A Lightweight Method for Computing Ball Spin in Real Time

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ABSTRACT

The present paper poses a new method for computing the rotation of a ball in sport training situations, when the ball is approaching the goal line. The proposed method significantly reduces the hardware requirements associated to the capture, as well as the computational complexity necessary to obtain the results. The system's objective is to improve the player's technique and training methodology, and it is treated within the scope of the Institute's research line on signal and image processing areas. Experimental results will be presented using digitally generated images.

Keywords: Image processing, spin speed calculation, ball, real time

1. INTRODUCTION

In any sports discipline, training sessions are necessary to improve players techniques. At present, technology allows us to obtain additional information beyond the data that can be recovered by visual observation. In the case of football training, thanks to the filming and slow motion playback of free shots, players and coach can observe, discuss and learn from them.

But more, better and precise information can be obtained through the digital capture and processing of free shots. By adaptinh the environment and the ball, it is possible to compute the spin speed of the ball in each free shot and also determine its predominant direction.

This information is crucial, since the ball spin movement makes its path deviate towards one side or the other while it is in the air due to a phenomenon known as Magnus force. This force is really steep at the end of the ball flight, when the player has applied much spin effect in the shot. [1, 2, 3, 4].

Other methods have been proposed to compute the spin speed [5, 6, 7, 8]. In general, even though they present good results, they are based on complex ball's labeling, in highly specialized hardware or in costly running algorithms. The proposed method simplifies the hardware requirements and the ball's labeling techniques as follows.

2. PRELIMINARY ANALYSIS

When executing a free shot, the rotating directions that the ball may adopt are without doubts infinite. This means that it can spin in an endless quantity of possible directions. We may wonder then, can the variants presented by the ball spin be classified?

Initially, let's take as reference three main axes over which the ball can perform the spin movement. As shown in Figure 1, we have three possibilities: the ball spins over axis X, axis Y, or axis Z. Naturally, the absolute movement over an axis annuls the movement possibility over the rest.

But it is clear that the number of axes that the ball center goes through is infinite. According to the position of them, we may say that the ball adopts an absolute movement over an axis or a combination of forces over more than one, with which it is not possible to make a useful classification.

This problem is due to the fact that the analysis carried out has been based on taking as interest point the mass center of the ball. It is then necessary to correct the previously posed question: can the variants presented by the ball spin according to a particular point of view be generalized or classified?

For the ends of the application, the point of view of interest will be the camera that captures the moving ball. Under this context, there exist three main cases, such as figure 2 shows.

The first of them is that which contemplates the two possibilities of lateral apparent spin. The second alternative is the cases in which the ball makes an apparent movement of frontal spin, in any of its directions (in the figure only four are shown). The third possibility contemplates the option in which the ball does not present any spin movement.

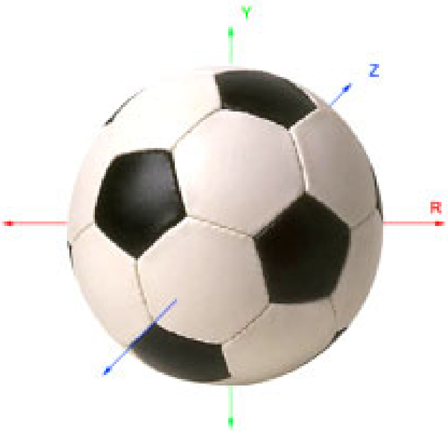

Figure 1 – Spin Axes based on the ball's mass center

Figure 2 – Spin cases according to the apparent movement in respect to the point of view of interest

Basing on this case generalization, we can develop a solution that exploits this characteristic with the aim of determining the speed in which the ball performs the spin movement, be it apparent lateral spin, apparent frontal, or a combination of both forces.

3. BALL MARKING

The main problem to solve is that of determining an optimal marking over the surface of the ball so as to know its movement at any instant. The analysis carried out presents the bases under which the ball marking method was projected. We tried to maximize the simplicity of its design.

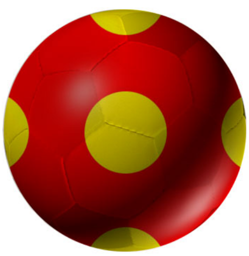

Figure 3 – Ball Labeling

The configuration of marks can be seen in figure 3. It presents six marks over the ball surface, two by axial axis. The colors shown - both of the ball and the marks- are based on a previous paper [9] which required the contemplation of certain special characteristics. For this case, they do not necessarily have to follow such color configuration. As later presented in detail, the developed algorithm carries the monitoring of the marks along the video sequence in order to determine the speed and direction of the ball spin. The detection of marks in each of the frames making up the capture is carried out by means of filtering technique.

4. FILTERING

There exists the problem of individually identifying each of the ball's marks. This is, given an image and a mark, determine the new position of such mark in the previous or next image. Yellow mark filtering is the first step, and it was carried out by thresholding per light intensity levels in RGB channels.

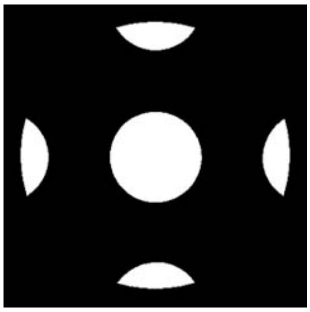

Figure 4 – Ball Filtering

Once the proper intensity levels are specified for each channel, the image is processed by performing the filtering with such thresholds.

In order to get higher robustness, filtering is carried out so that the isolated pixels not belonging to the marks making up the ball are ignored (which is necessary to take into account in adverse conditions, such as low lightness).

So as to achieve this, those pixels located far from the ball are discarded as well as those which are not linked to it, i.e., the 4-neighbors and the 8-neighbors are taken into account to determine the filtering. In this way, the method determines without errors each of the ball's marks. Figure 4 shows the ball after its filtering.

The objective of mark monitoring is to determine the position of each mark in the previous and next image which will be taken as reference.

5. MARK MONITORING

As previously explained, the ball may adopt an apparent lateral or apparent frontal rotation. If we also incorporate the presented marking model, this may lead to the conclusion that the ball spin of figure 3 can be given in the following ways:

1. The ball makes an apparent lateral rotation, with which (a) an apparently motionless central mark may appear; (b) the central mark partially goes through the centre of the ball; or (c) no mark may appear in its centre.
2. The ball makes an apparent frontal rotation, with which it is possible that (a) a central mark goes through the ball centre, or (b) no central mark goes through the ball centre.

In consequence, in order to obtain a precise value, it will be necessary to monitor the central and lateral marks and, according to the case, rely on one or both to make the spin computing. Figure 5 presents the schemes which sum up the presented alternatives.

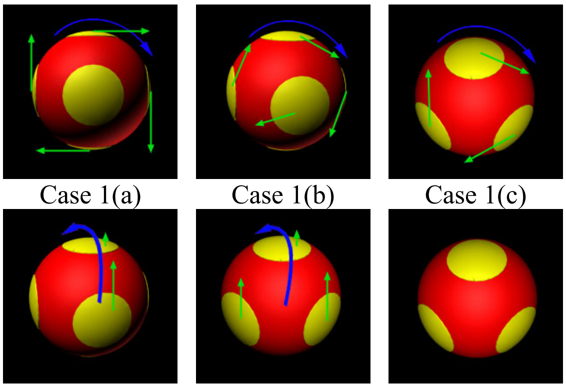

Figure 5 – Ways of ball spin cases

Next we will explain the developed method in detail, which is based on the analysis here described.

6. COMPUTATIONAL MODEL

Mark monitoring for a subsequent spin computing should be carried out in such a way that the marks of interest are not lost along the frames selected as optimal for measurement.

6.1. Defined Central Mark

The way to determine which the optimal frame is, is based on searching the most defined central yellow mark within the complete video sequence. In order to perform this task, for each frame, the centre of the ball is determined and the yellow intensity level is obtained within a search window V of size according to the ball diameter in pixels. Figure 6 shows this process.

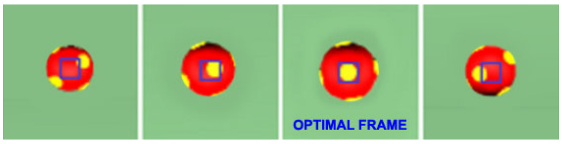

Figure 6. Selection of the optimal frame.

Let $i_1..i_n$ be the set of frames making up the video sequence of a shot capture, V the search window within the central zone of the ball, U the yellow intensity value that the search should surpass over window V.

Then, we should find frame i_c such that,

$$i_c = \max\{ V(i_k) > U,\ _{k=1..n} \}$$

As we shall see later, the developed algorithm contemplates cases in which alternatives 1(c) or 2 (b) of figure 5 are presented, in which i_c may not exist.

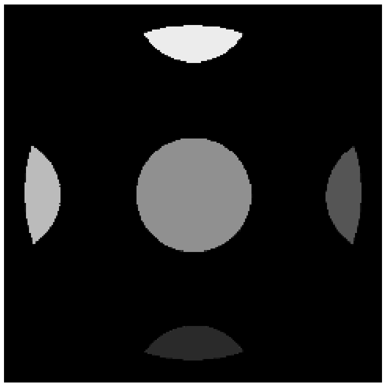
Figure 7 – Ball Labeling

Once i_c is found, the information of frames i_{c-1}, i_c e i_{c+1} will be used for spin computing. A labeling algorithm will be applied to each of the marks of the selected frames. Mark labeling consists in assigning an identifier (mark) to each of the marks obtained after the filtering. This task is carried out by an image rasterization process and the result can be seen in figure 7.

Since the ball is moving (this is even evident in the short sequence of three frames), the labels assigned to the marks may not be the same. The way to determine the position of each label along the video sequence is then presented in detail.

Let i_{c-1}, i_c e i_{c+1} be the selected frames, there will be a set of marks per frame. Thus, for each central frame, there will exist ${}^t i_c,\ _{t=1..4}$ labels t, highlighting also the central label c, with which i_c is obtained. This is, let

${}^{t}i_{c-1},\ {}_{t\,=\,1..5}$ be the five (as maximum) marks of the frame prior to i_c
${}^{t}i_{c},\ {}_{t\,=\,1..4}$ be the four (as maximum) marks of the frame i_c, plus the central mark ${}^{c}i_c$
${}^{t}i_{c+1},\ {}_{t\,=\,1..5}$ be the five (as maximum) marks of the frame posterior to i_c

It is then necessary to determine the position of the central label ${}^{c}i_c$ within the labels of the frames previous and next to the central. This means that the distinguished labels ${}^{c}i_{c-1}$ and ${}^{c}i_{c+1}$ should be found within ${}^{t}i_{c-1},\ {}_{t\,=\,1..5}$ and ${}^{t}i_{c+1},\ {}_{t\,=\,1..5}$.

For it, an outward cyclic search of a label from the central point of label ${}^{c}i_c$ is carried out in frames i_{c-1} and i_{c+1}. Given the characteristics of determining i_c, the first label that will be found will be ${}^{c}i_{c-1}$ and ${}^{c}i_{c+1}$, respectively. Figure 8 illustrates this situation.

Knowing the distance the marks have traveled between a frame and the next of the video sequence, its capture speed (FPS) and the size in millimeters represented by a pixel, we may thus determine the ball spin speed. The last parameter is obtained knowing the ball diameter in millimeters and determining how many pixels compose the ball in the equatorial zone.

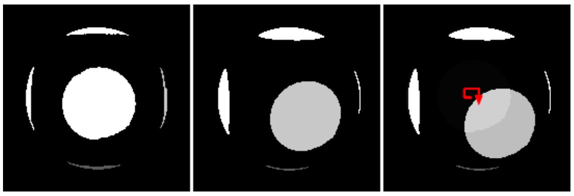

Figure 8. (a) Frame i_c. (b) Frame i_{c+1}.
(c) Search of label ${}^{c}i_{c+1}$ in i_{c+1} with respect to the centre of ${}^{c}i_c$.

We may conclude that the algorithm presented up to the moment is completely valid when the ball adopts complete apparent frontal rotation, like the case 2(a) of figure 5. But if the ball presents a combination of apparent frontal and apparent lateral rotation (case 1(b)), the results obtained will not be completely correct, since we are disregarding a rotation force.

What is more, in the case in which a complete apparent lateral rotation is presented (case 1 (a)), spin computing will be totally incorrect, since the position of ${}^{c}i_c$ will be the same as that of ${}^{c}i_{c-1}$ and ${}^{c}i_{c+1}$. For this reason, labels ${}^{t}i_{c-1\ (t\,=\,1..5)}$, ${}^{t}i_{c\ (t\,=\,1..4)}$ and ${}^{t}i_{c+1\ (t\,=\,1..5)}$ should be taken into account in the developed computational model.

Making an analogous procedure, and basing on the perimeter marks, we then obtain the lateral spin speed. Weighting both forces, we thus determine the total spin speed.

6.2 Non-defined Central Mark

As previously mentioned, it may appear the case in which i_c does not exist, such as cases 1(c) and 2(b), with which the ball does not rotate or rotates in a completely normal direction to the camera vision sense, with no marks going through the central zone of the ball.

For these cases, computing is carried out only basing on the perimeter marks. As i_c does not exist, the selected frames are the firsts of the video sequence, in which the ball has the higher centimeter/pixel relation, thus gaining precision.

7. USED RESOURCES

7.1 Software

In order to ease the initial tests, a virtual scale model of the place in which the training tests are carried out has been designed. Thanks to this model we were able to determine the technical requirements that the camera should fulfill and its optimal capture position.

Then an optimal language to carry out the application was established. The library OpenCV ("Open Computer Vision") [10] was selected as optimal together with the C++ Builder development environment.

7.2 Hardware

7.2.1 Camera

After a detailed analysis, the characteristics that the camera should have were determined:

- 640x480 pixel resolution
- 100 Frame per second (FPS)
- Shutter Speed 1/1000

Using images of 640x480 pixels we can get a relatively high precision - taking into account the distance between the camera and the ball.

Capturing 100 frames per second, the ball spin between a frame and the other will not be higher than 1/10 revolutions, since studies [1] have shown that the ball reaches a spin speed not higher that 10 RPS. We can be sure then that the selected marks for the spin computing will not be lost along the frames making up the sequence.

By means of a shutter speed of 1/1000, the problem of capturing images in which the ball presents a blurring effect will be avoided. A capture of 1/1000 makes the maximum displacement of the marks in such interval not higher than 7mm.

7.2.2 Capture System

The digital capture system should allow storing large quantity of data per second. Each sequence's capture with no compression will require a transference speed of approximately 90 Megabytes per second. For this reason, cameras with Firewire 1394a interface will be used.

8. OBTAINED RESULTS

First, we carried out a series of laboratory tests using images generated from a virtual model. These tests resulted in that the precision of spin computing is closer to +/- 0.3 RPS (revolutions per second).

At present, the corresponding field tests are going to be run. We expect that the use of the system on the players will lead to improve the precision of their free shots, since the information the system presents is useful to obtain a better control of the moment in which the ball starts falling down over the curve generated by the shot's path.

9. CURRENT RESEARCH LINES

We expect to develop a processing environment independent of the application in which the rotation module is currently embedded. Since we will not have the restrictions belonging to such application any more, the colors of the ball and the labeling may vary according to the requirements of each case.

The solution will be generalized not depending on a specific application, increasing the robustness and precision of the developed methods.

10. CONCLUSIONS

The implementation of a real time spin computing method has been carried out, which significantly reduces hardware device requirements associated to the capture.

In addition, the computing complexity needed to obtain the results has been reduced. For this, a simple labeling technique was designed allowing to know, at any moment, the movement made by the ball, dividing the possible spin situation in simple movement analysis cases.

A module allowing monitoring the visualization of the ball spin has been developed, together with the achieved numerical results. In this way, the analysis of these results allows improving the players technique and their training methodology.

In order to carry out the development, image processing and computer vision techniques, tools and methods have been researched, analyzed, and used.

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