QUANTITATIVE MEASUREMENT OF TEAMWORK IN BALL GAMES USING DOMINANT REGION

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ABSTRACT

This paper proposes a basic feature for quantitative measurement and evaluation of group motion in team sports. This feature called dominant region is a sphere of influence of each player or each team (the space where the player or the team is superior to others). Basic teamwork in ball games such as cooperative movement, space making and ball passing by players can be evaluated quantitatively by using dominant regions and their time variation. In the paper, the dominant region is applied to two different ball games; soccer games and handball games, in order to verify its applicability. How to use the dominant region in calculation of some basic teamwork is presented. From the experiments using actual games scenes, it is shown that the dominant region can be commonly used to quantitatively evaluate inferiority or superiority of teamwork in both soccer and handball games.

1 INTRODUCTION

Many researches concerning evaluation or measurement of human's motion or behavior from video sequences have been reported in various fields. In human's motion or behavior recognition, group motion as well as individual's motion is an important subject. However, a small number of studies has been made on analysis of group motion, compared with that of individual s motion. For example, some approaches for group behavior analysis were proposed by Kawashima et al (1994), Taki et al (1996) and Hosie et al (1998). In our research, a ball game in sports is selected as a concrete subject in group behavior, because the playing area of each individual is limited, the aim of each movement is clear, and the pattern of group movements is comparatively easy to understand. The ball game considered here has two groups (teams) which are composed of the same number of individual (players), and they compete with each other to get a score by moving a ball to the opponent s goal. There are two basic skills used by players in this ball game; one is to move a ball by him/her and the other is to send and receive a ball between the same team. It is necessary for moving a ball up to the opponent s goal to perform these basic plays continuously. Though there are some cases where forcible play or passing with a risk is needed in an actual game, it is in general important, in various attacks or in the recovery of a mistake to perform each play stably. The sphere of influence of each player or each team (the space where the player or the team can be superior to others) is expected as one of the objectives and basic features in order to have a sense of stability. Cooperative movement by several players which results in extension of the sphere of influence can be regarded as a basic group motion (teamwork) in team ball games. Also, cooperative movement in order to remove the sphere of influence of an attacking team by a defending team can be regarded as one of teamwork. So, the movement obtained as a result of each player or team trying to keep their own sphere of influence can be regarded as the competitive movement between teams.

In this paper, we define dominant region as a sphere of influence for each individual by modifying the Voronoi region. Then we present a motion analysis system for teamwork evaluation as an application of the dominant region to the sports field.

2 DYNAMIC SPHERE OF INFLUENCE

The space around each individual as stated above can be considered as a kind of sphere of influence. Generally, given a set of points in a space, spatial territory of each point can be expressed by the Voronoi region [Okabe et al (1992)]. We formulate this kind of region associated with each individual in group motion by extending the Voronoi region.

2.1 Voronoi Region

Let $\boldsymbol{P} = \{ p_1, p_2, \ldots, p_n \}$ be a set of n-points, $\mathbf{I}\boldsymbol{n} = \{ 1, 2, \ldots, n \}$ be a set of natural numbers and $\mathbf{R}^2$ be a set of real numbers, then the Voronoi region of $p_k \in \boldsymbol{P}$ is defined as follows:

$$\mathrm{V}(p_k) = \{ x \in \mathbf{R}^2 \mid d(x, p_k) \dagger d(x, p_m) \text{ for } m \neq k, m \in \mathbf{I}\boldsymbol{n} \} \tag{1}$$

where p_k indicates both the label and the location vector of the point, and $d(x,y)$ means the Euclidean distance from y to x. The set of Voronoi regions associated with members of P is called the Voronoi diagram, written by

$$\mathrm{W}= (\mathrm{P}) \cup \mathrm{V}(p_k). \tag{2}$$

Then, let $\boldsymbol{P}^{(t)} = \{ p_1{}^{(t)}, p_2{}^{(t)}, \ldots, p_n{}^{(t)} \}$ be a set of n-individuals at a certain time t. The Voronoi region for the individual $p_k{}^{(t)}$ is defined as:

$$\mathrm{V}(p_k{}^{(t)}) = \{ x \in \mathbf{R}^2 \mid d(x, p_k{}^{(t)}) \dagger d(x, p_m{}^{(t)}) \text{ for } m \neq k, m \in \mathbf{I}\boldsymbol{n} \} \tag{3}$$

This can be regarded as a kind of sphere of influence for each individual at the moment t, but it is no more than a static sphere of influence based on the distance.

2.2 Dominant Region

In an actual group, each individual moves with changing direction and speed according to their own physical ability. It is better for practical reasons to define the sphere of influence based on the shortest time rather than the distance in a dynamic environment like this. The sphere of influence of the individual $p_k{}^{(t)} \in \boldsymbol{P}^{(t)}$ is defined again as follows:

$$\mathrm{D}(p_k{}^{(t)}) = \{ x \in \mathbf{R}^2 \mid t_s\,(x, p_k{}^{(t)}) \dagger t_s\,(x, p_m{}^{(t)}) \text{ for } m \neq k, m \in \mathbf{I}\boldsymbol{n} \} \tag{4}$$

where $t_s\,(x, p_k{}^{(t)})$ called shortest time is the time necessary for the individual $p_k{}^{(t)}$ to move from his current position to the point indicated by x, on condition that the individual move with all his might. Also a set of shortest time for all positions is called shortest time pattern . That is, $\mathrm{D}(p_k{}^{(t)})$ is a region where the individual p_k can arrive earlier than any other individual when starting at t. This region called the dominant region of the individual p_k at the moment t. Though the dominant region is defined only by replacing the distance d with shortest time t_s , it is greatly different from the Voronoi at a point where the dominant region can express a sphere of influence based on each individual s movement and physical ability. In the same way, it is also different from what is called the weighted Voronoi region replacing the distance d with a linear function of d. When person in $\boldsymbol{P}^{(t)}$ are divided into two teams, a single region obtained by merging dominant region of all persons in the same team is called team dominant region of the team.

Figure 1 shows examples of dominant region formed by two players movements. As seen in the figure, the borders of dominant regions are not always linear, and the dominant region for one player does not generally become a single region. For practical computation of dominant region, you can see in Taki et al (1999)

3 BALL GAME ANALYSIS USING DOMINANT REGION

In actual group ball games, space management , ball passing and cooperative movement can be considered as significant factors in teamwork. We suppose here that good teamwork include cooperative movements of players with the purpose of making ball passing easier and getting more space to do it stably. Then, such group motions by players can be evaluated by using the dominant region proposed in the previous chapter. The system consists of two parts; motion analysis and teamwork evaluation. In the motion analysis part, a sequence of a game taken by several cameras is digitized, and static objects such as lines or goal posts on the playing ground and moving objects such as players or the ball are extracted and tracked respectively from each camera scene. Then players positions extracted from all camera scenes are transformed and merged into a playing field space. In the teamwork evaluation part, cooperative movement and ball passing by player, are quantitatively evaluated using the results of motion analysis. The final results are visualized as 2D and 3D animation.

3.1 Application to soccer games

3.1.1 Teamwork analysis

In this section, basic teamwork such as cooperative movement, ball passing and pressure works using dominant region, and shortest time pattern as stated above, are evaluated quantitatively.

Evaluation of space making: Increasing or preserving dominant space in both attacking and defending is most important and basic teamwork. So, for quantifying the space, the area of team dominant region and its time variation are used as a criterion. It is possible for flexible evaluation to give the degree of significance as a weight to each point on the dominant region based on the positional relation such as the distance between the point and a goal point.

Evaluation of ball passing: In evaluation of ball passing, it is very important to know whether a pass will be successful or not. Here we suppose that a pass is considered successful if the first player who can receive the passing the ball belongs to the same team. Not only the actual pass but also a simulated pass can be evaluated here. It is necessary in pass evaluation to compare the shortest time of all players with that of the ball at each point. The shortest time of the ball is the same formally as that of player. But the motion of the ball projected on the field space is considered to be approximately straight, and the shortest time is assigned only to points on the straight line. The ball can be received at the first point where the shortest time of the ball becomes greater than that of a player. Then, if the player belonging to the same team dominates the point, the pass can be evaluated as good.

Evaluation of pressure works: Putting psychological pressure on the opposite team is also a basic and effective tactics in both attacking and defending. We consider here only pressure directly caused by spatial factors, for example, density of players, distance from the goal and distance from the ball.
Pressure for player p_k is evaluated by linear combination of each factor;

$$Sp_k = l \cdot Dp_k + m \cdot Bp_k + n \cdot Pp_k \quad (l+m+n=1) \tag{5}$$

where Dp_k is the pressure concerned with distribution of dominant regions around the player, Bp_k is that caused by the distance between the ball and the player, Pp_k is that caused by the distance between the player and the goal point, and *l, m, n* are weights, respectively. Here, Dp_k, Dp_k and Dp_k are calculated by

$$Dp_k = 1 - \frac{T_r}{S_r} \tag{6}$$

$$Bp_k = 1 - \frac{d}{D} \tag{7}$$

$$Pp_k = 1 - \frac{g}{G} \tag{8}$$

Sr means the area of a circle around the player, *Tr* means the area of team dominant region of the player within the circle. *d* is the distance between the ball and the player, *D* means the maximum length of *d*. *g* is the distance between the goal point and the player and *G* means the maximum length of *g* on the field.

3.1.2 Experimental Results

In this section, the system as stated above is applied to actual soccer game scenes taken by common cameras. Four cameras are set in the upper row in a stadium and half of the soccer field is covered without a blind spot. Digitized image has width = 640 [pixel], height = 480 [pixel] and the number of gray level = 256, and its one pixel is equivalent to from 25 [mm] to 60 [mm] on the soccer field. It has enough image resolution, because the radius of ball that is the smallest object for tracking in this system is 220 [mm]. In this experiment, five sequences selected from two different games are processed. Each sequence is about 15 seconds, and in three scenes the attack advances up to the front of the opponent s goal and in two scenes the attack advances up to the middle range of the opponent s side and then the offense and defense are reversed.
For tracking of a player, stable results were obtained except in some occlusion cases. There were some cases where tracking worked well, but there were many failures in case that the players were completely occluded by other players. Also, tracking results become unstable when a player s posture is changed severely or when a player crosses some lines on the soccer field. In these cases, manual correction was performed.
Figure 2 shows examples of game scenes reproduced and animated from the tracking results, with mapping team dominant regions on them. By observing such a scene from arbitrary viewpoints, we can inferiority or superiority for the team visually. Figure 3 shows the change of the area of the team s dominant region of attacking and the defending team, respectively, and the horizontal axis means the frame number and the vertical axis means the area (the amount of the pixel dominated by the team). In the figure, the area of attacking team s dominant region increases in spite of on the opponent s side and then excels that of another team finally. That is, as for cooperative movement, it can be evaluated

that the teamwork of the attacking team was superior to that of the defending team, in the scene where the attacking team actually made a goal. It was very remarkable for the change of the dominant region in this example, and but in other examples same tendency was obtained. But in another example the tendency could not be obtained.

Figure 9 shows a result of pass simulation used in pass work evaluation. A white small circle in the figure indicates a player s position and a white line segment shows a dominant region of the ball passed to each of 36 directions. A player with the dominant region in which the end of the line segment is included can receive the ball. Figure 5 shows an example of pressure evaluation results by computer and human for a defensive player. The results by computer and human are almost similar up to about 300 frame, but in the latter part of this sequence there are some disparities in evaluation. The main reason is that this player missed a kick for clearing the ball just at the front of the goal of his own team. This means that there is a psychological factor that is very hard to evaluate by spatial features. However, we think that the evaluation method proposed here can be used for teamwork analysis except evaluation of such as psychological factor.

3.2 Application to Handball games

In this chapter, as another application we try to analyze teamwork in handball games. Basic ideas for motion analysis and teamwork evaluation are almost same as used in soccer game analysis. However, how to use the dominant region in the evaluation step is different from that case.

Figure 2 An example of 3-D animation with team dominant region. (Dark regions indicate the team dominant region of the attacking team)

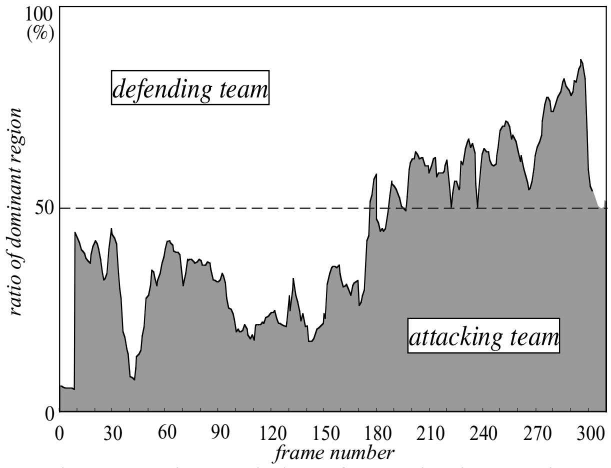

Figure 3. Time variation of team dominant ratio for the attacking team.

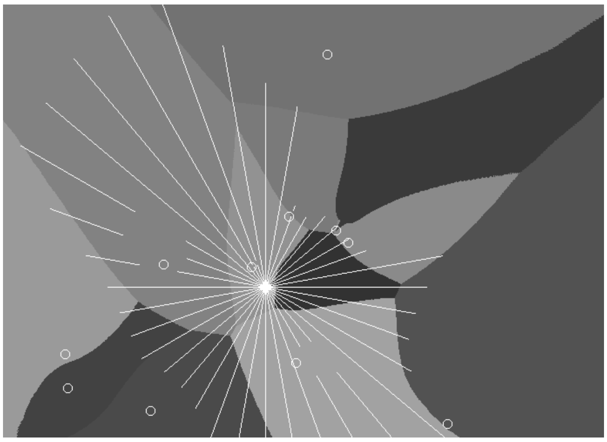

Figure 4. A result of pass work evaluation. (A white small circle indicates a player s position and a white line segment shows the dominant region of the ball)

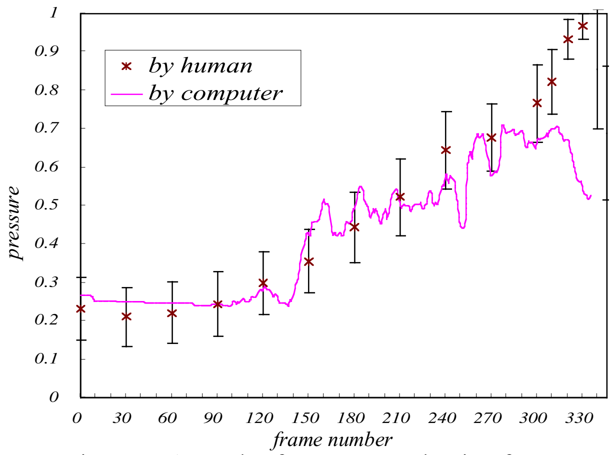

Figure 5. A result of pressure evaluation for a defending player by computer and by human.

3.2.1 Teamwork Evaluation

The attacking style in handball games is classified into two types. One is the quick attack that a player cuts the ball from opponent s team and then attack the goal without stopping, the other is the set attack that players break the defense line by quickly passing and then attacking the goal. The latter called cut-in-play is a basic teamwork used most frequently in handball games. Because all players except the goalkeeper must keep out of the goal area, the ball is shot from near the goal area line. So, it is desired for the attacking team to take many dominant areas around the line because it will become easy to shoot the ball. Based on the above consideration, we focus only the zone between the free throw line and the goal area line, as shown in figure 6, and call the zone interest zone . For evaluation of the teamwork quality in handball games, some features are proposed here.

The number of shooting points: Generally, if there are many points to make a shot, the possibility of the goal surely becomes high. Because the dominant regions of a player show the place where the player can arrive earlier than any other players, the player can make a shot from any points on the dominant region. Then, we use the number of connected components of the team dominant region where exists in the interest zone, and adjoins the goal area line. For example, three regions are observed in figure 6.

The spaciousness for stable play: For attacking team, the spaciousness around the goal area line shows that the team or the player can play stably from both technical and mental points of view. So, the ratio of the total area size of connected components of the team dominant region where exists in the interest zone, and adjoins the goal area line is used. In figure 6, the area size of *i*-th connected component is represented by S*i*. So, the ratio of the total area size to the interest zone is given as follows.

$$R_S = \sum_{i=0}^{N} S_i \Big/ S_{\max} \qquad (9)$$

Where N means the number of connected components and $S_{\max}$ means area size of the interest zone, respectively.

The variety of shot: It becomes possible to make a shot using various techniques from different directions, if there are many shooting points on the goal area line, because the shot from on the goal area line cannot be obstructed by other players except the goalkeeper. Then, the ratio of the dominated length on the goal area line by the attacking team or the defending team is used. The ratio of the dominated length to the length of the goal area line is given as follows.

$$R_v = \sum_{i=0}^{M} L_i \Big/ L_{\max} \qquad (10)$$

Where L*i* means the length of *i*-th segment on the goal area line, M means the number of the segments and $L_{\max}$ means the length of the goal area line, respectively.

3.2.2 Experimental Results

In this experiment, two characteristic scenes in a handball game are used. One is a scene where the attacking team gets a goal without stopping from goal throw (a case of quick attack), and the other is a scene where the team makes a shooting chance using some short passes around the goal area line and then gets a goal (a case of set attack). Figure 7 and Figure 8 show some examples of team dominant regions obtained from each scene, respectively.

Figure 9 and figure 10 show the time variation of each feature mentioned above. In figure 9, the value of each feature become high quickly, because the defending players could not back in their defending position and let the attacking players play freely. On the other hand, in figure 10, the value of each feature is low entirely, because the defending player stood in the attacking players way along goal area line.

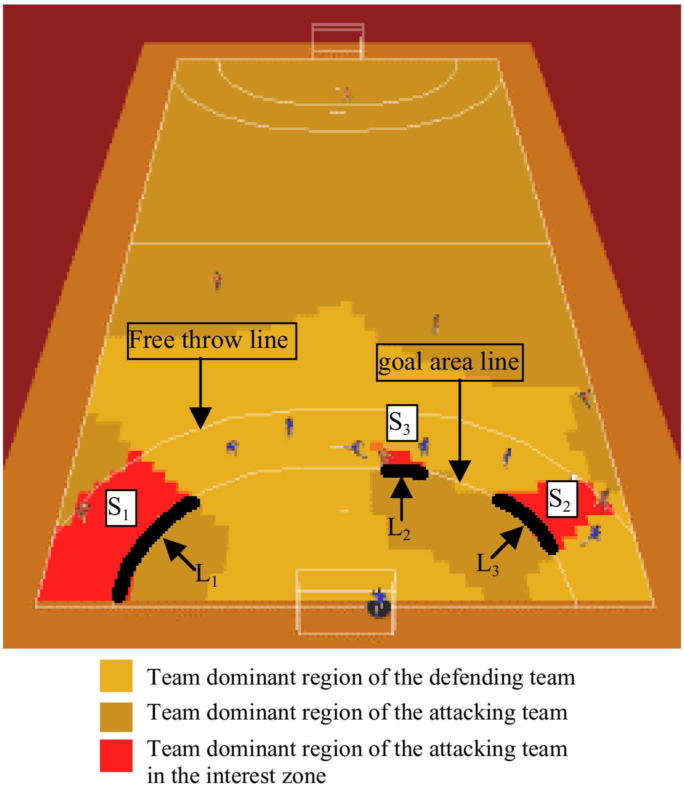

Figure 6. Examples of dominant region formed by two players movement.

However, there is a part with very high values of all features in figure 10. This means that the attacking players broke the defense line. After that, they really took a shooting chance around the goal area line. From these results, it was confirmed that the value and its time variation of each feature used here could be good criteria for evaluation of teamwork in handball games.

4 CONCLUSIONS

In this paper, a dynamic sphere of influence called dominant region and its application to group motion analysis in team sports were presented. From the experimental results using actual soccer and handball games, it was found that the dominant region could be used to quantitatively evaluate inferiority or superiority for each team s movement. Furthermore, it may be applicable to description and recognition of the states of group motion from the location and the changes of dominant region. The experimental scale is small yet, but the results almost corresponded with those by some professionals. This is meaningful in the sense of giving the first example of quantitative teamwork evaluation in ball games, and the basic idea can be useful for teamwork evaluation of other similar ball games such as hockey, American football and so on.

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REFERNENCES

Kawashima, T., Yoshino, K., Aoki, Y., 1994. Qualitative Image Analysis of Group Behavior. Proc. IEEE Conf. on Computer Vision and Pattern Recognition, pp.690-693.

Taki, T., Hasegawa, J., Fukumura, T., 1996. Development of Motion Analysis System for Quantitative Evaluation of Teamwork in Soccer Games. Proc. IEEE Int. Conf. on Image Processing (ICIP-96), pp. 815-818.

Hosie, R., Venkatesh, S., West, G., 1998. Classifying and Detecting Group Behaviour from Visual Surveillance Data. Proc. 14th Int. Conf. on Pattern Recognition Volume I, pp.602-604.

Okabe, A., Boots, B., Sugihara, K., 1992. Spatial Tessellations Concepts and Applications of Voronoi Diagrams. John Wiley & Sons, New York.

Taki, T., Hasegawa, J., 1999. Dominant region: A basic feature for group motion analysis and its application to teamwork evaluation in soccer games. Proc. IS&T/SPIE Conf. on Videometrics VI, 3641, pp. 48-57.

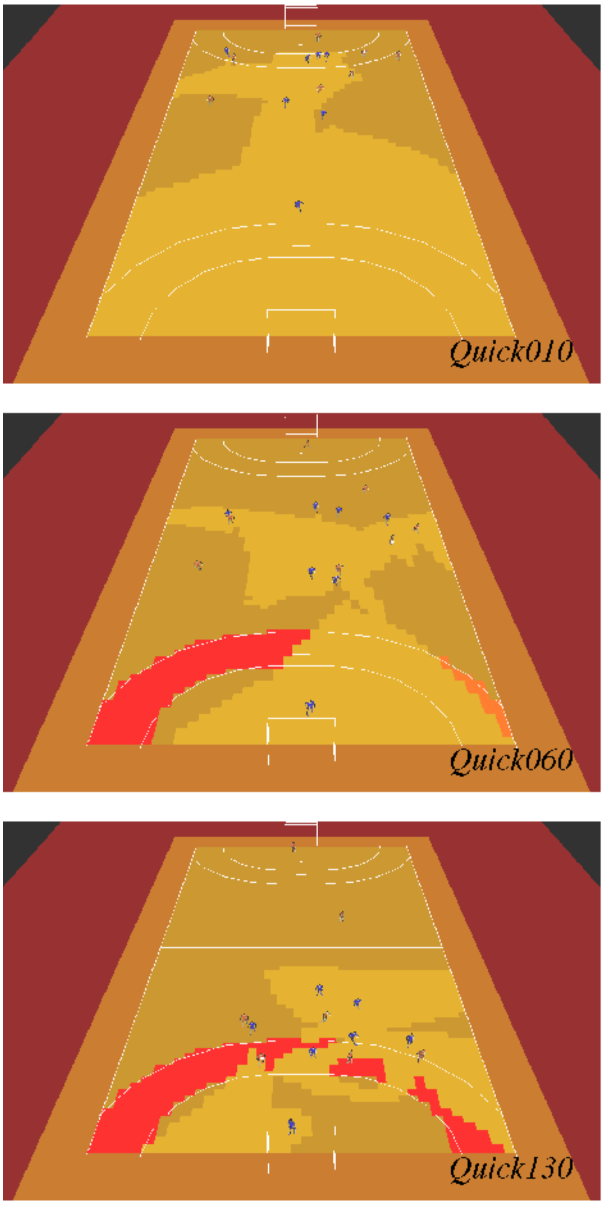

Figure 7. Time variation of the team dominant region in the quick attack.

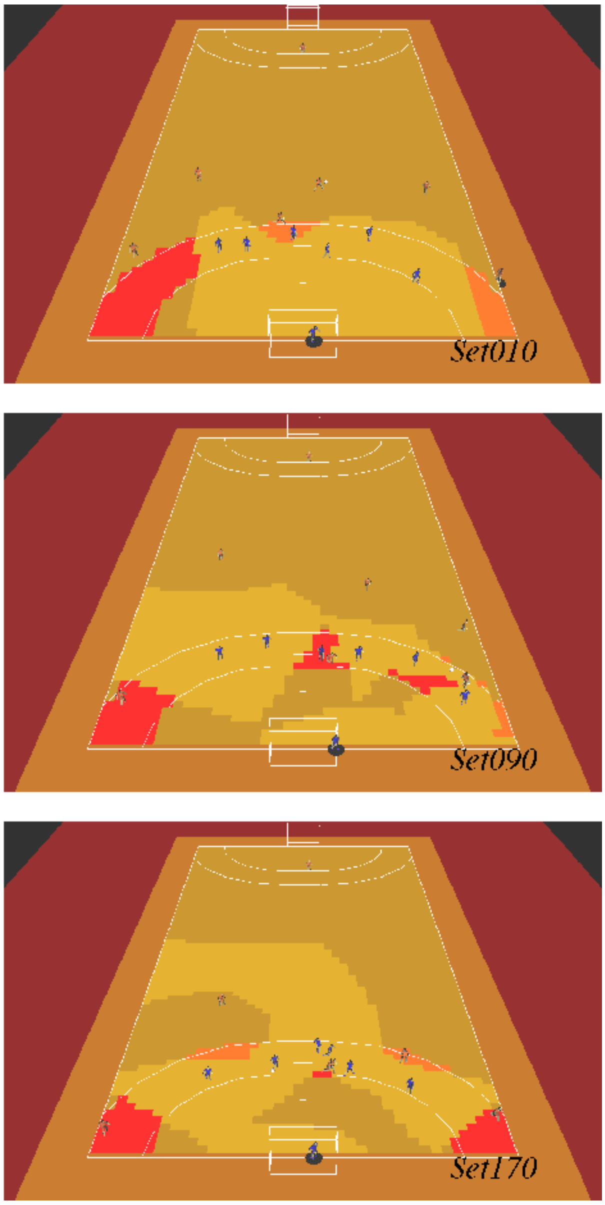

Figure 8. Time variation of the team dominant region in the set attack.

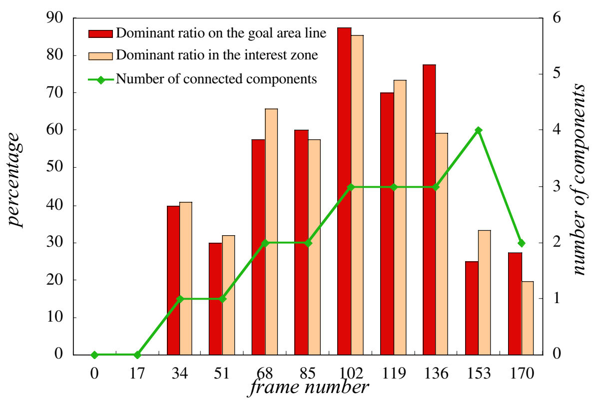

Figure 9. Time variation of each feature in the quick attack.

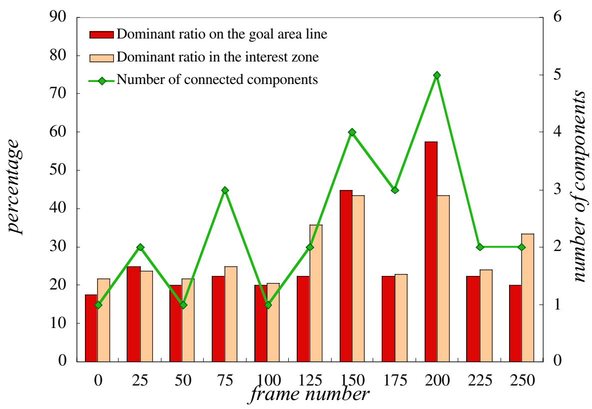

Figure 10. Time variation of each feature in the set attack.