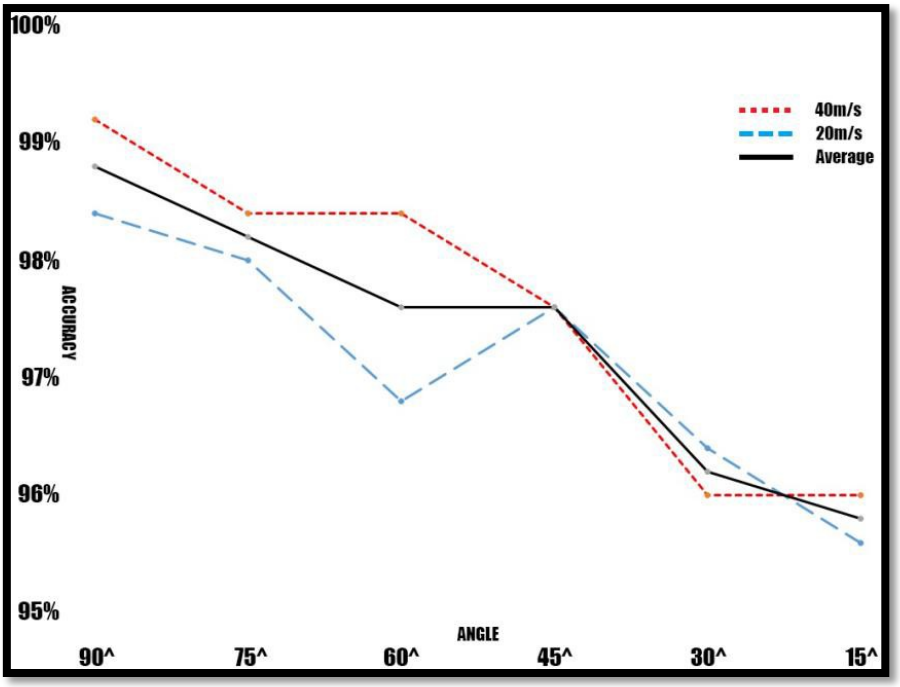

Figure 5. Accuracy percentage declines in line with angle reduction plethora of players and spectators are protest against entrance of new technology into the competitions.

4. Discussion

The principal aim of this study was to address a novel technology in judgment of presence of ball in the field in volleyball competitions that called 'Smart Line Judgement System'. The main outcomes portray that the SLJS could detect 97.4% of 3000 ball touches in less than one second after hitting the PCB.

A fair and clear judgement has become a prerequisite for national and international competitions. Goal-Line technology in football, Hawk-Eye technology in tennis and volleyball, and electronic Hugo in taekwondo are the main samples of technology impacts on sports arbitration. However, myriads of arguments exist against the utilization of new technologies in sport competitions [4, 9-10]. In volley-ball matches, additionally, plethora of players and spectators are protest against entrance of new technology into the competitions.

The time that wastes for each video referral is more than 30 seconds. Therefore, considering that five video referral request in each set, more than 12 minutes will be wasted in a five-set game. Now, add 20 minutes for team and technical time outs and 15 minutes for substitutions. For a volleyball match that every set lasts almost 24 to 27 minutes, wasting more than 40 minutes of wasted time can strongly impact the athletes' performance and increase the fatigue. In addition, though some coaches know that their request for the video referral is pointless, but they request it just for wasting the time in favor of their players and make an interruption in rivals' performance. Given that more than one third of video referrals in volleyball competitions are related to presence of the ball in the field, the SLJS could precisely detect the ball and help the referees as fast as possible. This technology, with the accuracy percentage of 97.4 in its first experimental investigations, could pave the way for a faster arbitration, and help in saving the time.

Regarding the financial affairs, the SLJS is way cheaper than Hawk-Eye technology. Using six or seven high-tech cameras make the Hawk-Eye technology very expensive that many countries cannot afford it. In some countries, in addition, the Hawk-Eye technology is only used for international competitions for the case that the maintenance costs are too much. In addition to all the above points, utilization of modern computers and applications for calibration, ball recognition, geometry algorithm, 3D position of ball and prediction of ball path requires an expert engineer that can highly increase the financial costs.

On the other hand, SLJS is a way cheaper technology that ball layers and PCB lines are its main expenses. The PCB lines are pressure- and water-resistance and the requirements for replacement is once a year. This technology, also, requires no stuff for ball detection for the case that no calibration, geometry algorithm and 3D position of the ball is needed. Hence, financially compared, the SLJS is more efficient and affordable. Besides that, the colorful LED embedded under the PCB lines can precisely detect the place of ball descend on the line. This feature not only helps the referees for a certain decision but also increase the visual effects for the spectators.

5. Conclusion

This study illustrates that the SLJS is a reliable technology that increase the fairness of arbitration; hence use of this technology could benefit both referees and athletes with correct and faster judgment. The key finding of this experimental investigation was that the SLJS is an affordable and efficient technology that could be used in other sports arbitration.

Given that this experimental study designed and performed in the laboratory, a better and reliable outcome could be gained if manufacturers of volleyball ball and playground help producing high quality semi-conducting ball and mat.

Author contributions

J. Sarvestan was designed the study, performed the experimental measurements, analyze the data, performed the numerical analyses, and write the manuscript. M. Khalafi was performed the experimental measurements, analyzed the data and performed the numerical analyses.

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Conflict of interest

Authors of this manuscript declare no conflict of interest.

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