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Computerised Video Analysis of Football – Technical and Commercial Possibilities for Football Coaching

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Computerised Video Analysis of Football – Technical and Commercial Possibilities for Football Coaching

Datoriserad videoanalys av fotboll- Tekniska och kommersiella möjligheter för fotbollscoachning

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Abstract

In this study, the possibilities for the Swedish Football Association to develop a tool for analysis of football, using video technology, are examined. Preparations for such a development are also made. The possibility to commercialise such a tool is another issue that is investigated.

The most important features, which the Swedish Football Association desires from a football analysis tool, are that it is portable, that is possible to move between different stadiums, and that it is cheaper than existing systems. It should also require as little manual work as possible. The tool should at least provide an animation of the game, possibility to look at how events happened and what their consequences were and information about the physical performance of all the players.

Seven companies in the sports analysis industry and their products have been examined. ProZone and Sports Universal are companies, which provide football analysis tools based on video tracking. Their systems provide useful information, but they are expensive and non-portable. None of the products available on the market today fulfil the requirements of the Swedish Football Association.

Four different research projects in sports related video tracking have been examined. The conclusions from these were that a combination of video analysis methods is the best way to perform the tracking. Examples of well working algorithms are template matching and RGB colour tracking. Multiple stationary cameras, each camera covering one particular part of the pitch, should be used.

An experiment has been conducted, where a football match was filmed with seven cameras in different positions. These recordings were analysed, using a tracking approach based on a simple idea; presented with an image of a football pitch with players on it, the pixels can be classified as foreground or background depending on whether they have the same colour as the background or not. The results were promising; tracking players who are isolated can be automated using existing techniques. But to solve the problem of occlusions, that is objects obscuring each other, the method has to be improved.

A strategic analysis of the market showed that if the Swedish Football Association is able to develop a relatively cheap football analysis tool, the conditions for commercialising such a product are very good.

Sammanfattning:

Datoriserad videoanalys av fotboll-
Tekniska och kommersiella möjligheter för fotbollscoachning

I den här rapporten utreds möjligheterna för Svenska Fotbollförbundet att utveckla ett verktyg, som använder videoteknik, för analys av fotbollsmatcher. Rapporten kan ses som en förstudie för utvecklingen av ett sådant verktyg. Möjligheterna att lansera ett sådant verktyg kommersiellt utreds också.

De viktigaste egenskaperna som det Svenska Fotbollförbundet önskar från ett verktyg för analys av fotbollsmatcher är att systemet ska vara portabelt, billigare än existerande system och att det inte krävs omfattande manuellt arbete. Verktyget ska åtminstone kunna visa en animation av matchen, ge möjlighet att undersöka hur olika matchsituationer uppkom och vad deras konsekvenser blev samt ge information om spelarnas fysiska prestationer.

Sju företag med relaterade produkter har undersökts. ProZone och Sports Universal är företag som säljer fotbollsanalyssystem baserade på videoteknik. Dessa system ger en mängd användbar information, men de är dyra och är inte portabla. Ingen av de produkter som finns på marknaden idag uppfyller de krav som Svenska Fotbollförbundet ställer på ett verktyg för analys av fotboll.

Fyra olika forskningsprojekt, som har med användning av videoteknik för analys av lagidrott att göra, har gåtts igenom. Slutsatsen från dessa är att det bästa är att använda en kombination av algoritmer för att med hjälp av videoteknik få fram spelares positioner och därur kunna beräkna statistik. Exempel på algoritmer som fungerar bra är så kallad ”template matching” och ”RGB colour tracking”. Ett flertal, stationära kameror, som täcker varsin del av planen bör användas.

Ett experiment, där en fotbollsmatch filmades med sju kameror i olika positioner, har genomförts. För att se om det var möjligt att följa spelarnas positioner i dessa inspelningar användes följande idé: en bild av en fotbollsplan med fotbollsspelare på kan delas in i pixlar som är förgrund eller bakgrund beroende på om de har samma färg som bakgrunden eller inte. Resultaten var lovande och visade att det går att positionsbestämma spelare som inte är skymda med existerande tekniker. Men för att lösa problemet som uppstår då spelare täcker varandra i bilden måste metoden förbättras.

En marknadsanalys visade att det finns goda möjligheter att kommersialisera ett verktyg för analys av fotbollsmatcher förutsatt att systemet är relativt billigt.

Preface

This thesis is the result of my master's project carried out at the Department of Numerical Analysis and Computer Science and at the Swedish Football Association.

First and foremost I want to thank my supervisors, Åke Walldius at the Department of Numerical Analysis and Computer Science, KTH, and Paul Balsom at the Swedish Football Association. Åke has been very enthusiastic and provided a lot of help with outlining the report and ideas regarding the content. Paul took the initiative to this project and has thus given me the opportunity to combine two of my greatest interests, football and technology. His knowledge of football analysis has also been very valuable to this project.

I also want to express my gratitude to Stefan Carlsson and Josephine Sullivan, researchers at Computational Vision and Active Perception Laboratory. Their help was invaluable for obtaining an understanding of the tracking process described in chapter six of this thesis.

Furthermore I want to thank Jonatan Karlman, who was doing his master's thesis during the same period as I. It was very valuable to have his companionship and to be able to discuss various aspects of my work with him.

I would also like to thank Tommy Söderberg at the Swedish Football Association and Bo Andersson at Djurgårdens IF for helping me with the experiment conducted. I also thank Åsa Klevard, Kalle Palmlöf, Johan Porsborn and Fredrik Setterwall for proofreading the thesis and providing ideas.

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1 Introduction

1.1 Background

The Swedish football association (The Swedish FA), who are responsible for the Swedish national football team, has as many others realised the value of video recording games. An extensive amount of equipment is used to capture and analyse the games. Important information for the coaching staff includes the patterns and effectiveness of the team, and physiological information such as movement patterns and workload of individual players. To gather this information, a number of different approaches can be used, but few have the same advantage as video recording. Most other means require modifications to the field or the players with sometimes extensive setup time. The biggest issue is however that the need for analysing opponents, makes anything else than video difficult.

Today, notational analysis in combination with video analysis is used to analyse games. This means that the events of the game are manually noted. These notes can be used for selective searching through a video recording of the game. This is done with a computer program, but it is only a way of searching specific events in a video recording of a game. The program performs no actual analysis.

On November 10th 2001, Sweden played England in a friendly international game at the Old Trafford Arena, where a system called ProZone is installed. This is a semi-automatic system for analysing football matches. It is very expensive to install and it is not portable. The Swedish FA got to try the system after this game and received a CD containing ProZone's match analysis. The analysis contained plenty of information about the game, for example an animation of the game, the distance covered by each player and the number of successful and unsuccessful passes made by each player. The Swedish FA thought that the analysis contained a lot of very useful information. But they thought that ProZone was too expensive to buy, especially since the games they want to analyse are played in different stadiums. After having tried ProZone the Swedish FA became interested in finding a system similar to ProZone, but with a lower price and preferably a portable system that can be used at any stadium.

1.2 Formulation of Problem

The Swedish FA is interested in developing a tool for automatic analysis of football matches using video technology. The idea of this assignment is to write a report for the Swedish FA, with the objective to investigate and describe the research in video technology, products available on the market, requirements from the Swedish FA, video analysis methods and the possibilities for developing a product. The Swedish FA has the purpose to use this report as a basis for developing a system that they will use on their own. They also have the intention to commercialise this system, which makes a market analysis important.

The first major problem to address when building a system like this is *how to track* all the players in a 90 minutes football match by using video technology (computer vision) and how to store the data for further analysis. This problem can be divided into two different parts. The first part is *how to obtain data* for the tracking process. This report concentrates on video recording as the primary method for obtaining data. Issues to be investigated are what kind of cameras to use, where to place the cameras and the number of cameras required. The second

part of the problem is how to perform the tracking process; that is how to get the players' positions on the pitch.

The second major problem to address is *how to use data* obtained in the tracking process. This includes for example how to convert the data obtained in the tracking process to useful information and how this information is to be presented. To be able to decide what information is to be considered useful, the requirements and wishes from the Swedish FA have to be thoroughly investigated.

Sports related research with video tracking algorithms is today widespread around the world. The research in the area of sports technology is therefore interesting to examine for new ideas about technical support. It is also interesting to examine products that are available today. A company overview will give the commercial side of the market and show the types of products that are available today. The requirements from the Swedish FA have to be investigated to get an understanding of the important and less important components for a future product. The objective is to outline technical solutions for a future product that is more automatic than systems available today and hence will reduce manual work, which will lower costs.

1.3 Primary Objective

The primary objective of this study is to examine the possibilities for the Swedish FA to develop a tool for automatic analysis of football matches using video technology, and to make preparations for such a development. The possibilities with products already available are also to be examined as well as the conditions for commercialising a football analysis tool.

2 Theory

The purpose of this chapter is to give a theoretical background to the techniques, methods, algorithms and models used in this report. The chapter has been divided into two different parts; one presenting technological theory and the other one presenting the economic theory behind the strategic analysis. The part containing technological theory deals with subjects that may be necessary to understand chapter 4.2, *Sports Related Research with Video Tracking Techniques,* and chapter 6, *Experiment: Obtaining Game Information.* The section *Economic Theory* gives the theoretical background to the models used in the chapter *Strategic Analysis of the Market.*

2.1 Technical Theory

This section deals with general concepts in computer vision and related areas that are considered to be important background knowledge to understand this report. It also deals with more specific concepts that will be mentioned several times in this report.

2.1.1 Image Processing

The purpose of this section is to give a brief overview of the fundamental steps in digital image processing. To understand the basics of image processing is necessary in order to understand some of the following chapters in this report. A video recording is a sequence of images (Bovik, 2000, page 227). Image processing can be applied to one single image or an image that is part of a video sequence.

The first step in the image processing is the *image acquisition*, that is to acquire a digital image. In this case, the image is acquired by a digital video camera. After a digital image has been obtained, the next step is *preprocessing* that image. The aim of the preprocessing is to improve the image in ways that increase the chances for success of the other processes. Preprocessing often deals with techniques for enhancing contrast and removing noise. The next stage of the image processing is called *image segmentation*. Segmentation is defined as partitioning an input image into its constituent parts or objects. In the case of analysis of a football match, the picture consists of a football pitch with 22 players. The task of the image segmentation is to locate the 22 individual players. The output of the segmentation stage usually is raw pixel data. These data must be converted to a form suitable for computer processing. A method must also be specified for describing the data so that features of interest are highlighted. In this case, the colour of the jersey of a player could be a feature of interest since that decides what team the player is on. The final stage of the image processing is *recognition and interpretation.*

Above, the major stages in the image processing have been described. The process can be simplified by using prior knowledge. Knowledge about a problem domain is coded into an image processing system in the form of a *knowledge database*. In the case of analysis of football, the knowledge database consists for example of knowledge of football rules. This knowledge could possibly be used to simplify the image processing.

2.1.2 Colour Image Processing and the RGB Colour Model

In automated image analysis, colour is a powerful descriptor that often simplifies object identification and extraction from a scene. This is certainly true for analysing football matches where the pitch is usually green and the two teams wear jerseys of different colours.

Owing to the structure of the human eye, all colours are seen as variable combinations of the three so-called primary colours, red, green and blue. In order to facilitate the specification of colours in some standard, generally accepted way, colour models are used. There are several colour models, where the RGB (red, green, blue) model is one of the most commonly used. Most colour cameras used for acquiring digital images use the RGB format.

In the RGB model, each colour appears in its primary spectral components of red, green and blue. Images consist of three independent image planes, one for each primary colour. When fed into a RGB monitor, these three images combine to produce a composite colour image (Gonzales, Woods, 1992, page 221-227).

2.1.3 Background Subtraction

A common way of extracting moving objects from a video sequence is *background subtraction.* Background subtraction discriminates a moving object from the background scene. The idea is to subtract the current image from a reference image, which is acquired from a static background during a period of time. This means that the two images are compared pixel-by-pixel, and all pixels that are the same in both of the pictures are removed, i.e. set to black. When analysing a football match, the reference image could be an image of the empty football pitch. This has the effect of subtracting the background from the current image, leaving only that which is different, that is only non-stationary or new objects. This technique has been used in several vision systems as a preprocessing step for object detection and tracking. A problem is that background subtraction is susceptible to illumination changes, such as shadows (Horprasert et al. 2000). *Adaptive background subtraction* is an algorithm where the reference image is constantly re-estimated. This approach makes the method less susceptible to illumination changes, but it is also more complex since it involves obtaining a new reference image during the tracking process (KaewTraKulPong, Bowden, 2001).

2.1.4 The Kalman Filter

There are several different filters, of which the Kalman filter seems to be most frequently used. Any type of filter tries to obtain an optimal estimate of desired quantities from data provided by a noisy environment. It would seem natural to think of a filter as a “black box” with electrical networks, but the filter is actually a data processing algorithm and in most practical applications it is just a regular computer program.

Any measurement will be corrupted to some degree by noise and device inaccuracies, so a means of extracting valuable information from a noisy signal would be desirable. There may also be a number of measurement devices, each with its own dynamics and error characteristics, providing information about a particular variable. To combine the information from these devices would also be desirable.

The Kalman filter incorporates all information that can be provided to it. It processes all available measurements, regardless of their precision, to estimate the current value of the variables of interest. The filter uses knowledge of the system and measurement device dynamics and the statistical description of the system noises, measurement errors, and uncertainty in the dynamics model. It also uses any available information about initial conditions of the variables of interest.

A Kalman filter is a *recursive data processing algorithm*. The algorithm is based on *conditional probability density*. The filter propagates the conditional probability density of the desired quantities, conditioned on knowledge of the actual data coming from the measurement devices. Once the conditional probability density function is propagated, the optimal estimate can be defined. This can be the *mean* or the *median*, for example.

If the system can be described through a *linear model* and the system and measurement noises are *white* and *Gaussian*, the Kalman filter can be shown to be the best filter of any conceivable form. "Whiteness" means that the noise value is not correlated in time, which basically means that the present value of the noise has no impact on future values of the noise. Gaussian noise means that the probability density of the amplitude of the noise takes on the shape of a normal bell-shaped curve. (Maybeck, 1979)

2.2 Economic Theory Underlying the Strategic Analysis

To examine the conditions for commercialising a football analysis tool, a strategic market analysis will be performed (see chapter 7, *Strategic Analysis of the Market)*. In this analysis the competitors, the potential buyers and the general situation on the market will be investigated. The competitors will be analysed with SWOT analysis and the general market situation will be analysed with Porter's five forces model. In this section the theory behind these two models is described.

2.2.1 SWOT Analysis

SWOT analysis is a tool for auditing an organization and its environment. SWOT stands for strengths, weaknesses, opportunities, and threats. Strengths and weaknesses are internal factors. An example of a strength could be a company's specialist technical competence whereas a weakness could be the lack of new products. Opportunities and threats are external factors. A developing market is an example of an opportunity and a new competitor in a company's home market could be a threat.

The idea is to list factors of the analysed organisation in the relevant categories. A problem with the SWOT analysis is that it is very subjective. Two people rarely come up with the same final version of SWOT. In this report, where the objective is to get a general overview of the competitors, the SWOT analysis seems well suited, though.[1]

[1] http://www.marketingteacher.com/Lessons/lesson_swot.htm

2.2.2 Porter's Five Forces

Michael Porter´s five forces model (Porter, 1980) will be used to perform a strategic analysis of the market. This model can be used to analyse the competitive environment on a market and to evaluate the attractiveness of the market for individual firms. The model is based on five forces, illustrated in figure 1. These forces structure the competitive situation on the market. The model can be used to analyse the strategic position of a particular company or to analyse the market as a whole.

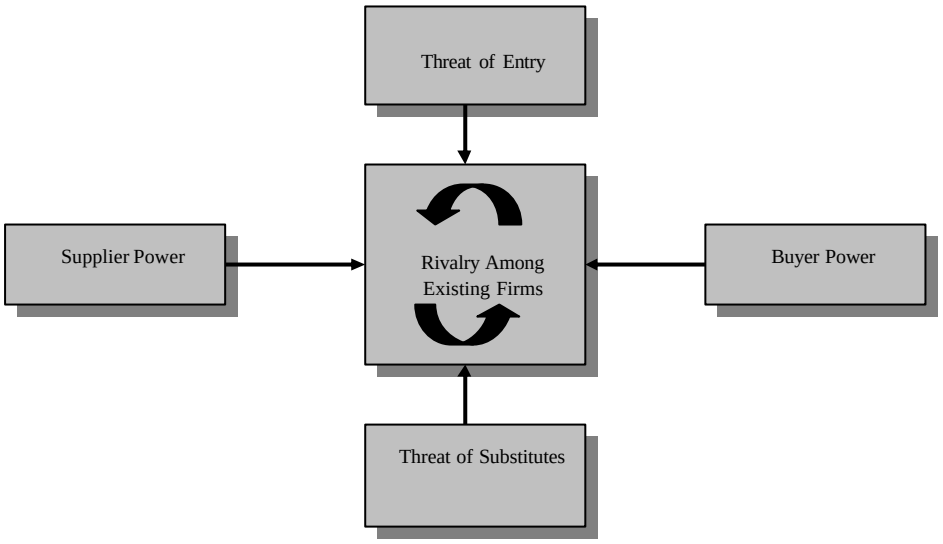

Figure 1, Porter´s five forces

The Five Forces

Rivalry among existing firms is one of the five forces. The intensity of rivalry among firms varies across industries, and is an important strategic aspect. There are a number of industry characteristics influencing the intensity of rivalry. The number of firms on the market is one important characteristic. The more firms there are on the market, the more they must compete for the same customers and resources. The rate of market growth is another factor, influencing the rivalry. Slow market share causes firms to fight for market share whereas in a growing market firms are able to increase revenues simply because of the expanding market. Other important aspects influencing rivalry are the level of product differentiation, costs of switching from one product to another and the amount of fixed costs.

In Porter's model, substitute products refer to products in other industries, which affect the demand of the product when their price is changed. An example is that the price of aluminium beverage cans is constrained by the price of glass bottles.

The power of buyers is the impact that customers have on an industry. Some factors that influence the buyer power are the concentration of the buyers, the volume that the buyers buy and the buyers' switching costs. Buyers are usually powerful when there are few buyers with

significant market share and when they buy a significant portion of output. Another important factor is whether the product is an essential product for the buyers or not. If the product is essential for the buyers, they possess less power.

An industry requires input resources such as labour and components. Suppliers can exert a significant power on the industry, for example by selling its raw materials at high prices. The relationship between suppliers and the firm is similar to the relationship between the firm and the customer. In the same way as for buyer power, the supplier power is high when the suppliers are concentrated and when there is a significant cost to switch suppliers.

It is not only the competitors that are present on the market today that pose a threat to firms in an industry, but also the possibility that new firms may enter the market. Some industries possess characteristics that inhibit additional rivals from entering the market. These are *barriers of entry*. An example of a barrier of entry is companies on the market possessing patents and proprietary knowledge.[2]

Criticism of Porter's Model

Porter's model has been criticised, mainly because the model addresses the profitability of industries rather than individual firms and therefore does not help particular firms to identify and leverage unique advantages (Zack, 1999). In this case though, the analysis has the aim to get an overview of the competitive situation on the market for football analysis tools, and Porter's model should be well suited for obtaining this overview, especially when combined with a SWOT analysis.

[2] http://www.quickmba.com/strategy/porter.shtml

3 Methods

This project was carried out in five steps. This chapter will describe the methods that were used in the different steps. The five steps were Introduction, Overview of previous work, User Requirements, Experiment and Strategic Analysis of the Market. These steps overlap and were carried out iteratively, but to simplify the description the five steps will be described as if they were different, distinctive parts of the project.

It was natural to start with an introduction to the subject in order to get acquainted with the subject and to specify the formulation of problem. To get a deeper understanding of the subject and to get ideas for solutions the next step was to obtain an overview of previous work done in this field. The third step was to thoroughly investigate the user requirements. To be able to suggest solutions and to design an experiment it was very important to find out exactly what the user expected from the tool. The fourth step was to design and carry out a project. This was done in order to get a picture of how the problems could be solved practically. The last main step was to perform a strategic analysis of the market. This was done since part of the formulation of problem was to investigate the possibilities to commercialise a football analysis tool. It is very important to have a clear understanding of the market to be able to draw conclusions about the possibilities to commercialise the tool.

3.1 Introduction

The formulation of problem was specified after several discussions with the Swedish FA and especially the national team's fitness advisor and match analyst Dr. Paul Balsom, who also came up with a major part of the initial ideas.

The first step was to obtain an understanding of general topics related to video tracking. The report is based on information gathered from a lot of different sources. Several books and research reports have been read and several people have been interviewed[3] about general topics such as computer vision, image processing, tracking methods and filtering methods. An understanding of these general topics was essential in order to appreciate further studies of research reports and for the video analysing experiment conducted.

3.2 Overview of Previous Work

It was also important to get an overview of the work and research already done in the field of video tracking. The Internet has served as a tool for information gathering. Websites of companies with products in related areas and websites, articles and research reports about research on video tracking of sports players have been used to get information on the work already done in the field of video tracking. In some cases the companies and the authors of the reports have been contacted for details.

Some of the products available on the market today have been tested and analysed to get an understanding of the requirements and possibilities for a future product. The football

[3] Lars Bretzner, Stefan Carlsson and Josephine Sullivan from the Royal Institute of Technology and David Jonsson from the company Interactive Institute.

analysing tool ProZone and the video editing tools Mastercoach and SportsCode have been tested in collaboration with the Swedish FA.

3.3 User Requirements

Dr. Balsom, match analyst at the Swedish FA, has been interviewed several times about the requirements that the Swedish FA has on a future product. He has expressed his own ideas and opinions regarding what kind of information that is important for a football analysis tool to provide. He has also given feedback to ideas which have been generated throughout the project. The interfaces of other football analysis tools, especially ProZone, have been reviewed in order to get input to what information that is important to provide. Combining the knowledge gained by interviews with Dr. Balsom, the review of other products' interfaces and general knowledge about interface design [4] a proposal to what information to present in a football analysis tool has been articulated.

3.4 Experiment

To understand and solve the complex issue about the tracking part of a video analysing system, an experiment has been conducted. The experiment began with filming a match from several positions and angles to get the input data for the tracking analysis. The match was played between Djurgården IF and IF Elfsborg in the highest division in Sweden (Allsvenskan). The date was the 5th of July 2002 and the game was played at the national stadium of Sweden, Råsunda Stadium in Stockholm. Seven independent digital cameras were used with the objective to cover the whole pitch either by single or multiple cameras. Figure 2 shows the locations of the cameras.

Figure 2, Råsunda Stadium, pitch view. Picture taken with video camera. The numbers correspond to camera positions and are explained to the right.

1. Camera on the roof capturing the whole opposite half of the pitch.
2. Camera situated on the highest point of the northern grandstand almost covering the whole pitch. In the first half a wide-angle lens was used.
3. Cameras covering one third of the pitch.
4. Only used in the second half with a wide-angle lens covering the middle section of the pitch.
5. Only used in the first half to cover the middle

[4] Especially knowledge about Human-Computer Interaction, which for example can be gained by the book Human-Computer Interaction by Dix et al.

The digitalized videotapes were then used to test computer vision techniques. The objective with the experiment was to examine the possibilities for an automatic tracking system using standard algorithms. This was done in close collaboration with the researchers Stefan Carlsson and Josephine Sullivan at the Department of Numerical Analysis and Computer Science at the Royal Institute of Technology in Stockholm, Sweden.

3.5 Strategic Analysis of the Market

An objective of this study was to investigate the conditions for commercialising a football analysis tool. In order to do this a strategic analysis of the market was performed. The focus was on analysing the general situation on the market, to analyse the competitors and to analyse the potential buyers. The competitors were analysed with the SWOT model and the general market situation was analysed with Porter's five forces model. These models are described in the section *Economic Theory Underlying the Strategic Analysis* (2.2).

4 Previous Work in Related Areas

The purpose of this chapter is to get an overview of work already done in the field of video tracking and analysis of football. The overview may show that there already are tools, which the Swedish FA could use or it may give ideas for the tool to be developed. The chapter is divided into two parts; one part examining the commercial market and one part examining previous research.

4.1 Company Overview

The purpose of the company overview is:

- to make an inventory of the products available on the market that could be of use to the Swedish FA
- to investigate the techniques used by the products on the market in order to get an input on what techniques to use for the product to be developed
- to get a picture of what the competitive situation is like on the market for sports analysing tools, especially regarding football

There are a number of companies providing products for analysing sports in different ways. There are also lots of companies using video tracking for different purposes. In this company overview, only the companies offering products perceived to be very closely related to the product to be developed have been taken into account. The companies have been divided into three different categories depending on which technology they are using to perform the analysis. The categories are video tracking, sensor technology and video editing. These companies are listed below including a short presentation of each company and its products. In the different categories, the companies, which are perceived by the author to be the most interesting for the Swedish FA to use today, are presented first.

4.1.1 Video Tracking Companies

ProZone

ProZone is an English company that offers a system for analysing football matches. ProZone's match analysis consists of four parts: Animation, Game Analysis, Fitness and Statistics. In the animation part, an animation with players represented by circles gives an overview of the movements of the teams as a whole and of the individual players. In all four parts a large number of numerical and visual data is presented about the game. Distance covered by each player, passes made and work intensity are examples of statistics that the system provides.

To obtain data about the game, the system uses eight cameras placed around the stadium in combination with manual operators. Computer vision technology is used to capture the movements of the players and the ball, but a lot of manual work is required, not only to register all the events that happen during the game, such as free kicks, corners and passes, but also to aid the automatic tracking. (Mylvaganam et al. 2002).

ProZone is a very expensive tool for analysing football games. It is a stationary system, which costs approximately 100 000 GBP to install at an arena. There is also a cost for each game being analysed. Among ProZone's customers are Manchester United and FC Arsenal.[5]

On November 10th 2001, Sweden played England in a friendly international game at Old Trafford Arena, where ProZone is installed. The Swedish FA got to try the system after this game and got a CD containing ProZone's match analysis. According to Dr. Balsom at the Swedish FA, the analysis contains all the information that they are interested in. But he also points out that it may contain too much information; it takes time to sift the information to get to the most important facts. After having tried ProZone the Swedish FA became interested in finding a system similar to ProZone, but with a lower price and preferably a portable system that can be used at any stadium.

Sport Universal

Sport Universal is a French company, which provides a number of products for analysis of football games aimed at football clubs as well as media providers. Their products are based on a passive tracking system that measures the movements of all moving objects on the pitch, that is all the players, the referees and the ball.

The system, called Amisco System, makes 25 measurements per second during the entire game, and the information provided is digitised in real time. The information about the game is obtained by a capture system and operators. The capture system is installed around the stadium and measures the movements of the players. The operators note all events, such as fouls, offsides and cautions, that happen during the game.

Sport Universal's major product is Amisco Pro, which is a software program that analyses the data obtained by the Amisco System. Their interface is very similar to ProZone's interface; the information they provide is essentially identical. Amisco Pro's match analysis consists of three parts: Animation Mode, Tactic Mode and Physical Mode. The animation mode provides visualisation of the entire pitch and the movements of the 22 players for the whole game duration. In this part of the analysis, data such as instantaneous speed and distance to the ball or to the opponent, can be accessed. The tactical mode gives the possibility to analyse events of the game in their context, which means analysing how they happened and what their consequences were. The tactical mode proposes a representation of the playing areas, for example surface covered, average positions and player trajectories. This mode can also be used for analysing the performance of individual players and comparing them with each other.

The company's major markets are the French and the Spanish markets. Five French football teams and seven Spanish football teams are currently[6] using the Amisco system. There are also two Italian teams using it. According to SportUniversal's web site[7], famous clubs such as Real Madrid, Real Sociedad, FC Nantes and Olympique de Marseille are among their customers.

[5] http://www.pnefc.net/today/view/news_article_detail/0,,10362~161769,00.html
[6] January 26th 2003
[7] http://www.sport-universal.com

Lucent Vision
LucentVision provides a product for analysing and visually presenting tennis games. Examples of features of the product include presence maps that show where the players mostly were situated during a match, virtual replays in which a ball trajectory can be viewed from any position, and a variety of numerical statistics, e.g. the changing speed of the ball during its trajectory.

The product is a real-time networked visual information system that archives sports action using visual processing. The system provides a variety of visual and textual content-based queries on the archived information, and presents the query results in multiple forms including animated visualization of court coverage and virtual-replay of action from arbitrary viewpoints.[8]

Computer vision techniques are used to track each player's movement in real-time, including their distance travelled and speed. The player tracking uses two cameras, each covering one half of the court, to track the player in that half.(Pingali et al. 2000)

Real-time tracking is also applied to the ball on all serves giving its three-dimensional trajectory and speed throughout its motion. A multi-threaded approach is taken to track the motion of the tennis ball. Six cameras around the stadium, four on the side and two at the ends of the court, are used to track the ball. Each of the four side cameras is paired with one of the end cameras to form a set of four stereo pairs that track the ball in 3D. Each thread tracks the ball in a pair of cameras using segmentation by motion, grey scale and shape matching, then performs stereo matching to obtain the 3D trajectory, detects when the ball goes out of view of its camera pair, and initialises and triggers a subsequent thread. This multi-threaded approach is scalable to any number of cameras and with a few modifications it is also scalable for tracking multiple objects.(Pingali et al. 2000)

4.1.2 Sensor Technology Companies

Orad
Orad's mission is to realize the potential of state-of-the-art tracking technologies, real-time image processing and 3D graphics for the worldwide TV broadcast, sports sponsorship and Internet markets. They offer several products for enhancing TV broadcasting and sports webcasting.

One of their products is called SporTrack, which uses miniature tags (weighing 20 grams) placed on the players in order to track them. This system provides a lot of statistical information about the course of the game, such as area covered by each player, accumulated distances and speed. It can also plot player trails and measure distances between players.

ToPlay Soccer is a product, which is targeted at sports media providers such as TV broadcasters, sports portals and web magazines. The media providers can operate ToPlay Soccer to give their users an interactive experience of the game on a PC. Among other things, the user can see the match from any angle on a 3D graphical display. The input to the system is any kind of video footage. This is run through a "tracking machine". To produce the

[8] http://www.bell-labs.com/org/1133/Research/Visualinfosystems/index.html

animation, the tracking data is loaded and the players' motion is refined manually and there is also a possibility to manually add highlights and game descriptions. In that way, this is a semi-automatic system. This system is made for webcasting, but with a few modifications it could probably be used for coaching purposes as well.

Trakus
Trakus' system, called Digital Sports Information, uses sensors to instantaneously capture the movement of athletes and objects during a sporting event. The aim of the system is mainly to provide real-time digital sports content for broadcasts on television, the Internet and other media but also to be a performance evaluation tool to coaches and trainers.

Currently the Digital Sports Information system is applied to ice hockey, golf and motor sports. The system can provide metrics such as location, speed, acceleration, endurance and intensity. It can also graphically reconstruct how plays unfold and create selective views of a game from any angle.

Trakus is currently developing systems for football and American football[9]. For these systems, a combination of sensors and a video-based processing machine vision system will be used for tracking the players and the ball.

4.1.3 Video Editing Companies

Sportstec
Sportstec is an Australian company that provides several products aimed at coaches and trainers in many different sports. Several football clubs use Sportstec's video analysis product, SportsCode. It is also used by the Swedish FA.

SportsCode does not perform an actual analysis of the game; it is only a tool for notating and editing a video recording of a game. The idea is that the analyst edits and codes the recorded game with aid from the program. Afterwards the data can be stored in a database and the game can be analysed by watching different sequences. Thus, this product makes the analyst's job easier and more effective, but it does not make an actual analysis, such as the case is with products like ProZone and Amisco Pro.

Sportstec has the entire world as their market and among their customers are the national teams of Sweden, Ireland, China, and South Korea and the FIFA referees. Sportstec was founded about two years ago (Johnstone, Courtney, 2002) and has since taken a big market share. MasterCoach has a product similar to SportCode, but SportsCode has taken most of MasterCoach's customers[10].

[9] Trakus' web site (http://www.trakus.com, 2/20-2003) claims that the system for American football was being prepared for the 2002 NFL season and that the first generation of the system for football was expected to be complete in late 2002. It is not clear whether this really was the case or not.
[10] Interview with Dr. Paul Balsom, Solna, Sweden, 25 July 2002

Digital Soccer
Digital Soccer is an Italian company, which provides analyses of football games. To perform the analysis they use a technological station with TV pictures and an operator. According to the company's web site[11], they have done thorough research on how to analyse football objectively and how to use statistical data in the analysis of a football game. The operator registers for example time, position and technical movements whenever a player gets the ball. A lot of numerical data about a game can be provided. Among other things, Digital Soccer offers game analyses, team reports, preview analyses and game video analyses.

Digital Soccer does not use any computer vision technology to analyse football games; the data about the game is obtained manually by an operator. The company is interesting from a competitor perspective though; according to their web site they have many famous Italian as well as international football clubs among their customers.

4.1.4 Current Analysing Tools from the Perspective of a Key User

This section has the purpose to give an insight into how the current analysing tools are used and how they are perceived by the user. In order to get this insight, Dr. Paul Balsom, match analyst for the Swedish national team and the Premiership club Bolton Wanderers, has been interviewed. This section is based on several interviews and discussions with Dr. Balsom. Dr. Balsom has experience from ProZone, SportsCode and analysing tools which are not on the market anymore. This section will therefore mainly cover ProZone, SportsCode and football analysing tools in general.

There are a few products that are widely used today by coaches in football clubs. Most of the products are only used as a tool for editing video clips. SportsCode is an example of such a product.

ProZone and Amisco (Sports Universal) are products that have a new dimension of tactical and statistical information incorporated into their software. These products are technically more advanced than SportsCode. They can therefore provide valuable information to analyse in a short-term and long-term perspective.

There is a big difference between the video editing tools and the new generation of software. The video editing tools are inexpensive and often portable systems. The coaches do all the analysis by themselves and the tools are just software with an interface that can handle the video recorded information. Once the coach has a match on video he can edit his own tactical video. These tools give the opportunity to build a comprehensive database of game and player information. But according to Dr. Balsom, the tool does not give the match analyst any information that cannot be obtained in other ways; it is only a way of structuring information. "You get what you put in and nothing else". What he means is that SportsCode performs no actual analysis.

[11] http://www.digitalsoccer.it

The new generation of football analysis tools are more focused on giving the coach information that is very hard or even impossible to obtain by just watching a game in real-time or afterwards. With tools like ProZone match analysts receive a lot of tactical and physiological information about the team and the individual players that is not available with SportsCode. Match information is sent to the coach and his job is then to analyse the results. Dr. Balsom states that ProZone gives all the information that a coach would be interested to analyse. The remaining question, though, is *how to analyse it.*

Some critics say that ProZone shows too much nonsense information that the coach cannot handle to analyse. The Premiership club Bolton Wanderers, where Dr. Balsom works part-time, has recently installed ProZone. They have one man working full-time just to process and analyse the information that ProZone provides. Dr. Balsom is the middleman between the coach and the full-time worker. This example shows the problem of information overload that elite football clubs struggle with today. The large amount of information, that is available, could be a negative thing if the user does not have the proper coaching knowledge, is not educated to use the software or just does not have enough time, according to Dr. Balsom. He is happy if he can get 20-30 minutes of his coach's valuable time within a week to discuss tactical aspects.

Another criticism about the new generation of software is that the systems are too static and not portable. The video editing tools on the other hand are user friendly and are based on what the user put in to the product. SportsCode for example is a portable system that can be used anywhere. ProZone is dependent on the installation of cameras on the clubs stadium and is therefore not a portable system. ProZone is too static and needs to offer more interactive options, such as better video editing facilities, to really be the ultimate analysing tool for the future, says Dr. Balsom.

A demand that is increasingly experienced by coaches today is the need to analyse real-time information for fast tactical decision-makings in a match. As stated by Dr. Balsom, coaches from Premiership clubs want to have specific tactical information about the game in half-time so they can see what went right and what went wrong in the first half. They can use this information to make tactical changes or tell players what they are doing right or wrong. According to Dr. Balsom there is not any product that fully meets this demand today.

4.1.5 Conclusions of the Company Overview

Six different products have been found that perhaps could be of use for the Swedish FA for analysing football matches: ProZone, Amisco Pro, Digital Soccer, ToPlaySoccer, SportsCode and SporTrack. Soon, there will be one more product available, Trakus Digital Sports Information for football. They all have drawbacks though. ProZone is too expensive and is a stationary system. The same applies to Amisco Pro. ToPlaySoccer is mainly aimed at media providers. It can certainly be used for analysis purposes as well, but a lot of manual work is required. SporTrack uses tags on the players, which makes it difficult to analyse opponents. SportsCode is used today by the Swedish FA, but does not meet their requirements fully. One problem is that it requires too much manual work. Thus, this company overview emphasizes the need for the Swedish FA to develop a tool for analysing football matches.

Three different techniques are used to obtain data from the games; computer vision technology, sensor technology and manual work. LucentVision uses only computer vision technology to track tennis players and ball. ProZone uses computer vision technology in

combination with manual work to analyse football games. Orad's product ToPlaySoccer is also based on computer vision technology, but also requires manual work. Thus, the company overview shows that it is possible to develop sports analysing tools based on computer vision technology, but that fully automatic systems for analysing football matches do not exist on the market today. Most of the companies do not reveal any details of the techniques they use to track players and to analyse games. Lucent Vision is the only company that provides information on their tracking algorithm on their web site.

The company overview shows that there are two main target groups for the companies on the market for analysing football matches: coaches and media. ProZone, Sports Universal, Digital Soccer and SportsCode seem to focus on the coaches whereas Orad and Trakus seem to focus on media. If the Swedish FA were to commercialise a football analysing tool, they would probably have coaches as their main target group and therefore mostly compete with ProZone, Sports Universal, Digital Soccer and SportsCode. Since the product would be cheaper and more automatic than ProZone and Amisco Pro, and provide unique information, which SportsCode and DigitalSoccer cannot deliver, the Swedish FA could probably find a niche of their own on the market. The competitive situation and the possibilities for the Swedish FA to commercialise a football analysing tool will be discussed in more detail in the chapter *Strategic Analysis of the Market*

4.2 Sports Related Research with Video Tracking Techniques

Through the history of video technology, researchers have tried to capture objects within an image sequence and convert the motion to a software program. Although the video analysis methods and techniques have existed a while, a major problem has been that digitalized video has required powerful computers as well as ample storage space. The rapid development in the technology of computers and the improvement of algorithms have made this problem less pressing.

Sports related research with video tracking algorithms is today wide spread all around the world. This includes research in athletics, tennis, American football, football (soccer) and indoor sports like handball and basketball.

The purpose of this chapter is to investigate and explain the most important research in the area of sports (in particular football) and video tracking. The chapter consists of summaries of five research projects dealing with video tracking of sports players. The aim is to give an overview of the research, without too many technical terms and complex algorithms. The focus has been to explore camera techniques and algorithms used, to inspect their accuracy and experimental errors, and finally to try to see what can be applied for a product that the Swedish FA could develop.

4.2.1 Tracking Multiple Sports Players through Occlusion, Congestion and Scale

This section is a summary of a research report with the title *Tracking Multiple Sports Players through Occlusion, Congestion and Scale* (Needham, Boyle, 2001). The aim of the research was to provide an automatic tracking system for sports teams and especially for football with the objective to track the movements for behavioural analysis. This project has provided information for sports scientists and coaches, such as physiological statistics of players

(speed, total distance, etc). The purpose was to analyse the performance of the games and design improved training schemes. From the point of view of behaviour modelling the motivation was to investigate problems of interaction between players and the relations between players' positions.

The tracking system was developed with video analysis and the testing of the system was built around one single camera on an indoor court. A framework of multi-object tracking, using a condensation-based approach handled the video analysis techniques. It is a powerful technique allowing the propagation of conditional densities over time, and is used with contour tracking to track an object through cluttered scenes. An initial drawback to this scheme occurs when tracking multiple targets. If several one-body trackers are employed, each with the same tracking algorithm, then two or more can be combined onto the same target for which their model best fits. To tackle the problem each player was being tracked independently and fitted to a probability model.

Ground plane information was used and a Kalman filter was adopted to improve the predictive step of the algorithm. This would help to estimate the position of each player and aid in tracking through occlusions.

Because of the physiological interest in player performance, their position on the pitch was the main feature of interest. More exactly this project has put a lot of effort into the accuracy of where the feet are to determine players' position.

This research found some interesting, yet not surprising, problems:

- The size of the pitch means that the resolution of an image of the game varies greatly between the nearest and the furthest parts of the pitch, see figure 3.
- Large variations are observed in the shapes of football players' silhouettes.
- The football players move at variable speeds, often suddenly changing direction, which makes their movements hard to predict.

Figure 3, Resolution problems. Picture taken with video camera.

The research report states that the following types of techniques had been used: *image segmentation*, *background subtraction*, *adaptive background subtraction,* and *colour space models*.

The research showed that when performing background subtraction on a temporal background model it worked well to extract moving objects in a scene, when the scenes were relatively empty of objects. A problem, with sports activities in general, is that the players sometimes stand still in a match. The effect can sometimes be that the players become incorporated into the background model through dynamic background maintenance.

The colour space models were able to segment foreground and background objects (players and non-players) quickly and were robust to small camera jitters.

The tracking of sports players was solved with a multiple object condensation based tracker as opposed to multiple single object trackers. In this algorithm an instance of a player is represented as a sample, which is part of a *sampleset*, a collection of samples (players being tracked). Finally a *supersampleset* represents a collection of samplesets. Each player is represented with a number of relevant attributes.

The predictive step of the condensation algorithm was first solved with a simple model. Each of the tracked players samples, in each of the N samplesets, was allowed to vary (by adding *Gaussian noise*). This allows for tracking of a player who moves at a speed of $7.5ms^{-1}$.

A better method was developed to improve the tracking performance. A *Kalman* filter was tested for each tracked player. Kalman filters are used because they address the problem of estimating the position of the player at the next discrete time step.

The research team has made an evaluation of the performance of the tracking. In order to evaluate the tracking, the true ground plane positions of the players were needed to be determined. They considered an error of maximum one meter from the true position as acceptable for further behavioural analysis. The result showed that with the improvements of the Kalman filter the performance was within the acceptable region.

Conclusions
In the initial scheme only 28 percent of the automatic tracking gave acceptable positions of the players. With the improvements, 56 percent of the trajectories were within a metre of the hand marked-up trajectory, and hence usable for behaviour modelling.

The researchers see a great interest in future work with more complex models from shape recognition and the positional behaviour analysis of sports players. They also suggest an investigation of using multiple cameras instead of a single one.

4.2.2 Tracking Players in Sports Games – (Handball)

This section is a summary of a research report written by two researchers from the University of Ljubljana (Perš, Kovacic, 2000). The aim of this research was to track handball players with two wide-angle cameras during the whole match. Figure 4 shows the location and view of the cameras. The objective is to obtain trajectories for every player, in the whole field and in every instance of time. The one hour long match was videotaped at 25 frames per second and then digitised to M-JPEG format. The two cameras were placed 10 metres above the playing field with a 103° lens. The 25 frames per second with 384x288 pixel resolution gave 12 GB of compressed digitalized video data for a single match.

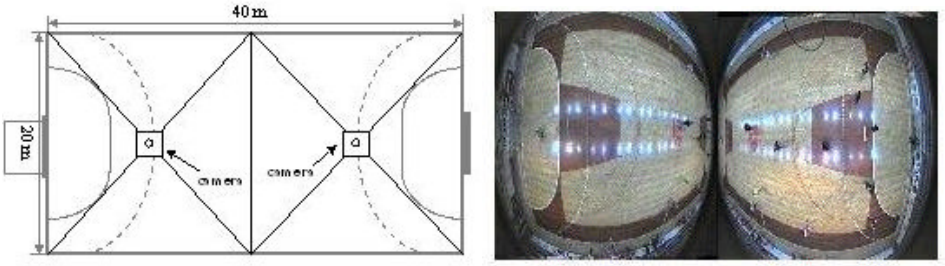

Figure 4, The two camera positions with wide-angle view

A linear model has been used for obtaining the scaling factors, camera orientation and position. Radial lens distortion was a major problem and a model of radial distortion was built. The tracking process was made after the match and is supervised by a human operator. The operator's task is to define the positions of the starting players before the tracking is started and to correct tracking errors. According to the report, a post-processing method was used for the obtained trajectories to reduce jitter. It was also stated that a Gaussian filter could be used to improve the performance.

Three tracking methods were developed:

- Motion detection
- Template tracking
- RGB (Colour) tracking

Motion Detection

The order in which the algorithm is being implemented:

1. Image of the empty playing court
2. Current frame
3. Difference image
4. Thresholding
5. Filtering by median filter
6. Blob assignment

The drawbacks of the motion detection is that the algorithm is sensitive to:

- Light reflections
- Shadows
- Non-uniform illumination

Template Tracking

This method is used to exploit the visible difference between the players and background objects. The researchers found that it was extremely difficult to build an accurate model of a player, especially at low resolution. They used a set of templates, which represented the basic appearance of a player together with an algorithm to calculate the position of the player. The drawback found was the difficulty to adapt to the background objects.

RGB Colour Tracking
This approach is using RGB colour representation to identify players. The problem with this approach showed to be that only a few pixels correspond to the true colour of the player's dress. The colour-tracking algorithm simply searches for the pixel that is most similar to the operator-defined RGB value but the negative effect is the high amount of jitter that will be exposed.

Results of the Tracking Methods

- Template tracking showed to increase the accuracy and to eliminate jitter.
- RGB (colour) tracking showed to be reliable but an inaccurate estimate.
- The initial estimate for the next frame is based on the output of the colour-tracking algorithm to prevent adaptation to the background objects.

Testing of the System
The three different algorithms were tested against a true-position estimate manually obtained by human operators. The operators were performing manual tracking at 2 frames per second. Table 1 shows the results of this testing.

Table 1, Shows number of interventions required, mean position error for a single player and the path length of a single player for the different methods and in the latter case compared to manually obtained results.

Method	**Motion detection**	**RGB (colour) tracking**	**Colour and template tracking**	**Manual (ideal) results**
Number of interventions on a 30 second test sequence	45	12	14	-
Mean position error for a single player (cm)	35.3	33.4	28.0	-
Path length of a single player (m)	73	82	75	77

Conclusions
A combination of colour and template tracking algorithms requires few operator interventions, and results obtained contain low amount of jitter. The conclusion was therefore that this was the most appropriate method for use in the automated player tracker. Operator supervision is still required.
The following problems were found:

- Large area to cover (20x40 metres)
- Rapid player motion
- Large amount of data to process (25 fps * 3600 seconds = 90.000 images)

The results obtained by automatic tracker are less accurate than those obtained manually and have to be filtered to reduce jitter. The conclusion is that sports experts can use the obtained results for further analysis.

4.2.3 Where are the Ball and Players? Soccer Game Analysis with Colour-Based Tracking and Image Mosaic

This section is a summary of a research report dealing with football analysis with colour-based tracking and image mosaic (Seo et al. 1997). The aim of this research was to solve the following three problems:

1. Ground field extraction
2. Player and ball tracking and team identification
3. Player positioning

The results were evaluated from several tests consisting of real image sequences (broadcasted TV signal) from a football match.

Field Extraction
The ground field had to be extracted in order to track players, to find the half line, a side line and the centre circle and to make mosaic image for computing image-to-model transformation. The accuracy of this process was very important because it was used in all the following procedures. They used colour histogram information, RGB, under the assumption that the region of the ground is nearly green and occupies almost all areas of an image.

Player Tracking
Players move non-rigidly, frequently collide with each other and are occluded by other players. *Template matching* (similar to the method *Template tracking* in the handball research) and Kalman filtering was applied for player tracking. The main problem of player tracking was occlusion, which was solved by using histogram back projection for occlusion reasoning.

Team Identification and Ball Tracking
Players of the same team were grouped together. Comparing spatial colour distribution (RGB) of player templates made it possible to solve the problem. A similar method for ball tracking was used. The ball was however more difficult to track since it is very small in the image and if the player has the ball, it is frequently being occluded by the player. The ball tracking problem was solved by manually initialising the position of the ball at the start. If the player is running near the ball, the player is marked “has ball”. An example of the result of player tracking and team identification is shown in figure 5.

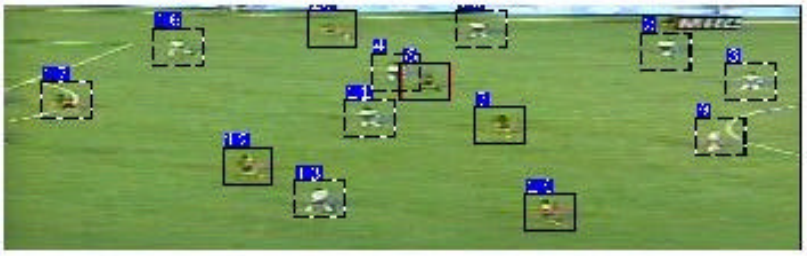

Figure 5, Player tracking. Boxes of different colours identify each team. Picture taken with video camera.

The Field Model
A player is located at a certain position on the field, but since this research used a mobile camera that is panning and zooming, the tracking of the players becomes harder than with a stationary camera. To find the players position on the field model, a transformation had to be computed between the "real world" image and the field model. Several reference points were used to solve this problem.

Conclusions
The region of ground field was extracted on the basis of colour information. Template matching and Kalman filtering was used to track players. Colour histogram back-projection solved the occlusion reasoning part. The location of the players was computed for a field model that was constructed. A transformation between the input image and the field model was then computed using feature points. By the image-to-model transformation, the absolute positions and all the trajectories were determined for the field model.

4.2.4 Tracking using a Local Closed-World Assumption: Tracking in the Football Domain

This section is a summary of a research report dealing with tracking in American football (Intille, Bobick, 1995). The aim of this research was to investigate the possibilities to go from a manual video annotation system to an automatic or semi-automatic digital system in American football. The old system used a specialised database software where an operator would manually annotate every play, recording attributes such as yard line, down, yards to go, formation, type of play and the result. The new system would instead use digital media so that video can be accessed and viewed directly from a computer.

For the annotation input they were using player trajectories. It is a computer vision football-player tracker that uses contextual knowledge to track football players as they move around the field.

They used a mobile camera with a wide-angle lens, which gave a considerable amount of distortion when the camera was zoomed out. Once the video has been digitalized the players range in size from about 20 by 20 pixels to about 10 by 10 pixels. The most difficult problems with the players were:

- The unpredictable and rapid movement
- The collisions at high velocities
- The fact that they act as non-rigid objects

The mobile camera problem was solved with a conversion of the original image sequence into a rectified one. This was solved as the square grid lines of the field appear as squares in the image.

Closed-World Tracking
A closed-world is a region of pace and time in which the specific context is adequate to determine all possible objects present in that region. For example, the closed-world can contain two players, yard-line and grass. The internal state of the closed-world, e.g. the positions of the players, is however unknown and must be computed from the incoming visual data.

Closed-world analysis provides a complete description of closed-world image regions. By knowing which objects are present in a closed-world, a tracking system can select features, which are most likely to be reliable, in separately tracking each of them. Again consider the case of an isolated player. Since the background can be better modelled than the player, a robust strategy is to select features that can be used to assign pixels to the background. Any pixel not so assigned can be assumed to be a player.

The recovered player paths have been obtained using median filtering over the entire image sequence. The result of this tracking technique is that the automatic tracker can obtain half of the player trajectories automatically.

Conclusions
The videos of American football games are analysed to extract player trajectories and to generate symbolic descriptions of the actions involved. They incorporated contextual knowledge such as the number and the type of objects on the ground into low-level tracking. Players are marked manually in an initial frame and tracked automatically in subsequent frames by a special algorithm called closed world tracking, which operates on rectified images, i.e. back-projections of the video frames with respect to the original camera.

4.2.5 Research Systems Summary

This chapter has examined and explained research in sports technology, in particular football, where video analysis has been used. The focus has been to explore camera techniques and algorithms used, to inspect their accuracy and experimental errors, and finally to try to see what can be applied for a product for the Swedish FA.

The different camera techniques emphasize a series of interrelated questions: Mobile or stationary camera, one or several cameras, broadcasted TV sequences or other video sequences, normal lens or wide-angle lens. The single stationary camera with normal lens operated by the researchers themselves is the easiest way to avoid technical problems, but a negative effect is the limited analysis spectrum. Chris Needham and Roger Boyle, from the University of Leeds, used the camera technique described above. They saw a problem with the size of the pitch, which made the resolution of the video unsatisfactory, even though they used a small indoor court. Their suggestion was to try to use multiple cameras to cover the whole pitch from different angles in order to overcome problems of low resolution.

Another example where stationary cameras were used was the handball research project from the University of Ljubljana. They used two (wide-angle) cameras right above each centre half of an indoor court. Because of the angle of the camera positions the reflections of the flood-lights became a problem, but apart from that it seemed to work very well, with two stationary cameras. To cover the whole indoor court they had to use wide-angle lenses. The American football research, by the MIT Laboratory, also used wide-angle lenses. The positive effect is, of course, that you can cover a wider area with this type of lenses, but on the other hand it can give a distortion effect that will increase the difficulty to analyse the video.

When the research is dealing with mobile cameras the video sequence is almost always taken from a broadcast TV signal. A drawback is that the researcher is not in control of what is being filmed. More problems come with the zooming of the camera and the fact that it is much harder to make a field model of the pitch when you are dealing with broadcast TV signals. The research from the University of South Korea, which uses TV signal, is not really interested in analysis of the whole match. In that project the focus was on reconstructing what the objects on that particular TV sequence can give.

There are some tracking algorithms that are used in more than one of the examined research reports and seem to work very well. These are described below.

Filters can be used in a predictive step to estimate the position of the player at the next discrete time step. The Kalman filter has been used as a predictive step in order to improve accuracy of the automatic tracker in some of the research projects with great success.

The other algorithms are more focused on the actual image (video) analysis part. The RGB colour tracking (different names are used in each specific project) was used in three of the four examined research projects. The objective is to track the players for team identification. This method performs good and fast segmenting, and is also reliable. On the downside is that it sometimes was hard to identify a player because of the low resolution and the few pixels that correspond to a specific player.

Another method that was used in the examined projects is the template (shape) tracking technique. This method was used in two of the examined research projects with successful results. The main part of this algorithm is to find the shapes of the players (objects) and then compare them with the background e.g. pitch. In conclusion the template tracking technique showed to increase the accuracy and to eliminate jitter but it was hard to build a model for it.

As a result of the algorithms above it can be concluded that there is not just one method that can or should be applied to an automatic tracker model. The answer is instead, which the research reports show, that several algorithms should be used together to increase the effectiveness and accuracy of the model. The research at the University of Ljubljana used a combination of colour and template tracking algorithms that gave less jitter and required less operator interventions.

In most of the examined research projects the tracking models have been tested in some way. The conclusions are that it seems to be very difficult to make an acceptable fully automatic tracker based on just video analysis. Hence, a real-time system does not seem to be realistic at this stage. The good news is however that with a combination of well-constructed tracking techniques, a semi-automatic system can be built. The tracking process can be made offline and should be supervised by a human operator who corrects the faults of the tracking process.

Several problems have been discovered in the different research projects:

- The size of the pitch, whether it is an indoor court or the whole football pitch. It is difficult to cover the whole pitch and even if you are using multiple cameras there seems to be a problem with the low resolution.
- The unpredictable and rapid movement of the players makes automatic tracking algorithms hard to use because of the difficulty in estimating the player's position.
- The occlusion of players and the ball makes the team (and player) identification and ball tracking hard to follow with an automatic system.

- The players move as non-rigid objects and can have many shapes, e.g. moving arms or players lying on the pitch, which can make the template matching a bit hard to use.
- For an analysis of a whole match a large amount of data has to be processed and stored.

4.2.6 Research Systems Conclusions

The best way to perform a video-tracking analysis of a whole football match seems to be by using multiple stationary cameras and let each camera cover one particular part of the pitch. Wide-angle lenses should be used if it does not make the tracking more difficult. Some sort of filtering technique, e.g. Kalman filter, should be implemented to make the tracking algorithm more accurate. Finally a combination of video analysis methods would make the performance of the tracking algorithm more efficient. Examples of well working algorithms are template matching and RGB Colour tracking.

5 Game Coverage – User Requirements

An important part of developing a football analysing tool is to decide which information to present to the user. Another important aspect of the development of a football analysis tool is to create an interface, which presents the relevant information in a user friendly manner. Dr Paul Balsom, match analyst of the Swedish national team and Bolton Wanderers, has been interviewed to get an understanding of what kind of information he, and the Swedish FA, are interested in getting from a football analysing tool, and what ideas he has regarding the presentation of the information. The interfaces of ProZone and SportsCode have been examined to see examples of how interfaces in football analysing tools can be designed. This chapter states which information that is important to present and in general terms how the information could be presented in an interface. The content is based on interviews and discussions with Dr Balsom, investigations of interfaces of other products and other ideas generated during this project.

5.1 Articulation of User Requirements

The Swedish FA is interested in getting tactical, physical and statistical information about their team and their opponents. The different types of match analysis information can be divided into categories. Amisco divides the information into three different categories: Animation Mode, Tactic Mode and Physical Mode. ProZone on the other hand divides the information into four different categories: Animation View, Game Analysis View, Fitness View and Statistics. In this report, a combination of Amisco's approach and ProZone's approach will be used. The information will be divided into three different categories: Video and Animation View, Tactical View and Fitness View. This is an approach which will be used in this report to structure the information that is relevant to present in an analysis tool, and it is also a way to structure the information, which could be used in a real interface. This approach seems logical and gives a good overview of the information. Below, the information that is considered to be relevant in each of the three different categories will be described.

5.1.1 Video and Animation View

The animation view could be used in any instance of a game to capture the specific events that are being analysed. All types of interesting events should be listed in a specific file where the user could choose an event and then play it with an animation tool or with the video sequence. It should also be possible to follow the game chronologically with the animation tool or the video sequence.

The animated view of the pitch should consist of all the 22 players, the ball, and the referee and visualise their movements on the pitch. The animation view together with graphical options should present the marking distance, the distance between a player and the ball and the distance to the closest opponent. It should also present an animated offside-line, the density of the team blocks and the length and width of the team, that is the distance between the two players in the team that are furthest away from each other in the two main directions. This gives a new viewpoint for analysing a football match.

The recorded video coverage of the match, with multiple cameras that give different views of the game, would also be a powerful tool in analysing situations.

The animation view should also be used to make video editing from one or several matches. The video clipping is a powerful tool to use, not only for the coaches themselves but also for players in an educational perspective. Coaches can use the information gathered from several matches and make a video sequence of particular events that show recurring patterns.

5.1.2 Tactical View

The purpose of the tactical view is to analyse all actions in their exact context, that is to look at how events happened and what the consequences were. This gives an in depth analysis of player actions and team strategies. The individual and team performance could be evaluated in all actions and playing phases by efficiency measurement.

The tactical view should offer an interactive representation consisting of an animated view, a video view together with statistical information represented in a graphical form. All the events that take place in a match should be mapped together with the involved players. Such events are: goals, shots, passes, crosses, clearances, ball gains, ball lost, running with the ball, dribbles, headers, throw-ins, free-kicks, tackles, fouls, off-sides, trajectories, zone coverage, player positioning etc. It should also show an exact representation of the playing areas such as surface covered and average positions. The animation view together with illustrative designed graphics would be an important tool to visualise the results of the analysed sequence.

Analysis of the two playing teams should be available in the tactical view. The analysis could be used for comparing selected players, e.g. Team A strikers vs. Team B defenders, or by studying individual players.

5.1.3 Fitness View

The intention with the Fitness view is to give the analyser in depth information about the physical performance of all the players. The Fitness view should consist of measurements of the total distance covered, total distance covered in walking, jogging, running and sprinting, recovery time, movement profile, average speeds, top speed and detailed analysis of sprints such as distance run in sprints, number of sprints, average recovery time between each sprint etc. The analyser should have the opportunity to compare players against themselves, other team mates or opponent players.

Accurate measurements of players' movement pattern during a match would be used for further studies about their physical performance. The physical statistics could be used in a short-term or a long-term view. The short-term view is for example to look at a single match and see which players have covered most distance. In the long-term perspective, data from several matches or even football seasons could be used to detect and prevent physical problems. All the data collected would be used to elaborate an individualised physical preparation platform.

5.1.4 Advanced Features

The information mentioned above, in the sections 5.1.1, 5.1.2 and 5.1.3, is basic information, usually in the shape of numbers and figures. Most of this information is provided by, for example, ProZone. There is some kind of information, which is more ingenious and more advanced. Some ideas for other types of information or functions, which could be built into the football analysis software, will be presented in this section. Obviously, there are countless functions that could be interesting; in this section just a few ideas which have been generated during this project will be described.

Analysis of Formations

Usually a football team tactically consists of three parts: defence, midfield and attack. Often there are four defensive players (and the goalkeeper), four midfielders and two attacking players, or three defensive players, five midfield players and two attacking players.

Players in the same part of the team are often supposed to cooperate in a specific way, and move together. For example the defensive players may be told to move together in a straight line or two of the midfield players may be told that the distance between them shall never exceed 30 meters.

It would be very interesting for a coach to be able to analyse how well the different parts of a team followed the instructions regarding formation. What happened when they did not follow the formation is another interesting question for a coach. A function which makes it possible to analyse how well predetermined formations were held could be incorporated into the interface of a football analysing tool. It would be an interactive tool where the coach could state what kind of formations that he wants the players to follow. In the analysis of the game, the tool will tell the coach in what situations the formation was broken. Probably it is too complicated to analyse very advanced formations, but formations such as “move in a straight line” or “do not exceed a distance of 30 meters between player A and player B” would be possible to analyse. According to Dr. Balsom, this could be sufficient to be able to make very interesting analyses.

Multiple Game Analysis

ProZone and Amisco analyse one game at a time and make no comparisons with previous games. The kind of data that is provided would be more interesting if it were related to previous games. For example, the distance covered by a player is not a very interesting figure in itself, but could be very interesting if compared to previous games. If one player has covered 30 per cent less distance than his average covered distance in the previous ten games, it could be because he has an infection and cannot work as hard as usual. It would also be valuable for coaches to compare games where they have had different tactical formations in order to compare the outcome. It is then possible to see what the consequences of a specific tactical formation were. It is also interesting to see if some events occur frequently during a period of time. If a player stands misplaced in one game it is not as alarming as if he does so during the entire season.

There is no doubt that it would be very valuable for coaches to compare games with each other and to be able to access data from several games during a period of time. Thus, the football analysis tool should be integrated with a database of previous games, and functions should be built into the software to make it possible for the user to access this database. This would enable the user to analyse one game more thoroughly by being able to compare it with

previous games, and it would also make it possible to analyse several games at the same time, for example analysing an entire season.

Event Chains
One of the main reasons to use a football analysis tool is to identify event chains, that is to identify what events that led up to a specific situation. For example, if a team scores it is interesting to see what events that happened just before the scoring. For instance, a goal could have come after five successive short passes in a row in the team. It could also have come after that a defensive player lost the ball to an attacking player who shot immediately. To know what events occurred just before one goal is not very important but if there is recurring patterns in what kind of events that have occurred just before a goal, it is very interesting information. If, for example, goals very often are made after a number of short successive passes within the attacking team, the coach can draw the conclusion that a way of scoring is to use short passes in the offensive play.

The software program should be able to aid the match analyst in the identification of recurring event chains. A requirement for this is that there is a database of event chains from previous games, as described in the previous section. Some kind of event chains could possibly be identified in just one game, but in most cases several games have to be analysed in order to identify recurring event chains. A way of identifying event chains is to compare the five events (passes, shots, dribbles etc) that happened just before every goal and then compare if there are similarities.

5.2 Presentation of Information

The amount of information that a football analysing tool could present is enormous. It is a risk that the information could be overloaded when it is to be presented to the user. This is, according to Dr. Paul Balsom, the case with ProZone. Some information is described in too much detail which makes it hard to analyse. It is important that the information is presented in the right context where it can be analysed for its purpose. This sounds obvious but can be difficult when dealing with a large amount of data.

The sections above have dealt with what kind of information to present but also generally how to present the information. One suggestion is that the information is divided into three different categories as described in section 5.1. In this report the design of the interface will not be covered in more detail. If the Swedish FA decides to develop a football analysing tool a lot of effort will have to be put on designing an interface for presentation of the information. Lots of user tests and evaluations will have to be made in order to make a good interface. This is always important when designing an interface, especially in this case since football coaches, who will be the users of the systems, rarely are used to using computers.

6 Experiment: Obtaining Game Information

Comment: Inte klockrent med experiment, hur får jag med det men ändå att kapitlet inte helt handlar om experimentet?

In chapter 4.2, *Sports Related Research with Video Tracking Techniques*, a few research projects, which had tried to obtain information about games, were examined. In this chapter the issue of obtaining game information will once again be examined. In this case however, the content will not be based on previous research but on an experiment which has been conducted in this project (see chapter 3, *Methods*). This chapter will not only be based on this experiment, though. It will also provide a clear overview of the important steps in obtaining game information.

There are two ways of obtaining information about a football game. One way is to use automatic tracking of the ball and the players and the other way is to obtain information manually. Some information cannot be obtained manually and is thus dependent on the results of the tracking process whereas other information is impossible to obtain in the tracking process. In the latter case manual work by an operator is the only way to obtain the required data.

The problem of tracking the players and the ball in a football match can be divided into two different parts. The first part is how to obtain the data for the tracking process. In this experiment the method of obtaining data was video recording. Issues to be investigated are where to place the cameras and the required number of cameras. The second part of the problem is how to perform the tracking process; that is how to get the players' positions on the pitch. The problem of tracking all the players in a football match will be discussed in this chapter, mainly based on the experiment that has been conducted.

In this chapter, the issue of tracking all the players in a football match and the issue of obtaining information manually will be discussed. According to the discussion above, the issue of tracking all the players in a football match has been divided into two different parts, Video Recording Solutions and Tracking Input.

6.1 Video Recording Solutions

This section has the purpose to address the problems involved in getting the input data for the tracking process and to propose solutions to these problems. Several parameters have to be considered to reach the main objective, which is to track all the players and the ball in a 90 minutes football match by using video technology.

The tracking process requires that the entire pitch is being filmed the whole 90 minutes with a high level of resolution. Using more cameras, letting each camera cover one specific part of the pitch, can easily solve the resolution requirement. ProZone and Amisco from Sports Universal are products that both are non-portable systems and use six to ten cameras depending on the specific stadium where the system is installed. This gives them high resolution, which makes the automatic part of the tracking process more effective. The problems with this approach are that more cameras will lead to higher installation costs, that the tracking process will become more complex and that the use of many cameras makes it hard to make the systems portable.

One of the requirements that the Swedish FA has on a future product is that the cost has to be lower than for products like ProZone and Sports Universal. It is therefore desirable to keep the number of cameras as low as possible. It is thus necessary to decide the minimum number

of cameras that still deliver sufficient resolution. Another requirement is that the Swedish FA wants to have a portable system. There are many parameters that have to be considered before a solution can be presented. Issues to be investigated are where to place the cameras and how many cameras that it is necessary to use.

6.1.1 Camera Solutions

In the experiment conducted seven different cameras were placed around the stadium to examine as many alternative solutions as possible (see chapter *Method* for overview of the placement of the cameras). Below three ways of capturing a football pitch are described.

One Camera on the Short Side
This alternative is based on using just one camera. This camera is placed on a relatively long distance from the pitch in order to cover the entire pitch. There are two problems with this approach. The first is that many stadiums do not have a place to set up a camera to cover the whole pitch. The other problem is that the distance to the pitch will make it hard to meet the resolution requirement.

Two Cameras on the Short Side
This approach is using two cameras to capture one side each of the pitch. The same problems as described in the one camera example are shown here. The resolution is a bit better but probably not acceptable.

Three or Four Cameras on the Long Side
This alternative is based upon that the cameras are placed along the whole long-side. A problem with this is that it is hard to make a portable system out of four cameras placed in different positions. Four normal cameras or three wide-angle lenses is the minimum requirement to cover the whole pitch. The resolution requirement would probably be acceptable with this approach.

6.2 Tracking Input

One way of obtaining information from a video recording of a football game is to analyse the recording in order to get the players' positions on the pitch during the game, that is to track the players. This section will deal with the issue of tracking based on the experiment previously described.

After the recording of the game, the next step in the experiment was to analyse the recordings. This was done at the Department of Numerical Analysis and Computer Science at the Royal Institute of Technology together with Stefan Carlsson and Josephine Sullivan. In this section their initial approach to tracking players in a football game is described as well as the results obtained by analysing the recordings [12] using their approach. In the end of this section, possible improvements and complements of the tracking method are discussed.

Statistical Background Model
The approach is based on the following, simple intuitive idea: The colour of the football pitch is known. Presented with an image of a football pitch with players on it, the pixels can be classified as foreground, that is being part of an object on the pitch, or background depending

[12] The recordings made at the game Djurgårdens IF – Elfsborgs IF at Råsunda Stadium, 5th of July 2002, were used as well as recordings made by the Swedish FA from the game AIK – Malmö FF.

on whether they have the same colour as the background or not. This obviously requires that the colour of the players is not the same as the colour of the pitch. This algorithm can locate the objects on the pitch but it cannot distinguish between players.
A video camera usually produces 25 frames each second. Thus, the positions of the players change slowly in the image from one frame to the next, which makes it simple to follow their movements if it is possible to locate their position in the different frames.

This approach is similar to the approaches used in the research projects described in sections 4.2.1, *Tracking Multiple Sports Players through Occlusion, Congestion and Scale*, and 4.2.2, *Tracking Players in Sports Games – Handball*. The difference compared to the latter project is that the Statistical Background Model uses adaptive background subtraction, which probably will reduce the problems of sensitivity towards non-uniform illumination, light reflections and shadows, which was experienced in that project. The method used in the research project described in section 4.2.1 and the Statistical Background Model are very similar, except that the Statistical Background Model is less complex. The reason for the use of the Statistical Background Model in this experiment is to get a deep understanding on how a tracking algorithm works theoretically as well as practically and to see how well it works, not by reading a research report but by doing it as a part of the conducted experiment.

Mathematical Model
Mathematically, a statistical model for the appearance of the colour of each pixel in the football pitch when no players are present is the following:

$$B^k(x) \sim \mathrm{N}(m_x^k, (s_x^k)^2) \text{ for k = r, g, b} \qquad (1)$$

where $B^k(x)$ denotes the redness (k = r), greenness (k = g), or blueness (k = b) of the pixel at coordinate x on the pitch. $\mathrm{N}(m_x^k, (s_x^k)^2)$ is the notation to denote a Gaussian distribution with mean m_x^k and variance $(s_x^k)^2$. Presented with an image of the football pitch with players on it, denoted by $(I_t^r(x), I_t^g(x), I_t^b(x))$, pixels are classified as foreground or background depending on whether they fit the background model or not. Pixels are classified as foreground if $\left|I_t^k(x) - m_x^k\right| > 1.96 s_x^k$ for k = r, g, b. Otherwise they are classified as background.

Construction of a Background Image
The appearance of a football pitch is not static. The position of the sun, the clouds and the stadiums affect what shadows are cast on the field. Therefore the background image has to be updated now and then. For varying length time segments though, there is only random jitter affecting the appearance of each pixel in the pitch and therefore the model in equation 1 is adequate.

However, as the game is being played it is not possible to get a clear view of the pitch as the players, referees and the ball are covering parts of it. Since all of these objects are moving, it is possible to see all of the grass pixels at some stage over a long enough time interval. Using advanced statistical methods it is possible to learn the model described in equation 1 even though the training data is contaminated, that is it is possible to construct a background image even when the game is in progress.

Practical Procedure
Having an input image and a learnt background image, the first step is to subtract the background image from the input image. Then the thresholding equation (that is the way to classify pixels as either foreground or background) described above is applied to distinguish the players from the background. Morphological filtering and grouping of foreground pixels is the final step in locating the players. This gives segmented foreground pixels, which is easily transformed into an image with boxes around the foreground identities. Figure 13 is an example of such an image.

Result and Discussion
Figure 6 displays typical output after having used the above described procedure.

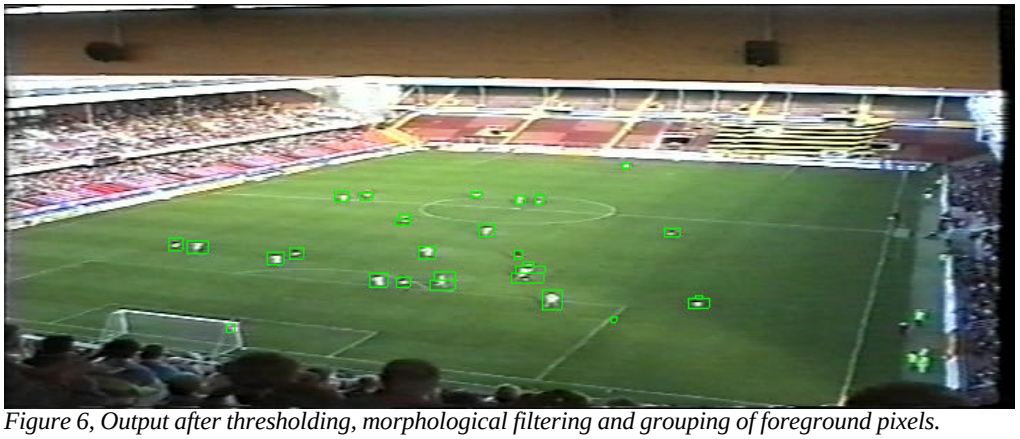

Figure 6, Output after thresholding, morphological filtering and grouping of foreground pixels.

It is important to note that all the players are located. There are errors though. In some cases a player has been identified as more than one blob and some areas of the pitch are classified as foreground even though they do not correspond to foreground objects. This is to be expected from any low level computer vision process. Better statistical modelling of the scene, combined with a higher level process could alleviate some of these errors (Rowe, Blake, 1996).

These initial results are promising. Using simple techniques it is possible to obtain a good segmentation of the foreground objects. The conclusion from this experiment is that using this approach it is relatively easy to segment out players from the football pitch. Tracking players who are isolated can be automated fairly simply.

Possible Improvements and Complements to the Method
Problems occur when players occlude each other and afterwards. During and after an occlusion the method is not able to distinguish between the players involved in the occlusion. In the experiment conducted, the resolution of the players was too small to distinguish one player from another using colour information. Previous research (see section 4.2.2.3) has shown, though, that it is possible to use colour information to track players. In that research they had problems with the colour tracking because only a few pixels correspond to the true colour of the player's dress, but still colour tracking worked fairly well. Using colour tracking after an occlusion could probably be a way to solve many ambiguities.

Colour tracking would probably solve the cases where two players of different teams, hence wearing differently coloured jerseys, occlude each other. When players from the same team occlude each other it is more difficult. There are methods that could solve this problem but they require a high resolution. For example, if the resolution were very high it could be possible to use the number on the players' back to distinguish between them, but that would require a much higher resolution than the one in the conducted experiment, and does not seem feasible at all.

At this point, there is no point in further examining methods for distinguishing between players when the colour information does not suffice. Using the Statistical Background Model in combination with colour tracking is probably good enough for building a prototype for a semi-automatic football analysis tool. There would be some ambiguities, which would have to be solved by manual interventions. Further investigation of methods that could reduce the number of manual interventions required would be interesting at a later stage, when the first prototype of the system has been evaluated.

6.3 Manual Input

Some information cannot be obtained without manual work by an operator. It is impossible to distinguish between specific events, such as goals, shots, passes and bookings, that happen in a football game for an automatic system, and it is even hard for a human operator. According to Dr. Balsom, the operator has to have more than general football knowledge to be able to classify events correctly, such as if a ball is to be considered as a clearance or a long pass.

It should be possible to insert information during the game in real time or after the game with a video recording as a source of information. Either way, an interface for inserting the data is required. The design of the interface for operator input is an important part of the development of a football analysis tool, since it decides what kind of information about the game events that the system will be able to provide and how accurate it will be. It is not the main focus of this report, though, to go into details about the design of the operator input interface. However, some general thoughts about the operator input interface are presented below.

An important issue is what kind of events that are to be inserted. It is rather obvious that goals should be notated when they happen, but what about for example tackles? The more kind of events that are supposed to be inserted, the greater is the risk of operator mistakes. The only kind of events that should be inserted is the kind of events that is interesting for the end user to get information about. There is no point in inserting information about events that are of no interest for the end user. This would make the operator's task unnecessarily difficult and would increase the risk of information overload for the end user. Thus, it is important to define what kind of events that may happen in a football game and which of those that are of interest to get information about. The definition of game events should be made by football experts. In the interface, these events could be divided into groups, such as for example player events, goalkeeper events and referee events. Examples of player events could be touches, dribbles, headers, tackles, crosses, clearances and other events that the football experts are interested in.

The game events occur often, usually with little time between the events, and the events have to be classified as well as associated to a player (for example "goal" by Fredrik Ljungberg or "successful dribble" by Zlatan Ibrahimovic). Therefore it is very important that the interface

makes it possible to quickly and accurately insert information about events in the game. Since the operator has to make quick decisions on how to classify events, especially if the information is inserted during the game, it is inevitable that some mistakes will be made. It is therefore necessary to make the interface very intuitive in order to reduce the number of mistakes. It would also be good if the system could be "intelligent", that is to be able to detect mistakes in some way.

It is important that it is possible for the operator to follow the game at the same time as the event information is entered. An intuitive idea is to use a speech based interface . It would then be possible for the operator to follow the game without looking at a computer display. There may be problems with using a speech based interface at a football arena, where the noise of the crowd will disturb the system (Dix et al. 1997, pp 557-559). It is also more difficult to give immediate feedback to the operator using an entirely speech based interface. It would be a good idea to investigate the possibilities of using a speech based interface, but also design a more traditional computer display interface as a complement.

One way of reducing the number of mistakes made by the operator is to make use of the fact that the occurrence of a first event precludes some of the other events from following the first event. For example a goal cannot follow the ball going out of play. Thus, it should not be possible to enter the event "goal" if the preceding event was "ball going out of play". It is also possible to use information from the tracking input to detect errors made by the operator. For instance, if a corner takes place, the player associated with the corner has to be a player on the team, which has the half of the court, where the corner is, as its attacking half.

If a traditional computer display interface is used, the operator will probably click on the event that just occurred and the player which is associated with the event. To make it easy for the operator to do this quickly, it is possible to make use of knowledge of probabilities of one event following another. If for example, the previous event was a shot it is likely that the next event will be a goalkeeper event . Thus the goalkeeper events could be highlighted or placed on top of the screen in order to make it easy for the operator to quickly find the correct event.

If the Swedish FA decides to develop a football analysis tool, a lot of effort has to be put on designing a user friendly input interface. Football experts have to give input on the classification of events, and user tests have to be conducted to obtain an ultimate interface.

7 Strategic Analysis of the Market

If the Swedish FA develops a tool for analysing football matches, they could either use it on their own or they could commercialise the system. This section will briefly investigate whether it would be attractive to launch a product on this market and what the conditions for an introduction would be. This is not the main focus of this report, though, and if a launch really is to take place this issue has to be examined more thoroughly.

7.1 Analysis of the Competitors

To analyse the competitors is an important part of a market analysis. The main companies on the market for football analysis tools have been described in the section *Company Overview*.

In this section, a SWOT analysis will be performed for each competitor (see section *SWOT Analysis, 2.2.1*, for a theoretical overview of the SWOT analysis). SWOT analysis is a tool for auditing an organization and its environment. SWOT stands for strengths, weaknesses, opportunities, and threats. Many of the companies have similar opportunities and threats, since they are external factors often affecting the entire market. In this analysis the threats and opportunities that are specific for the different companies have been emphasized.

7.1.1 ProZone

Strenghts
ProZone has a system, which provides all kinds of information presented through a thoroughly worked out and user friendly interface. According to Dr. Paul Balsom at the Swedish FA, ProZone provides all the information that a football coach could be interested in.

ProZone has several Premiership clubs as their customers, for example Manchester United, FC Arsenal and Bolton Wanderers. These clubs have all paid a large amount of money in order to get ProZone installed at their arena. Thus, they are not likely to switch to another analysis tool in a near future. ProZone was the first company to market a football analysis tool to the English market. This has given them a pioneer advantage (Porter, 1980) in the UK. Their customers also pay continuously as ProZone charges a fee for each game being analysed.

Weaknesses
To install ProZone at an arena costs about £100 000. After installation each game to be analysed costs a certain amount of money as well. Thus, ProZone is only affordable for big and wealthy clubs, which means that there are not very many clubs that are potential customers for ProZone. This makes ProZone vulnerable to competition and decrease in demand. Since they only have a very limited amount of potential customers they have to be sure to sell their product to a large number of these potential customers.

Another problem for ProZone is that the system is not portable. This means that although a club installs ProZone at their arena, it will only be certain to get its home games analysed. The fact that ProZone is very expensive and not portable does not make ProZone an attractive tool

for national teams, since they usually do not play very many games at the same arena each year.

One of ProZone's strengths is that they provide all kinds of information about a game. This can also be seen as one of their weaknesses, since they sometimes may provide too much information. It takes a lot of time to go through all the information and most clubs that use ProZone have one full-time employee working only with ProZone[13]. Thus the actual cost is even higher than the price charged by ProZone.

ProZone is only established in the UK. Since the number of potential customers is very limited they will probably be forced to expand to other markets in the future. Since their product is expensive they will probably focus on "major" leagues, such as France, Italy, Germany and Spain. Their competitor Sports Universal is already established in France, Italy and Spain and it may thus be difficult for ProZone to expand into those markets.

Opportunities
ProZone could probably develop a less advanced but cheaper tool for analysis of football games. In that way, they could increase the number of potential buyers dramatically. This would also be a way to get into other markets. Then, they would not have to focus on the big leagues, but could also market their products to smaller markets, such as Sweden.
The more customers they get in the same league, the more games they will be able to analyse. This means that the problem of portability will decrease as they get more customers in the same league. When a club, which has ProZone installed at their home arena, plays an away game at an arena where ProZone also is installed, they will also get this game analysed.

Threats
Since ProZone's product is very expensive and the number of potential buyers is limited, ProZone is vulnerable to competition and decrease in demand. For example, a downturn in the football business could be very troublesome for ProZone.

7.1.2 Sports Universal (Amisco)

Sport Universal's system, Amisco, is very similar to ProZone's system. Therefore the SWOT analysis of Sport Universal is similar to the one of ProZone. The analysis of Sports Universal will therefore be concise, and almost everything mentioned in the SWOT analysis of ProZone about their system's features also applies to Sports Universal.

Strenghts
Just like ProZone, Sports Universal has a football analysis system, which provides interesting information through a user friendly and thoroughly worked out interface. Sports Universal and ProZone provide almost the same information in their analysis and their interfaces are very similar to each other.

Sports Universal also has a pioneer advantage on the markets where they are established. Once a club has installed a system at their arena, they are not likely to switch to another system. Sports Universal also has a good chance to build a good reputation in the markets where they are active. Sports Universal has customers in France, Italy and Spain. This is an important strength, since these countries have three of the biggest football leagues in Europe.

[13] Interview with Dr. Paul Balsom, Solna, Sweden 13th of July, 2002.

Weaknesses
The weaknesses of Sports Universal are almost identical to ProZone's weaknesses. The main weaknesses are that the system is expensive, that it is not portable and that it requires a lot of manual work. Just like ProZone, the system provides a lot of information, which may cause information overload.

Opportunities
Sports Universal is already established in three markets, but obviously has the opportunity to expand into other markets to increase their customer range. Sport Universal could probably develop a less advanced but cheaper tool for analysis of football, which would make it easier to expand into other markets and also increase the number of potential buyers.

Threats
Since the number of potential buyers is limited, Sports Universal is vulnerable to competition and a downturn in demand. At present, many Italian clubs are facing big economic problems. Sports Universal is active on the Italian market, so this could pose a threat for the demand on the Italian market.

7.1.3 Sportstec

Strenghts
Sportstec's video analysis tool, SportsCode, is relatively inexpensive, flexible and easy to use. It can be used virtually anywhere and anytime. All that is needed is a video recording of the game to be analysed and an Apple computer. The analysis is made by the user which could be seen as an advantage. In that way, "outsiders" do not have to be involved in the analysis process as the case is with products like ProZone and Amisco.

Sportstec has the entire world as their market and has customers all over the world. Their product is suited for all kinds of football teams; big clubs and national teams as well as lower division clubs use it. Their product is not even limited to football, but can be used in most types of sports. Thus, they have a large market on which they can sell their product.

Weaknesses
SportsCode does not perform an actual analysis. Basically, SportsCode is a video editing program which allows the analyser to notate and store important video sequences. Thus, the actual analysis is entirely left to the analyser, and SportsCode does not give any new information to the user. This could be a weakness as competitors, such as ProZone and Sports Universal, probably could persuade clubs that their products give information that otherwise could not be obtained.

This tool also requires a lot of manual work done by the user himself. Another weakness is that the program only runs on Apple computers. According to Sportstec that is because Apple is superior for working with video, but many buyers probably use PCs.

Opportunities
SportsCode is one of few analysis tools that is affordable also for smaller clubs. The awareness of the importance of technological aid in football analysis is increasing, and is probably reaching lower division clubs more and more. This could make lower division clubs interested in buying SportsCode.

Threats
Tools, such as ProZone and Amisco, could become cheaper, which would pose a big threat against SportsCode. These competitors could also create other versions of their products, which are cheaper, but still perform some kind of analysis, which would give the users an extra benefit in addition to what SportsCode can deliver. It will probably be very difficult for ProZone and Amisco to compete with price against Sportstec, though.

7.1.4 Digital Soccer

Strenghts
According to Digital Soccer's web site they use a scientific approach to analysing football. They have, for example, cooperated with the School of Statistics of Bologna for mathematical elaborations. What this scientific approach actually means is not clear, but the idea is to make the analysis less subjective. It is definitely a strength if they can show that they have a thorough scientific approach to the analysis. They have several famous Italian as well as international clubs as their customers, which is a strength, since it gives them a good reputation.

Weaknesses
The obvious weakness with Digital Soccer's analysis is that it entirely is done manually. Regardless of whether this makes the analysis worse than the analyses of competitors using technological aid or not, this is a weakness. Digital Soccer's competitors using technological aid will probably try to convince potential customers that their analysis is more complete than Digital Soccer's thanks to their technical superiority.

Opportunities
Digital Soccer could perhaps develop a technical aid, such as a tracking system, and then combine their scientific approach to analysing football with modern technology.

Threats
The service that Digital Soccer provides could be seen as rather substitutable. Although Digital Soccer probably claims that they have unique knowledge of analysing football, their customers could get the impression that all Digital Soccer does is notating what happens during a game, which could be done by someone, employed directly by the team.

Digital Soccer's home market is the Italian market. Many Italian clubs are having economic problems right now, which could make the clubs more prone to make the analysis themselves instead of hiring Digital Soccer to do it.

7.1.5 Orad

Strengths
Orad has offices in Israel, the US, the UK, Japan, Hong Kong and Germany and distributors all over the world. They are thus widely spread over the world, which is considered as a strength.

It seems like Orad has competencies within several different areas. For example, they have products working with real-time video processing, pattern recognition algorithms and sensor technologies.

Weaknesses
Orad's system SporTrack uses tags, which are worn by the players. Putting tags on the players has some drawbacks. It might be uncomfortable for the players. Although the tags only weigh 20 grams, it might have a negative psychological effect on the players. Moreover, putting tags on players makes it difficult to analyse opponents.

Orad focuses entirely on media providers as their target group. They have several products that are marketed to TV broadcasters. Since all their products are targeted towards media providers it is natural that also their sports analysis tool is targeted towards media providers. On the market for sports analysis tools this could be a weakness though, since they miss out on many potential customers, that is the football clubs.

Opportunities
Orad's target group today is media providers, both TV broadcasters and web broadcasters. Orad sees a great opportunity in the web casting business, which they believe to be under development. Another opportunity for Orad is to broaden their target group into sports teams as well.

In the US the TV companies exercise a lot of power during sporting events. For example, breaks are taken in sports games to fit in to the TV commercials. There could be a tendency in European sports to go in the same direction, since it is common in European football that a media company owns a football club. Examples of that are Fininvest in Italy, which holds a majority holding in AC Milan, and Canal+ in France, which holds controlling interests in Paris Saint-Germain and Servette Geneva.[14]. This could be an opportunity for Orad, since the TV broadcasters then could make the players wear tags.

Threats
Using sensors is today probably the most accurate way to analyse sports games. It does have drawbacks though as mentioned earlier. If another technique, for example video analysis, could reach the same accuracy as sensor technique, it would probably not be possible to market a product based on sensor technology.

[14] Sir Norman Chester Centre for Football Research: http://www.le.ac.uk/snccfr/

7.1.6 Trakus

Strengths
Trakus' system, Digital Sports Information, uses sensors to capture the movements of athletes. They are now developing systems for American football and football where a combination of sensor technology and video-based processing will be used. It is a strength to be able to deal with these different techniques.

Currently their system is applied to golf, ice hockey and motor sports. They have thus managed to apply their system to several different sports.

Weaknesses
Using sensors to capture the movements of the players has drawbacks as already mentioned. The main drawbacks are that a sensor has to be put on the players and that it is difficult to put this sensor on the opponents.

Another weakness is that they do not have a developed system for analysing football today. They expect it to be finished in late 2002.

Opportunities
Just like Orad, Trakus' main target group is the media providers. The development of the web casting industry is an opportunity for Trakus.

The opportunity mentioned for Orad, that TV companies tend to get more and more power during sports events, also applies to Trakus.

Threats
Just like Orad, Trakus could get problems if another technique would prove to be as accurate as sensor technology in tracking players.

7.1.7 Summary of the Analysis of the Competitors

ProZone and Amisco are two very similar products. Their strengths are that they provide a lot of valuable information in a user friendly way and that they are established in major markets. Their major weaknesses are that the systems are not portable and that they are too expensive.

A cheaper alternative is SportsCode, which basically is a video editing program. This requires a lot of work from the user. The program does not perform an actual analysis but is a way of making the analyst's job easier.

Digital Soccer provides a football analysis service. They have several major football clubs as customers and they claim to analyse football games in a scientific manner. However, they do not use any technical aid in the analysis. They should therefore not be able to provide information which the human eye cannot obtain. An opportunity for this company is to develop some kind of technical aid, for example a tracking solution.

Orad and Trakus are two sports analysis tool providers, which have media providers as their main target group. An opportunity for them is to broaden their market and also market their products towards for example football clubs. These companies should thus be seen as competitors in the market for football analysis tools.

7.2 Who are the Potential Buyers?

To be able to carry out a strategic analysis of a market it is necessary to know which the target group is, that is who the potential buyers are. The company overview (section *Company Overview*) showed that the two major target groups for the companies on this market are big football clubs and/or media providers. As already mentioned, it is common in European football that a media company owns a football club[15]. For the companies providing tools for analysing football this means that they sometimes may deal with customers wanting systems both for coaching purposes for the football club as well as for media broadcasting.

The Swedish FA wants to develop a tool to analyse their own games in the first place. It would also seem natural that they would sell the product to other football associations and teams. One of the aims with the development of this product is to make a cheaper product than the products available today. If the product is cheap enough, the system could also be sold to smaller low-division clubs. For simplicity, the main target group in this strategic analysis is assumed to be football clubs, although the Swedish FA is recommended to also consider media companies as potential buyers.

7.3 Competitive Environment

Michael Porter´s five forces model (Porter, 1980) will be used to perform a strategic analysis of the market (see section *Porter's Five Forces, 2.2.2,* for a theoretical overview of Porter's five forces model). This model can be used to analyse the competitive environment on a market and to evaluate the attractiveness of the market. The model is based on five forces, which decide the competitive situation on the market.

7.3.1 Rivalry Among Existing Firms

ProZone, Sports Universal, DigitalSoccer, SportsCode, Orad and Trakus, which are the main actors on the market for analysis of football games, are presented in the section *Company Overview*. ProZone, Sports Universal, DigitalSoccer and SportsCode have football clubs as their main target group, whereas Orad and Trakus seem to focus on media providers. All of them, except for SportsCode, offer their products to both clubs and media providers, though. ProZone is a big actor on the English market and DigitalSoccer focuses on the Italian market. Sport Universal focuses on the French, Spanish and Italian market while Trakus seems to focus on the American market. Orad and SportsCode do not seem to have a specific geographic "home market" although most of Orad's sales are on the English and the American market.

There are not very many companies on the market for analysis of football games. Furthermore, the actors on the market today are geographically divided and focus on different target groups. Of the four companies mainly focusing on the football market, ProZone and Sports Universal are very expensive and is only an alternative for big, wealthy clubs. SportsCode and DigitalSoccer are not as expensive, but do not provide the same unique information as the more technically advanced competitors, such as ProZone. The competition among the existing companies is rated as low, especially in certain market segments, for example certain geographic markets, such as Sweden, and also for certain types of products. If

[15] Sir Norman Chester Centre for Football Research: http://www.le.ac.uk/snccfr/

a product were developed which is cheaper than ProZone and Sports Universal but still providing some kind of unique information, this would virtually be alone in that niche on the market.

7.3.2 Threat of Substitutes

For a football club, an obvious alternative to buying a system that analyses their games is to do the analysis themselves. This is often done with so called notational analysis. Notational analysis can be used in combination with video analysis, where the notational analysis is used as a mechanism for selective search through a video recording of the game. The notational analysis can be done manually, which sometimes is very accurate and does not require an investment in an analysis tool. The disadvantage is that the time required for data processing can be very long. Today it is more common, though, to use computerized systems for notational analysis (Reilly, 1996, pp. 345). SportsCode is actually an example of such a program. The drawback with notational analysis is that it does not deliver any analysis; it is only what the analyst can see with his own eyes that will be part of the analysis. It is an important challenge for providers of video tracking tools for analysis of football to convince the customers that their tools provide additional benefits in comparison to notational analysis.

To be able to rate whether there is a high threat of substitution it is important to know whether the buyers of the system are big and wealthy clubs or also smaller clubs. For big clubs the threat of substitution is regarded as relatively low. If they are convinced that a video analysing tool will provide valuable information they will most certainly be very interested in obtaining this information. For smaller clubs in lower divisions, the threat of substitution is higher. For them, tactical details may not be regarded as important as for big clubs and hence they may want to spend their limited amount of money on other things than video analysis.

7.3.3 Buyer Power

The amount of power that the buyers have depends on the target group of the product. If the target group mainly is big elite football clubs, as the case is for ProZone, the buyers have a significant amount of power. For an expensive system like ProZone, the number of potential buyers is very limited. Another fact, giving the buyers power, is that there are substitutes available (section *Threat of Substitutes*). Thus, it is not absolutely necessary for a club to purchase a system like this. Thus, the bargaining power of the buyer is high. A way to reduce that is to develop a product that can be sold not only to big elite football clubs, but also to smaller low-division clubs. This would increase the number of potential buyers dramatically, and thus reduce their bargaining power. To make this realistic, the product has to be cheap and not require too much work from the user.

Especially in the introduction phase of the product life cycle, the buyers will have very much bargaining power, since it is very important to get customers as references. Some of the big clubs, for example Manchester United, will probably have an enormous bargaining power, since it is very attractive to have their name on the reference list. It is also probable that once a club has bought a system like this, it will stick to this system for a long period of time. On the English market, ProZone has an advantage since they already have sold their system to some clubs in the Premier League. This is another reason for the Swedish FA to try to develop a product that can be sold to low-division clubs.

7.3.4 Supplier Power

The hardware that is needed to create a system for analysing football games using computer vision technology is basically some cameras and a computer. These products are standard products that are not too expensive. Thus the hardware suppliers' power is very low. The main value of a system like this is not the hardware but the work done to create the software. The people who are hired to develop the system, programmers and software engineers, may possess power, since it definitely requires specialist competence to develop a tool like this. Once the program has been developed this power decreases, and the amount of power cannot be considered as a strong force.

7.3.5 Threat of Entry

Technological knowledge and knowledge of football are required to be able to develop a tool for analysis of football. Additionally it is important to have contacts in the football area. There are a significant number of companies and organisations possessing these characteristics, although they are not on the market for tools for analysing football games today.

Products like SportsCode have already been mentioned (section *Threat of Substitutes)*. It seems like a natural step for the companies behind these products to expand into the market for analysis of football games. LucentVision was presented in the section *Company overview*. Their tracking system for tennis players and tennis balls could probably be applied to football as well. Many of the research programs presented in the section *Sports Related Research with Video Tracking Techniques* could most certainly be commercialised.

There are also many other companies working with sports technology[16]. An example is QuesTech, which is a company working with sports broadcast enhancements like ball tracking in baseball games. Many of these companies use technologies that probably could be used for a tool for analysis of football.

There are definitely many existing companies that could enter this market. But the threat of entry also comes from new businesses entering this market. There are no real barriers of entry, so it would be possible for a new company to enter the market. It is probable that such a company would be the result of a football club or association commercialising a product developed for their own use. The reason for this is that football clubs and associations have great knowledge of football and also contacts in the football area.

In conclusion, the threat of entry is very high, especially from existing companies in related areas but also from new businesses.

7.4 Conclusions of the Strategic Analysis

The analysis of the market environment showed that the buyer power and the threat of entry are the strongest forces on the market for football analysis tools. The supplier power is very low and the competition on the market today is not very high, at least not in most of the market segments. If the Swedish FA develops a cheap product that does not require too much work from the user, the buyer power could be reduced, since the number of potential buyers then would be much larger than for an expensive system. This would also decrease the

[16] Some of them are listed on the Sports Technology Hotlist: http://www-white.media.mit.edu/~intille/st/st-csts.html

vulnerability towards new entrants. The downside of this is that the threat of substitutes may increase as the customers include smaller clubs. But if the Swedish FA is able to communicate the benefits of a video tracking system compared to the substitutes, this threat would be minimized.

The strategic analysis of the competitors showed that the two major competitors, ProZone and Amisco both have some major weaknesses. They are too expensive and they are not portable. A system, which does not have those weaknesses, is SportsCode. SportsCode's weakness, however, is that it does not provide an actual analysis of the game. It is only an aid for the analyst's job.

The combined outcome of the Porter analysis and the SWOT analysis of the competitors suggests that if the Swedish FA could develop a cheap and portable tool for analysis of football games they would be in a very good strategic position for commercialising this product. They would virtually be alone in that niche on the market. That would obviously not last forever, but it is a great advantage to be first out on this market. Once a club has bought a system like this, it is not likely that they will switch to another system.

8 Conclusions

There is no football analysis tool on the market today, which fully meets the requirements of the Swedish Football Association regarding price, degree of manual work, portability and usefulness of provided information. The Swedish Football Association thus has a need for developing a football analysis tool.

This study shows that it is technically feasible to develop a football analysis tool, which is cheaper than products available today. This tool could provide most of the requested information and be portable as well. It does not seem feasible, though, to develop a fully automatic football analysis tool. The system has to be semi automatic, requiring manual work to a certain degree.

The best way to perform a video-tracking analysis of a whole football match seems to be to use multiple stationary cameras and let each camera cover one particular part of the pitch. An approach, giving acceptable resolution, is having three or four cameras placed along the long side of the pitch. Four normal cameras or three cameras with wide angle lenses is the minimum number of cameras required to cover the entire pitch.

There are several algorithms, which could be used for player tracking. Previous research shows that template matching and RGB Colour tracking are well working algorithms and that that a combination of algorithms is needed to make the performance of a tracking system efficient. It also shows that a filter, for example the Kalman filter can be used as a predictive step in order to improve accuracy. Within the framework of this report a tracking algorithm, Statistical Background Model, has been tested. The conclusion was that it was relatively simple to automate tracking of isolated players. When players occlude each other problems occur, though, and the algorithm would have to be combined with other algorithms, for example RGB colour tracking, to be able to solve ambiguities occurring during and after occlusions.

If the Swedish Football Association could develop a cheap and powerful tool for analysis of football games they would be in a very good strategic position for commercialising this product. They would virtually be alone in that niche on the market. Football clubs and media providers are potential buyers.

9 Discussion

This chapter has the purpose to discuss things that have affected the project and the report in one way or another, and to speculate on the effects that this report would have on future developments.

Part of this project was carried out during the summer of 2002, a timing that led to a few problems. It was sometimes difficult to contact or meet people because of vacations. In the beginning of the summer the World Cup also made it harder to contact important people at the Swedish FA.

A few attempts were made to perform tracking analysis with freeware products, but no real progress was made. Interviews with people at institutions and organisations made it clear that this was the most difficult part of the system. The collaboration with researchers helped a lot to overcome this problem. Their general comments and thoughts gave valuable information to the project, which would have been hard to get otherwise.

The close collaboration with the Swedish FA has definitely affected this report in a good way. The expert information that they possess in the area of analysis of football would have been very hard to get hold of otherwise. It could have been good, though, to get information on this topic from other sources as well, since relying on only one source makes it a bit subjective. There are not too many people available though, who possess expert information in the area of football analysis. My contact person on the Swedish FA, Dr. Paul Balsom, is very experienced and works both with the Swedish national team and a Premiership club in England. His knowledge and opinions are therefore very valuable to have in a project like this.

It should be stated that the experiment conducted was dependent on the stadium where the game was played. The experiment required a fairly big stadium with high stands, to get the required camera angles in order to perform the tracking process. The conclusions were on the other hand drawn in a general perspective for any type of stadium. It would have been good to record several different games to get an understanding of what difficulties might arise during a recording of a game. A difficulty could for example be that one of the teams wears green jerseys. The segmentation algorithm used in the experiment would then probably not work very well. The lack of time and equipment was the reason that only one game was recorded in the experiment conducted in this project. It would also have been interesting to test more algorithms on the recorded material. To combine several tracking algorithms would be interesting for future research and development in this area.

The primary aim of this report was to fulfill the requirements of the specification for this project. It should be stated though that the report only should serve as the starting point for further development that is required to produce a video analysis product. One aspect of the product, which has not been covered in depth in this report, is for example different possible solutions regarding the interface design. Instead the study has been concentrated on articulating the key requirements for subsequent design solutions. If the Swedish FA wants to commercialise their product a more thorough market analysis is also required.

This report has focused on meeting the demand of football match analysts and football coaches, but the interest in football analysis tools is far beyond the scope of those professions. Observations from the research projects examined indicate that this kind of tool also could be used in other sports than football. Team sports in general seem to have a great demand for analysis tools. A lot of commercial interest seems to come from television and web casting companies. They see their chance to give spectators information about athletic performance that they normally cannot give.

Different sources from organisations and match analysts state that the amount of effective information, that could be collected from a match and used in tactical and fitness purposes, is enormous. They also state that the products available today only deliver a fraction of the potential that the data could give.

Apart from the technical aspect lays the difficulty in controlling the information overload to make it useful for analysis. Knowledge and experience of what coaches and analysts actually need, seem to be the key factors to successfully develop a football analysing tool.

The Swedish FA possesses this knowledge and experience in their organisation and therefore could get a huge benefit of a video analysing tool as described in the report, not only for their own use, but also in a commercial perspective. Interesting clients would be major Swedish football clubs, European clubs and national teams.

An issue that the Swedish FA has to be aware of is that if they chose to commercialise this product a big effort on marketing and software updates will be required. This is probably something that the Swedish FA as an organisation is not very well suited for doing. Also, the development of a product requires a lot of technical knowledge which the Swedish FA does not posses at the moment. Probably the best solution for the Swedish FA would be to co-operate with a company with knowledge within programming and computer vision. It would have to be a close collaboration where the Swedish FA combines their knowledge of football analysis with the technical knowledge within the company. The company would be responsible for development, updates and marketing. In this way, the Swedish FA would get an analysis tool and probably they could negotiate to get a fair amount of the profit of the product.

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