Spatial and Spatiotemporal Analysis of Soccer

Ho-Chul Kim
Department of Computer Science and Engineering
Pusan National University
Pusan, South Korea
mitznari@pnu.edu

Oje Kwon
Department of Computer Science and Engineering
Pusan National University
Pusan, South Korea
kwonoje@pnu.edu

Ki-Joune Li
Department of Computer Science and Engineering
Pusan National University
Pusan, South Korea
lik@pnu.edu

ABSTRACT

Soccer matches consist of spatial and spatiotemporal objects including a ball, players, and a field. Players and ball are also moving objects. This means that spatial and spatiotemporal analysis on ball and players could be useful in studying soccer tactics. From this view point, we extend the application areas of spatial information science to soccer tactic analysis. First we define a feature model to specify the basic units of analysis. Second, we study the morphological properties of each feature type. Third, a set of operations are defined for each feature type. Fourth, we perform an experiment with a real data set of the 2006 World Cup final match to validate the usefulness of our framework. Even though we focus on soccer match, we expect that this framework can be applied to similar sports such as handball and basket ball.

Categories and Subject Descriptors

H.2.8 [**Database Management**]: Database Applications—*Spatial databases and GIS*

General Terms

Modeling

Keywords

Soccer analysis, Trajectory, Spatial and spatiotemporal features, Morphology

1. INTRODUCTION

It is an important task of soccer coaches to analyze precedent matches for making proper tactics and preparing next matches. With recent progress of several video analysis and sensor technologies, it is now possible to gather match data including trajectories of players and ball. Several systems have been developed for these purposes and are being used by several big football clubs in Europe [2]. However, most of these systems are limited to statistical analysis such as ball possession ratio and number of shoots in goal, which are abstract factors to explain soccer matches. We may need more concrete and analytic framework to extract useful information on soccer matches.

A soccer match is composed of several types of spatial objects including a ball, players, and field, which are in fact spatial objects. It means that spatial analysis on ball, players, and field is a useful tool for studying soccer tactics. Furthermore we can also apply spatiotemporal analysis on the trajectories of players and ball to extract useful information, since they are moving objects. Consequently, soccer matches can be considered as a novel application area of spatial and spatiotemporal information sciences.

Few researches have been done for soccer tactic by means of spatial and spatiotemporal analysis. And they only focused on specific tactic analysis[3, 1] without a general framework. In this paper, we provide a general framework with a feature model and several analysis methodologies based on spatial and spatiotemporal analysis on soccer matches. First, we will introduce a general model for basic features in soccer matches. Then, we will study morphological properties on these features, which will be used for the analysis of soccer tactic. A set of basic operators will be given to realize the morphologic properties. In order to validate our framework, we show an example of analysis on soccer matches, which is an influence factor of strikers on the defenders of the adversary team.

The rest of this paper is organized as follows; We will propose a general model for the basic features in soccer match in section 2. In particular, the morphological properties of these features will be studied in section 3 and a set of operators for morphologic analysis is to be defined in section 4. In section 5, we will give an example of analysis to show the usefulness of the framework and we will conclude the paper in section 6.

2. FEATURE MODELING

In order to provide the framework of soccer tactic analysis, we need first of all, a model of basic features that will be used as units of analysis and stored in databases. In this section, we propose a basic model as depicted in figure 1, which will serve as the basis of the framework. Note that the objects related with soccer field such as penalty box and half line are not defined in this model, since we consider them as instances. And the referees are also not included in this model as they do not affect the match itself.

We define two abstract feature types `Point Feature` and

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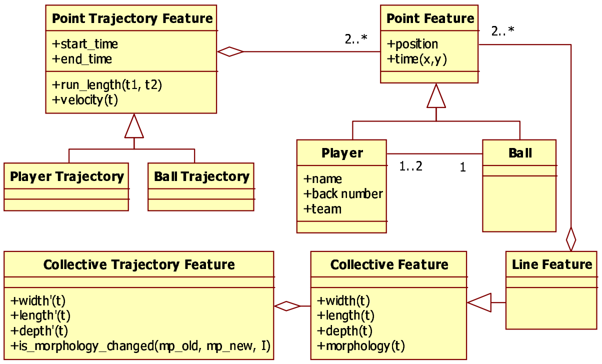
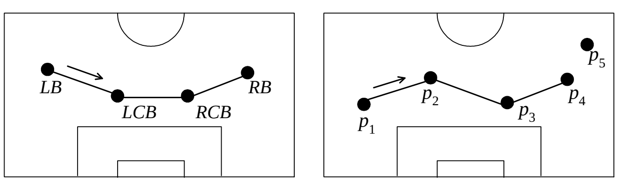


Figure 1: Basic feature model

`Point Trajectory Feature` as the root classes of the model of figure 1, which correspond to spatial and spatiotemporal objects respectively. And `Ball` and `Player`, which inherit from `Point Feature`, have the coordinates of the ball and players at each sampling time instance. `Ball Trajectory` and `Player Trajectory` represent the feature types of ball and player trajectories respectively.

Each object of `Point Feature` has (x, y) coordinates at each time instance t. Note that we employ (x, y)-coordinate reference system to specify the position of spatial objects from the left-bottom corner of the field. And we assume the continuity of temporal domain even though there may be several breaks of match such as ball-out. Due to the breaks, we cannot assure the continuity of the ball trajectory.

Since a soccer is a collective sport, it is required to analyze the positions of players as a collection as well as position of each individual player. For example, the defensive tactics would be better understood by analyzing the shape of the defensive players in a collective way, rather than the position of each individual defender separately. For this reason, we define `Collective Feature` and `Collective Trajectory Feature` in the model, which are in the bottom part of the diagram of figure 1. In this paper, we handle `Line Feature` which belongs to the `Collective Feature`.



(a) Line Feature by Role (b) Line feature by Left-to-Right order

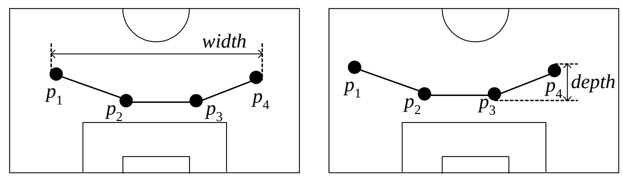
Figure 2: Two options to make line feature

Line feature is used to analyze the linear properties of a specified group of players. It is determined by connecting a set of individual players by a given order. Firstly, it can be determined by the role of players. For example, given a defensive group of the 4-back system, we connect the four defensive players by (Left-Back, Left-Center-Back, Right-Center-Back, Right-Back) as shown in figure 2-a. Second, we simply connect them from left to right according to the current position at a given time instance like figure 2-b.

The connecting order may be decided depending on the requirement of analysis, and we assume the second option for forming a line feature.

3. MORPHOLOGICAL PROPERTIES

Morphology, which is a study on form or shape, is a useful concept to analyze the collective tactics of soccer. For example, the width of 4-back defensive line feature is an important parameter to analyze defensive tactics (figure 3-a). If it is large, then the 4-back efficiently defends the attack of the adversary through right or left wing but is relatively weak to the attack through the central area with accurate passes. If the depth of the defensive line feature is small, then it is efficient to deploy offside trap but difficult to protect the critical area behind the defensive line (figure 3-b). In this section, we study spatial and spatiotemporal morphological properties of line feature in a soccer match.



(a) Width of 4-back (b) Depth of 4-back

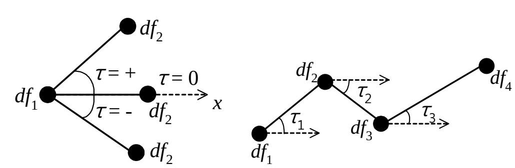
Figure 3: Example of morphology

3.1 Morphology of Line Feature

The morphological analysis depends on the role of line feature, whether it is the defensive line, mid-fielder line or forward line. And it also depends on the formation, whether it is 4-4-2, 3-5-2, 4-5-1, etc. In this paper, we assume 4-4-2 formation which is widely used in modern soccer and focus on the defensive line feature. Then the defensive line feature is defined as $DL = (df_1, df_2, df_3, df_4)$ where the i-th defender df_i is located at left side of df_{i+1}.

Morphological classification of 4-back line feature: in this paper, we propose a morphological classification method with the angle θ_i between (df_i, df_{i+1}) and x-axis. Note that df_i is always at the left side of df_{i+1}, θ_i is between -90^o and 90^o. Then we define the type of morphology in terms of (τ_1, τ_2, τ_3), when τ_i is defined as follows (figure 4);

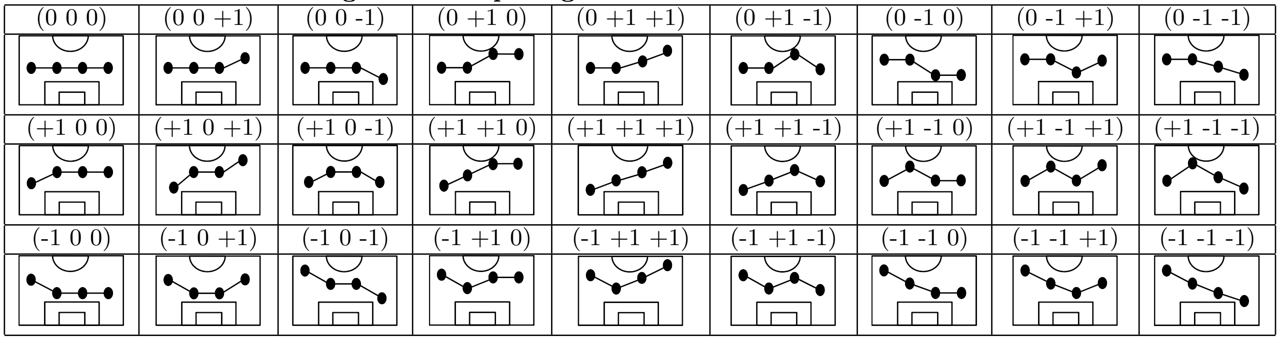
$$\tau_i = \begin{cases} +1, \text{ if } \theta_i > 0^o \\ 0, \text{ if } \theta_i = 0^o \\ -1, \text{ if } \theta_i < 0^o \end{cases}$$



(a) τ_i (b) (τ_1, τ_2, τ_3)

Figure 4: Definition of τ

Figure 5: Morphological classification of line feature



When we determine whether $\tau_i = 0$, a small value of tolerance ϵ_θ is given. According to our empirical work, $\epsilon_\theta = 10^o$ is proper, and $\tau_i = 0$ when $-\epsilon_\theta \leq \theta \leq \epsilon_\theta$. As a consequence, we have 27 morphological types as shown in figure 5. This classification of morphology is very useful in analyzing defensive tactics and we will show an example of analysis with this classification in section 5.

Morphological measures of 4-back line feature: In addition to the morphological classification, we need morphological measures to describe a line feature in quantitative ways. In this paper, we propose important morphological measures. But they are not complete and other measures may be defined depending on application types.

- width: $w(DL) = max(df_i.x) - min(df_k.x)$
- depth: $d(DL) = max(df_i.y) - min(df_k.y)$
- angle vector: $av(DL) = (\theta_1, \theta_2, \theta_3)$
- distance vector: $dv(DL)$=($||df_1$,$df_2||$,$||df_2$,$df_3||$,$||df_3$,$df_4||$)

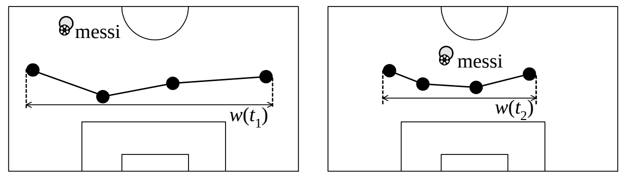
where i and $k \in \{1, 2, 3, 4\}$.

3.2 Spatiotemporal Properties of Morphology

In order to analyze the dynamic aspect of collective features, we need to study spatiotemporal properties of collective feature morphology. Two spatiotemporal properties are discussed in this subsection, which are related with quantitative measures and the evolution of line feature morphology, respectively.

Change of morphological measures for 4-back line feature: the evolution of quantitative measure m is described by the differential value at time t as $f'(t) = \frac{dm}{dt}$. For example, we observe a significant reduction of the width of 4-back line feature, when Messi is approaching to the penalty area as shown in figure 6. Then the reduction rate is described by means of $width'(t)$, which is helpful to understand the reaction of the defensive line against Messi. The evolution of other morphological measures defined in the previous subsection can be described in a similar manner with the differential values.

Change of morphological types for 4-back line feature: Like the change of morphological measures, the evolution of morphological types of a collective feature is also helpful to understand soccer tactics. For example, if the morphological type of a 4-back line feature is changing from the (-1 0 +1)-type to (0 0 0)-type, it may imply that they are preparing an offside trap as shown in figure 7.



(a) Width of 4-back at t_1 (b) Width of 4-back at t_2

Figure 6: Change of width

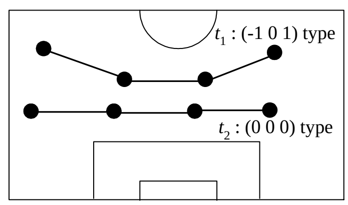


Figure 7: Change of morphological type

The change of morphological type is simply expressed by a tuple (m_{old}, m_{new}, t), where m_{old} and m_{new} are the morphological types before and after t, respectively.

4. MORPHOLOGICAL OPERATORS

In this section, we propose a set of morphological operators based on the discussion in section 3, which serves as the interfaces of the framework for applications. They are classified into spatial operators and spatiotemporal operators.

The set of spatial operators includes the operators for quantitative measures and morphology classifier. The list of operators and definitions are summarized in table 1. However, it is not a complete list and other operators may be appended depending on the requirements.

Note that the operators in table 1 are defined as member functions of each class, such as $LF.depth(t)$, where LF is an object of `Line Feature`. Since every feature in a soccer match is moving except the field object, the operators have a common parameter t to specify the time instance. While

Table 1: Spatial Operators

Classification	Operator
Morphological Measure	- $length(t)$ - $width(t)$ - $depth(t)$
Morphological Type	- $morphology(t) \in M$, where M is the set of 27 morphologies.

the morphological measure operators return the scalar or vector values of each feature, the morphological classification operator returns one of 27 morphology types defined in the previous section.

Spatiotemporal operators are used for the query on the change of quantitative measures or morphological time. They include the functions to retrieve differential values of quantitative measure at a given time instance and to query on the change of morphological types as shown in table 2.

Table 2: Spatiotemporal Operators

Classification	Operator
Morphological Measure	- $length'(t)$ - $width'(t)$ - $depth'(t)$ - $angles'(t)$
Morphological Type	- $is\_morphology\_changed(m_{old}, m_{new}, I)$ where m_{old} and m_{new} are the old and new morphology types respectively

Since it is difficult to compute the differential value of measure $m(t)$ at time instance t, we replace it with the equation, $m'(t) = \frac{m(t_{k+1})-m(t_k)}{t_{k+1}-t_k}$ where t_k and $t_{k+1}(t_k < t_{k+1})$ are two consecutive sampling times. If t is the current time, t_k and $t_{k+1}(t_k < t_{k+1} < t)$ are the most recent sample times. *is_morphology_changed* return a `Boolean` value. It returns `true` if and only if morphology has been changed within the given interval I as the specified old and new status.

5. EXAMPLES

One method to evaluate the performance of striker is to analyze the influence on the defense line. If a striker gives a strong influence on the defensive line, then she/he may be considered as a good striker. In this paper, we evaluate the influence factor of striker on the defense line of the adversary team by counting the number of morphology changes when she/he enters the defensive area which is defined as a convex hull covering defensive line in this paper. If the morphology is frequently changed by the movement of a striker, she/he certainly influences on the adversary defensive line.

Influence Condition: Suppose that p is a striker and DL and DA is the defensive line and defensive area of the adversary team, respectively. We consider that the morphology of DL is changed if

1) DL.`morphology`$(t_k) \neq DL$.`morphology`(t_{k+1}) and
2) p.`spatial_relationship`(DA, t_k)=`Inside`.

Then we count the number of cases where the influence conditions are satisfied for every sampling time t_k. Table 3 shows the result of analysis. Toni (1) of the Italian team gave the most influence on the French defensive line and Henry was the most influential striker of the French team on the Italian defense.

Table 3: Results of Influence Factor Analysis

Team	Player	Number of Morphology Changes
Italy	Toni	1079
Italy	Totti	231
France	Henry	687
France	Zidane	260

6. CONCLUSION

Since a soccer match is composed with 23 moving objects of 22 players and a ball, it is an application area of spatial information science that spatial and spatiotemporal approaches can be applied to tactic analysis. However, few researches of spatial and spatiotemporal analysis have been done for sports tactic analysis. In this paper, we proposed a framework for the tactic analysis of soccer matches based on spatial and spatiotemporal analysis with the trajectories of the 23 moving objects. In particular, we studied spatial and spatiotemporal analysis methods with morphological properties of a collective feature type. In order to validate the usefulness of the framework, we applied it to analysis example with real soccer match, which is the final match of the 2006 World Cup between the French and Italian teams. The results show that the framework is helpful in finding useful information and making soccer tactics.

To the best of our knowledge, this study is one of the first work on the framework for the analysis of soccer tactics with trajectory data and we have a number of research issues for further study. First of all, we need more work on the analysis of collective features, since only line feature type was handled in this paper. Second, the study on performance and accuracy is also important issue for further research, since there are several factors that influence on performance and accuracy of the results of analysis. We expect that the framework could be extended to other sports such as handball, American football, and basketball.

Acknowledgement

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