

VTS | Football: Tracking and Analysing Football Shots

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Abstract: This paper describes VTS | Football, a tool for tracking and analysing football shots. The system tracks the trajectory of the ball using two synchronized cameras, removing all the geometries that are not similar to a ball and extrapolating the position of the ball when it is hidden by the goal keeper. Once the trajectory is obtained, the user can analyse the shot using a tool that has been developed for this purpose. He/she can organize the training sessions, follow the evolution of a player, compare performances of different players and visualize the shot in a 3D virtual environment. To make the visualization smooth, an interpolation algorithm based on least squares methods has been developed and to make the visualization attractive a football player and a crowded stadium have been added to the virtual scene.

1 INTRODUCTION

Improving the execution of free kicks in football is an important aspect in training process since statistical results of football (Liga, 2015) demonstrate that:

- Less than 80% of penalty shots finish in a goal
- Less than 4% of free kicks finish in a goal
- Around 70% of games end as a tie or victory by one goal
- At the end of the season the difference in points by achieving objectives is minimum. For example, in the Spanish league, in the last 5 seasons, the average points difference between being relegated to the second division and staying in the first is 0.80.

These data show that improving performance in set-pieces achieving one more goal in any of the games played throughout the league may represent achieving the point that helps to win the league, play in Europe or not be relegated to the second division.

Nowadays, the coach has a lot of tools for training several aspects of the game, including free kicks; however they have not objective information about the shot in order to assess the improving of each player.

During the latest years, authors of this work have been working on Visiona Training System (VTS), a platform that is able to reconstruct the trajectory of a

ball and objectively compare it with the ideal trajectory. This platform has three key requirements that are also innovation over state-of-the art systems:

- Flexibility. The software should be useful for different ball-based sports.
- Low cost. The whole system should be low cost, mainly by using regular hardware.
- Mobility. The system has to be portable, but also provide advanced usability on training sessions: it has to take advantage of mobile devices to configure and use it.

The scenario of free kicks in football is an ideal test-bed for first market approaches of VTS platform. Therefore, a dedicated instance of the platform, called VTS | Football has been developed. VTS | Football offers objective and real data on the exact point where the ball crosses the plane of the goal and its speed and it also includes specific functionalities for football trainers.

This papers explains the VTS architecture and the different modules that compose VTS | Football. Next section is focused on related work, then Section 3 explains the VTS reconstruction architecture, and sections 4 and 5 the training and visualization tools respectively. Finally, section 6 presents conclusions and future work.

2 RELATED WORK

Using software technologies for supporting sports is quite common nowadays. There exist several tools that are focused training, help to refereeing or analytics. Good known examples are (NACSport, 2015) or (VideoSTAT, 2015).

Going into visual computing based tools, very specialized software can be found. Formula 1 drivers, for example, make use of advanced simulators that virtually represent the car and the tracks. These simulators are even able to reproduce the forces and real effects that applies to the car, temperature changes or specific weather (R&D, 2015).

Other specialized example is the system developed by Jong and Myung, which is able to analyse golf shots. This platform is composed by set of cameras that records and reproduce the shot, helping golf players in their train session (Jong-Sung & Myung-Gyu, 2012).

An interesting system is designed by Bideau et al. (Bideau, et al., 2004). They propose a virtual reality platform using a CAVE, where handball goalkeepers trains against virtual handball players.

In the football case, there is a similar development created by Hoinville et al. (Hoinville, et al., 2011).

Regarding 3D reconstruction, there are several mature techniques that can be used as basis to a system like VTS | Football. PatchMach (Barnes, et al., 2009), presented by Barnes et al., and its combination with the Agglomerative Correspondence Clustering (ACC) algorithm are used in non-rigid elements.

And some techniques, such as those developed by Sattler et al. (Sattler, et al., 2011) or Schneider et al. (Schneider, et al., 2011) perform global optimization that improve the resulting virtual model.

The combination of these techniques with specific hardware, for example depth and RGB cameras is being widely studied (Newcombe, et al., 2011) (Eitz, et al., 2012).

The maturity of these techniques is proved by their inclusion into commercial software, but not applied to sports (Aqsense, 2015) (ICY, 2015) (Chimera, 2015).

In general, related systems found in state of the art are robust but very specific, lacking a dynamic reconstruction algorithm that can be applied to other sports different than football. Moreover, VTS | Football is composed by low cost and portable hardware that can be easily set up. The application

of general purpose reconstruction techniques is also an innovative approach comparing existing systems.

3 VTS | FOOTBALL DESCRIPTION

VTS | Football provides a tool that transforms the goal area into a virtual target so that the coach can improve training of all of the phases of the game in which shooting is appreciated and it is particularly useful in the training of set-pieces such as free kicks and penalties.

VTS | Football is a system based on machine vision technology. Machine vision is a field of artificial intelligence which is based on the programming of a computer so that it is able to analyse and interpret a real world scene after processing one or more images captured by some cameras.

Once digitized, these images have to be processed by a computer, where the appropriate image processing algorithms have to be developed in order to obtain the necessary information from the inspected scene.

Our technology allows calculating the ball's last trajectory and offers the exact coordinates with which it has entered the goal and its speed.

This information is also obtained in real time, and allows correcting the player during training sessions or, on the contrary, the player can train and VTS | Football will store the resulting information to be analysed later on.

3.1 Hardware

As can be seen in Figure 1, the system consists of two synchronized cameras strategically placed on both sides of the field and focusing to the goal. Both cameras are controlled by the PC which is inside an electric cabinet.



Figure 1: Capture system (two cameras and a PC) localization in the football field.

The hardware generates as output a group of synchronized images containing the ball movement through the shot trajectory.

3.2 Calibration

The stereo system must be correctly calibrated in order to obtain the relative position between both cameras and the goal.

A calibration pattern with previously known characteristic points is positioned in more than 20 different locations. The images of the calibration pattern captured by both cameras are then processed and every characteristic point is automatically located in each image. This information is used in order to calibrate both intrinsic and extrinsic parameters of the stereo system applying standard camera calibration algorithms defined by (Zahng, 2000).

3.3 Software

The images generated by the hardware are processing by a software module. This module is able to detect the ball in each pair of images and calculate its exact position in each moment. For this development we found two main challenges.

First of all the system is place outdoor which means that the system should work under different meteorology conditions. We develop a module that permits the system to auto-adjust the different camera parameters to the illumination conditions.

Besides, since the system is used during the training, any object such as another player, a bird or the goalkeeper can hide the correct visualization of the ball. For that, we have implemented two algorithms.

The first one permits to eliminate any object from the scene that has not the geometry similar to a ball. The second one permits to extrapolate the data when the ball is hidden by other object.

Finally the system is able to analyse the data for the trajectory obtained directly in the reconstruction, the speed and the coordinates of the ball where it crosses the plane of the goal.

Figure 2 shows how the system reconstructs the scene. The image shows at the top the synchronized pair of images captured in a given time instant. Underneath, the image shows how the system has deleted any static information, so the moving objects have been clearly detected.

At that point, algorithms for blob analysis have been implemented in order to extract different properties of candidate blobs shown in Figure 2, so that the system can segment the blob that represents the ball in each image. Some of the conditions that

are imposed are geometrical properties, such as area and contours, and coherent positions belonging to the current detected trajectory.

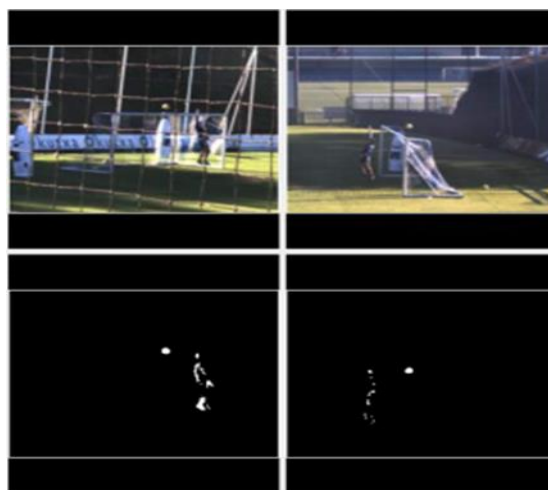


Figure 2: Reconstruction system, removing all static information and highlighting the ball and the keeper.

Once the blobs representing the ball have been segmented and located in both cameras, the 3D point is calculated via 3d stereo triangulation and a new position of the trajectory is obtained.

4 USER TOOL

User tool allows the coach to:

- Organize the training sessions by features, shoot parameters, players list, comments...
- Control the system indicating it when the system should start to reconstruct the shot.
- Visualize the results of each shot (speed, trajectory as 3D animation and the point where the ball crosses the plane of the goal as an image).
- Scoring each of the shots on templates predefined by the coach.
- See the evolution of all players throughout the season or within any date range.
- Comparing players including according to predefined variables.

Figure 3 shows a screenshot of the statistics feature. What the application does is showing a curve with all the kicks that the selected player has done. The coach also can filter a specific type of shot (penalties, free kicks, corners...) by using the same parameter that he/she uses for the training session.

The tool also allows comparing any player against any of his teammates, generating plots with the average score along time for each compared player, taking into account training sessions performed under identical conditions, regarding distance to the goal, scoring template used, etc.

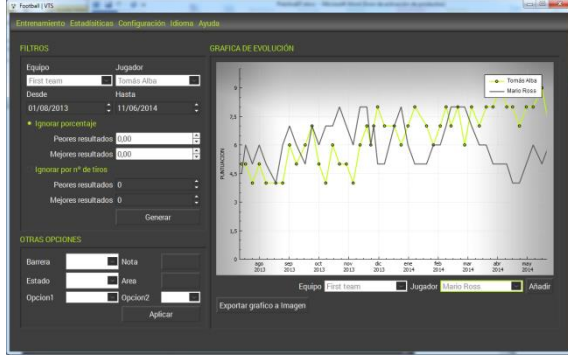


Figure 3: Statistics application comparing several players.

5 SHOT VISUALIZATION

As stated before, the user can visualize any shot captured by the VTS | Football system in order to analyse the trajectory more precisely (e.g. when the coach wants to show how the trajectory of the evolved to make the player see why the ball went out).

The user can watch the selected shot in a similar way to any video player. He/she can play or pause the ball at any point of the trajectory or watch it faster or slower. Moreover, the point of the view can be changed at any point. For example, a shot can be watched from a point located quite far away from the goal, to analyse the trajectory, but at the end, the user can pause the animation and move the camera to a point where the entrance of the ball is better shown. Figure 4 shows the shot visualization application. The trajectory of the ball is highlighted in yellow so that it can be analysed easily.



Figure 4: Shot visualization application showing the trajectory of the ball, the player and the spectators.

For this visualization, the application takes the n points captured in the real trajectory and makes an interpolation to obtain an approximated trajectory in a virtual 3D football field. The next subsection shows how this interpolation is done.

5.1 Trajectory Interpolation

For the interpolation, it is considered that the ball at time t follows the following curve:

$$\mathbf{p} = \mathbf{a}t^2 + \mathbf{b}t + \mathbf{c} \quad (1)$$

Where $\mathbf{p} \in \mathbb{R}^3$ is the location of the ball and $\mathbf{a}, \mathbf{b}, \mathbf{c} \in \mathbb{R}^3$ are the coefficients of the curve. Even the equation 1 is very simple, since it is quadratic in three dimensions, it is sufficient to interpolate even spinning balls. In the following, the notation will be reduced to one dimension, assuming that every step will be done three times, once per coordinate.

$$p = at^2 + bt + c \quad (2)$$

When rendering the ball in time t , the trajectory generator takes m captured points, (t_i, p_i) , that surround such time. Then, using the least squares method the following function must be minimized.

$$f = \sum_{i=0}^m (at_i^2 + bt_i + c - p_i)^2 \quad (3)$$

So, the first partial derivatives of f must be 0.

$$\frac{\partial f}{\partial a} = 0 \quad \frac{\partial f}{\partial b} = 0 \quad \frac{\partial f}{\partial c} = 0 \quad (4)$$

Equation 5 and 6 show the equation obtained with the first derivative with respect to a and the other two are computed in a similar way.

$$\sum_{i=0}^m 2(at_i^2 + bt_i + c - p_i)t_i^2 = 0 \quad (5)$$

$$a \sum_{i=0}^m t_i^4 + b \sum_{i=0}^m t_i^3 + c \sum_{i=0}^m t_i^2 = \sum_{i=0}^m t_i^2 p_i \quad (6)$$

And putting all the equation together we obtain an equation system like the following.

$$\begin{pmatrix} \sum_{i=0}^m t_i^4 & \sum_{i=0}^m t_i^3 & \sum_{i=0}^m t_i^2 \\ \sum_{i=0}^m t_i^3 & \sum_{i=0}^m t_i^2 & \sum_{i=0}^m t_i \\ \sum_{i=0}^m t_i^2 & \sum_{i=0}^m t_i & \sum_{i=0}^m 1 \end{pmatrix} \begin{pmatrix} a \\ b \\ c \end{pmatrix} = \begin{pmatrix} \sum_{i=0}^m t_i^2 p_i \\ \sum_{i=0}^m t_i p_i \\ \sum_{i=0}^m p_i \end{pmatrix} \quad (7)$$

The equation system is resolved with a simple LU Decomposition method and a, b, c are obtained. Thus, inserting them in equation 1, the position where the ball will be rendered in time t is obtained.

5.2 Adding the Starting Point

Another utilization scenario has been identified for VTS | Football tool. The reconstruction and visualization tool can be used for marketing events, where a visitor shoots some balls to goal and he/she can visualize his/her performance.

In that case, the aim of the applications is not only to have a realistic reproduction, but also an attractive visualization. For that, several virtual elements have been included in the 3D virtual environment. Figure 5 shows the stadium that has been modelled, based on real stadiums and the virtual player that has been introduced so that it looks like the player is shooting the ball.

Besides, thousands of spectators have been placed in the stadium. The simple visual characters are replicated and animated via shaders in the GPU. This way, there is no loss of performance efficiency because of the rendering of such amount of virtual characters.

When locating the player in the field a new problem arises. The points of the trajectory that have been captured don't start at the floor; they are near the goal. Thus, a starting point, the point where the virtual player kicks the ball has to be computed.

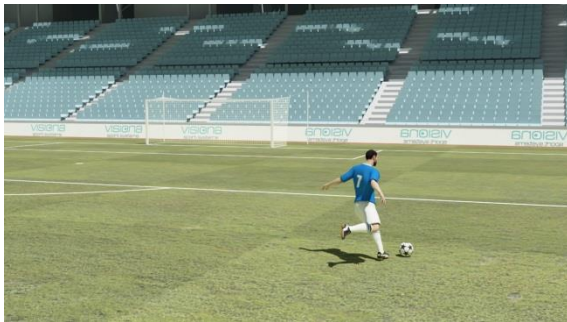


Figure 5: The virtual stadium and the virtual player that have been modelled for the application.

Since, a perfect realism is not essential in this scenario; a simple method has been used for this

computation, assuming that the ball follows a Uniformly Accelerated Motion. Specifically, the formula of such motion in the vertical axis y is used to obtain the time difference between the starting point and the first captured point.

$$\begin{aligned} p_{y1} &= p_{y0} + v_{y0}t_1 + \frac{a_y t_1^2}{2} \\ v_{y1} &= v_{y0} + a_y t_1 \end{aligned} \quad (8)$$

Where the known variables are p_{y1} the altitude of the first captured point; $p_{y0} = 0$ the altitude of the starting point; v_{y1} vertical velocity at the first captured point (computed with the difference between the first captured two points) and $a_y = -9,8$ the acceleration in the vertical axis (gravity). The unknown variables are v_{y0} , the vertical velocity at the starting point and t_1 , the time difference between the first captured point and the starting point $t_0 = 0$.

The accelerations in the axes x and z, a_x and a_z , are also assumed to be uniform. Thus, they can be computed with the difference between the first and the last captured points.

$$\begin{aligned} v_{xn} &= v_{x1} + a_x(t_n - t_1) \\ v_{zn} &= v_{z1} + a_z(t_n - t_1) \end{aligned} \quad (9)$$

In the same way, v_{x0} and v_{z0} , velocities at the starting point are computed. And finally, we obtain the starting point $(p_{x0}, 0, p_{z0})$.

$$\begin{aligned} p_{x1} &= p_{x0} + v_{x0}t_1 + \frac{a_x t_1^2}{2} \\ p_{z1} &= p_{z0} + v_{z0}t_1 + \frac{a_z t_1^2}{2} \end{aligned} \quad (10)$$

6 CONCLUSIONS AND FUTURE WORK

In this paper authors presented the work done around Visiona Training System platform and its VTS | Football instance. VTS is a system that provides a virtual reconstruction of ball trajectories and allows their measurement against ideal trajectories. The platform is based on three main premises:

- Flexibility for using it in different sports
- Low cost hardware
- Portability and usability

The paper has explained the technical architecture of VTS platform and it has detailed the reconstruction and visualization algorithms.

Moreover, it presents tools that have been implemented specifically for the VTS | Football instance.

Future work is mainly focused on getting both technical and commercial feedback of VTS | Football software and apply it to new instances of the platform for other sports.

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