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Digital Playbook - A Teaching Tool for American Football

Mario Vorstandlechner; Institute of Software Technology and Interactive Systems; Vienna University of Technology; Austria
Margrit Gelautz; Institute of Software Technology and Interactive Systems; Vienna University of Technology; Austria
Christoph Putz; AFC Vienna Vikings; Austria

Abstract

A playbook in American Football can consist of hundreds of plays, and to learn each play and the corresponding assignments and responsibilities is a big challenge for the players. In this paper we propose a teaching tool for coaches in American Football based on computer vision and visualization techniques which eases the learning process and helps the players gain deeper knowledge of the underlying concepts. Coaches can create, manipulate and animate plays with adjustable parameters which affect the player actions in the animation. The general player behaviors and interactions between players are modeled based on expert knowledge. The final goal of the framework is to compare the theoretical concepts with their practical implementation in training and game, by using computer vision algorithms which extract spatio-temporal motion patterns from corresponding real video material. First results indicate that the software can be used effectively by coaches and the players' understanding of critical moments of the play can be increased with the animation system.

Introduction

In recent years, computer vision and visualization techniques have gained increasing interest in the analysis and presentation of sports events. In the context of team sports, research has often focused on the automated detection and tracking of players on the field, with the goal to provide statistical analysis or enhance the viewing experience, for example, by adding computer graphic elements that highlight critical aspects of the game ([12], [16]). On the other hand, teaching tools which convey the strategic concepts of a specific sport can largely benefit from visual analytics, which facilitates the communication between trainers and athletes. In our work we focus on the development of a digital playbook for American Football, with the goal to support the coaches in their task of teaching complex tactical concepts to the players and evaluating the implementation and effectiveness of the theoretical concepts in real play scenarios.

While strategic concepts play an important role in most team sports, playbooks in American Football constitute particularly rich collections of complex play scenarios that require significant effort to learn. A sample sketch from a playbook can be seen in figure 1. It shows a simple offense formation, in which players are represented by specified symbols. The square and the circles in the central part of the picture represent the players of the offensive line and the quarterback behind them. The two circles further to the left and right denote the x- and z-receivers, whose task it is to catch the ball. The routes which they should run once the ball has been snapped are indicated by solid lines. A dotted line denotes an alternative route, a so-called 'option route'. The receiver decides which way to run depending on what the defenders are doing. Generally, the correlation of time and space is very important for football players to gain deeper knowledge of the strategies and awareness of what to look for on the opponent side of the field. As a consequence, static drawings can only insufficiently communicate the different stages and options of an unfolding play.

In this paper, we propose a concept for a digital playbook as a teaching tool for American Football and demonstrate parts of its implementation. Commercially available teaching tools (e.g., [4], [14]) typically provide either only static playbooks, or very simple animations, which do not sufficiently reflect the highly dynamic interactions between players on the field. We seek to overcome this limitation by incorporating animation tools and comparison with corresponding real play recordings using computer vision analysis, in order to enhance the players' understanding of the tactical concepts and associated responsibilities on the field.

The overall structure of the proposed framework is depicted in figure 2. The input consists of the play design provided by experts and related video material recorded during a training or game. Relevant information from the input and processed video material (e.g., computed trajectories) is stored in databases for further usage. The key component of the system is the play animation based on the input expert knowledge, which constitutes the main contribution of this paper. Furthermore, the framework includes computer vision techniques for extracting line marks and players' trajectories on the field, with the ultimate goal to provide instructive visual comparisons between the animated concepts and real player behavior in training and competition.

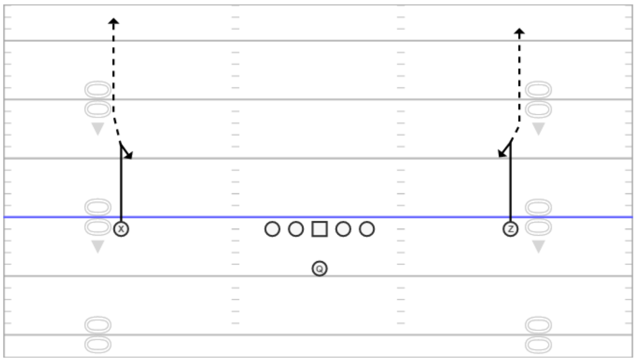


Figure 1. Simple offense route concept, created with the coaching software hudl [5].

After reviewing related work in Section 2, we focus on the play animation module in Section 3. We demonstrate how expert knowledge about offense/defense strategies along with the players' suggested or anticipated reactions on the field are visualized by our system. We show some first results of the video analysis algorithms for field line detection in Section 4. The benefits of the proposed system are evaluated by experts from the Vienna Vikings, the largest association of American Football in Austria, and discussed in Section 5. The conclusions and an outlook on planned future work are presented in Section 6.

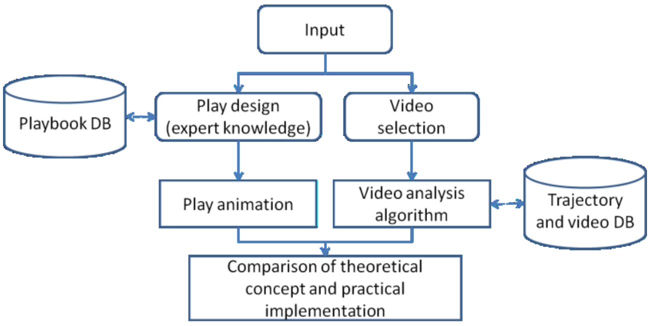


Figure 2. Framework of the digital playbook.

Related work

Recent developments in technology have lead to new possibilities regarding the broadcasting of sports events, such as analyzing game footage of American Football games. In this section we will take a look at systems which use low-level features of broadcasting material to extract semantic information, like finding highlights in sportscasts or classifying plays, and sport simulation applications are discussed which allow the simulation of American Football plays.

Li and Sezan [9] state that the amount of audio-visual information is increasing rapidly and therefore automatic video summarization will be beneficial for many different tasks. In [3],[11] and [13] the authors propose systems to compress broadcasting data. They therefore use low-level features like the field color, often referred as the dominant color, line marks and other parameters to extract high-level semantic information. Liu et. al. [11] use the boosting chain [18], a learning system for object recognition, to select beginning and end of a play. The field color is manually labeled before the shots of a game are analyzed, and although this leads to promising results, we seek for an automatic approach for finding the field color in our application. In [3] the authors propose a generative model using hidden Markov-Models for finding the meaning of video shots such as "play" or "break". Ravitz et. al. [13] propose a multimodal approach to find potential highlights in broadcasting data. They therefore monitor the energy level of the audio stream and the dominant intensity of the video stream. Both outcomes are then combined to reduce the false alarm rate. For the visual part they don't use the whole images to reduce sideline noise, a fact that we adapted in our system.

Generally the field color and line marks are widely used for video analyzing purposes, for example at tracking the players on the field for tactical analysis. Beetz et. al. [1] point out that through camera based observation, tactical analysis of players and strategies become available for viewers and coaches and can be used for finding the strengths and weaknesses of players, formations, or discover certain behaviors and skills of players. This can be a challenging task because of rapid movement changes in team sports, as the authors of [10] and [19] mention.

In [17], Xia et. al. describe simple segmentation algorithm which uses gray scale images and their intensity values to find interesting regions on the field. Then the marked pixels get grouped together, holes get filled out, and through contour finding the interesting objects are then spotted in binary images. Li and Chellappa [8] build a probabilistic, generative model for extracting high-level semantic information out of American Football videos through tracking offensive players and assigning their movements to strategies. A so-called "co-occurrence" function is describing the position and the path of a player through distinct parameter values. A database is filled with expert knowledge of player trajectories and data of various strategies. The system can simulate co-occurrence functions for any concept in the database, and the probabilistic model finds the most likely strategy of a play. In [10], Liu et. al. use well known characteristics of a certain type of sport to ease the process of player recognition, e.g. for better occlusion handling. In many team sports the player movements are depending from each other and therefore strongly correlating, as they state with the example of basketball where defenders are covering attacking players. With game-context features like one player chasing another, a conditional model is built to increase the accuracy of noisy detections. Tani et al. [15] developed a similar system for categorizing plays. The classification happens through computing the minimal distance between player movements in the video and the ground truth trajectories of pre-defined plays. The difference here is that they also show a visualization of the corresponding system which clusters the plays after various aspects and allows coaches to analyses games.

In contrast to video analyzing systems, the simulation of football plays is not as prevalent. The player interactions in such are heavily based on expert knowledge because American Football is such complex sport with many dependencies between almost every player on the field. Also, the modeling of the player movements has to be taken into account. All systems have in common that extensive expert knowledge is necessary to correctly simulate the players behaviors. Deutsch and Bradburn [2] present a simulation of rushing plays in American Football through a Monte Carlo model which allows to generate plays of various strategies. With a heuristic approach each player and his strategy is modeled based on his current velocity, the player positions on the field, and the knowledge of failures and successes of previous actions. The blocking- and tackling-processes are also simulated. In [7], Laviers and Sukthankar introduce a multi-agent learning algorithm which improves the process of planning team scenarios. They use the output of the Rush2008 simulator [6], where plays are simulated based on various user choices before the play, and the best strategies can be saved in a playbook. The authors model player behavior on 3 levels: spatial, temporal and coordination, and the system is used to simulate defense reactions on certain offense rushing plays. In contrast, existing commercial software products like "playbookdesigner" [4] and "tactics3d" [14] allow the creation of digital plays and a simple animation, and although this creates a first look at the correlation of space and time for certain plays, the problem is that without any player behavior modeled it's hard to simulate game situation. Because our system is used to teach strength and weaknesses of concepts and for simulating very specific game situations, the player behavior modeling must not be as extensive as in [2] and [6]. Furthermore, the tackling- and blocking-processes are also not modeled in our approach.

The use of low-level feature like the dominant field color and line marks, as proposed in [11], is adapted in our system to detect the playing field, and the line marks are used to track the player positions. In [10] the use of sport characteristics like defenders chasing an opponent can help to improve the quality of the player tracking, which will be applied in the tracking process of our system (which is currently a work in progress). We also adopt the simulation of evader and pursuer as in [2] to model the process of defenders pursuing their opponents. The player movement modeling is based on expert knowledge from football coaches to ensure a realistic behavior of players.

Play animation

Play design and manipulation

To create, manipulate and animate plays, an object oriented framework was built with Java and Hibernate to ensure that the distinct parts of a play, such as players and routes, can be easily manipulated and saved. The user can add and delete players, select their routes and responsibilities and also select parameter values which define their actions in the animation part. In figure 3 a complete play with offense and defense formations is shown.

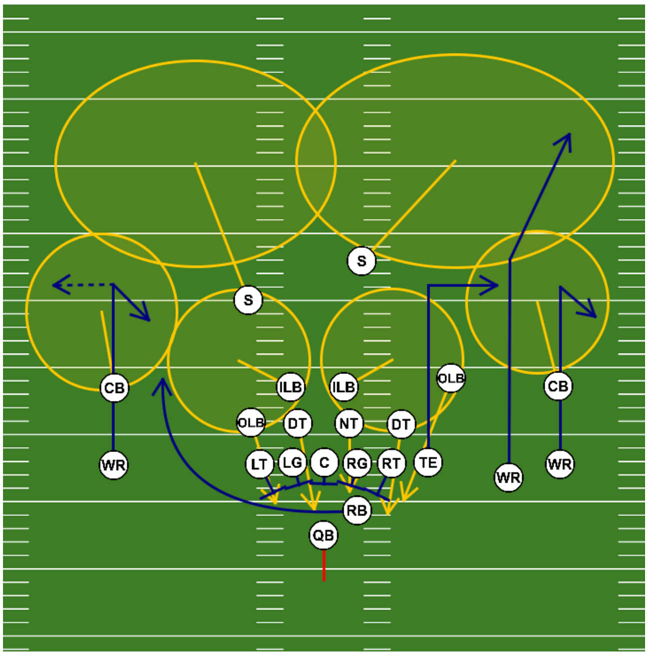


Figure 3. Visualization of offense and defense formations in the digital playbook. Players are marked as white circles, letters indicate the player position. Blue arrows represent offense routes, yellow arrows and lines represent defensive assignments.

The blue lines mark the paths run by offensive players, the yellow marks show the various responsibilities of the defensive players. The yellow circles indicate zones which have to be covered by the respective defensive player, the yellow arrows represent players which rush the quarterback. The letters inside the white circles stand for the common position names in American Football.

When a user is creating or manipulating an offense formation, he can choose between a running or a passing play. Depending on the selection, either the quarterback's path or the path of the ball carrier, which can be selected by the user, are marked by a red line as shown in figure 3. The choice also changes the behavior of the players on the field. If a running play is chosen, the offense players will block for the ball carrier, and also the behavior of the defensive players will change. In a passing play, the defense will stay with their coverage assignments, but in a running play the players will chase the ball carrier after the quarterback hands the ball off. These behavior changes are further described in the following section.

Player behavior modeling

As the authors of [7] state, the modeling of a multiagent system, particularly team sports with complex strategies, can be very challenging. The mentioned system is simulating a play from the beginning to the end, including the blocking/tackling process based on physical principles. For our purpose such deep simulations are not necessary. Because coaches use the software for simulating specific situations and teaching general strategic strengths and weaknesses, the modeling of tackling and blocking is not required. On pass plays, the receivers will run their routes and the defenders will cover the offense as defined, but the actual pass will not be simulated because an animation to this point is enough to show the players where the strengths and weaknesses of a certain concept lie. Therefore only certain aspects of the players' behaviors are modeled based on expert knowledge:

- Offense players will block the nearest defender approaching their position. The progress of the actual blocking/tackling is not simulated, so in the simulation the blocking is always successful if a player reaches his assigned opponent. In that way the animation can be used to teach defensive concepts like stunts where two defenders are crossing their routes to mislead blockers.

- Defensive players in man coverage follow their respective coverage assignments across the field. In zone coverage their movements are depending on the actions of the offensive players, and what assignments their teammates have. When the defense is facing a run play, the defenders will leave their coverage and chase towards the ball carrier after the ball is handed off.

- For the process of a player chasing an opponent, we use the same metrics as the authors of [7]where both players, the evader and the pursuer, are running towards a certain point. This point represents the shortest path for the opponent's running lane.

In addition the software allows the user to select various parameters to further adjust the players' actions in the animation process. These settings can be seen in figure 4. With the *Position* parameter the player position of the current formation, like wide receiver (WR) or running back (RB), can be chosen. With the *Role* parameter the user can select the player behavior. On the offense, a player can run a chosen route, or he can block defenders for the ball carrier in running plays. On the defense, players can rush the quarterback, or move in man or zone coverage. *Set Route* enables the user to assign a pre-defined route for the selected player. The route tree consists of the common routes in American Football. The parameter *Speed* defines how fast a player is moving in the animation in order to simulate how faster players will affect certain concepts. Finally, with adjusting the *Aggressive* parameter the user modifies the general behavior of defenders. It can be used to illustrate what happens when a player is overreacting and how this can affect the whole play, like shown in figure 5. For example, if a defender is in zone coverage, he will try to cover the offensive player who approaches his defined zone. Such a zone can be seen in figure 6 a), marked by the yellow ellipses.

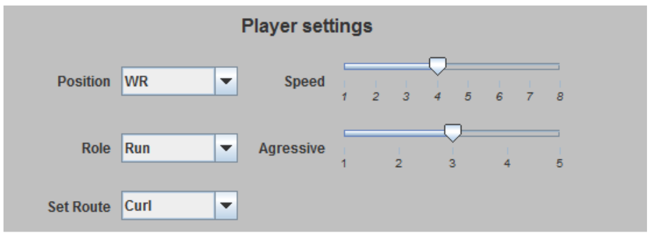
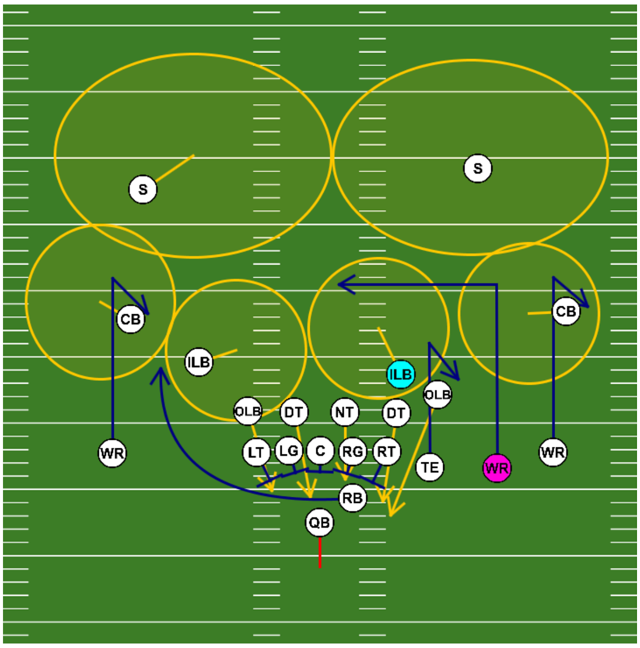
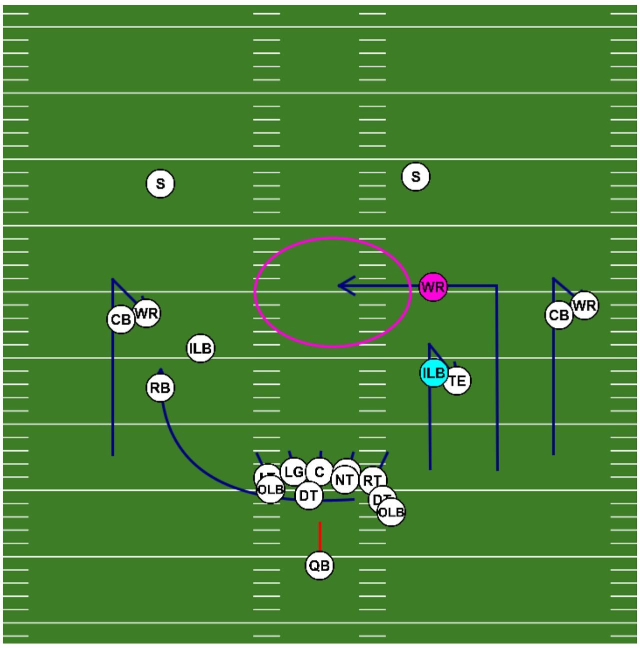


Figure 4. Player settings area in the digital playbook, can be used to change behavior of players in the animation.



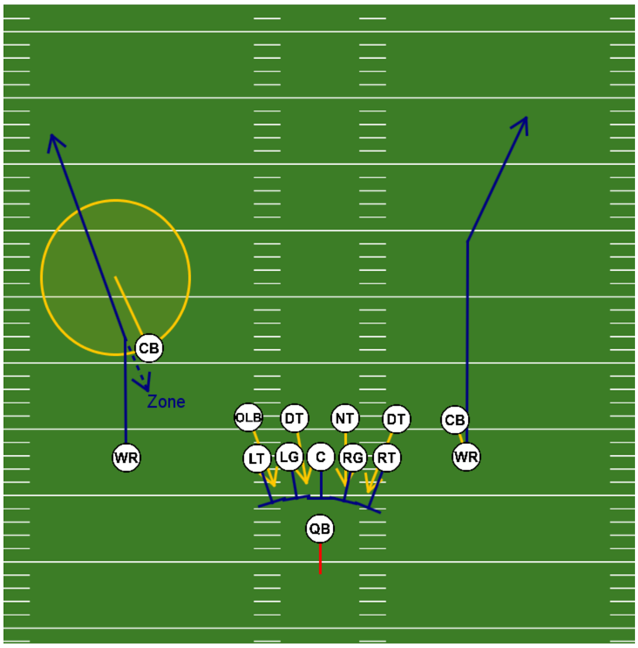
a) Offense and defense play concepts, including drawn coverage of the defense, before start of animation.



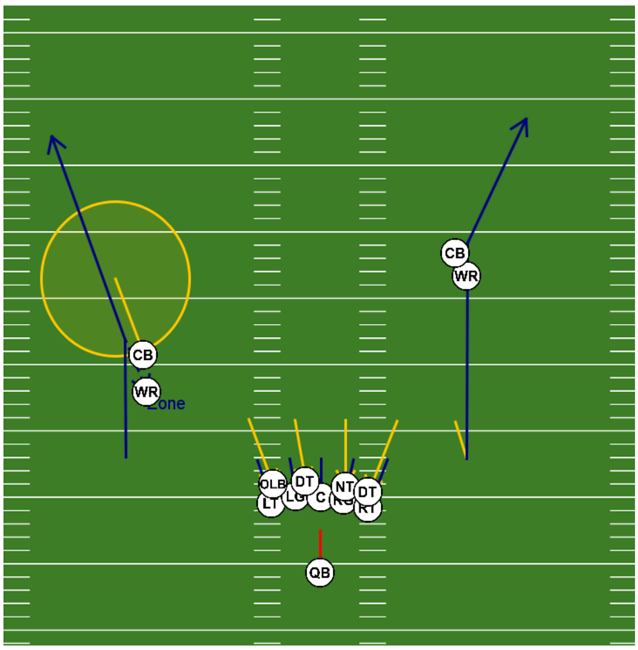
b) Simulated player positions at a later time in animation (without coverage drawings for better representation).

Figure 5. Example of how the parameter 'Aggressive' can affect a play. The player which overreacts is marked cyan, the player which will benefit from this is marked pink.

If the defender narrows the gap to the attacker too early and too aggressively, holes in the defense will open up which then can be exploited by the offense, as shown in figure 5. In subfigure a), the defense inclusive their coverage assignments is shown. The marked player's (ILB) parameter for aggressiveness is maximized, therefore he will be over pursuing the first opponent approaching his coverage zone, which will be the opposing tight end (TE). That action results in a big hole in the middle of the field, which is marked in subfigure b). This allows offense an easy completion if the quarterback recognizes the mistake. With such simulations coaches can show their players what happens when they are acting too cautious or too aggressive, and also how one can align before the play to compensate for such possible mistakes.



a) Simple offense and defense play concepts before start of animation



b) Simulated player positions at a later time in animation

Figure 6. Example play animation, offense players routes are marked by blue lines, defense players responsibilities are marked by yellow lines.

Play animation

When all player settings are adjusted, the play can be animated. After the animation has started, the user has the possibility to pause and resume it at any given point. When the animation is paused, a slider can be used to select every point in time of the simulation and manually go back and forth in the animation to show critical moments of a concept more detailed. In figure 6 a) a simple example shows the progress of the animation through different states. Various player behaviors can be recognized in the images:

- The wide receiver (WR) on the left side runs an option route and will turn around at the return to the quarterback in figure 6 b), because the opposing cornerback is in zone coverage, as indicated by the yellow circle.

- On the other side, the cornerback is in man coverage and therefore will strictly cover his opponent wide receiver.

- The offensive players in front of the quarterback are defending him from the four defenders assigned with yellow arrows which indicate that they are rushing the quarterback. In figure 6 b) the missing simulation of the blocking process is visible by the defending rushers stopping at the assigned blocking points of their opponents.

Video analysis

The overall goal of the video analysis module is to track players on the field, in order to deliver input for a final comparison between the theoretical routes suggested by the animated playbook and the actual routes taken by the players on the field (see figure 2). In the following, we describe the algorithms for field color modeling and line mark detection which we have implemented as initial steps towards the realization of the subsequent tracking task.

Field color model

In the first step, the football field is extracted based on the dominant field color. We employ a binned histogram approach to account for varying field color and changes in illumination. Some border regions of the image are initially excluded to suppress undesired effects on the color distribution from the surrounding. The HSV (Hue, Saturation, Value) color space is used for the assignment of pixels to histogram bins. The bin combination of values (from the three channels H, S, and V) with the most entries indicates the dominant color in the frames, which we use as our field color model. All pixels that correspond to this model, within a certain tolerance range, are selected as belonging to the playing field, like shown in the top right image of figure 7. Before using the result of this step for the line mark detection, the holes in the field area are field, and spatially not connected areas are removed.

Line mark detection

The line marks on the field are detected by applying a Hough transform. This is a common way to find lines in images because collinear points transformed into the Hough space are resulting in intersecting curves. At the beginning, a Canny edge detector extracts the edges in the previously computed field color image which is shown in the top right image in figure 7. By applying the edge detector on the extracted field area, falsely detected lines outside the football field are reduced. Then the Hough transform is performed. As stated before, by finding curves with intersections in the Hough space we also find the coordinates of the lines in the original image. Through using the assumption that all white lines are uniformly distributed, missing line parts occluded by players or other objects can be interpolated.

Afterwards, further assumptions - for example, about the intersections of the field borders with other line marks - are used to remove false alarms and only keep lines which actually lie on the playing field. The result is shown in the bottom left image of figure 7, where the black lines represent the line marks.

In the post-processing step, these marks are used to find the contours of the football field through eliminating the areas outside of the surrounding lines. An example of a field segmentation using this approach is shown in figure 7 in the bottom right image. The lines crossing the field, indicating the distance to the nearest end zone, are tracked throughout the video sequence and will be used for defining the player positions from the start to the end of a play. With this approach the algorithm gets more robust to camera movements.

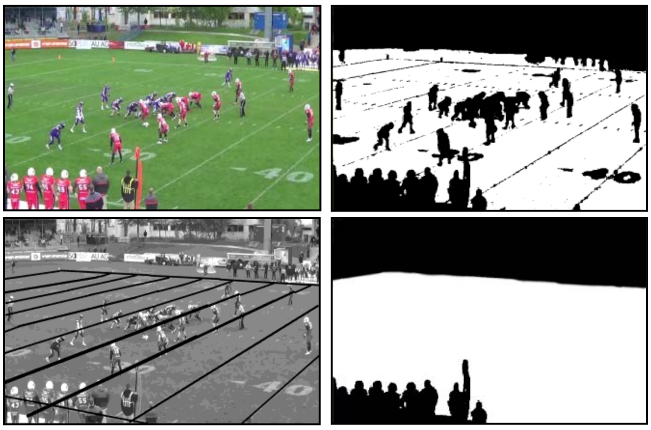


Figure 7: Comparison of the original video frame (top left), field extracted by dominant color (top right), line marks detected by Hough Transform (bottom left), extracted field area after post-processing (bottom right).

Evaluation

We have started evaluating the animation part of our system by getting feedback on the functionality and usage of its current implementation from experts on American Football. A current version of the system is shown in figure 8. Several interviews with professionals from the Vienna Vikings team during the design process and after software implementation confirmed the usefulness of the proposed approach. In particular, the following major advantages of our framework were identified by the coaches as significant improvements for the training process.

- The animated play book can close the current gap between static drawings and actual training on the field, The translation from static sketches into dynamic spatio-temporal actions of the players on the field requires a complex learning process, which can largely benefit from the intermediate step of animation. Through the player behavior modeling based on expert knowledge, these animations become more realistic.

- The interactive usage of our animation tool allows convenient manipulation and variation of different play strategies. The advantages and drawbacks of specific positions or behaviors in particular game situations can be easily simulated by choosing suitable parameter settings, and thus conveyed to the players in an instructive way.

- The system enables an efficient comparison of the effects of different defense concepts in reaction to a chosen offense strategy (and vice versa), which can raise the players' awareness for the strengths and weaknesses of a given play strategy.

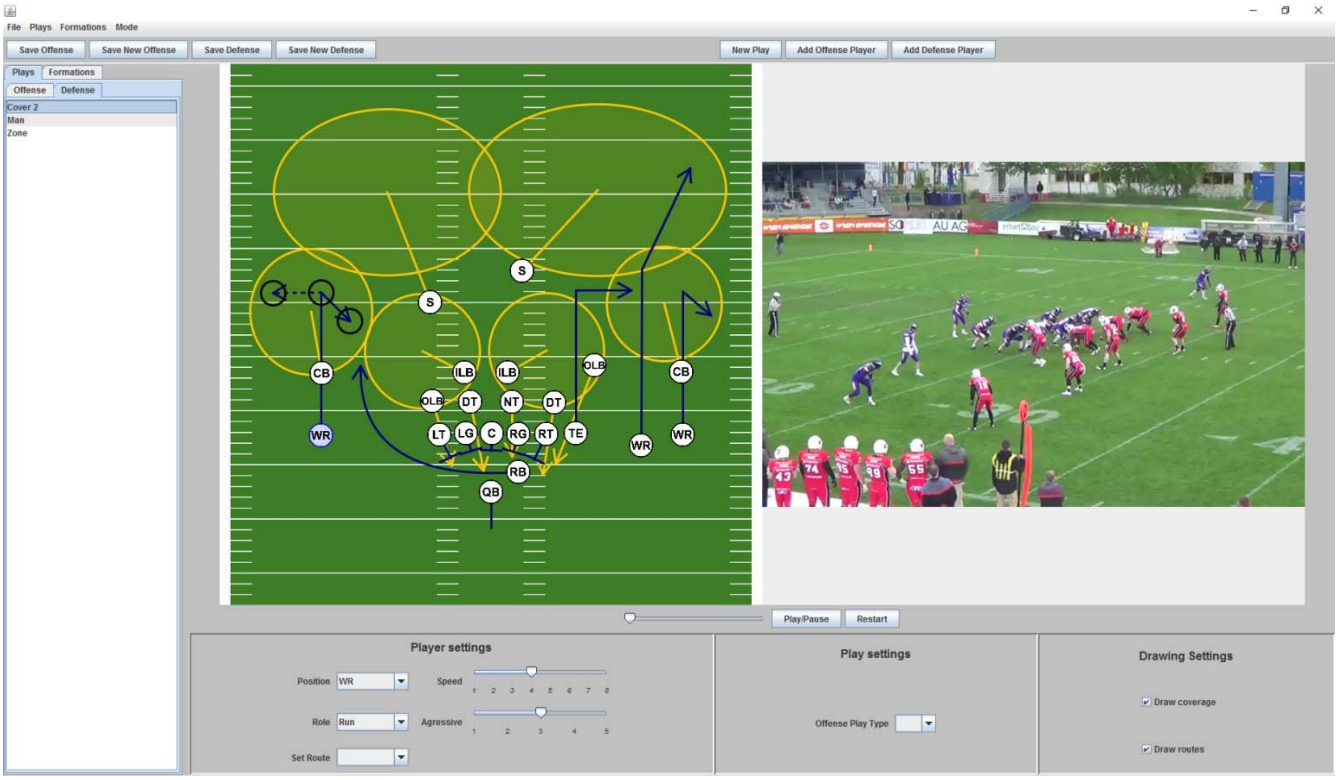


Figure 8: Digital playbook application user interface. On the left side is the animation part, on the right side the selected video sequence is shown.

- The planned direct comparison between animated concept and real play, with associated theoretical and real player trajectories, should improve the overall understanding of the play. In particular, the joint visualization is expected to help the players establish better connections between the learned theoretical concepts and their practical implementation and experience on the field.

Regarding the video analysis module, first tests have shown that the implemented algorithms deliver promising results. Experiments with a larger variety of test images and comparison with the corresponding animated trajectories will be carried out after development of the player tracking algorithms at a later stage of the project.

Summary and future work

We have proposed a teaching tool for American Football that allows coaches to create a digital playbook in which different offense/defense strategies and interactions between players can be modeled based on expert knowledge. The theoretical concepts described in the playbook are conveyed to the players in an instructive way using animation techniques that visualize different player behaviors on the field. In addition to the animation module, we suggest the incorporation of video analysis techniques for field mark detection and player tracking, and demonstrate the first steps towards their implementation. The next steps of our work will focus on the development of a player tracking algorithm and the subsequent projection of the extracted trajectories into the geometry of the animation. Simultaneous visualization of the simulated paths and the routes actually run by the players on the field will enable a direct comparison of real game footage with the underlying theory of a play. As an option, we also consider the incorporation of a second camera that captures the playing field from a different viewing angle, in order to increase the robustness of the tracking algorithm in the presence of high scene dynamics and large occlusions between players. While our study focuses on American Football, the principal concepts may also be transferred to other team sports that rely heavily on tactical expertise.

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Author Biography

Mario Vorstandlechner received his BSc from Vienna University of Technology in 2014. He is currently working on his Master Thesis at the same university. His research interests include computer vision, image processing and visualization techniques, with a current focus on object tracking and image segmentation in sports applications.

Margrit Gelautz is an associate professor at Vienna University of Technology (TU Wien), Austria. She received her PhD in Telematics from Graz University of Technology in 1997. Her research focuses on 3D vision, stereo processing, motion analysis and image matting, with special interest in 3D film and sports applications.

Christoph Putz is an American Football coach at the AFC Vienna Vikings. He is with the team since 2004 and is currently the Defensive Assistant and Defensive Backs Coach.