UNIVERSIDADE TÉCNICA DE LISBOA
FACULDADE DE MOTRICIDADE HUMANA

Development of a Tracking System Using Invisible Markers for Association Football

Dissertação elaborada com vista à obtenção do Grau de Mestre em Treino Desportivo

Orientador: Professor Doutor Duarte Fernando da Rosa Belo Patronilho Araújo

Júri:

Presidente: Professor Doutor Duarte Fernando da Rosa Belo Patronilho de Araújo

Vogais: Professor Doutor António Jorge Dias Parola

Professor Doutor Pedro José Madaleno Passos

Professor Ricardo Filipe Lima Duarte

José Pedro dos Reis Carmo Silva

2012

Aos meus avós

Agradecimentos

Ao Professor Duarte Araújo, pela insubstituível orientação, pela confiança que depositou em mim ao ter colocado este desafio, pelo seu conhecimento, dedicação e motivação. Mais do que um professor, uma referência.

Ao Professor Ricardo Duarte, pela paciência, pelas imprescindíveis sugestões e por, mais do que ter apontado o caminho, ter corrido ao meu lado durante todo este tempo.

Aos Professores João Carlos Lima e Jorge Parola, do Departamento de Química da Faculdade de Ciência e Tecnologia, da Universidade Nova de Lisboa, pelos ensinamentos, pela constante orientação e pelo interesse que sempre demonstraram, quer neste projecto, quer no meu desenvolvimento.

À YDreams e em especial ao Fernando Nabais, Edmundo Nobre e Nuno Cardoso, que mesmo tendo outras responsabilidades profissionais, mantiveram-se empenhados e ofereceram os seus conhecimentos que permitiram desenvolver e concluir este trabalho.

À Ana Marta, ao Jorge Gonzalez, à Raquel Gavara e à Raquel Rondão, do Departamento de Química da Faculdade de Ciência e Tecnologia, da Universidade Nova de Lisboa, pela constante paciência demonstrada, pela ajuda e pelo carinho com que me receberam nesta curta incursão no mundo da química.

Aos treinadores, do Grupo Desportivo Estoril-Praia Vinícius Eutrópio, José Martins e aos seus jogadores, pela disponibilidade na aplicação prática deste estudo.

À Cíntia Carvalho e à Sara Ribeiro, pela companhia, pelo apoio e pelos bons momentos que me proporcionaram na fase mais crítica deste trabalho.

À minha família pela paciência, compreensão e apoio incondicional. No fundo, por tudo!

Resumo

Actualmente no futebol, a obtenção de informações como posição e movimentos dos jogadores é de grande interesse por parte dos técnicos devido ao potencial para relacionar o desempenho à táctica e ajudar na elaboração dos programas de treino.

Durante a última década, avanços tecnológicos nesta área incluíram a introdução de sistemas mais sofisticados que estão a ser utilizados no futebol de elite; no entanto, o desenvolvimento de um sistema totalmente automatizado ainda é necessário.

O objectivo deste estudo é contribuir para o desenvolvimento de um sistema de *tracking* não-intrusivo, automático, usando um marcador invisível para os seres humanos.

Seleccionámos um marcador que absorve na região do infravermelho (IV) do espectro electromagnético (Epolight 1110) e preparámos soluções contendo o marcador. Testámos as soluções em amostras de tecido para avaliar os tons de cinzento, assim como a resistência do marcador à água. Foram embebidas T-shirts com as soluções criadas, que foram usadas por jogadores de futebol numa situação *in situ* de 1vs2 onde se procedeu ao *tracking* dos mesmos.

Os resultados mostraram que esta abordagem é válida para discriminar e acompanhar os jogadores. Concluímos que é possível usar marcadores IV para distinguir diferentes jogadores e, com algoritmos de computação gráfica adequados, é possível monitorizar automaticamente os jogadores.

Palavras-chave: futebol, tracking, infra-vermelho, marcador, Amisco, Prozone, GPS, análise de jogo, análise cinemática, coordenação.

Abstract

Nowadays in association football, obtaining information such as position and movements of the players is of great interest to coaches due to the potential to relate performance to tactics and to assist in planning training programs.

Over the last decade, technological advances in this area included the introduction of more sophisticated systems that are being used in elite association football; however, the development of a fully automated system is still needed.

The aim of this study is to contribute to the development of a non-intrusive, automatic, tracking system, using a marker invisible to humans.

We select a marker that absorbs in the infrared region (IR) of the electromagnetic spectrum (Epolight 1110) and prepared solutions containing the marker. We tested the solutions in fabric samples to assess the tones of gray, as well as the resistance of the marker to water. T-shirts were soaked in the solutions created, and were used by football players in a 1vs2 *in situ* task where we proceeded to the tracking.

The findings showed that this approach is a valid possibility to discriminate and track players. We concluded that it is possible to use IR markers to distinguish different players and, with the appropriate computer graphics' algorithms, to automatically track the players.

Keywords: association football, tracking, infrared, marker, Amisco, Prozone, GPS, game analysis, motion analysis, coordination.

Contents

List of Figures

List of Tables

Introduction

Association Football is a worldwide sport and there is a great interest in better understanding the principles to increase the performance of a team during a game (Figueroa et al., 2006). For many years, the eyes of the experts have been the only way to assess the effectiveness and performance of teams and players (Gréhaigne & Duprat, 2009). A significant body of research related to the optimization of performance in sports has emerged over the past two decades (Carling et al., 2008). This increased research activity has been particularly evident in Association Football, where the importance of scientific research and applied work entered in the professional practice (Carling et al., 2008).

Consequently, the quantitative analysis of team/player activity is nowadays an important factor in the coaching process. Obtaining accurate positional and movement information about sports players is of interest to coaches because of the potential to relate performance to tactics, and to assist in the design of better training programs (Iwase & Saito, 2003; Figueroa et al., 2006; Barris & Button, 2008; Carling, 2009). In Association Football, data concerning total distance traveled at different intensities, number of sprints, middle distance sprint or the number of duels won and lost are variables to take into account to identify key elements of performance according to different positions occupied on the ground (Dellal et al. 2009).

Motion analysis data, drawn from match-play, have also been employed to help design laboratory based protocols to simulate soccer-specific intermittent exercise and examine factors such as the effects of training interventions, nutritional strategies, temperature and fatigue on performance (Carling et al., 2008).

Over the past decade, technological advances have included the introduction of increasingly sophisticated motion analysis systems that are now being used in elite soccer (Carling et al., 2008; Barris & Button, 2008). Computerized analysis has progressed from simple analysis of events like shooting, passing, duel, to the development of the so-called *tracking*, where the movement of players is tracked, recorded and reproduced as simulations in two dimensions (Carling, 2009).

Nowadays, an automated motion detection system can offer applications, such as: planning tactics and strategies; measuring team organization; providing meaningful kinematic feedback; and objective measures of intervention effectiveness in team sports (Barris & Button, 2008).

However, according to Glazier (2010), much of the work being conducted in performance analysis lacks sound theoretical rationale and, consequently, is descriptive rather than explanatory. Glazier (2010) defends that performance analysis must focus much more on the processes of coordination and control underpinning the performance outcome and not just the performance outcome itself, and the recent advances in player tracking technology could help establishing the effect of different constraints on pattern formation among individuals in a game. Although player *tracking* systems such as Prozone™ and Amisco™ are still relatively new and not without limitation, they do have enormous potential, especially if interfaced or synchronized with other performance-monitoring technologies (e.g. heart rate monitors), for mapping spatio-temporal relationship among individuals under different organismic, environmental and task constraints (Glazier, 2010). The data produced by these player tracking systems could be used to inform tactical decision making, direct technical development strategies and prescribe modifications to strength and conditioning programmes (Glazier, 2010).

The evolution of motion analysis tracking systems

First studies on motion analysis had origins in ergonomics and attempted to relate work-rate of individual players to its physiological consequences (Carling et al, 2005). Former studies involving players' movement during the game were made by Reilly and Thomas (1976) which employed audio recorders to register the estimated location of players. The classical Reilly and Thomas' (1976) method used a coded map of the playing pitch and cues along each sideline to help estimate distances covered by one player. A running commentary of events was recorded on tape and later transcribed for collation. The method was validated by simultaneously video-recording the locomotion of the same player and counting stride frequencies at each intensity distance per stride at each category of activity having been previously calibrated (Carling et al. 2005).

Another method used by Bangsbo (1991) involved the positioning of video cameras near the side of the pitch, at the level of the midfield line. Each camera was used to film a separate player. After the game, subjects were videotaped for reference purposes whilst performing specific activities (from walking to sprinting) in order to provide calibration values. The video-tapes were played back on a television monitor and coded for various match activities. Total distance covered was calculated as the sum of the distances covered during each individual type of activity.

Bloomfield et al. (2007) used the "PlayerCam" Service (Sky Sports, British Sky Broadcasting Group, UK), which is an interactive facility that provides a separate camera focused only upon a single player, to record movements and actions of 6 players per match. A total of 55 players from 12 different teams were recorded. The footages were synchronized and manually digitized using the Observer System Version 5.1 (Noldus Information Technology, The Netherlands). This is a behavioral analysis system, which automatically calculated the time spent in the previously defined activities. The TACTO software (Fernandes, Folgado, Duarte, & Malta, 2010; Duarte et al., 2010) is another manual tracking system used in the last years, mainly for research purposes. This software can be used in many sports and can be adapted to different goals, ranging from measurement of physical performance, measuring players' behavioral patterns and even to do the codification of action categories (Duarte et al 2010). Still, the digitization process is very laborious, because the players are tracked with the mouse cursor, which means only one player can be tracked at a time.

In general, these video-based methods used for manually track the movement displacement trajectories of players' demonstrated high levels of reliability, objectivity and validity (Carling et al. 2008). However, laborious process and extensive time consuming requirements involved with manually tracking multiple players in team games has meant that researchers have typically avoided to analyze all the available players (Barris & Button, 2008).

One of the first works regarding automatic tracking of sport players was made by Intille and Bobick (1994) which developed a technique called "closed-worlds" applied in the tracking of American Football players. A "closed-world" is defined as a region of space and time in which specific context is adequate to determine all possible objects present in that region, for example: players, yard-lines and hash-marks. The authors reported that this method works even when object motions are not smooth, small or rigid, and when multiple objects of different types are interacting. They also concluded that their algorithm generally performs better when the objects being tracked have distinctive color features.

Neadham and Boyle (2001) proposed a method named condensation which uses the Kalman filter for multi-object tracking. The method was applied for sequences of futsal video images. However, according to the authors, only 56% of the trajectories were usable for behavior modeling.

One of the most challenging problems, related to the tracking of soccer players, concerns the occlusion and the players' congestions which occur, especially, in cases of free kicks and corners (Gabriel et al. 2003; Iwase e Saito, 2003).

Iwase and Saito (2003) used multiple view images to avoid the occlusion problems. The first step was to perform inner-camera operation, independently, in each camera, to follow the players. In the cases where the players were occluded, inter-camera operation was performed. Tracking information of all cameras was integrated by using the geometrical relationship between cameras, called homography (Iwase & Saito, 2003). The results showed that robust player tracking is possible using multiple cameras (Iwase & Saito, 2003). Yet, they used 8 cameras aiming only at the penalty area. In order to cover the whole field, much more cameras where needed increasing the cost of this system (Figueroa et al., 2004).

Kang et al. (2004) used multiple stationary cameras along with color information and joint probability data association filter for tracking soccer players. They were able to show the efficiency of this method in tracking multiple moving objects with partial and total occlusions.

Figueroa et al. (2006) presented a system for analyzing a whole soccer game, based on at least four static cameras which together cover the entire field. They used computer vision processing, which groups together image pixels to form blob-like entities based on proximity and visual appearance, to track the players. In cases of occlusions or contacts of the players, their corresponding blobs were split and took into account features such as number of components, area of the blobs and players trajectories (Figueroa et al., 2006). The overlapped regions related to the four cameras were used for synchronization and also to solve some cases of occlusions. Figueroa et al. (2006) only needed to track manually 6% of the frames.

An investigation carried out by Barros et al. (2007) used an automatic tracking system (DVideo, Campinas, Brazil) to measure distances covered by Brazilian football players. In each game, four digital cameras were fixed at the highest points of the stadiums, each covering approximately a quarter of the field, but with overlapping regions. The trajectories of 112 different players were tracked in four games, although only the results of the players who participated in whole games were analyzed (Barros et al., 2007). After measuring the players' positions, the 2D coordinates of the players were reconstructed using Direct Linear Transformation algorithms (2D-DLT) (Abdel-Aziz, & Karara, 1971). Situations where players were not tracked automatically only occurred when players were occluded and were corrected manually. The percentage of automatic tracking was around 95% for each player. However, the investigators claimed that it took approximately 16 hours to get the results (Barros et al., 2007). Also it uses a lower number of digital film images per second (7.5 Hz) in order to reduce the amount of data to be processed, which decreases the capacity to measure in detail changes in running speed and direction (Carling et al., 2008).

In terms of data processing speed and accuracy, according to Carling et al. (2008), electronic transmitting devices are the future of the computerized *tracking* analysis in sport. Indeed, equipment such as global positioning systems (GPS) and accelerometers are increasingly used in the measurement and evaluation of human physical activity (Barris & Button, 2008). Briefly, the GPS systems are based on the emission of radio signals in a synchronized way by 24 satellites in orbit around the earth. Each satellite is equipped with an atomic clock which emits, at the speed of light, its time and its position. The GPS receiver (worn on the subject) compares the time emitted by each satellites signal. The lag time, measured by the receiver, between 2 satellites emissions is translated into distance by trigonometry (Schutz & Chambaz, 1997).

Bekraoui et al. (2009) applied a GPS system to the measurement of total distance covered and mean speed of 9 players occupying different positions along two football matches. For validation, a shuttle run test on 20m, where speed was controlled by the investigators, was used. Bekraoui et al (2009) found a correlation of, approximately, 94% and concluded that the average total distance traveled by players and the duration of different types of travel speed obtained using GPS were very close to those reported in literature. According to Bekraoui et al. (2009), GPS can be used to describe displacements of players and the area covered during each half of a game. Other advantages of GPS referred in literature are: portable (light and small size); non-obtrusive free-living measurements; continuous measurement with on-line data obtained on a miniature screen; free access to the GPS satellites in any part of the world, at no financial cost; reasonable cost of GPS receivers; data could be stored and subsequently retrieved; the technique can be used to independently validate measurements of velocity of walking and running by other techniques such as by accelerometry, and; does not require any on-site logistics to process the information (Schutz & Chumbaz, 1997; Carling et al. 2005; Carling et al., 2008). However, GPS may failure to measure displacements when access to the sky is obstructed by tall buildings or measurements occur in indoor settings (Schutz & Chumbaz, 1997; Carling et al., 2005; Carling et al., 2008). Along with that, the signal may not maintain the same frequency along the time.

Another electronic system available is the LPM Soccer 3D® developed by INMOTIO in collaboration with PSV Eindhoven Football Club (Carling et al., 2008). The LPM Soccer 3D® uses a small lightweight microchip transmitter which is worn in clothing or in the strap around the chest of each player, but instead of using satellites, the signal is sent to several antennas positioned around and outside the playing field (Carling et al., 2008). This system provides positional measurements at over a 100 times per second (100 Hz), leading to the production of highly detailed and previously unavailable information on the player accelerations, decelerations and changes in direction (Carling et al., 2008). A disadvantage in the use of this technology is that in Association Football, electronic devices are restricted to measure players' performance only during practice sessions or friendly matches, because they require a receiver to be worn by each athlete, which is currently forbidden by FIFA International Board (Carling et al., 2005; Carling et al. 2008).

As none of these systems can be used to track players during soccer matches, professional clubs opt for other solutions. Several sports performance analysis systems now exist on the commercial market providing the clubs with the information they need (Barris & Button, 2008).

SoccerMan™ (Berne, Switzerland) is a football game-reconstruction system that is designed to generate a descriptive animated 3D scene from a given video sequence. This description includes information on the ground texture as well as a 2D description of the players (Bebie & Bieri, 1998). This 3D scene can then be examined from any virtual viewpoint with a 3D viewer, assisting in the verification of referee decisions, television game analysis, training support, teamwork evaluation and the classification of football scenes (Needham & Boyle, 2001). Initially, cameras are calibrated to extract background and player information from the video sequence and the system assumes that the camera remains in the same position throughout the match (Barris & Button, 2008).

One of the most known video-based tracking systems in Europe is the Amisco™ (Sport Universal, Nice, France). It was developed in the late 1990's by Sport-Universal Process in collaboration with the French Football Federation and was the first system to achieve the simultaneous analysis of the work rate of every player in a team throughout an entire match (Carling et al., 2008). It provides a passive (marker-less) tracking system that measures all moving objects on the football pitch with a sampling of 25 Hz from the multiple capture systems installed around the stadium (Carling, 2003; Setterwall, 2003; Dellal et al., 2009).

Similarly, Prozone™ (WestYorkshire, England) is another video-based multi-player tracking system, similar to Amisco™, designed for the analysis of football performance that requires multi-camera systems that is custom-fitted at sports stadia (Barris & Button, 2008). This system was validated by Di Salvo et al. (2006) through the analysis of players' displacements and speed on a football field. In both systems (i.e., Amisco™ and Prozone™) complex trigonometry, proper mathematical algorithms, image-object transformation methods for obtaining 2- or 3-dimensional space coordinates such as Direct Linear Transformation (DLT) are used to calculate the positions of the players

(Carling et al., 2008). Technology is facilitated by supportive information such as shirt color, optical character recognition of shirt numbers and prediction of running patterns to help maintain accurate player identification and tracking (Carling et al., 2008).

However, in all systems presented previously, operators are required to continuously verify if the players are being correctly tracked (Setterwall, 2003; Barris & Button, 2008; Carling, 2008).

Most of these video tracking systems used to date in elite football do not provide a real-time analysis. Results are generally available within 24-36 hours of the final whistle. This time lag, however, seems acceptable for the many top-level clubs who have adopted these systems over the last decade (Carling et al., 2005; Carling et al., 2008).

The most recent commercial, video-based, automatic tracking systems, such as TRACAB™ image tracking system, now provide real-time analysis, albeit using similar tracking methodology based on multi-camera and image processing techniques (Carling et al. 2008). The TRACAB™ system exploits enhanced techniques for video image processing and by using mathematical algorithms originally designed for object tracking and missiles guidance in the military industry. The main benefit of this system is that it provides coaches with a high level of instantly available detail concerning match performance, allowing informed decisions to be made during the match that may potentially influence the final performance outcome (Carling et al. 2008).

A major advantage of both the manual and automatic video-based tracking systems is that they do not require players to carry any electronic transmitting device, and can be used to track players in competitive settings (Carling et al. 2008). Their major disadvantages is the high costs associated, the necessity of installing multiple cameras and a computerized network with, at least, one dedicated operator to organize the data collection, and further operators to perform the analysis (Barris & Button, 2008; Carling et al., 2008).

However, despite the considerable technological advances, issues in automatic player tracking still present many challenges to researchers (Barris & Button, 2008). In summary, early methods used to track players, typically, involved a range of data collection techniques from live observation to post-event video analysis and do not ensure that all the players will be tracked for the entire game. Furthermore, these techniques are extremely monotonous and laborious in terms of the capture and analysis of data. Even systems like Amisco™ and Prozone™, besides of the high costs of the service which is currently only available for wealthier clubs, still need some operators to check if the player is being tracked correctly.

Another technology, that is the most popular in movement analysis, is the video-based optoelectronic systems (Chiari et al., 2005). These systems are used to track, by means of a system of charge-coupled device (CCD) cameras, the 3-D position of a set of fiducial points, constituted from either retroreflective (passive) or light-emitting (active) markers (Chiari et al., 2005). These markers are usually infrared (IR) light emitting diodes (LEDs) (van der Esch et al. 2011) or retro reflective spherical markers that reflect the IR light (Zheng, Barrentine, Fleisig & Andrews, 2008). Analytical close-range photogrammetry then allows the estimation of 3-D position data from digitized, noisy image data, using the geometrical properties of central projection from multi-camera observations (Chiari et al., 2005).

Retroreflective markers are used along with infrared stroboscopic illumination produced by a set of light-emitting diodes placed around the lens of each camera (Chiari et al., 2005). On the other hand, active markers are pulsed-sequentially, so the system can detect automatically each marker by virtue of the pulse timing, and marker tracking is more easily performed (Chiari et al., 2005). Since markers get brighter than the background, a simple threshold detection algorithm can extract the 2-D coordinates of the pixels covered by a marker (Chiari et al., 2005).

Chiari et al. (2005), state that this method has also his constraints, like: visibility constraints, since the markers can become obscured from camera views; calibration inaccuracies; electronic noise due to the interference of other electronic devices; the imprecision with which marker images are converted into image points; the digitizing process itself and; marker imaged shape distortion which can result from velocity effects, partially obscured marker images, merging of markers with each other or with phantom signals. Also, the set-up of the laboratory including: the number and placement of cameras, the size of measurement volume, the outcome of the calibration procedure, and its management over time, is an additional critical aspect affecting this method (Chiari et al., 2005).

Yet, the visibility constraints can be overcome by using multiple cameras (Chiari et al., 2005). In fact, for the reconstruction of 3-D coordinates, each marker must be seen simultaneously by at least two cameras, but in practice more than two are recommended (Chiari et al., 2005)

Nevertheless, this technology is used for many purposes, including the medical field (e.g. Quaresma et al. 2010; Amado, et al., 2011) and in sports, especially in biomechanics, to analyze the kinematic of different techniques in different sports (e.g. Zheng, Barrentine, Fleisig, & Andrews, 2008; Kim, Kwon, Yenuga, & Kwon, 2010; Sheppard, et al., 2011).

In this study we will use markers that, instead of reflecting, absorb on the IR spectral region. The reason for that is that almost every fabric, such as cotton, reflects the IR radiation. So, when we use a filter to see the IR radiation, the fabrics appear white although they are red or blue at naked eye. The opposite occurs with substances that absorbs that radiation. When saw in the IR, they appear black, making it possible to create different tones of grey (between white and black) by changing the concentration of the markers and so, to distinguish different players wearing the same shirt color.

Aim

As Barris & Button (2008) highlighted, the development of an automated system that collects uninterrupted footage of games and provides accurate positional information would be desirable and advantageous to sporting teams and coaches. Although results of the studies reviewed have shown various levels of successful tracking, they also have significant limitations. The manual tracking systems are very laborious and the video-based tracking systems, besides their high costs, are not completely automatic, needing an operator to control the tracking process, and only give the results 24 hours after the game. Systems that use electronic devises do not need an operator and are cheap but, on the other hand, these are not allowed to be used in official matches. It is also important that this system works in different weather conditions because Association Football games are often played in the rain. Consequently, the aim of this study is to contribute for the development of a non-intrusive, automatic tracking system, using a marker that is invisible to humans and capable of being used by athletes. To achieve that we selected the appropriate IR marker, created solutions with different concentrations to make different tones of grey and used them on fabric samples. After assessing the concentrations, we used the solutions on T-shirts that were worn by association football players to do the actual tracking in a 2*vs*1 situation.

Methods

Stage 1 - Studies on paper sheets

The first stage of this study consisted in the selection of appropriate IR markers to assure that the dye is the less visible as possible and, at the same time, to have a good contrast in the IR, to prepare the solutions with the markers and to assess their concentrations, to be used, later, on fabrics.

Materials

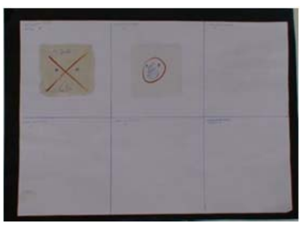
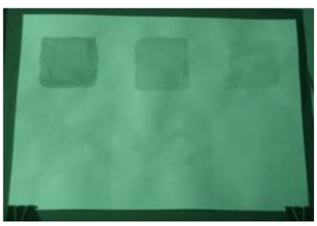
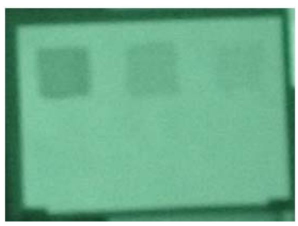
The markers used were Epolight 1110 which has an electromagnetic radiation peak absorbance at 1100 nm and PRO-JET 900 that has a peak absorbance at 900 nm, both in powder form. To make the solutions, pure methanol was used as solvent and a white sheet of paper (Inacopia Office 80g/m^2) where the solutions were applied. An OSRAM ultra-vitalux solar lamp was used in indoor conditions and the images were recorded with a video digital camera (Sony HDR-HC3) equipped with a SCHOTT-RG850 filter that cuts off light below 850 nm.

Procedures

We prepared solutions of methanol containing Epolight 1110 and PRO-JET 900 with concentrations of 2.6 g/L and 4.8 g/L, respectively and four dilutions of each one were made, with a ratio of 1/5 (the second solution has 1/5 of the concentration of the first one, the third 1/25, and so on) with the following values for Epolight 1110: 0.52 g/L, 0.104 g/L, 0.021 g/L and 4.16x10^{-3} g/L. For PRO-JET 900 the values were: 0.96 g/L, 0.192 g/L, 0.038 g/L and 7.68x10^{-3}.

With the solutions created, we painted five squares (with approximately 5 cm of side) in a white sheet of paper divided in 6 parts (one square was not painted for reference). The solutions were tested in indoor conditions (i.e., in the chemistry lab), with the solar lamp, and in outdoor conditions without direct sun exposure. The objective was to find the marker that was less visible at naked eye and more visible with the IR filter. The images were assessed by visual inspection, by two experts in photochemistry and image processing.

Results

1A

1B

1C


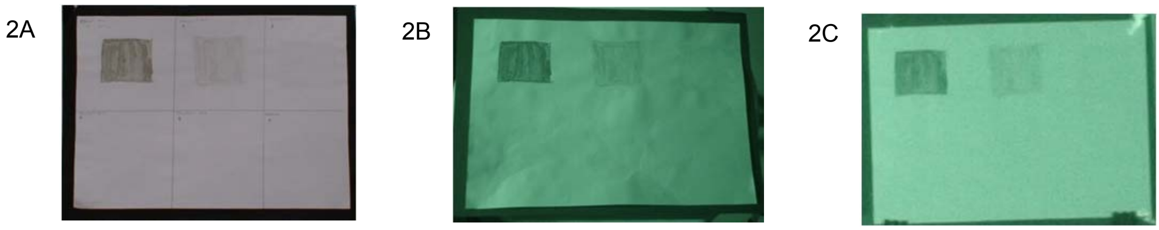


Fig. 1. Concentrations of Epolight 1110 (1) and PRO-JET 900 (2) in different light conditions. (A) Without filter; (B) Cut-off filter with solar lamp; (C) Cut-off filter outdoors.

The images shown in Figures 1 demonstrated that PRO-JET 900 is much more visible at naked eye than Epolight 1110 (see Figure 1 A). From all the five concentrations tested for each marker, the experts identified the three most concentrated solutions, with the cut-off filter, from both markers both with the solar lamp and in outside conditions. However, according to the experts view, Epolight 1110 had less concentration and yet a better contrast/visibility relation than PRO-JET 900. Therefore, PRO-JET 900 was excluded. Also, the three most concentrated solutions of Epolight 1110 were selected to be tested on fabric samples, namely: 2.6 g/L, 0.52 g/L and 0.104 g/L.

Stage 2 - Studies on fabrics

The objective of this research stage was to test the solutions on fabric samples, optimizing concentrations to create different tones of gray, assessing the gray tones in different light conditions and testing the resistance of the marker to water and washing, to assure that the fabric keeps its grey tone when in contact to water.

Materials

The fabrics used were from a black T-shirt, 100% cotton (Filwhite). The solar lamp, digital video camera and infra-red filter used were the same as in Stage 1.

Procedures

Four squares of fabric were cut, with approximately 7.5 cm of side and three of them were soaked in the solutions previously selected, during 10 minutes. Next, they were drained, dried and putted on a white paper (one of the squares was not painted to serve as reference). The comparisons of the gray tones in the tissues were tested, in interior conditions using a solar lamp and outdoors with uniform light conditions, with and without a direct exposition to the sun, and recorded with the digital video camera. Again, two experts visually inspected the images.

To test the resistance of the dye to water, the most concentrated sample was putted into a cup full of water that was stirred during 10 minutes. The same sample, after being dried, was tested again in a cup with water and with a common detergent and stirred during 10 minutes.

Results

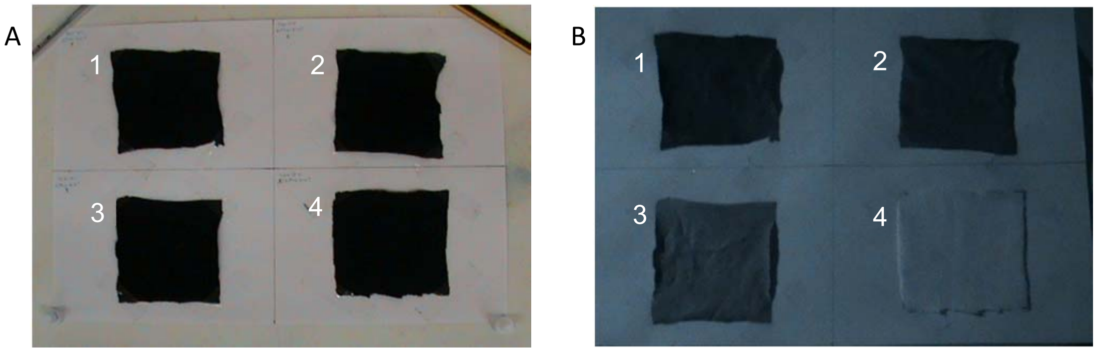


Fig. 2. Fabrics painted with Epolight 1110. (A) Without filter. (B) With cut-off filter. Concentrations: 1- 2.6 g/L; 2- 0.52 g/L; 3- 0.104 g/L; 4- None

Results presented in figure 2A showed that all the fabrics appeared to be different from each other in the IR region. However, based on the experts' opinion, the least concentrated square (down left) was considered too dark and still suitable to allow the creation of another solution that has a gray tone between that IR color and the white one.

A new solution was prepared with 0.052 g/L, one half of the concentration of the one used on fabric 3 (0.104 g/L), and then soaked another piece of fabric on it.

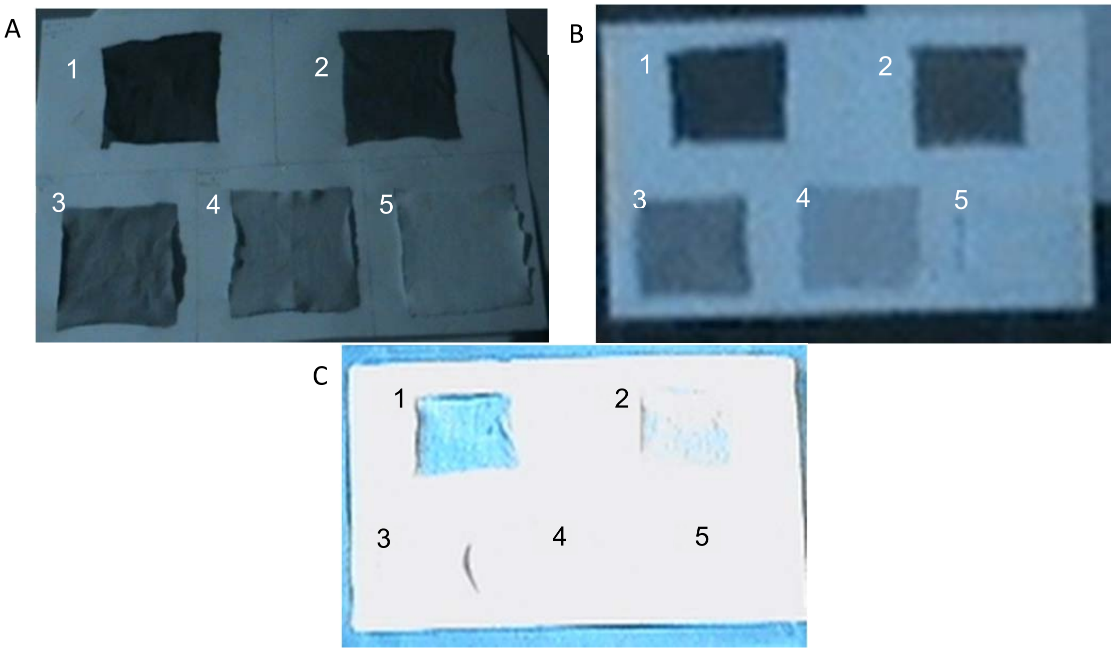


Fig. 3. Fabrics painted with Epolight 1110 with a new concentration. (A) Solar lamp; (B) Outdoors in shadow; (C) Outdoors, with sun exposure.

The images show that all the concentrations are different and distinguishable of each other (see Figure 3A). In outdoors conditions, without sun exposure, the squares are visible and distinguishable (see Figure 3B). However, with the direct sun light exposure, the image became saturated and only two squares were visible, which means that if players are exposed to sun-light, the cameras will not be able to identify them (see Figure 3C).

As the two most concentrated dyes (Figure 3, fabric 1 and 2) are very similar, we excluded the most concentrated one (fabric 1), leaving just to three final solutions with the following concentrations: 0.52 g/L, 0.104 g/L and 0.052 g/L, that were selected to paint the t-shirts.

Fig. 4. Water resistant test. (A) Fabric in IR after being submerged in water (B) Fabric in IR after being submerged in water with detergent; (C) Colored water after the test.

In the water resistance test, after being submerged in water, the fabric kept is original dark grey tone (Figura 4A), which means that the marker does not desorbs when in contact with water. When detergent was added to water, the fabric desorbed some dye to the solution (observed by the color of the water in Figure 4C) but in small quantities since the fabric kept a dark grey tone (see Figure 4B).

Stage 3 - Studies on t-shirts using 'in situ' football tasks

The aim of this research stage was to assess the visual discrimination of the players in a real training situation. To do that, the tones of the color in a gray scale for each T-shirt were measured.

Materials

Four black T-shirts, 100% cotton (Filwhite) were used. To make the solutions, pure ethanol was used as solvent. The images were recorded with the same digital video camera equipped with the same IR filter.

Participants

Data was collected with 20 male, professional football players, aged between 20 and 34 years (*M* age = 24.19 years) from the same squad competing in the Portuguese Second league, in the 2010-2011 season.

Procedures

We soaked 3 black shirts (but one shirt was not painted), in 1 liter of ethanol containing the marker with the following concentrations: 0.52 g/L, 0.104 g/L and 0.052 g/L. The shirts were soaked and stirred for 15 minutes, drained, dried, passed through water to remove traces of ethanol and placed to dry again.

The four shirts were used by professional football players in a 10 vs 10 ball possession exercise during a common practice session. The images were recorded during the day, but the whole field had a uniform illumination because the weather was cloudy, so there was no direct sunlight exposition. The field was divided in 3 zones, Zone 1 is the nearest and Zone 3 the farther one from the camera (see Figures 5 and 6).

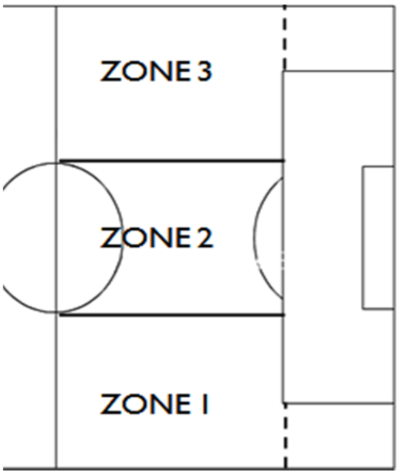


Fig. 5. Division of the field.

Fig. 6. Frame from the 10vs10 ball possession exercise in IR.

For the analysis, 20 frames were taken in a random sampling procedure from each shirt, in each zone. To measure the tone of the color in a gray scale, with values varying from 0 (black, strong IR absorption) to 255 (white, low IR absorption), the software Corel PaintShop Photo Pro X3 was used. The SPSS 19.0 (SPSS Inc, Chicago, IL, USA) was used for statistical analysis. A mixed-model ANOVA was used to test differences on the grey tones between the T-shirts and between Zones.

Results

Table 1 presents the mean and standard deviation values of the color tone, in a gray scale, of all the four T-shirts, in the three zones.

Table 1. Mean ± standard deviation values of the grayscale values of the shirts, in three different zones.

	Concentration (g/L)			
	0.490	0.098	0.049	None
Zone 1	48.00 ± 3.71	66.90 ± 5.71	78.30 ± 3.11	85.65 ± 3.54
Zone 2	54.20 ± 3.33	72.45 ± 2.87	81.65 ± 5.06	90.55 ± 3.12
Zone 3	56.45 ± 4.59	68.90 ± 3.93	79.10 ± 3.67	90.95 ± 4.98

Table 1 shows that all the t-shirts have different mean values. The shirt with the most concentrated solution presented the lower values in all zones, as expected. This shirt was the darkest one in the IR region (between 48.00±3.71 and 56.45±4.59, $F(3,76) = 750.53$; $p \leq .001$; $\eta^2 = .967$). The player, who wore a shirt that has not been soaked, had the highest mean values (between 85.65±3.54 and 90.55±4.98, $F(3,76) = 750.53$; $p \leq .001$; $\eta^2 = .967$).

In a multiple comparisons test between all the T-shirts, every t-shirt was significantly different from the others ($p \leq .001$). This demonstrates what we saw with naked eye, namely, that the t-shirts were distinguishable from each other and that the software could distinguish them.

In a comparison between the 3 zones we found differences between Zone 3 (the farthest) and the other zones ($p \leq .001$). This means that the T-shirt values changed more when the players were in the farthest zone.

With the mixed model ANOVA we analyzed the influence of the zones on the grey tone of the T-shirts and the interaction of zone/t-shirts. The Mauchly's Test of Sphericity reveals that the sample was not homogeneous ($p \geq .005$). Without the sphericity assumed we had to betake to Greenhouse-Geisser correction ($p \geq .005$). The tests of within-subjects effects showed that the zone where the players were, had a significant effect in the grayscale values ($F(2,152) = 37.631$; $p \leq .001$; $\eta^2 = .331$), as well as the interaction between zones and t-shirts ($F(6,152) = 4.498$; $p \leq .001$; $\eta^2 = .151$). The effect size was much larger for the t-shirts which means that the concentration of the dye had more influence in the values of the grey tone, than the zones where the players were. Although the value for the zones was lower, it was still considered a medium effect size.

Stage 4 – Developing the player tracking system

The aim of this latter research stage was to track the players as a mean to study coordination processes between two defenders and between that dyad and an attacker. We studied players in a 1*vs*2 *in situ* task.

Materials

Six black shirts, four without the dye and two containing the dye with 0.52 g/L and 0.052 g/L concentrations were used. The images were recorded with the same digital video camera and IR filter as in the previous research stages.

Participants

Data was collected on 11 male, U-19 football players (6 defenders, 4 forwards and 1 goalkeeper) from a team competing in the First Portuguese Division.

Procedures

The experimental task consisted of a 1*vs*2 sub-phase, where the player who had the ball tried to score against the opposition of two defenders, while the defenders had to recover the ball and lead it through one of the smaller goals marked with cones (see Figure 7).

The task begun with the player with the ball at 30 m, and the defenders at 5 and 10 m from the center of the goal. The six defenders formed pairs and each pair performed 20 trials as first defender and 20 trials as second defender. Each pair performed two trials with each of the four forwards, in each of the five starting positions, defined to manipulate the initial alignment of the players in relation to the goal.

The players' positions and movements were recorded by two digital cameras placed perpendicular to the lateral line and above the height of the players at approximately 6 m of the ground. The field, the ball and the goal were according the official laws of football.

The image processing consisted in stabilizing the image and applying a Canny filter that acts as a background subtraction and detects the edges of the players and a colorize filter that makes the correspondence between a color and each player.

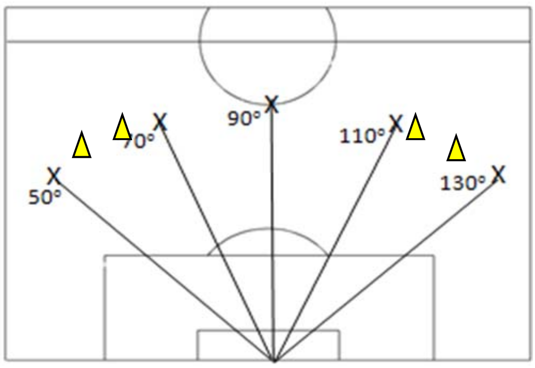


Fig. 7. Experimental task schematic representation, highlighting the different starting positions, as a function of the manipulated alignment of the players, in relation to the goal.

Dependent variables

The distances, in meters, between the attacking player and the two defenders (variable 1, and the distance between each of the three players and the center of the goal were assessed (variable 2).

Results

Figure 10 illustrates one single frame extracted from a 1*vs*2 sub-phase performed by the players, where the attacker tries to score after dribbling the first defender.

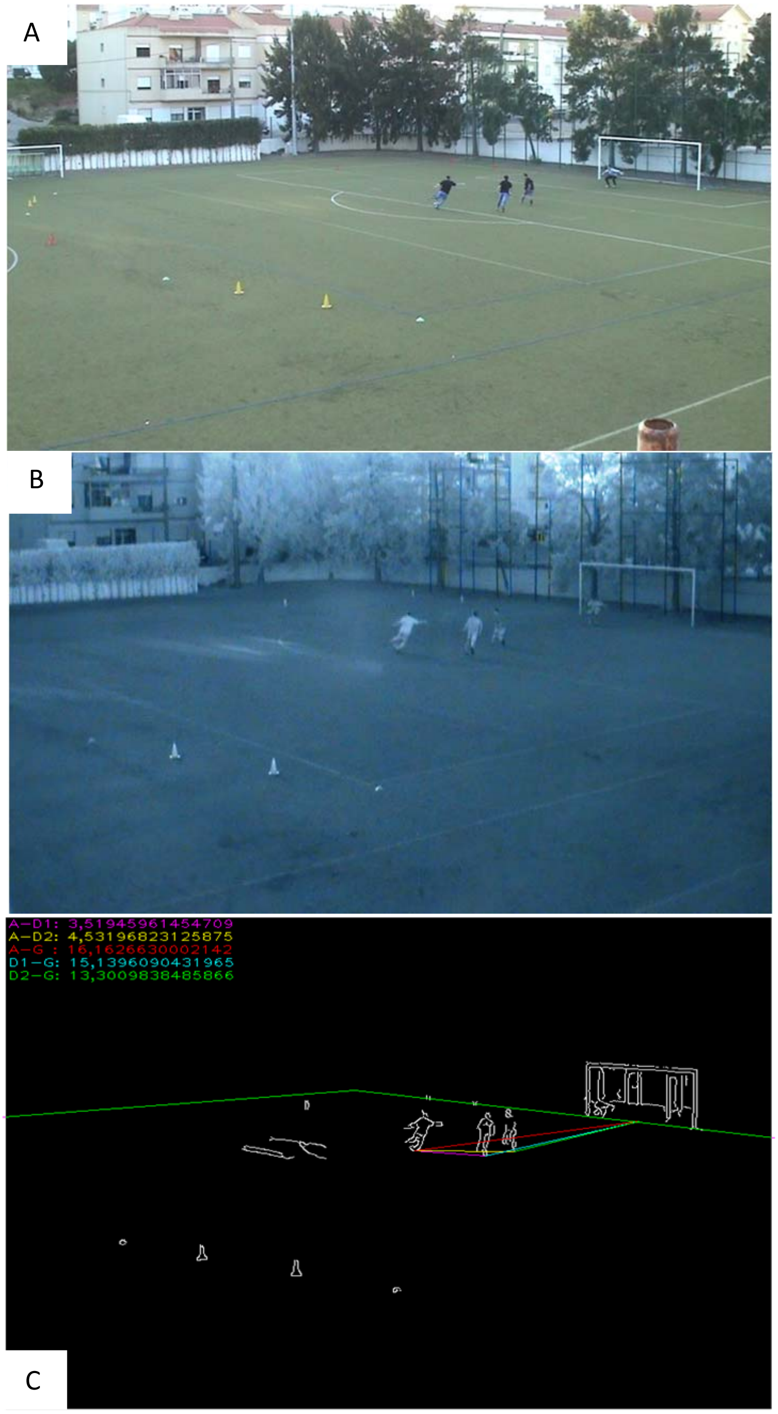


Fig. 8. Exemplar trial of a 1vs2 sub-phase. (A) Without filter (normal view); (B) With the cut-off IR filter; (C) Snapshot from image processing determining the distances (dependent variables).

As it was shown in Figure 8, although every player is using the same shirt color (observable in Figure 8A), the signal from the players were distinguished (observable in Figure 8B), with the cut-off filter. Based on this and using the image processing techniques previously described, the technology associated with IR markers was able to allow the measurement of the distances between the players and between the players and the goal (showed in upper left corner of Figure 8C). The distance of the attacking player to the defenders was 3.52 m and 4.53 m, and his distance to the goal was 16.16 m. The distances of the first and second defenders to the goal were 15.14 m and 13.30 m, respectively.

General Discussion

The aim of this study was to track football players with a non-intrusive, automatic tracking system using a marker that is invisible to humans.

In the first stage of the study, we concluded that Epolight 1100 serves our purpose better than PRO-JET 900, because it is less visible, which is one of the main objectives of this study. The importance of using an invisible marker means that we can track the players without them carrying any other device, beyond the regular equipment used in competition. This overcomes one of the major limitations of the use of GPS (or lightweight chips), referred by Carling et al. (2008), and of the optoelectronic systems.

On the next step we assessed the dye's concentrations and applied them on fabric. We could create five different grey tones, distinguishable at naked eye, which allows following more players. Despite a football team has eleven players on the field, we believe that combining the five colors, using the shirts and the shorts, we can follow all the players because everyone will have a different pattern. Also, the use of two cameras, in the same place, to record real training situations offered us the possibility to expand the number of players that can be tracked, because the camera without the IR filter can be used to disambiguate the results from the camera with the filter. For example, if we have two teams with different colors in the visible spectrum, the camera without the filter could distinguish between the members of the two teams and the camera with the IR filter could make the distinction within each team.

On this study, the fabric used was cotton because it is cheaper and easy to find shirts with just one color however, further investigation is need in other fabrics namely the ones used in sports equipment, like polyester.

In relation to light conditions, we observe that in interior conditions and without direct solar exposure, we can identify the fabrics, which opens the possibility for this system to work in indoor lightning conditions, like in basketball or handball, or at night with stadium lighting. However, these conditions still require further testing.

One of the advantages of the system is the dye's resistance to water. This issue is very important because with the course of the game the shirts will get wet, either by sweat or rain, and it is necessary for the shirts to maintain their color and to not pass to players' skin.

When the shirts were used in a real training situation, the shirt with the most concentrated dye had a darker tone and the one that had not been soaked is the lighter one as expected. However, we find that as long as the players move away from the camera, the shirt color becomes darker. That happens because, as the object is farther away from the camera, less light is captured and as the object is closer, more light is captured. Although the variation of color, the shirts are all different from each other which means, it is possible to distinguish all of them. As Intille and Bobick (1994) stated, the technique that they developed, called "closed-worlds", performs better when the objects being tracked have distinctive color features. This means that this system can be a good complement of that algorithm. Also, as reported by Carling et al. (2008), technology used by Amisco™ and Prozone™ is facilitated by information like shirt color.

In the experimental task, we were able to track the players and measure interpersonal distances. The limitations of the experimental tasks, namely the ones related to the use of a regular handycam with normal objective, and the position of the camera in a place that received some direct solar exposure, only allowed tracking the players for short sequences. Also, when the players move away from the camera they become smaller, making them to occupy fewer pixels in the image and, consequently losing accuracy. As stated in several studies (e.g. Iwase & Saito, 2003; Kang et al., 2004; Figueroa et al., 2006; and Barros et al., 2007) and also as used in commercial video-based tracking systems like Amisco™ and Prozone™, the use of multiple cameras can avoid those problems and the ones related with the occlusion of players. Also to generate an animated 3-D scene, more than two cameras capturing the same object are recommended (Chiari et al., 2005).

We can reduce these influences if the task is performed in smaller spaces. With that, we are able to track players for longer, study bigger sequences and, along with that, complex human behaviors in representative contexts, like in small sided games. Future improvements in this automatic tracking system can be the use of filters that reduce the light intensity, especially when with direct sunlight exposure, the use of more and with greater resolution cameras, placed correctly and with high quality lenses.

Although we only managed to track short sequences, we succeeded in measuring the interpersonal distances and the distances between the players and the goal line. These distances along with other variables, such as speeds and angles can now be calculated using this tracking system. As stated by Passos et al (2008) variables like interpersonal distances, are used as potential control parameter to study phase transitions in a 1vs1 situation. These measures are used in other studies, concerning decision making and coordination processes in team ball games (e.g. Araújo, 2006; Passos et. al 2008; Duarte, et. al 2010).

The results allow verifying the capability of this tracking system to obtain performance data of athletes or team, in a non-intrusive way, enhancing decision-making in training or competition and can evolve to a real time performance analysis system.

Conclusions

The development of elite sport, is forcing the need for better and more quantified information on the athletes and teams, providing analysis on the elements of individual and collective performance. This information becomes more valuable, if the elements that result could lead to the decision-making in real time on aspects related to the physical behavior of athletes and their positioning in the field. The current systems do not provide information in real time and some cannot be used in competitive scenario. The developmental stages presented in this research open expectations in the creation of an innovative and non-intrusive tracking system able to discriminate the different players in a real competitive scenario and even providing real-time information.

The findings showed how the approach described in this paper proved to be a valid possibility to discriminate and track players. We concluded that it is possible to use IR markers to distinguish different players wearing the same shirt color and, with the appropriate computer graphics' algorithms, currently under development, to automatically track the players.

References

Abdel-Aziz, Y.I. & Karara, H. M. (1971). Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry. *Proceedings of the ASP Symposium on Close-Range Photogrammetry,* 1-18

Amado, S., Armada-da-Silva, P. A., João, F., Maurício, A. C., Luís, A. L., Simões, M. J., et al. (2011). The sensitivity of two-dimensional hindlimb joint kinematics analysis in assessing functional recovery in rats after sciatic nerve crush. *Behavioural Brain Research*. 225 (2), 562-573

Araújo, D. (2006) *Tomada de Decisão no Desporto*. FMH Edições, Lisbon

Barris, S. & Button, C. (2008). A review of vision-based motion analysis in sport, *Sports Medicine*, *38* (12), 1025-1043

Barros, R.et. al. (2007). Analysis of the distances covered by first division Brazilian soccer players obtained with an automatic tracking method. *Journal of Sports Science and Medicine, 6*, 233-242

Bebie, T. & Bieri, H. (1998). Reconstructing soccer games from video sequences. *Proceedings of International Conference on Image Processing*. Chicago, 898-902

Bekraoui, N., Cazorla, G. & Leger, L. (2009). Validite et limite de la technique du GPS dans l'analyse de la tâche en football. In B. Zoudji (eds.) *Science et Football: Recherches et Connaissances Actuelles*, 363-377

Bloomfield, J., Polman, R. & O'Donoghue, P. (2007). Physical demands of different positions in FA Premier League soccer. *Journal of Sports Science and Medicine, 6*, 63-70

Carling, C., (2003). Outils d'évaluation des strategies de jeu en sports colletifs. *Expertise et sports de haut niveau: actes des Entretiens de l'INSEP*, 77-79

Carling, C. (2009). Analyse du football de haut niveau: outils d'analyse et exemples de donnees sur la performance en match. In B. Zoudji (eds.) *Science et Football: Recherches et Connaissances Actuelles*, 349-355

Carling, C., Reilly, T. & Williams, A. (2009). *Performance assessment for filed sports: physiological, and match notational assessment in practice*. Routledge, London

Carling, C., Bloomfield, J., Nelsen, L. & Reilly, T. (2008). The role of motion analysis in elite soccer: Contemporary performance measurement techniques and work rate data. *Sports Med*. *38* (10) pp. 839-862

Carling, C., Williams, M. & Reilly, T. (2005). *The handbook of soccer match analysis*. Routledge, London.

Chiari, L., Della Croce, U., Leardini, A., & Cappozzo, A. (2005) Human movement analysis using stereophotogrammetry. Part 2: Instrumental errors. *Gait Posture*, *21*(2), 197-211.

Dellal, A., Ignatowicz, L., & Dyon, N. (2009). Comment les nouvelles technologies vont etre exploitees pour affiner les analyses de l'activite du footalleur de haut niveau – en fonction du temps de jeu effectif? In B. Zoudji (eds.) *Science et Football: Recherches et Connaissances Actuelles*, 379-386

Di Salvo, V., Collins, A., Mcneill, B., & Cardinale, M. (2006). Validation of Prozone: a new video-based performance analysis system. *International Journal of Perform Analysis in Sports, 6*, 108-19

Duarte, R., Araújo, D., Gazimba, V., Fernandes, O., Folgado, H., Marmeleira, J. & Davids, K. (2010). The ecological dynamics of 1vs1 sub-phases in association football. *The Open Sports Sciences Journal*, *3*, 16-18

Fernandes, O., Folgado, H., Duarte, R. & Malta, P. (2010). Validation of the tool for apllied and contextual time-series observation. *International Journal of Sport Psychology,* 41, 63-64

Figueroa, P., Leite, N., & Barros, R. (2006). Tracking soccer player aiming their kinematical motion analysis. *Computer Vision and Image Understanding, 101*, 122-135

Gabriel, P.; Verly, J.; Piater J. & Genon, A. (2003). The state of the art in multiple object tracking under occlusion in video sequences. *Procedures Advanced Concepts for Intelligent Vision System,* 166-173

Glazier, P. (2010). Game, Set and Match? Substantive Issues and Future Directions in Performance Analysis. Sports Medicine, *40* (8), 625-634

Grehaigne, J. & Duprat, E. (2009) Des outils d'observation et d'evaluation de l'activite des joueurs en football. in B. Zoudji (eds) *Science & Football: Recherches et Connaissances Actuelles*, 333- 347

Intille, S. & Bobick, A. (1994). Visual tracking using closed-worlds. *Technical Report 294*, MIT Media Lab Perceptual Computing Section

Iwase, S. & Saito, H. (2003). Tracking soccer players based on homography among multiple views. *Procedures SPIE, 5150,* 283-292

Kang, J., Cohen, I., & Medioni, G. (2004). Tracking people in crowded scenes across multiple cameras. *Asian Conference on Computer Vision*

Kim, J. W., Kwon, M. S., Yenuga, S. S., & Kwon, Y. H. (2010). The effects of target distance on pivot hip, trunk, pelvis, and kicking leg kinematics in Taekwondo roundhouse kicks. *Sports Biomechanics, 9*(2), 98-114

Needham, C. J., & Boyle, R. D. (2001). Tracking multiple sports players through occlusion, congestion and scale. *British Machine Vision Conference*, *1*, 93-102

Passos, P., Araújo, D., Davids, K., Gouveia, L., Milho, J. & Serpa, S. (2008). Information-governing dynamics of attacker-defender interactions in youth rugby union. *Journal of Sports Sciences*, *26,* (13), 1421-1429

Quaresma, C., João, F., Fonseca, M., Secca, M. F., Veloso, A., O'Neill, J. G., et al. (2010). Comparative evaluation of the tridimensional spine position measured with a new instrument (Vertebral Metrics) and an optoelectronic system of stereophotogrammetry. *Medical and Biological Engineering Computing, 48*(11), 1161-1164.

Reilly, T., Thomas, V. (1976). A motion analysis of work rate in different positional roles in pro football match-play. *Journal of Human Movement Studies*, *2*, 87-97

Schutz, Y. & Chambaz, A. (1997). Could a satellite-based navigation system (GPS) be used to assess the physical activity of individuals on earth? *European Journal of Clinical Nutrition*, *51*, 338-339

Setterwall, D. (2003). Computerised video analysis of football: technical and commercial possibilities for football coaching [dissertation]. Stockholm: CID, NADA

Sheppard, J. M., Dingley, A. A., Janssen, I., Spratford, W., Chapman, D. W., & Newton, R. U. (2011). The effect of assisted jumping on vertical jump height in high-performance volleyball players. *Journal of Science and Medicine in Sport, 14*(1), 85-89.

Van der Esch, M.; Steultjens, M.; Harlaar, J.; van den Noort, J.; Knol, D. & Dekker, J. (2011) Lateral trunk motion and knee pain in osteoarthritis of the knee: a cross-sectional study. *BMC Musculoskeletal Disorders,*12:141

Zheng, N., Barrentine, S. W., Fleisig, G. S., & Andrews, J. R. (2008). Kinematic analysis of swing in pro and amateur golfers. *International Journal of Sports Medicine, 29*(6), 487-493.