Recognising Group-Tactical Manoeuvres from Player Positions

Bachelor Thesis

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Abstract

This thesis presents a novel methodology for recognising group-tactical manoeuvres in soccer by analysing player positions using advanced computational techniques. Leveraging tracking data from Bundesliga matches, the study focuses on detecting key tactical behaviours such as dropping midfielders, inverted players, and over- and underlap manoeuvres. Team formations are represented as shape graphs in a goal-aligned coordinate system with player positions derived from the shape graphs. The thesis introduces rule-based algorithms to classify player movements and detect specific tactical patterns, offering insights into how these manoeuvres influence game dynamics. The effectiveness of the proposed methods is showcased through a discussion of the detected manoeuvre instances, and overlap runs are compared against established approaches.

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Chapter 1

Introduction

Association football (soccer) is one of the most beloved sports of all time, with the 2024 European Championship (UEFA EURO 2024) fan zones attracting a total of 5.8 million visitors, and the championship exceeding a cumulative TV audience of five billion [1].

With each team's ultimate goal being to win in their respective league, analysing matches and the play behaviour of their opponents and their own players has become essential for teams. Tactical analysis has become critical for gaining insights into a team's strategies and improving decision-making. Commonly, this analysis has been performed manually by experts who identify and categorise tactical manoeuvres from video footage. However, this process is time-consuming and can be subject to an analyst's opinion.

Recent work in detecting tactical manoeuvres in soccer and other invasion sports has focused on machine learning approaches [2, 3, 4], which require extensive, labelled datasets. Due to the inherent complexity of neural networks, the reasoning behind a detected manoeuvre might not be straightforward.

This thesis proposes a rules-based approach to detecting tactical manoeuvres, explicitly focusing on patterns such as overlapping runs and defensive formations. Our method leverages domain-specific knowledge to define rules that capture key tactical behaviours, offering a balance between automation and interpretability. Focusing on well-defined tactical patterns, our approach aims to provide actionable insights to support real-time decision-making for coaches and analysts.

Through validation on real game data, we demonstrate the effectiveness in identifying key tactical manoeuvres. This work contributes to the broader field of soccer analytics by presenting a practical and adaptable methodology, helping clubs enhance their tactical preparations and overall performance.

Chapter 2

Background

This thesis uses a goal-aligned coordinate system [5] to represent the spatial position of soccer players on the pitch, detect game phases (3.2.1) and distinguish manoeuvres (4.3). The detection methods presented in the thesis build upon *shape graphs* and position labels[6]. This chapter aims to explain these concepts (2.2 and 2.3) as well as a short explanation of the underlying data (2.1).

2.1 Data

For this thesis, data from three German Bundesliga games was used. The data was gathered by Sportec Solutions AG[1] and provided by a Bundesliga club under a confidentiality agreement for research purposes. Due to this, any examples and results discussed in this thesis will not contain IDs, names, shirt numbers, or event dates. Sportec Solutions AG has gathered the tracking, event and play direction data. Based on this, the shape graph and position label data were prepared by H. Sotudeh.

Tracking Data The tracking data has been sampled at 25 fps (frames per second). Each frame tracks the momentary position of every player and the ball. A player's position is his x and y coordinate on the pitch. The ball's position also tracks its z coordinate, representing the elevation from the pitch if the ball leaves the ground. The pitch is represented as a coordinate system whose origin is located at the centre mark. Figure 2.1 shows an example frame from one of the games.

Event Data The event data is a collection of on-ball actions during the games. An event consists of its time stamp and the involved players. Any

[1] https://www.sportec-solutions.de

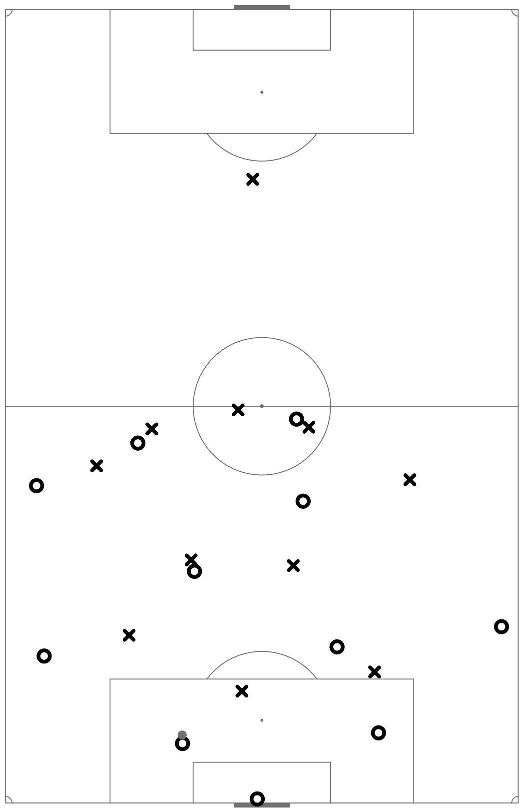


Figure 2.1: Example frame of the tracking data. The home team is shown as circles, and the guest team is shown as crosses. The ball is shown in grey.

of the provided events involves at most two players. The event data is used to compute the player possessing the ball, which is relevant for detecting overlap and underlaps.

Play Direction The play direction data stores which team plays on which pitch half during the games' half times.

Shape Graphs Based on the tracking data, information about each team's shape graphs (2.3) has been created. It has a resolution of 25 fps, and phases where the game was interrupted have been removed. The shape graph data stores the edges of a team's shape graph and, for each frame, a list of the players that are on the outer face of the graph[2].

[2]For any planar graph, a *face* is a region bounded by a set of edges. This definition includes the region outside the graph, the *outer face* [7]. In this context, a player is on the outer face if they are part of the cycle bounding the team, creating the outer face simultaneously.

Position Labels Complementary to the shape graphs, position labels (2.3) for every player have been created. The position data stores vertical and horizontal levels for every player except the goalkeepers. It has a resolution of 25 fps, and phases where the game was interrupted have been removed.

Team Ball Possession The team ball possession data stores which team is in ball possession during phases of the game. A ball possession phase is denoted by a start and an end frame and the team with the ball. However not the exact player.

2.2 Goal Aligned Coordinate System for Invasion Games

A goal-aligned coordinate system for invasion games [5] is a coordinate system that has two origins $\underline{G}$ and $\overline{G}$ aligned to each of the two goals (Figure 2.2a). Further, it defines the following conventions:

1. The pitch is oriented vertically with the two goals at the bottom and top.
2. A team-specific perspective with an upward direction of play.
3. All coordinates are specified in standard units of measurement for length.

A point in the goal-aligned coordinate system is expressed as

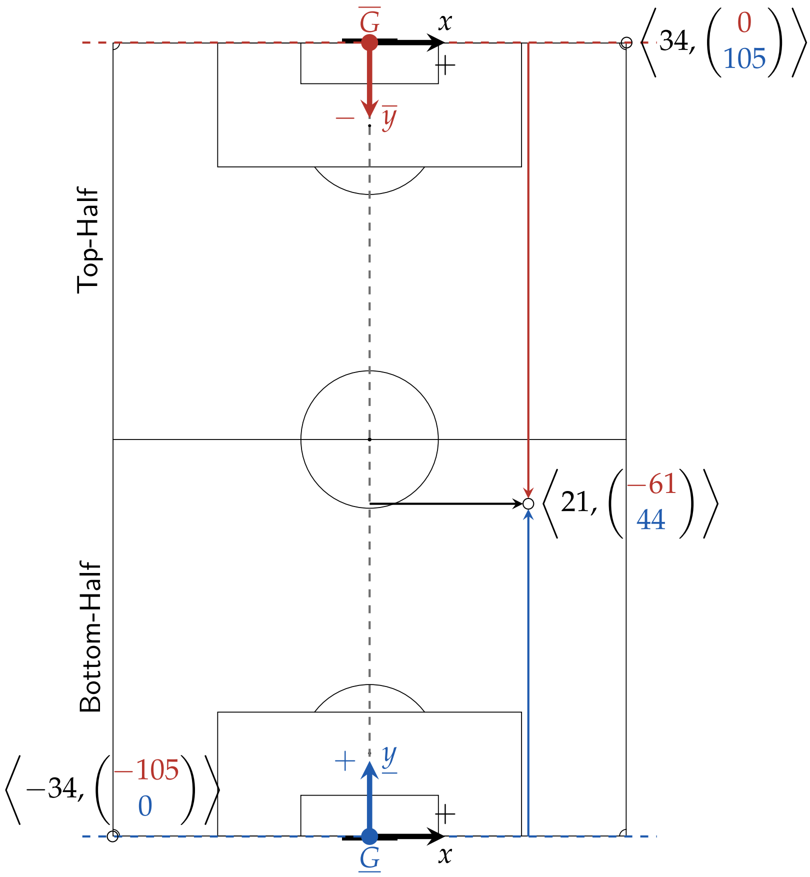
$$\left\langle x, \begin{pmatrix} \overline{y} \\ \underline{y} \end{pmatrix} \right\rangle \tag{2.1}$$

where x is the signed distance from the vertical axis through $\underline{G}$ and $\overline{G}$. $\underline{y}$ and $\overline{y}$ are the distances from the horizontal axis through the respective origin $\underline{G}$ and $\overline{G}$. Any single location can be expressed as either $\langle x, \underline{y} \rangle$ in the coordinate system centred at $\underline{G}$ or as $\langle x, \overline{y} \rangle$ in $\overline{G}$ [5].

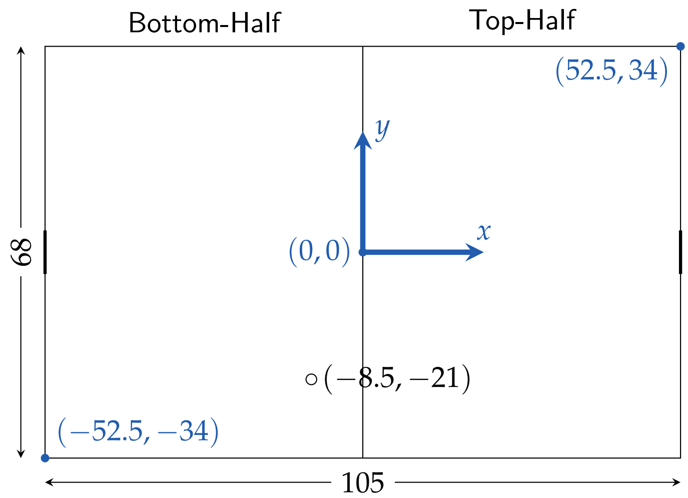
The goal-aligned coordinate system for the thesis has been adapted to have the goal lines[3] at the y coordinates 0 and 105. The touchlines[4] are located at the x-coordinates -34 and 34. These values have been chosen to simplify transforming the input tracking data to the goal-aligned coordinate system. Because all three games have been played on a pitch with the dimensions $68\,\text{m} \times 105\,\text{m}$, this choice simplifies the transformation to a rotation without scaling along the x or y axis.

[3] A goal line is the line parallel with the goal [8]. It marks the boundaries of the pitch along the goals.

[4] The touchlines mark the boundary of the pitch orthogonal to the goal lines [8] along the long axis.



(a) Goal aligned coordinate system [5] with the origins $\underline{G}$ and $\overline{G}$ at the bottom and top goals. The pitch has the dimensions 68 m × 105 m. The x-coordinate is represented in black, the $\underline{y}$-coordinate in blue, and the $\overline{y}$-coordinate in red. Taken and modified from [5].



(b) Horizontally oriented pitch of the provided tracking data. The origin is located at the centre mark, and the direction of play is along the x-axis.

Figure 2.2: Goal aligned coordinate system (a) and horizontally oriented coordinate system (b) used by Sportec Solutions AG.

The input tracking data uses a pitch oriented horizontally with the origin at the centre mark (Figure 2.2b). Since the teams switch the play direction after half-time [9], we need to split the tracking data into two segments for each team to transform it into the goal-aligned coordinate system. If a team's goal is on the bottom half and attacks the top goal, we say their play direction is *bottom-to-top* and if they attack the bottom goal, their play direction is *top-to-bottom*. To compute the x, $\underline{y}$, and $\overline{y}$ values for a player that is playing bottom-to-top from the input coordinates x' and y' we can use

$$\begin{bmatrix} x \\ \overline{y} \\ \underline{y} \end{bmatrix} = \begin{bmatrix} 0 & -1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} x' \\ y' \end{bmatrix} + \begin{bmatrix} 0 \\ -52.5 \\ 52.5 \end{bmatrix} \tag{2.2}$$

For the play direction top-to-bottom, we can use

$$\begin{bmatrix} x \\ \overline{y} \\ \underline{y} \end{bmatrix} = \begin{bmatrix} 0 & -1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} x' \\ y' \end{bmatrix} + \begin{bmatrix} 0 \\ 52.5 \\ -52.5 \end{bmatrix} \tag{2.3}$$

After computing the coordinates for each team and half-time separately, we can recombine them into a single set of tracking coordinates for the whole game.

An example use case for the goal-aligned coordinate system is determining whether the ball is in a team's half. In the input coordinate system, we first need to look up a team's play direction and then compare that against the ball position on the pitch. With a goal-aligned coordinate system, we only need to check if $\underline{y} < 52.5$ holds for the ball.

Unless explicitly stated, all examples and results in this thesis assume a goal-aligned coordinate system.

2.3 Player Positions Based on Spatial Expressions

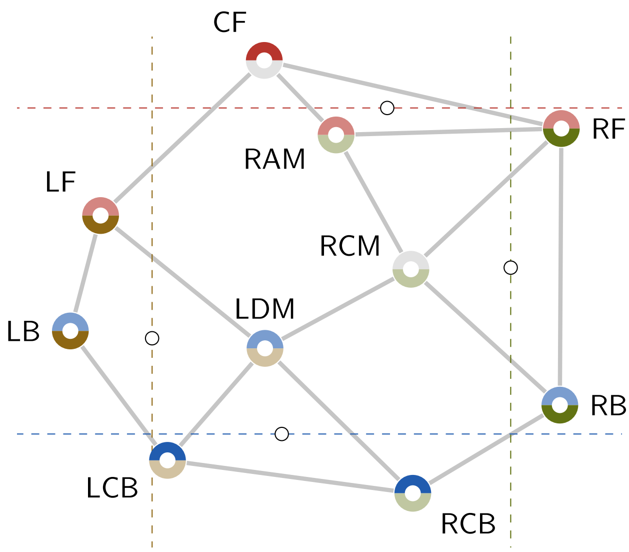
Centrally to this thesis are shape graphs and the derived position plots [6]. Shape graphs (Figure 2.3a) are based on Delaunay triangulations. The shape graph is created for every frame and includes all players of a team except the goalkeeper. The goalkeeper is excluded because their position labels are irrelevant to the analysis. If the team or players are mentioned in this thesis, the goalkeeper is not included unless explicitly stated otherwise.

A shape graph is derived from a Delaunay triangulation.

> *Definition 3.1.* Given a finite point set $P \subset \mathbb{R}^2$ in general position, a Delaunay triangulation is a planar graph $D(P) = (P, E)$ such that every internal face is a triangle whose circumcircle does not enclose another point of P. ([6])

Delaunay triangulations are dual to Voronoi diagrams [6]. A Voronoi diagram can be obtained by constructing the bisectors of every edge in the Delaunay triangulation. The bisectors produce a half-plane set whose intersection creates a Voronoi region. The union of all Voronoi regions creates the Voronoi Diagram [10].

Since we are interested in the (deliberate) changes in players' positioning throughout the game, unstable[5] edges are removed. Removing unstable edges increases the chance that small player movements do not change the triangulation of the graph. This results in a subgraph graph that, while no longer being a strict triangulation, is stable against small perturbations. And if the edges of the shape graph should change over multiple frames, it is because a player has moved in relation to the rest of the team.



(a) Example of a shape graph of a team's player position. The vertical and horizontal labels are displayed as the top and bottom semi circle respectively. The colouring of the labels is according to the colours shown in (b). The top-, right-, bottom-, and leftmost barycentres are highlighted with small circles. The lines used to classify the players pass through their respective barycentres.

<table>
<tr><th></th><th colspan="5">Horizontal Levels</th></tr>
<tr><th>Vertical Levels</th><th>L</th><th>LC</th><th>C</th><th>RC</th><th>R</th></tr>
<tr><td>F</td><td rowspan="2">LF</td><td>LCF</td><td>CF</td><td>RCF</td><td rowspan="2">RF</td></tr>
<tr><td>AM</td><td>LAM</td><td>CAM</td><td>RAM</td></tr>
<tr><td>M</td><td>LM</td><td>LCM</td><td>CM</td><td>RCM</td><td>RM</td></tr>
<tr><td>DM</td><td rowspan="2">LB</td><td>LDM</td><td>CDM</td><td>RDM</td><td rowspan="2">RB</td></tr>
<tr><td>B</td><td>LCB</td><td>CB</td><td>RCB</td></tr>
</table>

(b) Position matrix with the labels of the vertical and horizontal levels. Pairs of vertical and horizontal levels are translated into positions and shown as cells of the matrix.

Figure 2.3: Labelled shape graph and position matrix.

[5] [6] uses the definition of angular stability of Agarwal et al. [11]. For a polygon *abcd* that is split into two triangles by an internal edge *cd*, the edge *cd* is considered unstable if $\angle abc + \angle bcd > 135°$.

Positions in a shape graph are defined as pairs[6] of vertical (v) and horizontal (h) levels. The vertical levels are B (Back), DM (Defensive Midfield), M (Midfield), AM (Attacking Midfield), and F (Front). The horizontal levels are L (Left), LC (Left Centre), C (Centre), RC (Right Centre), and R (Right). A position is assigned by combining these levels into (v, h) pairs [6]. As shown in Figure 2.3b, the position of the centre back is the combination of the vertical level B and horizontal level C.

The position assignment is based on the relative player position in the shape graph and the resulting edges and internal faces. First, the barycentres [7] of all internal faces of the shape graph are computed. Then, the barycentres with the maximal and minimal vertical coordinates (topmost and bottommost) are selected. The relevant barycentres are shown in Figure 2.3a. Then, all players with a greater vertical coordinate than the topmost barycentre are assigned the vertical level F. All players with a smaller vertical coordinate than the bottommost barycentre are assigned B. All players adjacent to players with levels F or B are assigned to the AM or DM levels, respectively. The remaining players (not adjacent to F or B) are assigned the vertical level M. The horizontal levels can be assigned analogously with the left- and rightmost barycentres [6].

Computing the shape graph for every frame lets us reason about momentary player constellations, the team shape at a singular moment and over time, as well as a player's position and movement in relation to their teammates.

[6]The wing positions LF, RF, LB, and RB are not a single pair but a combination of two pairs.

[7]The barycentre of a face is the average position of all players making up that face.

Chapter 3

Manoeuvre Detection with Player Classification

Soccer tactics define manoeuvres played by a certain group of players, like a midfielder dropping into the defensive line, or a player that usually plays on the outside of the team inverting [12, 13]. This chapter introduces a method to categorize players based on their movement into different classes: 2.3 during their time of play in a game and presents two novel, rule-based approaches to detecting dropping midfielders (3.2) and inverted players (3.3).

3.1 Player Classification

We introduce the concept of an aggregated position to classify players during a game.

Definition 3.1 (Momentary Aggregated Position) *A momentary aggregated position is the union of at least two positions from the position matrix (Figure 2.3b). It is based on a single shape graph and thus represents a singular moment.*

Definition 3.2 ((Complete) Aggregated Position) *A complete aggregated position (or just aggregated position) of a player is the momentary aggregated position they played the most during a period of time.*

A momentary aggregated position is denoted in $\textbf{bold}_i$ where the subscript i denotes the frame from which it was computed. An aggregated position is denoted in **bold** to differentiate it from any labels or positions identified by the same letters.

For example, if we want to classify a player playing as a defensive midfielder, we can define the aggregated position **DM** as

$$\mathbf{DM} = \text{LDM} \cup \text{CDM} \cup \text{RDM} \tag{3.1}$$

A complete list of all aggregated positions used in this thesis is contained in Table 3.1.

Table 3.1: All aggregated positions are used in this thesis. For a visualisation of the positions, see Figure 2.3. Since the aggregated positions **LW**, and **RW** incorporate parts of the positions LB, LF, RB, and RF but not the whole position, the subscript denotes which vertical level is used. LB_{DM} means that the part (DM, L) is used, but not (B, L).

Full Name	Aggregated Position	Positions
Front	**F**	LCF, CF, RCF
Offensive Midfield	**AM**	LAM, CAM, RAM
Midfield	**M**	LCM, CM, RCM
Defensive Midfield	**DM**	LDM, CDM, RDM
Back	**B**	LCB, CB, RCB
Left Wing Back	**LWB**	LB, LM
Left Wing	**LW**	LB_{DM}, LM, LF_{AM}
Left Wing Front	**LWF**	LM, LF
Right Wing Back	**RWB**	RB, RM
Right Wing	**RW**	RB_{DM}, RM, RF_{AM}
Right Wing Front	**RWF**	RM, LF

By creating all momentary aggregated positions of a player for a given time interval of a game and selecting the one that appeared the most (i.e. taking the maximum), we can determine a player's aggregated position. Note that this is a metric of how the players played, not how they were supposed to play. If a team is supposed to play in a 4-4-2 formation, but the left midfielder consistently plays much more forward as their teammates in the midfield, that player will be classified as a **LWF** (left wing front) instead of a **LW** (left wing).

To compute a player's aggregated position, we look only at their position labels during phases where the team is out of possession, and the player is actually on the pitch. If a player is off the pitch due to a substitution or any other reason, it does not affect their aggregated position. FIFA's training centre defines the key principles for being out of possession as:

- Reduce the size of the pitch.
- Close the space
- Keep the shape
- Apply pressure

(FIFA Training Centre [14])

While there is no requirement for a team to adhere to these principles, we can assume that they are broadly followed. The most relevant principle for us is *Keep the shape*. The team shape is the positional structure of the team in and out of possession [15] and gives insights into how players are positioned as part of the team. The out-of-possession team's job is to frustrate the attacking team's attempt to play through them [14]. To this end, they should return to their assigned positions and press any direct opponents [14]. Players returning to their assigned possession to keep the shape out of possession can give us insights into which position a player is supposed to play. This is why we only consider play intervals where a player's team is out of possession.

3.2 Dropping Midfielders

In soccer, the term *dropping midfielder* refers to a defensive midfielder moving back (dropping) into the defensive line. By doing this, defensive midfielders support the full-backs during the build-up, opening up more passing opportunities and covering any space the full-backs might have conceded. The build-up phase refers to the first part of an attack, where a team has to get the ball from their part of the pitch to the opponent's goal. It usually starts in a team's defensive third[1] [17].

Two types of dropping midfielders can be distinguished. A centrally dropping midfielder, where the defensive midfielder moves between the centre backs (Figure 3.1b). And a sideways dropping midfielder, where they are moving to the outside of the centre backs, either on the left or right side (Figure 3.1c).

A centrally dropping midfielder can be employed if the centre backs are going wide[2]. By going wide, they move towards the wing positions to provide passing opportunities. However, this opens up a gap between them. This could be exploited by an opponent gaining the ball, running through them, and scoring a goal in the worst case. To mitigate this risk, a midfielder or defensive midfielder drops into the defensive line, covering the space conceded by the centre backs [12].

Alternatively, a defensive midfielder can drop outside. If they drop to the left or right side, the centre-backs are positioned closer together, and the midfield player moves to the left or right wing. This can help create an overload[3]

[1] For training and analysis purposes, the pitch can be divided into thirds along the y (long) axis. The resulting thirds are called *defensive*, *middle*, and *attacking third*. This naming is made from a team's perspective, where the own goal is located in the defensive third [16].

[2] *Going wide* or a player being in a *wide* position, refers to a player moving, or being, in a wing position of their team. A wide position is far from the x (vertical) axis.

[3] Overload refers to numerical superiority in an area of the pitch [18].

opening up more playable space, passing opportunities, and helping the ball progress up the pitch. Unlike when the backs go wide, the centre backs stay close together. This allows them to regain their defensive shape and allows the midfielder to return to his position without risking an opening should the opponent gain the ball [12].

3.2.1 Detecting Dropping Midfielders

In this section, we present the rules that are used to detect a dropping midfielder.

Detecting Build-Up

As a first step to detecting if a defensive midfielder is dropping, we must detect if a team is in the build-up. Since the goal of a build-up is to get the ball into the opponent's half to create an attacking opportunity, we have decided to relax the starting area from the defensive third to a team's own half. For this we can express the predicate $\textsc{Ball In Own Half}_{T,i}$ for a team T at frame i as

$$\textsc{Ball In Own Half}_{T,i} := \text{ball}_{\underline{y},i} < 52.5. \tag{3.2}$$

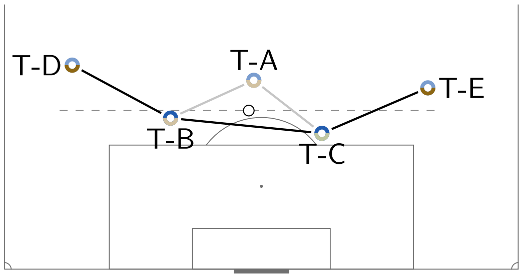
Where $\text{ball}_{\underline{y},i}$ denotes the $\underline{y}$-coordinate of the ball at frame i. We use the provided data about possession phases to determine if the team is in ball possession (section 2.1). Combining Equation 3.2 and the information about whether the team is in possession at frame i, we can define a predicate for detecting the start of a build-up as

$$\textsc{Starting Build-up}_{T,i} := \textsc{In Ball Possession}_{T,i} \land \textsc{Ball In Own Half}_{T,i}. \tag{3.3}$$

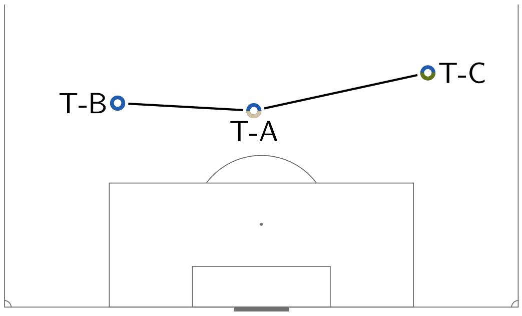
Detecting A Defensive Midfielder Moving Into The Defensive Line

The central play element of a midfielder dropping is them moving back into the defensive line. The defensive line is a collection of players making up the team's rear guard and is the last group of players in front of the goalkeeper. We combine information about the player's vertical position assignment and placement in the shape graph to distinguish a defensive midfielder dropping.

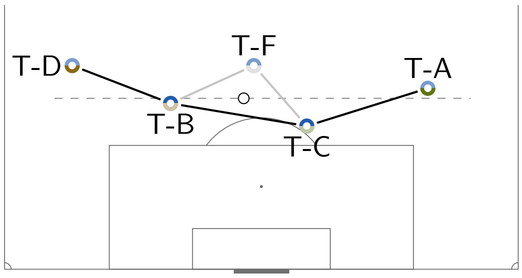
For a player to be classified as a defensive midfielder, their dominant vertical level has to be DM. From this, we can deduce that they are usually not on the outer face of the shape graph. If they drop far enough centrally between the centre backs, their vertical level will change to B (Figure 3.1b). However, their vertical level can remain DM, depending on how and where the player drops. As an example, consider the play progression from Figure 3.1a to Figure 3.1c where the player T-A drops sideways. They have almost the same



(a) Lower half of shape graph with players T-B and T-C playing centre backs and T-A playing defensive midfield. The outer face of the shape graph is highlighted in black. The line going through the backmost the barycentre is shown dashed.



(b) Play progression from (a) where T-B and T-C go wide, and T-A drops centrally between them. Player T-A's vertical level changes to B since he drops behind the backmost barycentre. The barycentre has been omitted but is in front of the players T-A, T-B, and T-C.



(c) Play progression from (a) where T-A drops sideways to the right of T-C. Because player T-F occupies T-A's previous space, T-A's vertical level remains DM. Their horizontal level changes to R.

Figure 3.1: Initial player placement (a) and two possible play progressions (b), (c) of a player dropping centrally or sideways to the right.

height on the pitch as the centre-back T-B but stay in front of the bottommost barycentre. Because of this, their vertical level does not change to B but stays at DM. Only considering their vertical level for the condition that a player is dropping would mean that the condition would be true even if the player stays in their assigned position.

We also consider their placement in the shape graph to resolve this issue. As the positions that make up **DM** are towards the centre of the position matrix, a defensive midfielder will not show up on the outer face of the shape graph in their default position. Therefore, if they show up on the shape graph's outer face, we can conclude that they have moved away from their normal position.

With this, we can define

$$\text{Is Dropping}_{p,i} = \text{vertical level}_{p,i} \in \{\text{B}, \text{DM}\} \wedge \text{On Outer Face}_{p,T}. \quad (3.4)$$

and

$$\text{Is Dropping Centrally}_{p,i} = \text{Is Dropping}_{p,i} \wedge \text{horizontal level}_{p,i} = \text{C} \quad (3.5)$$

$$\text{Is Dropping To Left}_{p,i} = \text{Is Dropping}_{p,i} \wedge \text{horizontal level}_{p,i} \in \{\text{L}, \text{LC}\} \quad (3.6)$$

$$\text{Is Dropping To Right}_{p,i} = \text{Is Dropping}_{p,i} \wedge \text{horizontal level}_{p,i} \in \{\text{R}, \text{RC}\} \quad (3.7)$$

Algorithm for Detecting Instances of Defensive Midfielders Dropping

We can define the following algorithm to detect instances of a team's defensive midfielders dropping during a game. The algorithm accepts the positional data of the team during the game, the information about the shape graphs, and the information about when the team is in possession as input.

1. Compute the aggregated position of every player T-A in the team T according to section 3.1.
2. For every player T-DM that was classified as **DM** and every interval the team is in possession, do
   - 2.1. Check if T is starting the build-up phase (3.3).
   - 2.2. If the team T is in the build-up, find the first frame i in this possession interval, where the player T-DM is dropping either centrally (3.5), left (3.6), or right (3.7).
   - 2.3. If such a frame i exists, count the number of frames n starting from i, where $\text{In Ball Possession}_{T,i+j} \wedge \text{Is Dropping}_{\text{T-DM},i+j}$ holds (3.4).

2.4. If $n > 50$ (longer than 2 s) output the frames $i, \ldots i + n$ together with the player T-DM.

2.5. Repeat step 2.1 for the remaining frames in the interval after $i + n$ or if no such remaining frames exist, go to the next interval.

Naturally, this approach can be extended to both teams playing the game. Any instance where the midfielder is dropping for fewer than 2 s we consider as noise and do not include in our analysis.

3.3 Inverted Players

This section details an approach to detecting full-backs and wingers moving into the central spaces. Full-backs defend the wide areas as the outer players in a back four. An *inverted full-back* is a full-back that moves inside the central spaces. This adds another player in the centre of the pitch. While an inverted full-back is a manoeuvre that is predominately played in possession, it can also be useful out of possession. An inverted full-back's role in possession is to create an overload. Their job out of possession is to disrupt the opponent's attempted counterattack. However, out of possession, they usually quickly return to their assigned position [13].

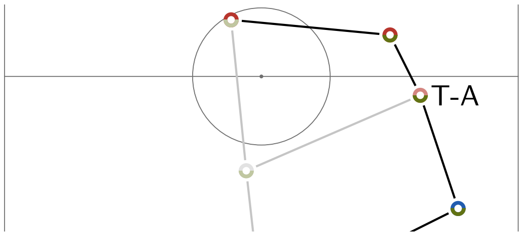
An *inverted winger*, also known as an inside forward, is a wide attacking forward whose role it is to attack infield with an off-ball run [4] or by dribbling diagonally towards the goal. A feature of an inside forward is that their stronger foot is towards the inside of the pitch. A winger can invert in or out of possession. In possession, their role is to attack inside towards the opponent's goal. Out of possession, they can be tasked with counter-pressing [5].

3.3.1 Detecting Inverted Players

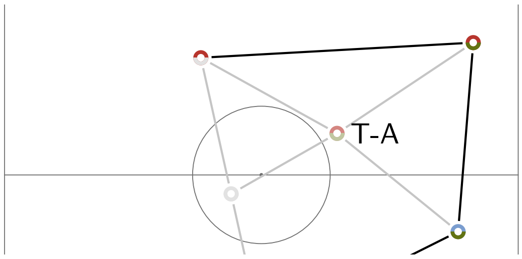
Common to both inverted full-backs and inverted wingers is their normal position on the team's wings. We use the aggregated position (Table 3.1) **LWB** and **RWB** to represent the full-backs. **LWF** and **RWF** are used to represent the wide attacking forwards. As such, their normal horizontal levels are L and R respectively, placing them outside the left- and rightmost barycentres. Meaning that they are on the outer face of the shape graph. Therefore, we can assume they are inverting if they leave the outer face.

[4] An off-ball run can be defined as a type of run that happens when a team is in possession. For this type of run, players present themselves as a passing option and receive the ball during or after their run [19]. This means that the player does not have the ball when they start their run but successfully presents themselves as a passing opportunity and receives the ball.

[5] Counter-pressing refers to applying pressure on the opposing player with the ball. The goal of players performing counter-pressing is to win back possession of the ball [20].



(a) Right side of a team with T-A playing as a right winger. The outer face is highlighted in black. Part of the shape graph is shown in grey.



(b) Play progression from (a) where T-A leaves their wing position on the team's outer face and inverts.

Figure 3.2: Initial player placement (a) and a possible play progression of a right attacking forward inverting (b).

Algorithm for Detecting Instances of Players Inverting

We propose the following algorithm to detect instances of full-backs and wingers inverting. It takes as an input the positional data, information about a team's outer face, and information about which time intervals the team is in possession.

1. Compute the aggregated position of every player T-A in the team T according to section 3.1.
2. For every player T-W that was classified as either **LWB**, **RWB**, **LWF**, or **RWF** and every interval where the team T is in possession, do
   2.1. Find the first frame i in the interval where T-W leaves T's outer face.
   2.2. If such a frame i exists, count the number of frames n starting from i, where $\neg\textsc{On Outer Face}_{\text{T-W},T}$ holds.
   2.3. If $n > 50$ (longer than 2 s) output the frames together with the player T-W.
   2.4. Repeat step 2.1 for the remaining frames in the interval after $i + n$ or if no such remaining frames exist, go to the next interval.

This algorithm only detects instances where the team is in possession. However, it can be easily extended to cover the out of possession phases.

Chapter 4

Over- and Underlap Detection

In addition to manoeuvres played by certain player groups, other manoeuvres are not bound to a certain player group. Two are *overlap* and *underlap* runs. This chapter discusses how we implemented an approach to detecting them using shape graphs and tracking data. Different definitions for overlap runs exist. Skill Corner defines a set of run types in their analytical data. Among these are overlap and underlap runs.

> An Overlap run is a Run with the following characteristics:
>
> - The runner is running in the wide channel or half spaces
> - The runner is running from behind to in front of the player on the ball or receiving the ball
> - The receiver is wider than the player in possession
>
> (SkillCorner [19])

> An Underlap run is a Run with the following characteristics:
>
> - The runner is running in the wide channel or half spaces
> - The runner is running from behind to in front of the player on the ball or receiving the ball.
> - The receiver is inside compared [*sic*] to the player in possession
>
> (SkillCorner [19])

Meanwhile, Anzer et al. use the following definition for their machine learning approach. An *overlapping run* is defined as two attackers versus one defender, with one attacker in ball possession dribbling towards the defender. The second attacker, who is performing the overlapping run, runs past the attacker in ball possession. The player performing the overlapping run has to move towards the opponent's goal line with speeds exceeding 10 km/h. The manoeuvre must also be performed in the offensive third [2].

Based on these definitions, we propose the following definitions for an overlap and underlap manoeuvre:

Definition 4.1 (Overlap Manoeuvre, Underlap Manoeuvre) *A player T-A performs an* overlap *or an* underlap *with a player T-B if the following conditions hold.*

- *T-A and T-B are part of the same team:*
- *T-A and T-B are close (Def. 4.2).*
- *T-A is behind T-B ($T\text{-}A_{\underline{y},i} \leq T\text{-}B_{\underline{y},i}$) at some point in time i when T-B has the ball, and in front of T-B ($T\text{-}B_{\underline{y},j} > T\text{-}A_{\underline{y},j}$), when T-B no longer has the ball.*
- *T-A has moved more along the $\underline{y}$-axis than T-B.*

The manoeuvre is an ***overlap****, if t the moment in time k when T-A runs past T-B, T-B is closer to the vertical axis than T-A.*

$$|T\text{-}A_{x,k}| > |T\text{-}B_{x,k}| \tag{4.1}$$

he manoeuvre is an ***underlap****, if t the moment in time k when T-A runs past T-B, T-A is closer to the vertical axis than T-B.*

$$|T\text{-}A_{x,k}| < |T\text{-}B_{x,k}| \tag{4.2}$$

The manoeuvre ends when another player gains possession of the ball or the game is interrupted.

Since we do not want to classify a player running past the ball possessor on the other side of the pitch as an overlap or underlap, we define two players being close in a shape graph as:

Definition 4.2 (Shape Graph Closeness) *Given a shape graph (P, E), two players T-A, T-B are* close *iff. $\{T\text{-}A, T\text{-}B\} \in E$.*

4.1 Extracting the Ball-Possessor from Event-Data

As a first step to detecting over and underlap manoeuvres, we have to compute the player possessing the ball at a given point in time. Since the provided possession phase data does not contain the player possessing the ball, we parse it from the event data.

The event data provided by Sportec Solutions AG is an ordered series of events. It defines 32 distinct types of events, such as passes, shots, ball claiming, etc. Every event involves between zero and two players. If two

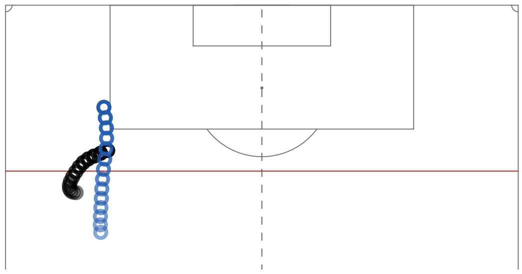


Figure 4.1: Example underlap manoeuvre detected in the opponent's half in provided data. The player possessing the ball is shown in black, player running past is shown in blue. The moment when blue runs past black is marked with a red horizontal line. Sampled at 200 ms

players are involved, they can be part of the same team or opposing teams. By parsing the events, we can reconstruct the sequence of players possessing the ball. For example, given the following three events of the home team's (H) players H-A and H-B:

1. Player H-A claims the ball at frame i.
2. Player H-A passes it to H-B at frame j. H-B receives it a frame k.
3. Player H-B shoots the ball at frame l.

We can reconstruct the ball possession sequence:

1. Player H-A has the ball from frame i until j.
2. Player H-B has the ball from frame k until l.

4.2 Player Movement During Over- and Underlap

Both SkillCorner and [2] define a threshold speed the running player needs to achieve to register as an over- or underlap. For SkillCorner a run has to be at least 0.7 s long and faster than 15 km/h [19]. [2] does not impose a time limit. However, the player has to run faster than 10 km/h.

In this thesis, we opted to avoid threshold values as they require fine-tuning. Depending on the values chosen, the produced results can vary widely. To avoid these, we opted to express the detection of a player running past independently of fixed values. The first condition we require is that the player T-A performing the run has to be first behind or next to the player T-B in ball possession and then in front of him.

$$\text{T-A}_{\underline{y}} \leq \text{T-B}_{\underline{y}} \qquad \text{and then} \qquad \text{T-A}_{\underline{y}} > \text{T-B}_{\underline{y}} \tag{4.3}$$

This ensures that T-A passes T-B at some point. To quantify that T-A is moving faster than T-B towards the goal line, we require that T-A moves more along the y-axis than T-B. We do this with the condition

$$\left|\Delta\text{T-A}_{\underline{y}}\right| > \left|\Delta\text{T-B}_{\underline{y}}\right| . \tag{4.4}$$

As player T-A can start the run at any time, T-B has the ball, and not the instant T-B gains it, we require T-A to be behind T-B and have a connection on the shape graph. This connection has to exist for the whole duration of the manoeuvre.

4.3 Algorithm for Detecting Overlap and Underlap Manoeuvres

We propose the following algorithm to detect instances of overlap and underlap manoeuvres in a match. It takes the tracking data, event data and the information about the shape graph as an input.

1. Compute the player-level ball possession according to section 4.1.
2. Divide the game into intervals based on the player's ball possession. An interval starts when a player gains ball possession and ends once another player gains ball possession or the game is interrupted.
3. For every interval with a player T-B in ball possession, do:
   - 3.1. Find players P of the same team that are behind and close (Def. 4.2) to T-B during the interval. If no such players exist, continue with the next interval.
   - 3.2. For every player T-A $\in P$ do:
     - 3.2.1. Find the first frame i when T-A is behind and close to T-B.
     - 3.2.2. Check if they are in front of T-B at the interval end j and if they have moved more (4.4) in the interval $[i, j]$.
     - 3.2.3. If this is the case, find the frame $k \in [i, j]$ where the player T-A and T-B have the same height on the pitch (T-$A_{\underline{y}} \approx$ T-$B_{\underline{y}}$). Else, continue with the next player from step 3.2.
     - 3.2.4. Output the frames from i until j and the players T-A and T-B, $j - i > 25$ (longer than 1 s). If $|\text{T-A}_{x,k}| > |\text{T-B}_{x,k}|$, label it as an overlap. Else, label it as an underlap.

Chapter 5

Marking

Marking in soccer refers to techniques defining how the player's responsibilities during defence should be assigned and executed. The two prominent marking techniques are *man-marking* and *zonal-marking*. The strategy behind man-marking is that every player has an opponent as a responsibility. The goal of a player man-marking an opponent is to shadow them closely, preventing them from receiving and playing the ball. Conversely, the opponent can try to either lose the player or manipulate the defending team. Since the defender is supposed to stay close to a specific opposing player, the opponent can try opening up a space in the defence by moving and letting the defender follow them [21, 22]. In zonal-marking, the defending team opts to control and defend areas of the pitch instead [23].

In this chapter, we first present a technique to detect instances where changes in man-marking lead to defenders being moved away from their designated position. Secondly, we present a way to determine if a team keeps their responsibilities defined by man-marking during an opponent's offensive manoeuvre or changes them.

5.1 Computing Man-Marking as Minimal-Matching

To create the responsibility pairings[1] of defending and attacking player, we compute the minimum weight maximum matching in a bipartite graph. Let $G = (D \cup A, E)$ be a bipartite graph, where D represents the defending players and A represents the attacking players. The goalkeepers are not included in D and A. D and A are disjointed. The edges E are defined as:

$$E = \bigcup_{(d,a) \in D \times A} \{\{d, a\}\} \tag{5.1}$$

[1]We define the term responsibility pairing of two players as meaning that the first player in the pairing is marking the second one.

The weight of an edge $\{d, a\}$ is the Euclidean distance between the two players d and a.

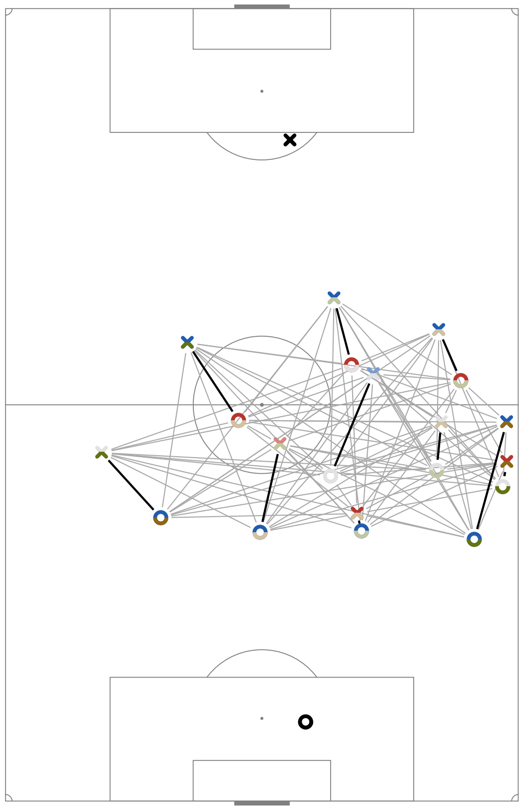


Figure 5.1: Responsibility pairings. The attacking team is shown as crosses and the defenders as circles. The edges of the bipartite graph are shown in grey and the minimal matching in black.

By computing a minimum weight maximum matching on G, we can compute player pairings that minimize the distance between all paired players. If both teams play with all their players, meaning no player has received a red card, the result is a perfect matching. To get the responsibility pairings of which defender marks which attacker during a game interval, we compute the matching for every frame in the interval. This gives us a sequence of responsibility pairings that can change over time if one defending player starts marking another opponent. Such a switch could happen if the defending player considers the second opponent a more significant threat.

5.2 Detecting if Marking Moves Player

Man-marking's major flaw is that a skilled attacker can manipulate and disrupt the other team's defence by forcing the defender to follow them. If defenders move away from their designated position, they concede space, which other attackers can exploit.

To detect if a defender is moving away, we classify them according to section 3.1. If a defending player's dominant position during an interval is not part of their assigned aggregated position, we can assume they have moved. The dominant position in this context is a player's position that appears most often during the interval. Based on this, we propose the following algorithm that checks if a switch in the responsibility pairings coincides with a defender moving out of position. The algorithm takes the tracking data and information about the position labels and possession phases as input.

1. Compute the aggregated position of every player T-A in the team T according to section 3.1.
2. For every phase where the team is out of possession, do
   - 2.1. Compute the responsibility pairings of the team for each frame.
   - 2.2. Create a time series for each player T-A in T that tracks which opponent they are marking during the out of possession phase.
   - 2.3. For every player T-A $\in T$ do
     - 2.3.1. Check if they mark the same opponent during the whole phase. If so, continue with step 2.3 with the next player or the next phase if all players have been checked (step 2).
     - 2.3.2. For every switch in the responsibility pairings of player T-A, check if the dominant position before or after the switch is not part of T-A's aggregated position. If so, output the frames for the responsibility pairing.

The dominant position is the position that appeared the most often during that interval.

5.3 Detecting Marking Changes as a Response to the Opponent's Actions

The second type of marking change that interests us is in response to the offensive actions of the opposing team. A team in ball possession performs offensive actions to progress the ball up the pitch and, if possible, to score a goal. Offensive actions include, but are not limited to, overlaps and underlaps. If a group of players performs an offensive action, the defending players' first option is to continue marking the same opponents. Alternatively, different defenders can assume responsibility and try to disrupt the attack. To detect this, we reformulate the graph from section 5.1 as $G' = (D \cup A', E)$ where A' is the attackers performing the offensive manoeuvre. The rest of the graph stays the same. Finding a minimum weight maximum matching on the graph G' will not result in a pairing for every player (except if $A' = A$). But it will minimize the distances of any defender to the attacker, giving us a better approximation of which defender is responsible for which attacker.

We propose the following algorithm to detect if defending players switch markings during an attack. The algorithm takes as an input the duration and involved players of an opponent's attack. In addition, it uses the tracking data of the defenders and involved attackers.

1. Compute the responsibility pairings during the attack using the complete defending team and the opposing players involved in the attack. A set of pairings for each frame of the attack.
2. For each attacking player, check if they are paired with the same defender during the duration of the attack. If the pairing changes, output the defending players that mark the attacker and when the switch occurs.
3. If all pairings stay the same, output that no changes have occurred.

Chapter 6

Evaluation

To the best of our knowledge, no off-the-shelf rules-based solution exists for detecting dropping midfielders, inverted players or man-marking in soccer games, we focus on presenting the results our approach produced. Overlap runs are compared against the rules-based approach of Anzer et al. [2].

In this chapter, players are identified as a letter prefixed by either H or G, depending on if they are part of the home (H) or guest (G) team. The actual team differ between matches, and H and G refer to different teams for each game. Similarly, if a result is labelled with the same team and letter combination over multiple games, it does not need to refer to the same player.

6.1 Dropping Midfielder

The analysis classified five players over the three games as defensive midfielders (**DM**). The results presented in Table 6.1 and Figure 6.1 were consistently executed during the three games.

Table 6.1: Minimum, mean, and maximum duration in seconds of each defensive midfielder dropping. How often and where they dropped is reflected in the columns Total, Left, Centre, and Right.

Game	Player	Min	Mean	Max	Total	Left	Centre	Right
1	H-E	2.04	7.98	30.64	17	3	3	11
1	H-F	2.04	3.84	6.72	3	2	1	1
2	G-E	2.96	6.94	14.6	5	3	1	1
3	G-G	2.04	6.98	23.44	98	46	26	26
3	H-E	2.12	6.26	29.32	37	11	13	13

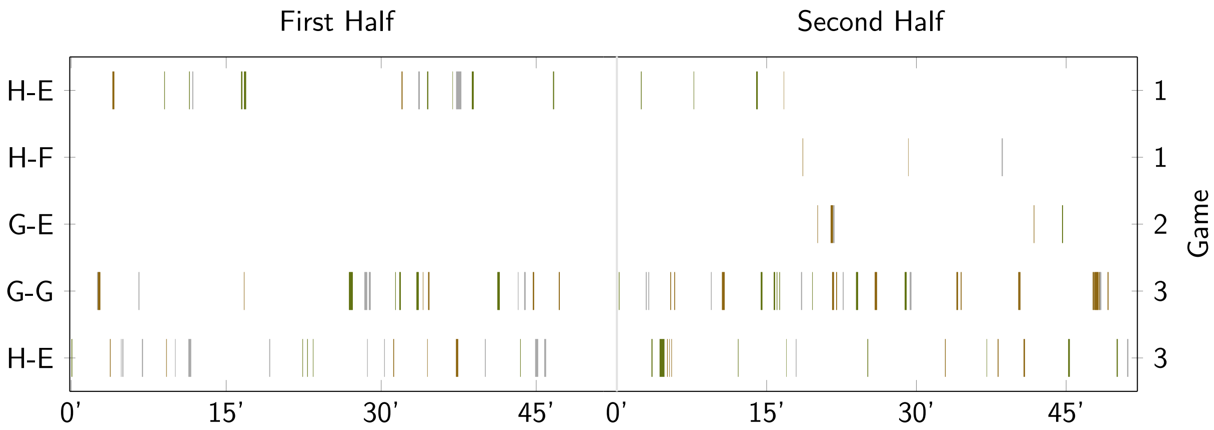


Figure 6.1: Instances of defensive midfielders dropping. Dropping centrally is marked with the colour grey, dropping to the left is marked in bronze, dropping to the right is marked in green. The game time is along the horizontal axis. The duration of each midfielder dropping is denoted in the length of the each line along the game time axis.

In the first game, player H-E was substituted with H-F around the 18th minute of the second half. Player H-E exhibited longer and more sustained dropping behaviour, with a maximum duration of slightly more than 30 s. This can suggest a more deliberate role in bolstering the defensive line. Conversely, player H-F, who took over in the second half, demonstrated shorter dropping times and fewer instances. H-F moved three times into the defensive line, compared to H-E's 17 times. H-F dropped on average for 3.84 s compared to H-E's average, which is closer to 8 s. This difference could indicate a tactical adjustment the H team adopted in the second half.

Similarly, G-E was substituted into play during the second half of the second game. Indicating a possible shift in how team G played defence during the second half.

Player G-G featured prominently in the defensive strategy of team G by dropping 98 times into the defensive line. Dropping mainly to the left, indicating that the full-backs either tend to move to the right or a winger opens up space that needs to be covered.

6.2 Inverted Full-Backs

Our approach identified 17 full-backs that inverted during the three games with varying frequency and duration. Table 6.2 and Figure 6.2 show the detected instances. The data indicates that **LWB** tended to invert more often than **RWB**. 59 times compared to 49. The maximum duration of a wing-back inverting shows a high variability by ranging between 3.68 s and 11.36 s.

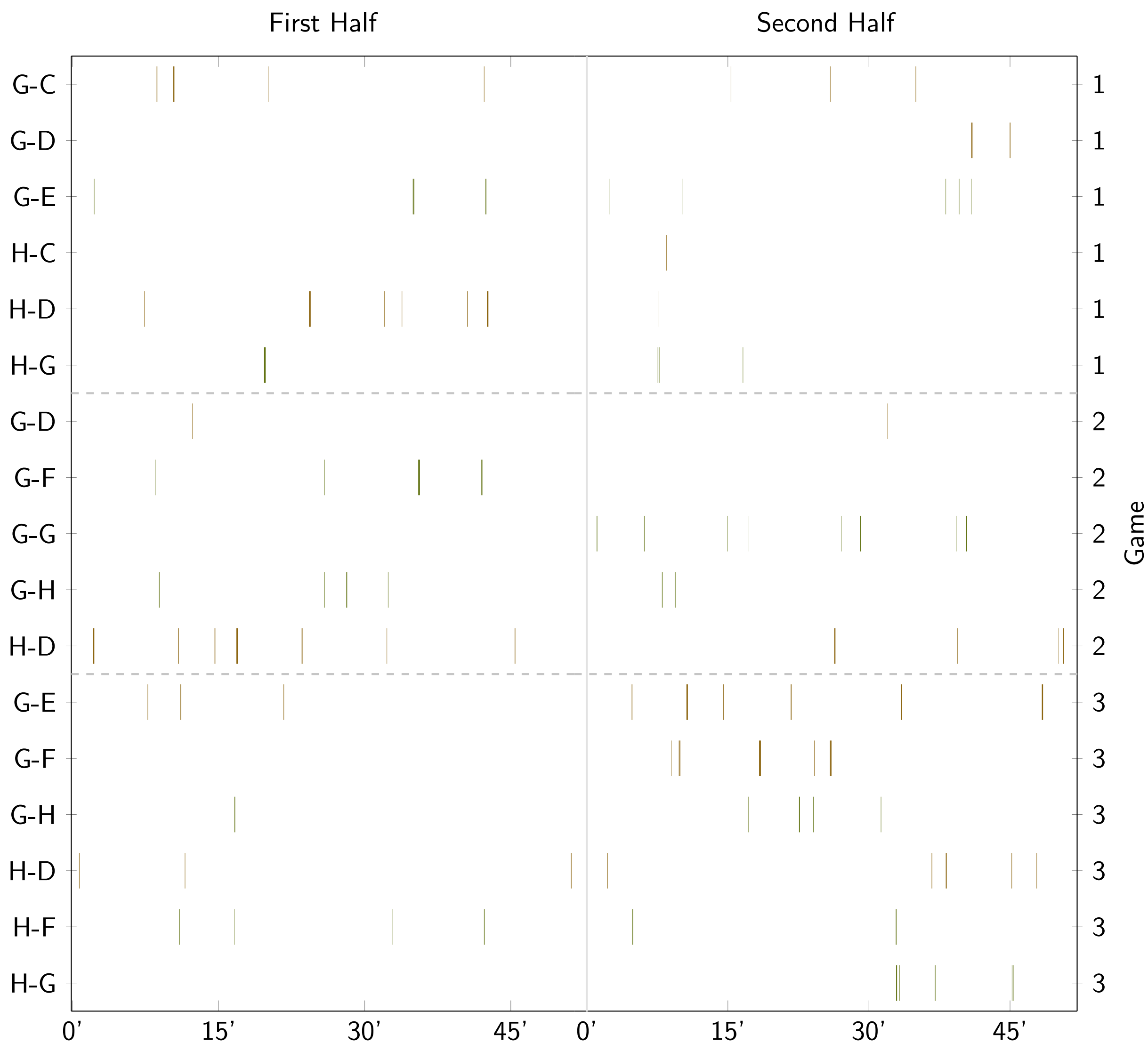


Figure 6.2: Instances of full backs inverting. **LWB** (Left Wing Backs) are shown in bronze, **RWB** (Right Wing Backs) are shown in green.

Table 6.2: Minimum, mean, and maximum duration in seconds of each full-back inverting. The column Total indicates how often they inverted. A. Pos. stands for aggregated position.

Game	Label	A. Pos.	Min	Mean	Max	Total
1	G-C	**LWB**	2.08	2.81	3.68	9
1	G-D	**LWB**	2.08	3.63	4.6	3
1	G-E	**RWB**	2.12	3.23	5.56	9
1	H-C	**LWB**	3.84	3.84	3.84	1
1	H-D	**LWB**	2.32	4.65	10.2	7
1	H-G	**RWB**	2.6	4.83	9.88	4
2	G-D	**LWB**	2.12	2.32	2.52	2
2	G-F	**RWB**	2.24	4.45	10.28	5
2	G-G	**RWB**	2.08	3.36	6.56	9
2	G-H	**RWB**	2.56	3.7	5.32	6
2	H-D	**LWB**	2.12	5.11	9.8	11
3	G-E	**LWB**	2.08	4.61	9.28	10
3	G-F	**LWB**	2.36	4.85	11.36	7
3	G-H	**RWB**	2.52	3.58	5.56	5
3	H-D	**LWB**	2.08	3.19	6.12	9
3	H-F	**RWB**	2.08	3.22	4.8	6
3	H-G	**RWB**	2.28	3.78	6.12	5

6.3 Inverted Wingers

The analysis identified 18 wingers inverting over the three games, as seen in Table 6.3 and Figure 3.2. Notable are the players H-N in game one and G-K in game three, as these invert with a very high frequency. H-N inverted 98 times, and G-K inverted 83 times. Notably, these two players exhibit long average durations when they invert. 8.67 s and 6.76 s respectively.

6.4 Over- and Underlap

6.4.1 Comparison of Overlaps with Anzer et al.

As a baseline for the detected overlaps, we compare them against the rules-based approach from [2].

> For the detection of overlapping runs, we also incorporate a rule-based detection, designed by professional match-analysts from the German National team. For all individual ball possessions (i.e., distance between player and ball < 2 m) in the offensive third (i.e., more than 17.5 m in the respective opposing half) and the outside lane (i.e. distance to the vertical midline of the pitch bigger

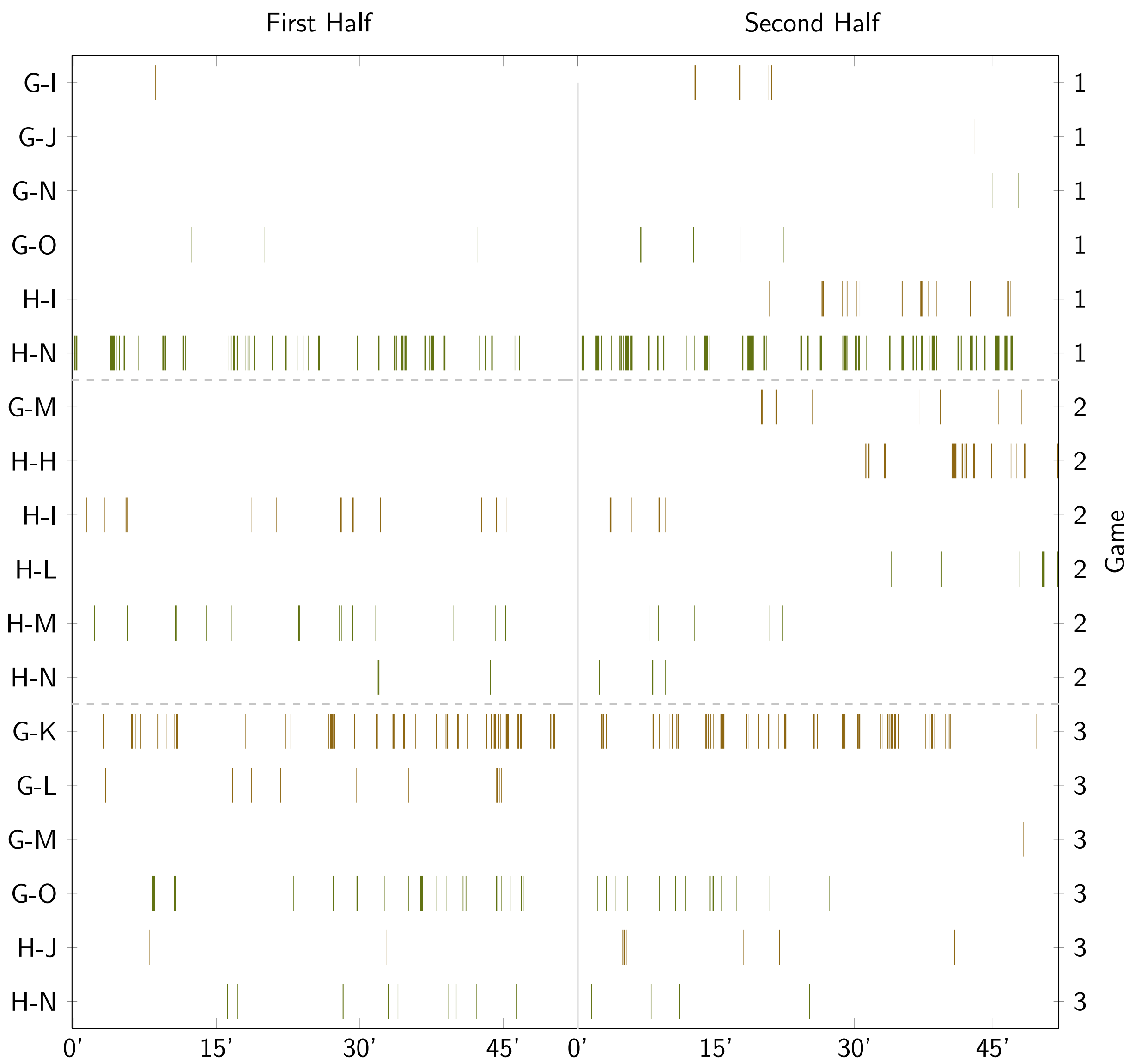


Figure 6.3: Instances of full backs inverting. **LWF** (Left Wing Front) are shown in bronze, **RWB** (Right Wing Front) are shown in green.

Table 6.3: Minimum, mean, and maximum duration in seconds of each full-back inverting. The column Total indicates how often they inverted. A. Pos. stands for aggregated position.

Game	Label	A. Pos.	Min	Mean	Max	Total
1	G-I	**LWF**	2.0	5.93	11.72	6
1	G-J	**LWF**	2.2	2.2	2.2	1
1	G-N	**RWF**	2.12	2.44	2.76	2
1	G-O	**RWF**	2.2	3.59	7.0	7
1	H-I	**LWF**	2.12	4.56	13.36	17
1	H-N	**RWF**	2.08	8.67	40.96	98
2	G-M	**LWF**	2.6	4.99	8.72	7
2	H-H	**LWF**	2.08	7.21	21.52	17
2	H-I	**LWF**	2.12	4.21	10.12	20
2	H-L	**RWF**	2.68	5.67	9.64	6
2	H-M	**RWF**	2.04	4.32	11.12	19
2	H-N	**RWF**	2.04	4.83	8.04	7
3	G-K	**LWF**	2.0	6.76	25.36	83
3	G-L	**LWF**	2.76	4.82	8.76	9
3	G-M	**LWF**	2.56	2.66	2.76	2
3	G-O	**RWF**	2.0	5.33	17.2	33
3	H-J	**LWF**	2.16	4.38	9.8	10
3	H-N	**RWF**	2.04	3.92	8.32	15

> than 17 m), the rule-based system classifies situations where a teammate passed by the ball possessing player on the side of the closest sideline (i.e., there are two consecutive frames t and $t+1$ in which the overlapping player passed behind the ball possessing player in the vertical direction of the pitch with a speed higher than 10 km/h. To ensure comparability to the proposed deep architectures, we add a context of $+/-$ two seconds to the detected timestamps, and compute F1-scores accordingly. (Anzer et al. [2])

We used the ball possessions we extracted from the event data for better comparability.

If we compare the overlap runs detected by our implementation and Anzer et al. (Table 6.4), only one overlap run has been detected by both (see figure 6.4c, 6.4d, the blue overlap run). Why only one run has been detected by both Anzer et al., and our approach is not known at the time of writing. It might have something to do with using the ball possession from the event files or an undetected issue with our implementation of Anzer et al. rules-based approach.

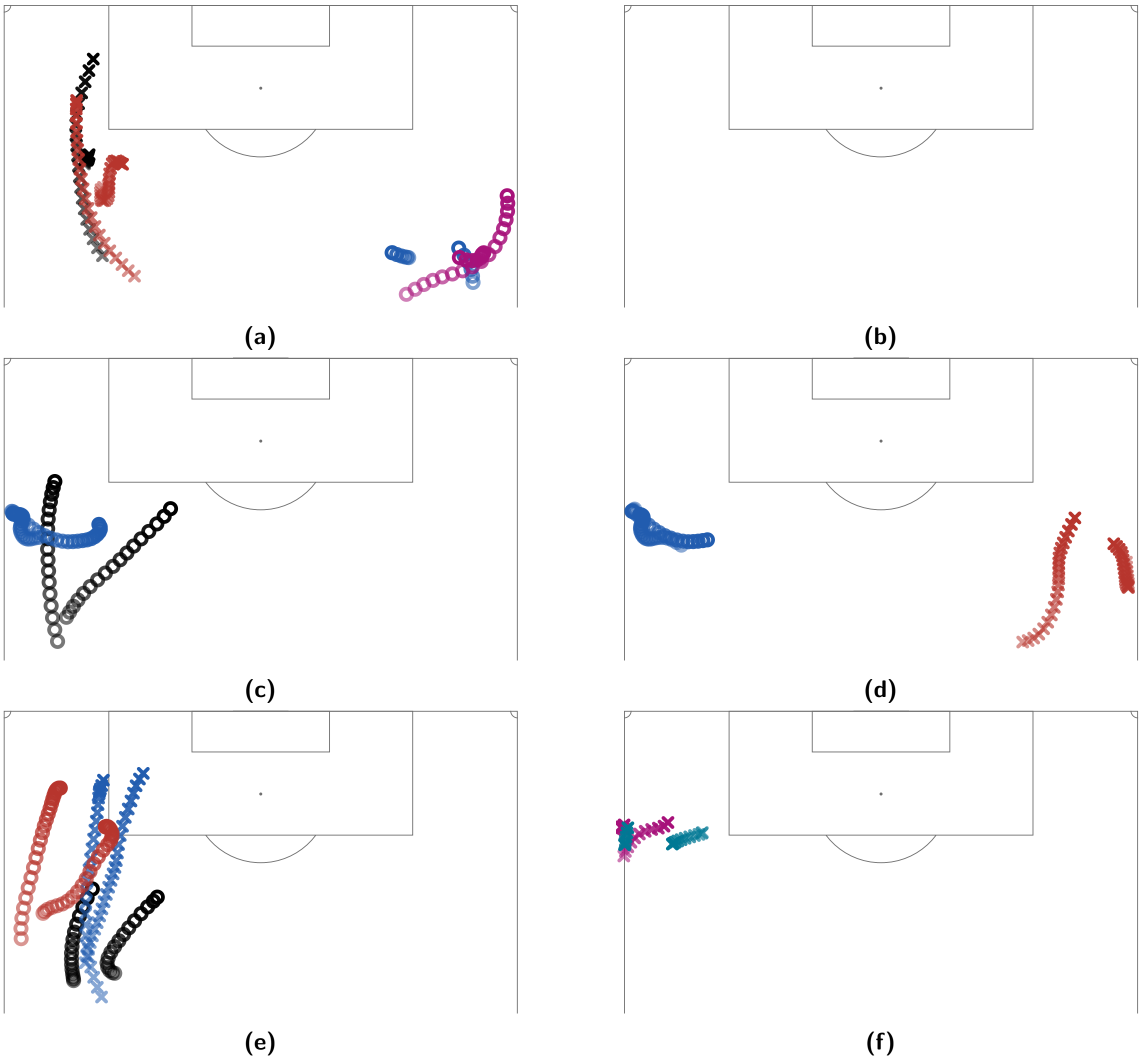


Figure 6.4: Overlaps detected in the offensive third and outside lane. Our implementation is on the left (Game 1: (a), Game 2: (c), Game 3: (e)), Anzer et al. is on the right (Game 1: (b), Game 2: (d), Game 3: (f)). The home team is shown as circles, the away team is shown as crosses. The overlap detected by both methods in (c) and (d) is shown in blue.

Table 6.4: Number of detected overlap runs. Since Anzer et al. restrict their overlap runs to the offensive third and outside lane, This table lists all overlaps detected by our rules-based approach. The number of overlaps in the offensive third and outside lane was detected by our rules-based approach are listed in the column *Of. third, O. lane*.

Game	Our Rules-Based Approach	Of. third, O. lane	Anzer et al.
1	H: 11, G: 7	H: 2, G: 2	H: -, G: -
2	H: 14, G: 3	H: 2, G: -	H: 1, G: 1
3	H: 6, G: 9	H: 2, G: 1	H: -, G: 2

6.4.2 Underlaps

Our approach identified a total of 73 underlap runs during all three games. Table 6.5 shows the number of detected instances. While the home teams performed approximately the same number of underlap as overlap runs, the guest teams seemed to favor the underlap runs. Performing between 5 and 9 more underlap runs than overlaps.

Table 6.5: Number of detected underlaps runs during all three games.

Game	Home	Guest
1	12	12
2	13	9
3	9	18

6.5 Marking

6.5.1 Marking with Position Change

Over the course of games 1 and 3, implementation detected 6831 instances where a player left their assigned position to mark another player.

Table 6.6: Number of detected position change switches in the games 1 and 3. The analysis for game 2 encountered a fatal bug, which could not be patched in time.

	Game 1	Game 2	Game 3
Number of switches with position changes	3391	-	3440

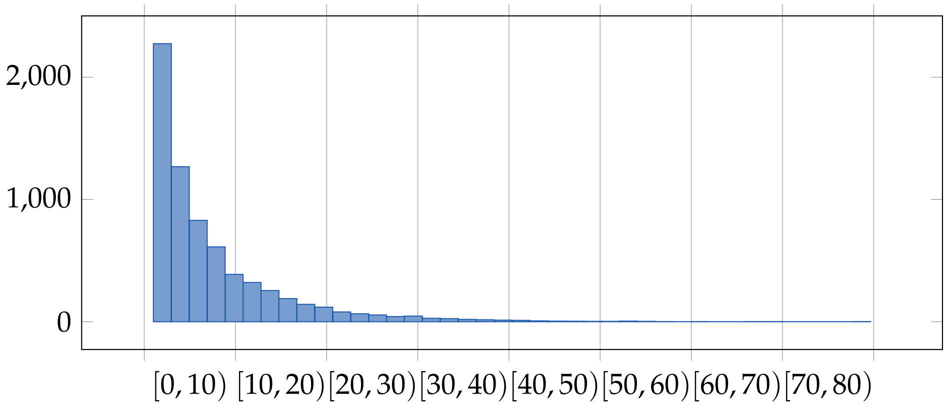


Figure 6.5: Histogram of the duration a player marks two opponents during a marking-switch where the player leaves his position for to mark at least one opponent.

Table 6.7: Number of response switches performed by each team in response to overlap and underlap runs.

Game	No Switches	Switches in Responsibility
1	H: 11, G: 3	H: 8, G: 20
2	H: 3, G: 9	H: 9, G: 18
3	H: 11, G: 4	H: 16, G: 11

Figure 6.5 shows that most marking changes with a position change occur very briefly. This could indicate that the way the responsibility pairings are computed is not suitable for this application.

6.5.2 Response Marking

Using the detected overlap and underlap runs as input, we analysed the marking changes of the opposing team. Table 6.7 shows the number of instances where players continued marking the same opponent and the number of times players changed their marking target. Overall, the players seem to favour switching the opponent they are marking, with 82 detected switches. Compared to 41 instances where the marking stayed the same.

Chapter 7

Conclusion

7.1 Summary

This thesis presents a novel methodology for recognising group-tactical manoeuvres in soccer by analysing player positions. The thesis leverages tracking data from Bundesliga matches, focusing on detecting the following behaviours:

- dropping midfielders,
- inverted full-backs,
- inverted wingers,
- overlap runs,
- underlap runs,
- detecting man-marking that moves a player away from their designated position and
- changes in man-marking as a response to opponent actions.

A set of algorithms and rules was developed to detect these types of behaviours. These algorithms leverage position labels derived from shape graphs in a goal-aligned coordinate system. The algorithms were evaluated across several games, demonstrating their ability to identify and quantify tactical behaviours.

7.2 Outlook

This thesis demonstrated the feasibility of using shape graphs and their derived position labels to detect tactical manoeuvres in soccer. Based on this, one potential direction for future work is refining existing algorithms and incorporating more complex manoeuvre types. Additionally, the methodology for computing man-marking pairings could be improved to reduce the number of responsibility pairings that exist for only a short time. Another avenue for improvement could be, to adapt the algorithms to handle real-time data. This would allow online detection of tactical manoeuvres during live games.

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