A FEATURE FOR QUANTITATIVE MEASUREMENT AND EVALUATION OF GROUP BEHAVIOR AND ITS APPLICATION

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ABSTRACT

This paper proposes a basic feature for quantitative measurement and evaluation of group behavior of persons. This feature called "dominant region" is a kind of sphere of influence for each person in the group and is defined as a region in where the person can arrive earlier than all of others. In this paper, we present a motion analysis system of soccer games as an application of the dominant region. The purpose of this system is to evaluate the teamwork quantitatively based on movement of all the players in the game. Two major factors for teamwork evaluation; space management and cooperative movement by players are quantified by using the dominant region of each player. The system consists of two parts; motion analysis and teamwork evaluation. In the first part, static objects such as lines on the soccer field and moving objects such as players, referees and the ball are extracted and tracked from motion images taken by several video cameras. Then, the positions of moving objects on the image space of each camera are transformed into, and merged on the soccer field space. In the second part, each player's movement extracted in the first part are measured, and then cooperative movements of players and pass works are quantitatively evaluated. The results are visualized in the form of 2D and 3D animations. From experiments using motion images of actual games, it is suggested that the proposed feature is useful for measurement and evaluation of group behavior in team sports.

1. INTRODUCTION

Measurement and recognition of moving objects using motion images have been attempted actively. Recently, various researches especially for humans are remarkable, and its application to many fields is expected. In human's gesture and motion recognition, not only individual's movement but also group behavior is one of important subject. "Group behavior" is formed when humans and/or animals in a group take action cooperatively or competitively each other for a certain aim. If patterns of such group behavior can be recognized automatically from visual information, it may be applicable to many fields including urban planning, surveillance for security services and sports game analysis. Because of it, recently, some researches for quantitative evaluation of human behavior from video are reported (Taki, 1996 and Kawashima, 1994).

In this paper, we investigate some basic features for quantitative evaluation of group motion. In group motion analysis, the positional relation among individuals in the group and its time variation are very important. So, 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 to the field of sports using the dominant region. We deal with group motion in ball games here because the purpose and range of the group motion are relatively clear. Finally, we apply the system to actual soccer games to show the performance of the system.

2. SPHERE OF INFLUENCE IN GROUP MOTION

The space around each player can be considered as a kind of sphere of influence associated with the player in group motion. We formulate this kind of region by extending the Voronoi region (Okabe, 1992).

2.1 Voronoi Region

Given a set of points in a space, a spatial territory of each point can be often described by the Voronoi region. Let $\boldsymbol{P} = \{ p_1, p_2, ..., p_n \}$ be a set of n points, where $2 \le n < \infty$ and $p_i \ne p_j$ for $i \ne j$, $i, j \in \boldsymbol{I}_n = \{ 1, 2, ..., n \}$, the Voronoi region of $p_i \in \boldsymbol{P}$ is defined as follow.

$$\mathrm{V}(p_i) = \{ x \in \boldsymbol{R}^2 \mid d(x,p_i) \le d(x,p_j) \; for\; j \ne i,\; j \in \boldsymbol{I}_n \} \tag{1}$$

where p_i 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 $\boldsymbol{P}$ is called the Voronoi diagram, written by

$$\mathbf{D}(\boldsymbol{P}) = \bigcup_{p_i \in \boldsymbol{P}} \mathrm{V}(p_i). \tag{2}$$

Then, let n be the number of players and a set of players $P^{(t)} = \{ p_1^{(t)}, p_2^{(t)}, \dots, p_n^{(t)} \}$, where t means a certain time, the Voronoi region for the player $p_i^{(t)}$ is defined as

$$V(p_i^{(t)}) = \{ x \in R^2 \mid d(x, p_i^{(t)}) \leq d(x, p_j^{(t)}) \; for \; j \neq i, j \in I_n \}. \qquad (3)$$

This is regarded as a sphere of influence for each player at the moment t.

2.2 Dominant Region

In an actual game, each player intends to keep or extend his dominant area in the playing ground by moving with changing the direction and the speed according to their own physical ability. Basically, any place is dominated by a player who can come there earlier than others. Therefore, it is better for practical use to define the sphere of influence based on the shortest time rather than the distance. The sphere of influence of the player $p_i^{(t)} \in P^{(t)}$ is replaced as follow.

$$D(p_i^{(t)}) = \{ x \in R^2 \mid t_s(x, p_i^{(t)}) \leq t_s(x, p_j^{(t)}) \; for \; i \neq j, j \in I_n \} \qquad (4)$$

where $t_s(x, p_k^{(t)})$ means the shortest time necessary for the player $p_k^{(t)}$ to move from his current position to the place indicated by x, on condition that the player move with all his might. We call t_s "shortest time". After all, $D(p_i^{(t)})$ is a region where the player p_i can arrive at earlier than any other player with starting at t, and called "dominant region" of the player p_i at the moment t. For calculation of dominant regions, a certain model of player's movement which makes it possible to calculate the shortest time t_s is needed.

When players in $P^{(t)}$ are divided into two teams, a single region obtained by merging dominant regions of all players in the same team is called "team dominant region" of the team. The set of dominant regions associated with all players in $P^{(t)}$ is called "dominant diagram" for $P^{(t)}$. Also, the set of team dominant regions associated with all teams is called "team dominant diagram".

2.3 Shortest Time (ST)

To calculate the shortest time to move from the position of player to the point x, the current position, the current moving vector and the acceleration vector of each player are needed. The current position and the current moving vector can be estimated from motion images, while the acceleration vector should be predetermined by the player's own will and physical ability. Then the accelerating ability is modeled here as acceleration patterns based on the physical ability of an average player. An acceleration pattern consist of all possible acceleration vectors. Our system uses an acceleration model as shown in Fig.1. The model indicated by Fig.1(a) is a simple acceleration model which has the same acceleration strength in every direction, unrelated to the moving speed of the player. While in the model indicated by Fig.1(b), the vector pattern varies with the moving vector of the player. This means that a human can accelerate in every direction with the same strength from standing still or moving at a very low speed, but as the moving speed become high, it becomes hard to accelerate in the moving direction.

2.4 Practical Computation

2.4.1 Approximation in Computing Shortest Time: The computation of shortest time based on the model shown in Fig.1(b) is complicated and takes much cost. So, we adopt the model indicated by Fig.1, approximately. Therefore, the shortest time t_m for the player $p_i^{(t_0)}$ to move to the point x can be obtained by solving the following equation;

$$x = \frac{1}{2} a^{(t_0)} t_m^{\ 2} + v^{(t_0)} t_m + p_i^{(t_0)} \qquad (5)$$

where $v^{(t_0)}$ and $a^{(t_0)}$ mean the moving vector and the acceleration vector of the player.

Because in a sports field as soccer field, the area of action is restricted, the average difference between the approximate value

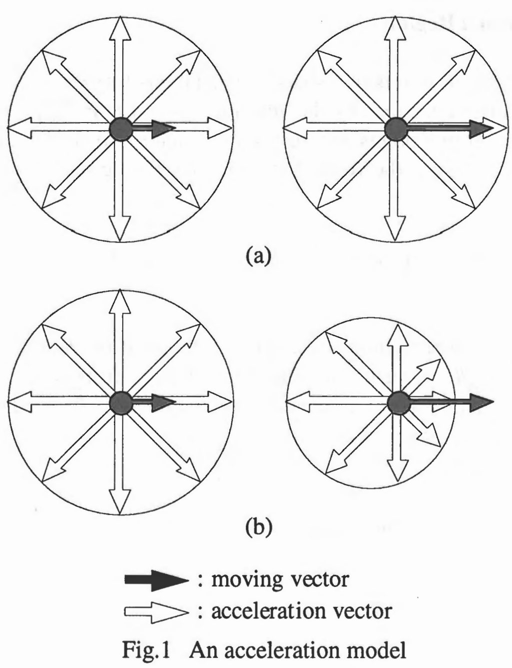


Fig.1 An acceleration model

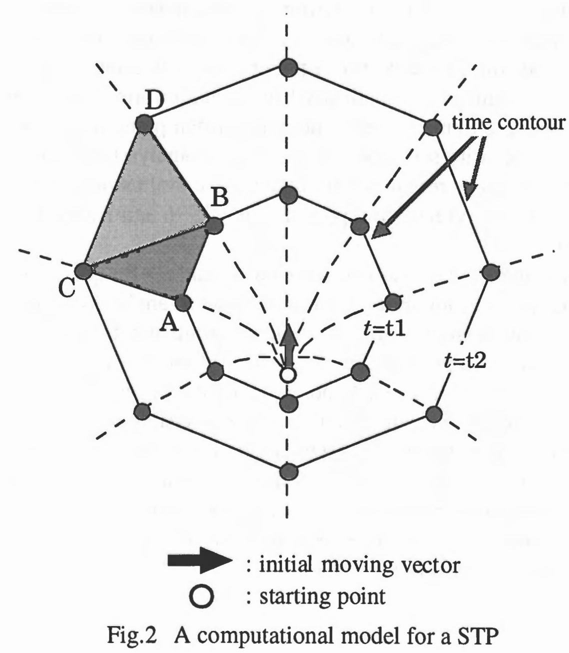


Fig.2 A computational model for a STP

and true value of the shortest time is not so big. The practical procedure for calculation of the shortest time is as follow. First, a digital image is prepared for each player at one moment. Second, compute x based on equation (5), changing the value of accelerating direction and shortest time, and then the pixel value on the image indicated by x is set the shortest time. Third, a pixel which the value is not set is interpolated using some set values as shown in Fig.2. On the occasion that some computational results are obtained for a pixel, the value is replaced by the minimum one. Finally, a digital pattern that each pixel is constituted of shortest time is obtained for each player. We call this pattern "shortest time pattern (STP)" of the player. In other words, STP of the player at a moment is defined as a pattern in which each point has the shortest time to move from that player's current position to that point.

2.4.2 Computation of Dominant Region: The dominant diagram can be obtained as a labeled pattern by a minimum operation for STPs of all players. In the dominant diagram, dominant region of a player p_i has the same label 'p_i'. Fig.3 shows dominant diagram for two players for various strength of acceleration and moving vector. In this figure, the upper-left shows that both strength of acceleration and moving vector are small, and as the figure goes down, the strength of acceleration gets increase, while as the figure goes right, that of moving vector gets increase. As seen in the figures, borders of dominant regions are not always linear, and the dominant region of a player is not always a single connected component.

3. APPLICATION TO TEAMWORK ANALYSIS IN SOCCER GAMES

In any team sport, it is important to evaluate the teamwork of players as well as the individual work of each player. A motion video of an actual game is very helpful for evaluating such cooperative works. However, motion image analysis by persons requires much

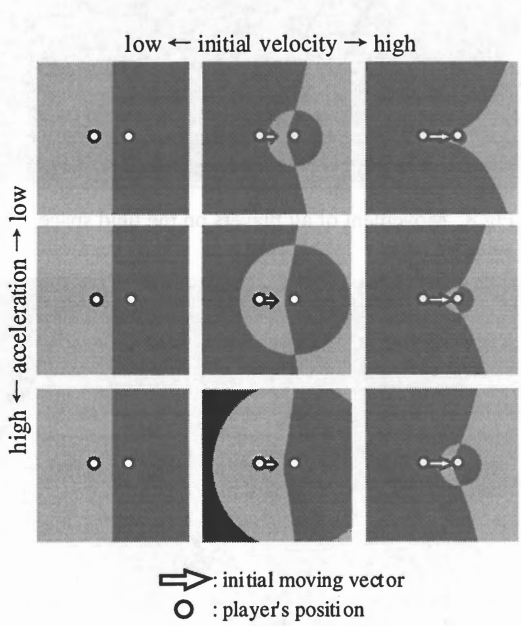


Fig. 3 Exmaples of varying dominant regions for some different initial moving velocity and acceleration.(White circles and arrows indicate the initial positions and moving vectors of players, respectively.)

time and a great deal of labor. Also it is hard to get objective results because each person has his own criteria in evaluation.
In a game, it is very important for the attacking team how to make and use spaces advantageous to attack, and inversely, for the defending team how to remove such spaces. Such space making and removing can be produced through cooperative movements of players in the game. Therefore, *space management* and *cooperative movement* are the major factors for teamwork evaluation. To quantify them, we can use two features; "shortest time pattern" and "dominant region" proposed in the previous section, for each player at each moment in a game. A teamwork evaluation system implemented for soccer games is presented here.

3.1 System Outline

The system can be divided into two parts; (1) motion analysis and (2) teamwork evaluation.
In the motion analysis part, first, motion images of an actual soccer game taken by several video cameras are digitized. Second, static objects such as lines on the soccer field are extracted. Third, moving objects such as players, referees and the ball are tracked. Then, the positions of moving objects on the image space for each camera are transformed into, and merged on the soccer field space.
In the teamwork evaluation part, cooperative movements of players and pass works are quantitatively evaluated using results of the first part, and the results are visualized in the form of 2D and 3D animations.

3.2 Motion Analysis

3.2.1 Camera Placement: In the telecasting of a soccer game, most scenes are local in that not all players appear in them, because the focus is on a player with the ball. However, it should be noted that not only movement of the player with the ball but also those of players without the ball in the game are very important for teamwork evaluation. In this sense, game images from telecasting are not suitable for our purpose. On the other hand, some researches of sports scene analysis using telecasted images have been reported (Kawashima, 1994, Gong, 1995, Bobick, 1995 and Yow, 1995).
We use several cameras placed along the touchline on the field, so as to cover all players and all the soccer field as shown in Fig.4. For every camera, the optical axis is set to be perpendicular to the touchline and the zooming rate is fixed in order to simplify the problem of motion image processing. Fig.5 shows an example of an original game scene taken by the second camera from the right side in Fig.4.

3.2.2. Extraction of Field Lines and Players: Extraction of static objects such as field lines from the scenes is a simple problem because every camera is neither moving nor zooming. For example, the procedure of field lines extraction consists of thresholding and line detection based on Hough transformation.
The procedure for tracking players is as follows. At first, a body part of each player is located manually from the first frame as an initial template for the player. The center of the template is regarded as the center point of the player. Then, each player is tracked frame by frame by correlation-based template matching. Each template is renewed at each frame. While the above tracking procedure will work successfully for a player moving in isolation, it may sometimes fail for a player occluded by another or a player falling down. In these cases, manual correction is applied.
Finally, a footing point for each player on the image is estimated

from the rectangle region of the player obtained by above template matching. Fig.6 shows an example of tracking result of players according to the procedure above mentioned.

3.2.3. Transformation into Field Space: Footing points of each player estimated from each camera scene are transformed into the soccer field space as shown in Fig.7, and merged on it. On the assumption that the soccer field is a plane and every player moves on the plane and the condition that the camera axis is perpendicular to the touchline, transformation from the image space into the field space results in the calculation of a simple ratio and cross ratio with regard to X and Y axis, respectively. The cross ratio for four points on a straight line is invariant to perspective view transformation. Finally, movements of all players on the field space as shown in Fig.8 are obtained. Fig.9 shows an example of game scenes reproduced by using positions of lines and players extracted from real scenes such as Fig.5.

3.3 Teamwork Evaluation

In this section, two basic teamworks; cooperative movements of players and pass works are evaluated quantitatively.

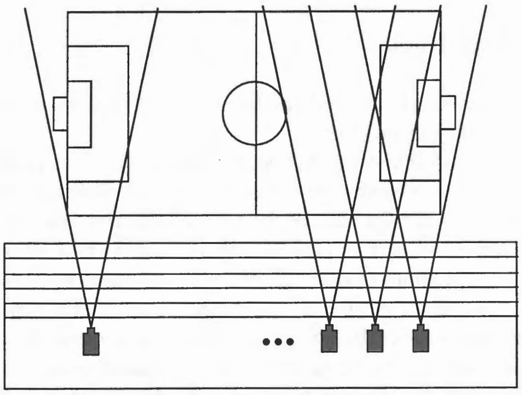


Fig.4 Camera placement and each image space

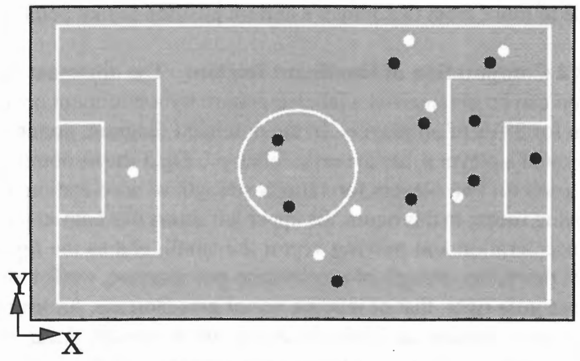


Fig.7 Position of players transformed into the soccer field space

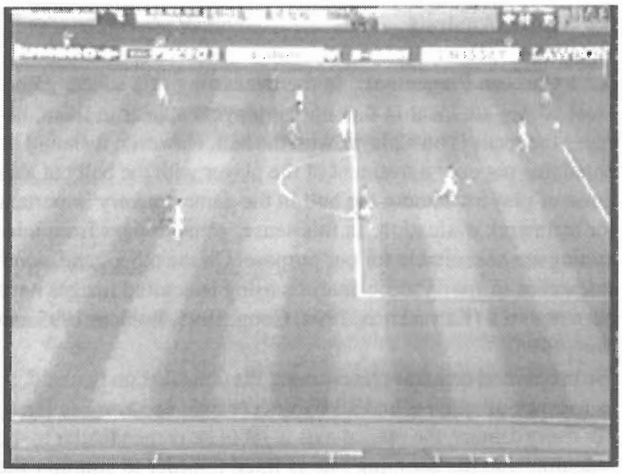


Fig.5 An example of input game scenes

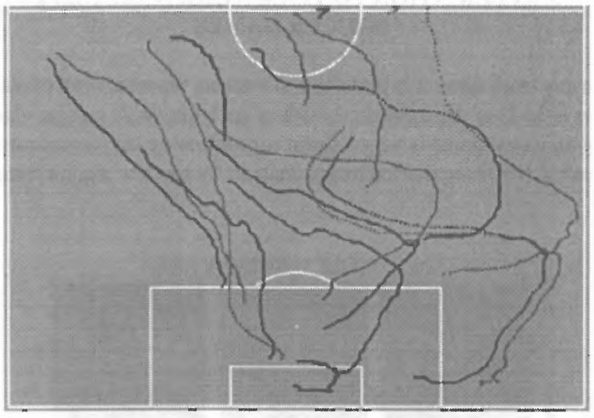


Fig.8 Movement of all players on the field space

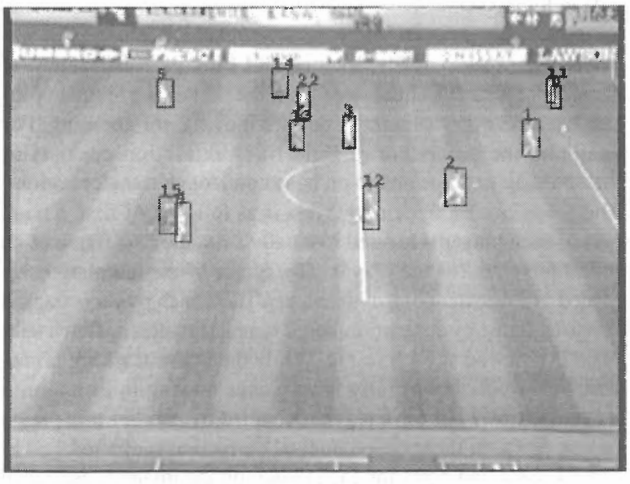


Fig.6 An example of tracking results

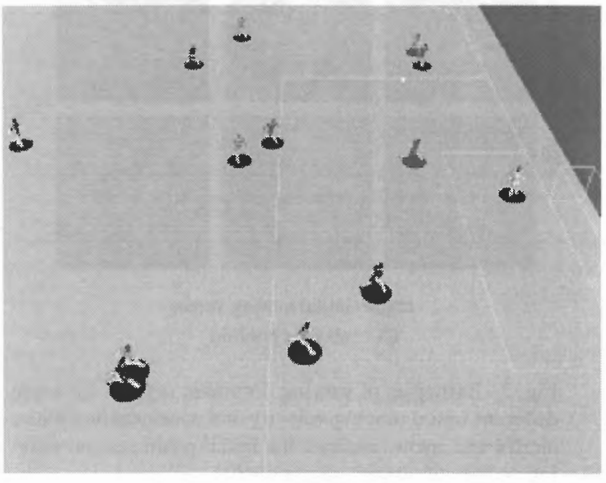
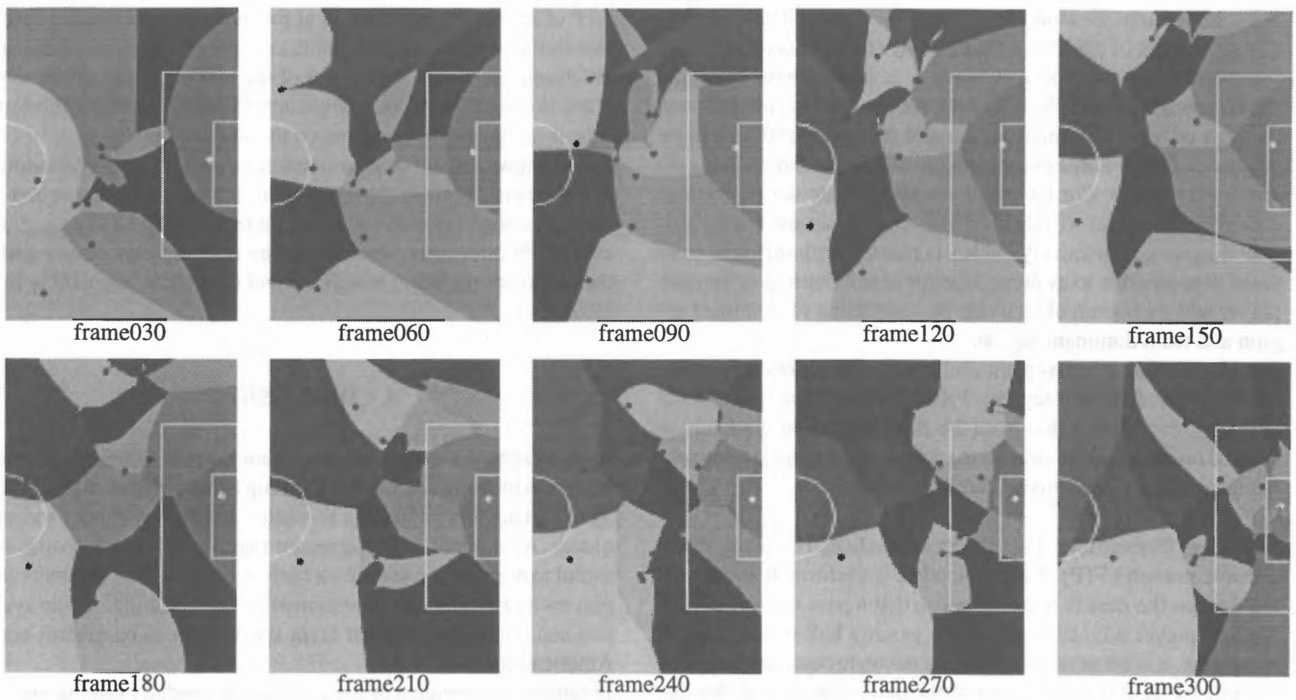
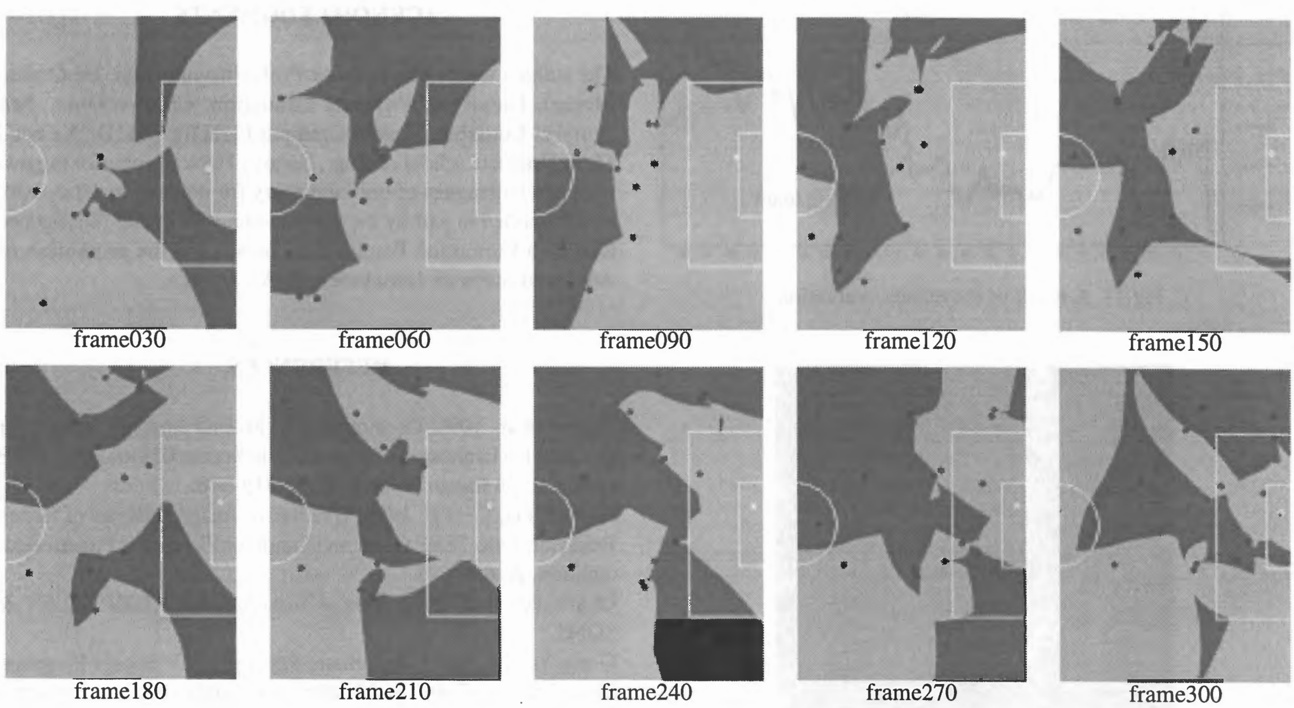


Fig.9 An example of reproduced game scene



(a) Dominant diagram



(b) Team dominant diagram

Fig.10 Examples of dominant diagram from actual game scene

3.3.1 Movement Evaluation: First, we consider the cooperative movement of players. As previously stated, space making or space removing on purpose to attack or defend are most basic and significant teamwork. Then, to evaluate the spaces quantitatively, the area of team dominant region and its time variation can be used as a criteria. Some computational results are shown in Fig.10 and Fig.11. In the Fig.10, small circles indicate the position of each players, and (a) , (b) shows dominant diagram and team dominant diagram, respectively, which is painted with different gray tones. It is possible to evaluate superior or inferior region for each player and each team objectively by visualizing of dominant region and team dominant region.
Fig.11 is a result of movement evaluation. This shows area variations of team dominant regions. From this result, we find that the attacking team start to dominate the effective regions gradually in spite of on the opposite side. In the actual game scene, the attacking team made a goal finally in this example.

3.3.2 Pass Evaluation: Pass works are evaluated by using shortest time pattern (STP). Pass evaluation is performed at the moment when the pass is done. Suppose that a pass is successful if the first player who can receive the passing ball belongs to the same team. It is necessary for pass evaluation to compare the shortest time of all players with that of the ball at each point. We use STP of all players and the ball at the moment, and then perform minimum operation at each point, concretely. Because a ball can not accelerate itself, the motion of the ball projected on the x-y plane is considered to be straight approximately, and the shortest time is assigned only to points on the straight line.
Fig.12 shows a result of pass simulation used for pass evaluation. A white small circle in the figure indicates a player position and a white line segment shows a dominant region of the ball passed to each of 36 directions. The ball can be received by a player with the dominant region in which the end of the line segment is included.

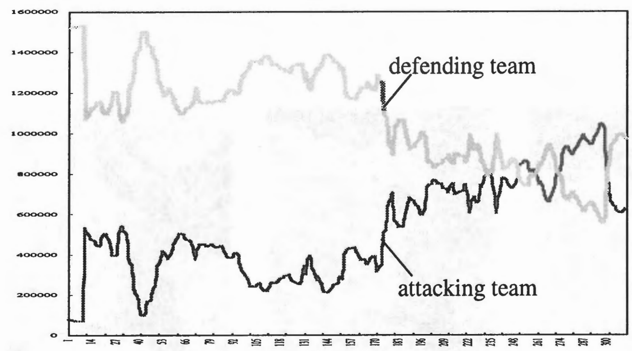


Fig.11 A result of movement evaluation

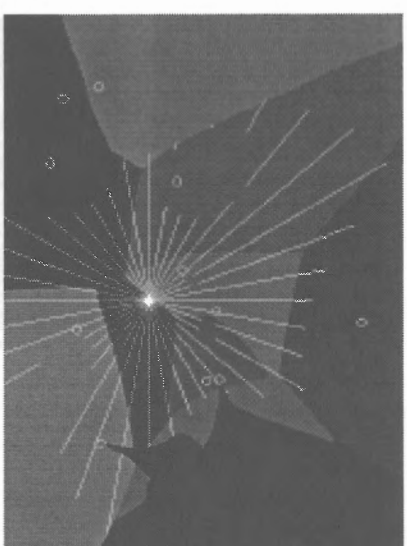


Fig.12 A result of pass evaluation. (A white small circle in the figure indicates a player position, white line segment show the dominant region of the ball.

4. CONCLUSION

In this paper, we proposed "dominant region" which is a basic feature to measure and recognize group behavior from motion images, and applied the feature to motion analysis system of soccer games. As a result, it is suggested that the proposed feature is useful to evaluate the teamwork such as cooperative movement of players and pass works quantitatively. The basic idea of the system can be applied to other team sports such as basketball and American football.
In future, improvement of the acceleration model, examination of other features using dominant region, evaluation for the system from a sports scientific point of view and generalization of group behavior analysis method will be studied.

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