Trajectory Analysis for Soccer Players

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Abstract

In order to make good strategies, soccer coaches analyze the archives of matches, which can be effectively considered as a set of trajectories. We can extract several useful information by analyzing the trajectories of moving objects, which consist of 22 players and a ball. Since each moving object interacts with others and produces a trajectory, its trajectory has a certain number of relationships with others, which are a basic type of information to make soccer strategies. In this paper, we propose a model to quantitatively express the performance of soccer players. This model is based on the relationships between trajectories of 22 players and a ball and allows to evaluate the performance of several players in quantitative way.

1 Introduction

The performance of a soccer player is usually described by statistics gathered from matches or by intuitive ways of experts. The traditional statistics of soccer games, such as the number of goals, ratio of ball occupation, running distance, etc. are however abstract and insufficient to describe several aspects of performance. The intuitive description on players by experts is also subjective and often lacks of consistency, although it explains some qualitative aspects of players. In order to make a good strategy of soccer game, we need therefore a quantitative model to describe the ability of each soccer player.

The behavioral information of soccer player is classified into two categories, which are motions and movements. The movement of player concerns only the change of positions, while the motion of player includes all types of gestures such as turns, dribbling, and headings except the change of positions. The motion is related only with the individual performance of a player and the movements are related with the collective performance of a team as well. The movements of players and the ball produce the trajectories. For this reason, the trajectory analysis of players and ball gives useful information to make good strategies of team and clarify the contribution of each player to her/his team strategy.

In this paper, we propose a model to quantitatively express the strategic performance of soccer players. Since we focus on the strategic aspects rather than individual performance, our model is based on the trajectories of players and ball and their relationships. Among several possible measures, we will propose four fundamental measures, which are considered as the basic ones.

The rest of this paper is organized as follows. Related work will be presented in section 2. We will investigate the properties of movements of players and ball and derive the requirements of model in section 3. A set of basic definitions concerning trajectories and regions will be given in section 4, and four fundamental measures will be proposed with these definitions in section 5. In section 6, we will present examples of analysis by our model and conclude the paper in section 7.

2 Related Work

A comprehensive and introductory explanation is given about the scientific analysis of soccer and soccer players in [1]. The analysis methods presented in this book are mostly based on physics and statistical data. By statistical analysis, we cannot however fully understand every aspect of soccer players. We need more accurate models to describe their performance in detail, one of which is by the trajectories of players and ball.

For this reason, a certain number of work have been proposed for the analysis of trajectory of players. These studies cover two important topics, which are 1) the collection of trajectories and 2) the analysis of trajectories.

For the first topic, a number of work have been proposed to detect and track the motions and movements of players and ball from video data. In [2], a trajectory-based algorithm was proposed for automatically detecting and tracking ball from soccer video. While this method was intended only for the detection and tracking of ball, another tracking method based on graph representation was proposed to discover the trajectories of players from video data in [3] and an interesting method for extracting trajectories from video with white lines of play field was also proposed by [4]. Other studies on this topic are found in [5] [6] [7]. A review on extraction methods of motions and movements is given in [8]. Even though these methods cannot completely extract trajectories of ball and players due to several problems such as collisions, a large part of trajectories can be automatically collected by them.

In comparison with the first topic, few attention has been paid on the second topic, which is for the analysis of movements of soccer players except [9] and [10]. In [9], a quantitative model was proposed to evaluate the ability of space management and cooperative movement in soccer by means of two factors, minimum moving time pattern and domain region. Another interesting model to evaluate the strategic ability of soccer team was proposed by [10]. This model first introduces the notion of dominant region of player and then divides the soccer field into a number of cells of voronoi diagram to define dominant regions. Although these methods introduced measures to quantify the performance of players and team, they still remain primitive and do not fully exploit the nature of trajectories such as relationship analysis between trajectories.

A more elaborate model of the relationships between players was proposed in [11] for analyzing basketball defensive strategies. In order to describe the local defensive movements of basketball players, they explored the spatio-temporal relationship extracted from video clips. This approach seems very attractive even though it concerns basketball. But their model is based on static relationships extracted from clips rather than trajectories and does not fully deal with the movements of players and ball.

In [12], an interesting study was presented on the discovery of meaningful pass patterns and sequences from time-series soccer record data. For example, we can discover some interesting pass patterns that may be associated with successful goals by this model. It focuses on time-series record data rather than trajectory data.

While a number of studies have been performed to describe the performance of players and analyze the strategy of soccer game, no rigorous model has been proposed for the relationship analysis of trajectories in soccer games. The objective of this paper is to provide a basis of formal model to analyze the relationships between trajectories of soccer players.

3 Trajectory in Soccer

There are 22 players and a ball in a soccer match and they produce the trajectories of a match by interacting with others. In order to analyze the relationships between trajectories of soccer players and ball, we need to fully understand their properties. The properties that we have taken into account for the study are listed as follows.

- The trajectories of players and ball are limited by the soccer field and playing time.
- The status of player is divided into *BP* (*Ball Possession*) and *non-BP*. The ball can be possess by at most one player. The player possessing the ball is called dribbler.
- When a player possesses the ball, the ball trajectory is determined by the dribbler.
- The trajectory of each player and ball is continuous within a *playing unit* (*PU*), where no break happens during a PU. It is evident that there are at least two PUs in a match, which is broken by half-time break. In practice, a match consists of more than two PU.

According to the possessing of the ball, we define receiving time, kicking time, dribbling interval as shown by figure 1. The time for BP is bounded by the receiving time $t_{receive}$ and kicking time t_{kick}.

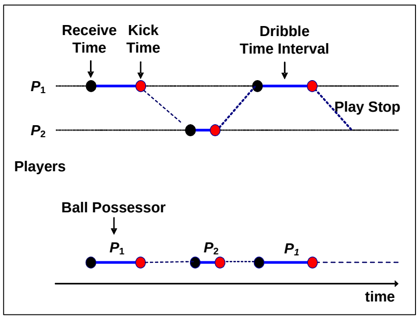

Figure 1. Receiving, kicking and dribbling

4 Trajectory and Moving Regions

In this section, we give a number of definitions, which are to be served as the basic concepts for the analysis of trajectory relationships.

4.1 Possible Region

A soccer player has to decide what to do at every moment during a game and the quality of the decision depends on his intelligence and physical ability. The performance analysis of soccer players is therefore a study about what a player should do and what she/he actually did during a soccer game. What she/he has done can be deterministically extracted from her/his trajectory of the game. There is however a kind of uncertainty about what she/he must do at a given instance.

In order to handle this uncertainty, we introduce *possible region*, which means the region where a moving object be possibly located at a given time. Once the location of a moving object m is given at time t_0, we can estimate the possible region of m at t ($t \geq t_0$). While the trajectory of moving point forms a curve in spatio-temporal dimension, the trajectory of a possible region is a three dimensional shape with volume. We denote the possible region at time t as $PR(m, t_0, t)$, where m is a moving object.

Definition 1 *Possible Region*
$PR(m, t_0, t)$ *is the region where moving object* m *could be possibly located at* $t(t_0 \leq t \leq t_0 + \mu)$ *expected at* t_0*, where* μ *is the observation duration constant.*

Figure 2 shows an example of possible region in spatio-temporal dimension. In general, the trajectory of possible region in spatio-temporal dimension forms a cone, since the location of moving object is fixed at the initial time and it expands from the initial point according time. Note that it is necessary to limit the maximum time by a upper limit $t_0 + \mu$, to avoid the meaningless increase of possible region. The observation duration constant μ depends on the speed of ball and players. For example, μ=2 sec. is empirically reasonable.

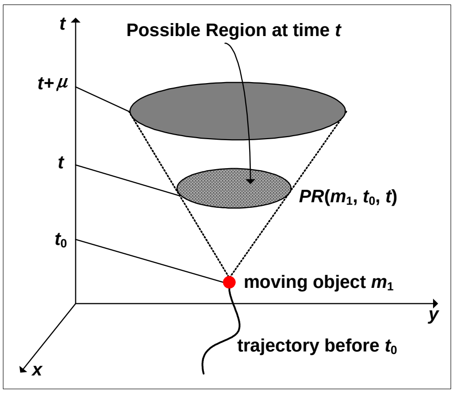

Figure 2. Example of Possible Region

There are two types of pPossible regions, *player possible region* (PR_P) and *ball possible region* (PR_B). Possible region depends on several factors such as velocity, orientation, acceleration, intention, etc.. The computation of possible region is beyond the scope of this paper of the movement.

4.2 Kicks

The interaction between players in soccer games consists of passes from a kicker to a receiver. For this reason, kicks and receives are basic elements in soccer games and we define kicks and receives as follows.

Definition 2 *Kicks*
A kick by player p *is a tuple* (p, t_{kick})*, and the set of kicks is defined as* $KX(p) = \{(p, t_{kick})\}$.

We can define receives by similar way but omit the definition in this paper. Note that a shoot or failed pass have only a kick, while a pass is bounded by a kick and receive.

It may be important to extract kicks and receives from the trajectories of players and ball. As shown by figure 3, we can extract the kick and receive times $t_{kick}, t_{receive}$ by giving a threshold value r for the distance between a player and the ball.

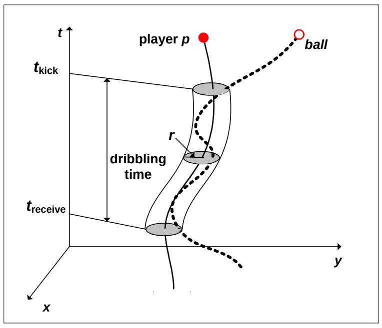

Figure 3. Extraction of Kicks from Trajectories

In practice, there are however several cases where the possessor of the ball is not clear and we need manual interpretation to decide the ball possessor. In this paper, we will not discuss on this issue for the reason of simplicity.

4.3 Catchable Regions

Passes in soccer game are an essential part of team play and we need a model to describe the interaction between players in terms of pass. In this subsection, we introduce a concept to describe more accurately the relationship between players via pass.

When player m_1 kicks the ball to another player m_2, we can compute the possible region where the receiver m_2 can get the ball, which is called *catchable region*. We denote the catchable region at time t ($t_{kick} < t$) as ($CR(k, p, t_{kick}, t)$), where k is the kicker, p is the potential receiver, and t_{kick} is the kicking time. In fact, the catchable region is a kind of possible region which can be defined as the intersection of ball possible region and player possible region as the following definition.

Definition 3 *Catchable Region*
The catchable region of potential receiver p *at* t *from*

kicker k *at* t_{kick} *is defined as* $CR(k, p, t_{kick}, t) = PR_B(k, t_{kick}, t) \cap PR_P(p, t_{kick}, t)$.

Figure 4 shows an example of catchable region. If the pass is actually made on the catchable region of player p, then p can receive the ball.

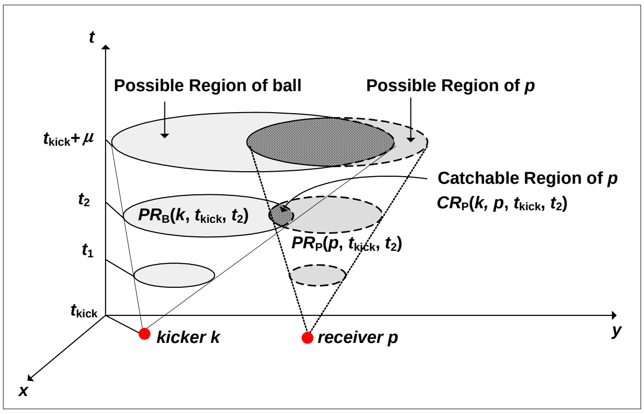

Figure 4. Example of Catchable Region

4.4 Competing Region and Safe Region

If a pass is made to a region where only a player of our team can get the ball, then it can be considered as a good pass. However, it must be a bad pass if it is made into a region where more than two players can get the ball. For this region, we define *Competing Region*(OR) and *Safe Region*(SR) of pass, which are illustrated in figure .

For example, the ability of midfielder can be measured by the ratio of the passes in safe regions. By similar reason, the striker with a high ratio of getting the ball in competing regions must be a good player. We will give these definitions in the next section.

Definition 4 *Competing Region*
The competing region of a player p *at a given time* t *for the ball kicked by kicker* k *at* t_{kick} *is defined as*

$$OR(k, p, t_{kick}, t) = CR(p) \cap (\bigcup_{q \in T_{opp}} CR(k, q, t_{kick}, t))$$

where $CP(p) = CP(k, p, t_{kick}, t)$, *and* T_{opp} *is the set of adversary players.*

Definition 5 *Safe Region*
The safe region of a player p *at given time* t *for the ball kicked by kicker* k *at* t_{kick} *is defined as*

$$SR(k, p, t_{kick}, t) = CR(p) - (\bigcup_{q \in T_{opp}} CR(k, q, t_{kick}, t)).$$

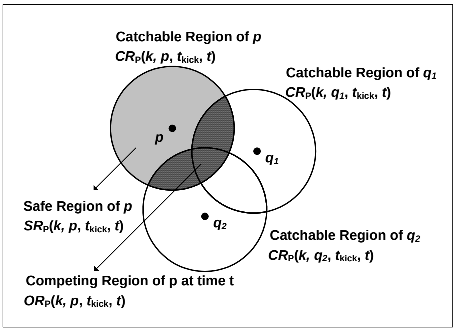

Figure 5. Competing and Safe Regions

5 Performance Measures of Player

In this section, we propose a set of performance measures based on the definitions given in the previous section. In addition to the measures to be defined in this section, we can introduce other measures by similar ways.

The first measure is related with catchable region. It is evident that a player with a large area of catchable reason is a good player, since she/he can receive passes relatively with ease. For this reason, we define catchable area as follow,

Definition 6 *Catchable Area*
The catchable area of player p *for a pass kicked by player* k *at time* t_{kick}, *is defined as*

$$CA(k, p, t_{kick}) = \frac{1}{\mu} \int_0^{\mu} area(CR(k, p, t_{kick}, t_{kick}+t))dt$$

where μ *is the observation duration constant.*

We define the average catchable area of player for a entire match to give more significant measure. The player with a large average catchable area lets other players of her/his team give passes easily.

Definition 7 *Average Catchable Area*
The average catchable area of player p, $ACA(p)$ *is defined as*

$$ACA(p) = \frac{\sum_{k=1}^{N} CA(p_k, p, t_{kick,k})}{N}$$

where p_k *and* $t_{kick,k}$ *are the kicker and time of the* k*-th kick respectively, and* N *is the total number of kicks for a match.*

By similar way, we can define the safe area and average safe area of player. These measures are rather intended to evaluate the performance of offenders than defenders. In fact, they describe the ease of pass more precisely than the catchable area or average catchable area.

Definition 8 *Safe Area*
The safe area of player p for a pass kicked by player k of our team at time t_{kick}, is defined as

$$SA(k, p, t_{kick}) = \frac{1}{\mu} \int_0^{\mu} area(SR(k, p, t_{kick}, t_{kick}+t))dt.$$

Definition 9 *Average Safe Area*
The average safe area of player p, $ACA(p)$ is defined as

$$ASA(p) = \frac{\sum_{k=1}^{N_{OUR}} SA(p_k, p, t_{kick,k})}{N_{OUR}}.$$

Note that N_{OUR} is the number of passes by our team, and we count only the passes kicked by our team in the following definition 9, since the pass from the adversary team does not make sense.

While offenders should try to make a large area of safe region, defenders are trying to make a large area of competing region for preventing the offenders of adversary team from safely receiving passes. We therefore propose the third measure intended to describe the performance of defenders as follows.

Definition 10 *Competing Area*
The competing area of player p for a pass kicked by player k of the adversary team at time t_{kick}, is defined as

$$OA(k, p, t_{kick}) = \frac{1}{\mu} \int_0^{\mu} area(OR(k, p, t_{kick}, t_{kick}+t))dt.$$

Definition 11 *Average Competing Area*
The average competing area of player p, $AOA(p)$ is defined as

$$AOA(p) = \frac{\sum_{k=1}^{N_{OPP}} OA(p_k, p, t_{kick,k})}{N_{OPP}}.$$

Note that N_{OPP} is the number of kicks by the adversary team.

While the safe area and the average safe area describe the performance of receiver, we need another performance measure for the kicker. The ratio of safe passes is intended in the definition for this purpose.

Definition 12 *Safe Pass Ratio*
The safe pass ratio of player p, $SPR(p)$ is defined as

$$SPR(p) = \frac{n(KX_{SAFE}(p))}{n(KX(p))}$$

In the definition 12, $KX_{SAFE}(p) = \{(p, t_{kick}) | \exists\, t\ (\geq t_{kick}), q \in T_{OUR}, p_B(t) \in SR(p, q, t)\}$ is a subset of $K(p))$, such that contains only the passes on the safe region, where $p_B(t)$ is the position of the ball at time t and T_{OUR} means the team of player p. Note that safe pass does not mean that this ball is to be received by our team.

6 Experiments

We performed an experiment to validate the performance measures proposed in this paper. For the experiment, we collected the trajectories of players and ball from a soccer simulation game, since the real data is difficult to acquire due to not only technical problems but also license issues. The positions of players and ball are gathered by every 0.2 second to extract the trajectories. And we observed several statistics such as average ball speed, player's speed, acceleration, etc. to determine the parameters, which are not explained in this paper, but to be used for the experiment.

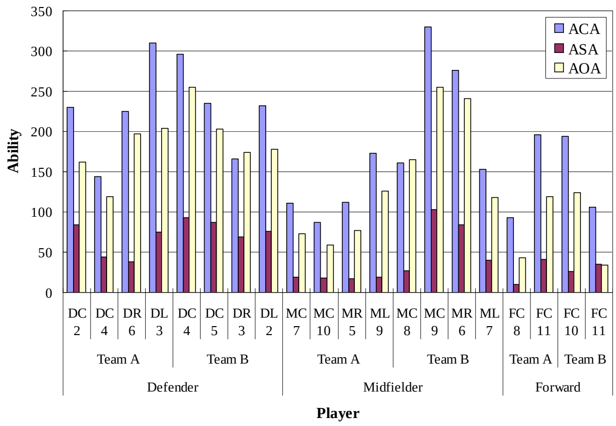

Figure 6. Experiment for ACA, AOA, and ASA

Figure 6 shows the results of experiment for the average catchable area, average competing area, and average safe area of each player. It describes a lot of information about the performance of players. For example, let us compare the performances of DL3(Defender Left) of team A and DC4 (Defender Center) of team B. Since DL3 has larger ACA than DC4, she/he is at more proper distance from the ball possessor than DC4. But since DL3 has a smaller ASA than DC4, she/he is more pressed by the adversary than DC4. And DC4 has a larger AOA than DL3, she/he is better defender than DL3, because she/he presses the offenders of the adversary team. The safe pass ratio of each player is shown by figure 7.

7 Conclusions and Future Work

Soccer game, like other sports games, is a typical area of applications of moving objects, even though it has not been tried. For example, it would be very useful to analyze the trajectories of players to study the strategy of soccer games. In this paper, we proposed a model to analyze and evaluate the performance of players in quantitative ways. By

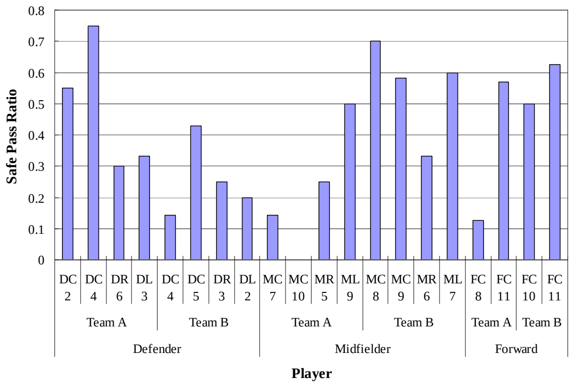

Figure 7. Experiment for Safe Pass Ratio

our model, which is based on trajectories of ball and players, we can extract useful information to make strategies of soccer games. In particular, several performance measures are introduced to analyze the performance concerning the interactions between the players of the same team and of adversary.

Since our work is just a starting point of the study on the analysis of trajectories for sports games, the future work includes several topics. First, we should extend our model to extract more useful and complex information from trajectories, because it only provides the basic primitives. Second, it is possible to apply our model to not only soccer games but also similar sports games with ball such as handball, hickey, and basket ball. Third, it would give interesting results if we analyze the relationships between important events like goals and the performance measures proposed by this paper with real data. Finally, we did not deal with the performance issues of processing in this paper. It is however evident that a number of join operations are required to compute catchable regions, competing regions etc. We should develop algorithms to reduce the processing time for join operations.

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