Analysis and Simulation of Group Behavior Using Dominant Region

Tsuyoshi Taki and Junichi Hasegawa
School of Life System Science and Technology, Chukyo University
101 Tokodachi, Kaizu-cho, Toyota, Aichi, 470-0393 Japan
email: taki@life.chukyo-u.ac.jp

Abstract - **For evaluation or prediction of human behavior, it is important that not only measurement of characteristic pattern from actual scenes, but also simulation for various situations based on general models for human behavior. In our approach, the changes of spatial feature formed by each individual's movement are used. The feature is called "dominant region" which is a kind of dynamic personal space.**

In the paper, we present a basic concept and calculating method of dominant region and its application. From the experiment, it is suggested that the proposed feature is useful for evaluation and simulation of human behavior.

I. INTRODUCTION

Recently, some scenes which many people gather and move in a comparatively large area like shopping quarter or the event hall are observed using a video camera or various sensors, and many studies on measurement of people's stream or simulation of crowd behavior have been made widely [1-3]. The base technology for observing a motion of such a group or a crowd is expected in various fields, such as a surveillance system for crime prevention, a landscape simulation, an elucidation of the people's action mechanism, and market research. However, it can be said that general technology for these applications is still a development way.

We are developing a general-purpose technique for evaluation and simulation of human behavior. Generally, people are acting being conscious of a suitable distance with others, in a group or a crowd. For example, passing-each-other action is considered. In the situation that two persons collide with each other, if they walk as it is, both or one side will change a course at suitable timing. Furthermore, if such a situation happens frequently, the course which does not need to avoid others as much as possible will be chosen, and people's stream will naturally occur there. It can be thought that such behavior is a thing based on a kind of dynamic sphere of influence which an individual or a group has. That is, maintaining one's sphere of influence and not infringing on others' sphere of influence are regarded as fundamental behavior. We modeled this dynamic sphere of influence based on the idea of the shortest time, and named it the domain region [4].

In this paper, the basic concept of the dominant region is described, and the teamwork evaluation in a team sport game and the simulation method for crowd behavior are proposed as the application. Moreover, the effectivity and the applicability of the dominant region are shown from experiments.

II. MODELING OF DYNAMIC SPHERE OF INFLUENCE

The space around each individual 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 Voronoi region [5]. We formulate this kind of region associated with each individual in a group motion by extending Voronoi region.

A. Definition of Dominant Region

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

$$V(p_k) = \{ x \in \mathbf{R}^2 \mid d(x, p_k) \le d(x, p_m) \text{ for } m \ne k,\ m \in \mathbf{I}_n \} \quad (1)$$

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

$$W(\mathbf{P}) = \cup V(p_k). \quad (2)$$

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

$$V(p_k^{(t)}) = \{ x \in \mathbf{R}^2 \mid d(x, p_k^{(t)}) \le d(x, p_m^{(t)}) \text{ for } m \ne k,\ m \in \mathbf{I}_n \}. \quad (3)$$

This can be regarded as a kind of sphere of influence for each player at the moment t, but it is no more than a static sphere of influence based on the distance. In an actual group motion, all individuals move 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 player $p_k^{(t)} \in P^{(t)}$ is defined again as follows:

$$D(p_k^{(t)}) = \{ x \in \mathbf{R}^2 \mid t_s(x, p_k^{(t)}) \le t_s(x, p_m^{(t)}) \text{ for } m \ne k,\ m \in \mathbf{I}_n \} \quad (4)$$

where $t_s(x, p_k^{(t)})$ called “shortest time” is the time necessary for the player $p_k^{(t)}$ to move from his/her current position to the point indicated by x, on condition that the player move with all his/her might. Also, the set of shortest times calculated for all x is called “shortest time pattern”. That is, $D(p_k^{(t)})$ is a region where the player p_k can arrive earlier than any other player when starting at t. This region called the “dominant region” of the player p_k at the moment t. The set of dominant regions associated with all players is called “dominant diagram”. Though the dominant region is defined only by replacing the distance d with shortest time t_s, it is greatly different from Voronoi region at a point where the dominant region can express a sphere of influence based on each individual’s movement and physical ability. The dominant region is also different from the weighted Voronoi region [5] defined by using a linear function of the d.

B. Calculation Model of Shortest Time

To calculate the shortest time of an individual to each point $\boldsymbol{x}$; the current position, the current moving vector and the acceleration vector of the individual 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 individual’s own will and physical ability. Then the accelerating ability is modeled here as acceleration patterns based on the physical ability of an average individual. An acceleration pattern consists of all possible acceleration vectors. Our system uses an acceleration model as shown in Fig.1. The model indicated by the figure, the vector pattern varies with the moving vector of the individual. 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 becomes higher, it becomes harder to accelerate in the direction of movement. If the acceleration model which reflects the physical ability of each individual is constructed based on the model like this, then the shortest time from the current position of an individual to each point can be approximately calculated using the model. Supposing that once the acceleration vector in order for p_k to move up to a certain point is given at the initial time, the vector is fixed while the computation, the locus of p_k becomes accelerated motion. Therefore, the shortest time t_s for p_k to move up to the point x is given by the following equation:

$$t_s = \min_{a \in A} \left\{ t \;\middle|\; \frac{1}{2}at^2 + v^{(t_0)}t + p_k^{(t_0)} - x = 0, \left(v^{(t_0)}\right)^2 - 2a\left(p_k^{(t_0)} - x\right) \geq 0, t \geq 0 \right\} \tag{5}$$

where $p_k^{(t0)}$ and $v^{(t0)}$ show the location vector and the moving vector of p_k at the time t0 respectively, and **A** shows the set of the acceleration vector in Fig.1. That is, the shortest time t_s is obtained as a positive real radical by solving the equation with regard to t as the direction of the vector **a** is changed.

The practical procedure for calculation of the shortest time is as follows:

(a) According to Eq.(5), $\boldsymbol{x}$ is calculated by changing the value of the accelerating direction and the time t.

(b) Then the value indicated by $\boldsymbol{x}$ is set to t as the shortest time. In the Fig.2, $\boldsymbol{x}$ is corresponding to the black small circle.

(c) The value which is not yet set is interpolated using some set values (for example, the set values of A, B and C are used in the Fig.2). Finally, a pattern where each point is constituted of shortest time is obtained for each individual. We call this pattern the “shortest time pattern (STP)” of the individual. The calculation of the shortest time pattern as stated above is performed for all of the individuals.

C. Calculation of Dominant Diagram

The dominant diagram is represented in the form of a labeled pattern. Each label indicates the individual’s ID whose value is obtained by a minimum operation for shortest time patterns of all individuals.

For fast calculation of dominant region, computer graphics techniques should be used. For interpolation process in

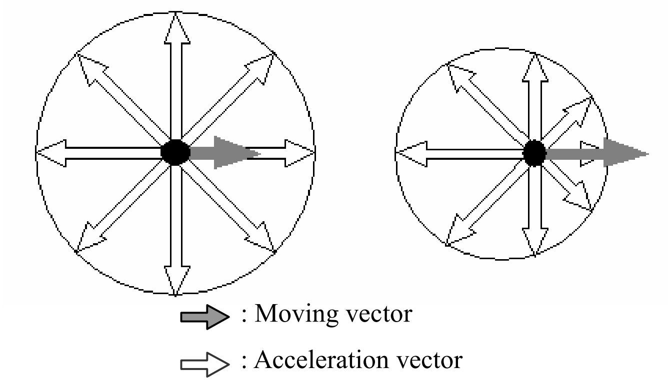

Fig.1 Acceleration model

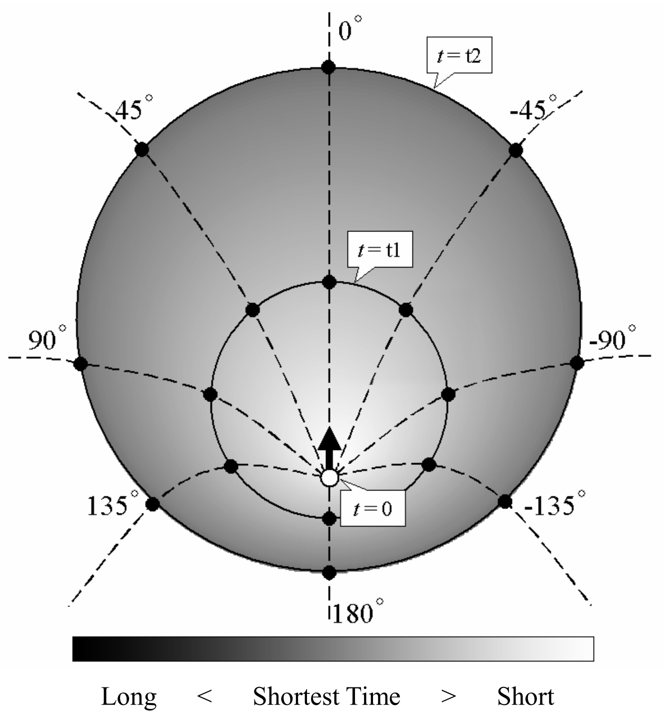

Fig.2 A computational model of shortest time pattern

generation of shortest time pattern, smooth shading method is applicable. And also, for minimum operation between shortest time patterns in generation of dominant region, depth buffer process is applicable. Because many graphics hardware can perform these operations, it is very effective in improvement in the speed.

Fig.3 shows dominant diagram for two persons. In the figure, a small rectangle indicates the position and a line indicates the moving vector of each person, respectively. Positional relation between two persons is the same in these figures, but each moving vector is different. Figure (a) shows a situation that left side person runs up to the right side person, and (b) shows that two persons run up to the same point with same strength of initial velocity. (c) shows a person follows another person. (d) and (e) show that two persons pass each other, and (f) shows two persons are standing still. As seen in these figures, borders of the dominant regions are not always linear, and the dominant region of an individual is not always a single connected component. For example, when an individual runs to another individual, his dominant regions are formed not only around the person but also behind another person. The behavior of dominant region corresponds with behavior which can be observed in actual game scenes, and the features like this are never represented by a simple Voronoi region. However, in the special case where the acceleration models of all persons are the same and moving vectors of all persons are zero, dominant region corresponds with the Voronoi region.

III. APPLICATION TO SPORTS GAME ANALYSIS

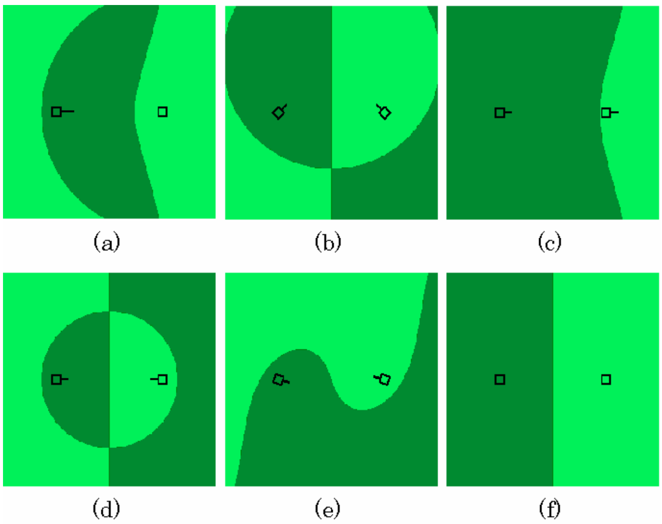

Fig.3 Example of dominant diagram formed by two persons

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 includes 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 shortest time pattern and the dominant region proposed in the previous chapter.

In this chapter, our ball game analysis system developed for verifying its possibility is shown with experimental results.

A. Application to Soccer Game Analysis

The system consists of two parts; motion analysis and teamwork evaluation. In the motion analysis part, a sequence of a soccer game taken by several cameras is digitized, and static objects such as lines or goal posts on the soccer 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 soccer field space. These methods are concretely stated to the reference [4]. In the teamwork evaluation part, cooperative movement by players is quantitatively evaluated using the results of motion analysis.

In this section, basic teamwork such as cooperative movement using dominant region and shortest time pattern as stated above, are evaluated quantitatively. Increasing or preserving space in both attacking and defending are 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 to the goal.

The system as stated above is applied to actual soccer game scenes taken by 8 cameras. Each camera is set in the upper row in a stadium and all the soccer field is covered without a blind spot. Digitized image has width = 720 [pixel], height = 480 [pixel] and 24 bit RGB color, 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.

Fig.4 shows an example of a sequence of dominant diagram obtained from actual game scene. In this scene, the attacking players ran up to the front of goal, and then, one of the players got a goal. In the figure, the original image and the dominant diagram are synthesized and displayed. And dark-colored regions show the team dominant regions of the defending team, while right-colored regions show those of the attacking team.

Fig.5 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

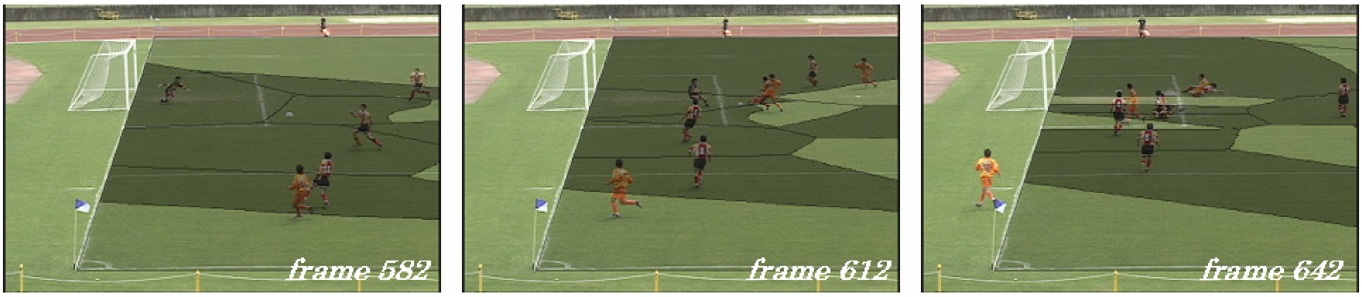

Fig.4 A synthetic display in the actual game scene of the dominant diagram.

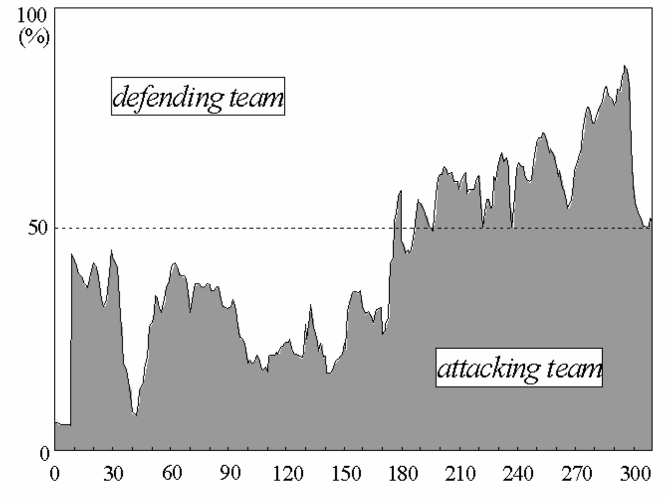

Fig.5 Time variation of team dominant ratio for the attacking team.

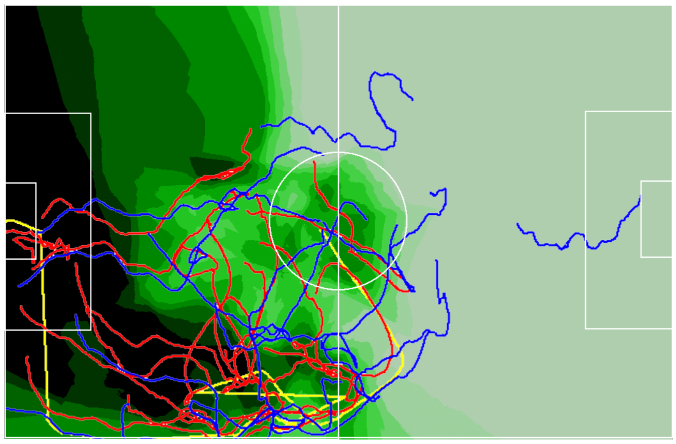

Fig.6 Time occupancy state of team dominant diagram for a play sequence.

this example, and but in other examples same tendency was obtained. But in another example the tendency could not be obtained.

Fig.6 shows the time occupancy rate of the team dominant region and the movement of each player and a ball in a certain play scene. This is simply obtained by calculating the mode for each point of the dominant diagrams for the scene.

B. Application to Handball Game Analysis

In this section, 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.

In handball game, the ball is shot from near the goal area line, because all players except the goalkeeper must keep out of the goal area. For example, in the Fig.7, the goal area line is indicated by the smaller arc and the goal area is the inside of the arc. The attacking style in handball games is classified into two types, “quick attack” and “set attack”. Quick attack means that players cut the ball from opponent’s team and then aim at the goal in short time. Set attack means that players make a shooting chance using some short passes around the free throw line (indicated by the larger arc in the Fig.7). This attacking style is a basic teamwork and is observed most frequently in handball games. 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 attacking style, we use only the team dominant regions between the free throw line and the goal area line for teamwork evaluation in handball games. We call the zone between these lines the interest zone. Features calculated here include the area size and the number of the team dominant regions in the interest zone and the dominant ratio on the goal area line.

In this experiment, two characteristic scenes, quick attack and set attack are used. Fig.7 shows an example of team dominant regions obtained from a set attack scene. In the figure, the team dominant regions in the interest zone are assigned another color.

Fig.8 shows the time variation of each feature mentioned above. In the case of set attack, the value of each feature is low entirely, because the defending player stood in the attacking players’ way along goal area line. However, there is a part with very high values of all features in the Fig.8. This means that the attacking players broke the defense line at the moment. After that, they really took a shooting chance around the goal area line. On the other hand, in the case of quick attack, the value of each feature became high quickly, because the defending players could not back in their defending position and let the attacking players play freely. 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.

C. Conclusion

In this chapter, we analyzed group motion in team sports by using proposed dominant region, by giving examples of actual soccer and handball games. We found it possible to quantitatively evaluate inferiority or superiority for each team's movement from the experimental results using dominant regions. 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. In the experiments, the proposed method was applied only to a soccer game and a handball game, but the basic idea can be useful for teamwork evaluation of other similar ball games; for example, hockey and American football.

IV. SIMULATION FOR CROWD BEHAVIOR

Recently, some studies on simulation for crowd behavior have been made widely. For example, in the research of Unuma [3], crowd behavior is modeled based on a kind of personal space and is performed in a virtual city as three-dimensional animation. Also, many researches for course selection using the potential field are reported in various fields.

In this section, a basic model for crowd simulation using the concept of dominant region is described.

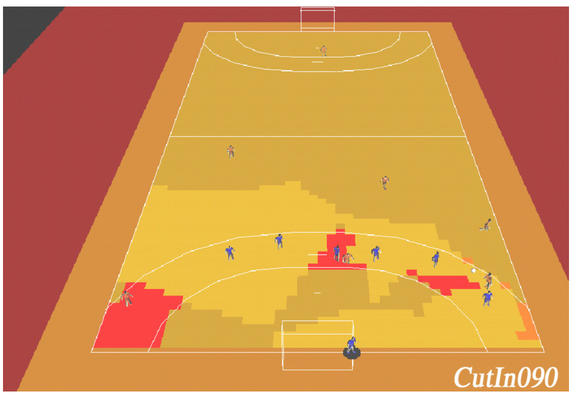

Fig.7 An example of 3D animation of team dominant region in set attacking.

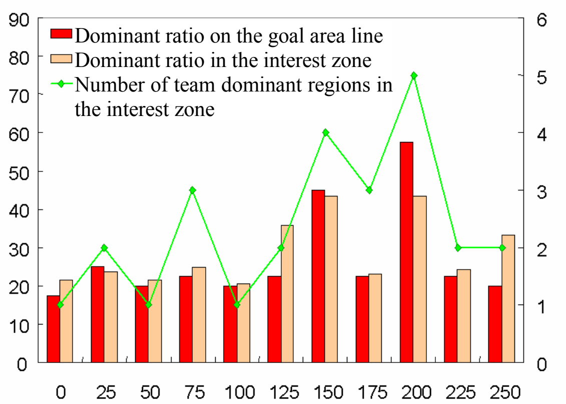

Fig.8 A result of changes of team dominant region in the set attacking.

A. Modeling a basic movement

(1) The region where each person can move within a certain time is calculated. This region is obtained as the dominant region. The extent of the dominant region is controlled based on the above time, and it is limited that other individuals pass through the region.

(2) When a person moves toward a destination, a expected trajectory within a certain time is calculated based on a suitable acceleration vector. In other words, this trajectory means a kind of antenna. Each individual detects obstacles or dominant regions of other individuals by changing the length and the direction of the antenna.

(3) If there is no overlap between the trajectory obtained from above step (2) and the region obtained above step (1), the suitable acceleration vector is applied as it is. If the overlap occurs, the direction or the strength of the acceleration vector is re-calculated, and back to step (2).

(4) The position of each individual is moved according to the acceleration vector.

Fig.9 shows a situation of collision detection and collision avoidance. In the figure (a), the trajectory estimated from a given acceleration vector is overlapping with the dominant region of another individual. Therefore, in the figure (b), a next candidate of acceleration vector is given, and the trajectory is estimated again.

A sequence of basic movements with collision avoidance is generated by repeating the above-mentioned steps. Furthermore, it is possible to generate a motion such as following to other person by setting the destination to someone's back.

B. Simulation of some basic situations

In the first experiment, the simulation for a situation that a

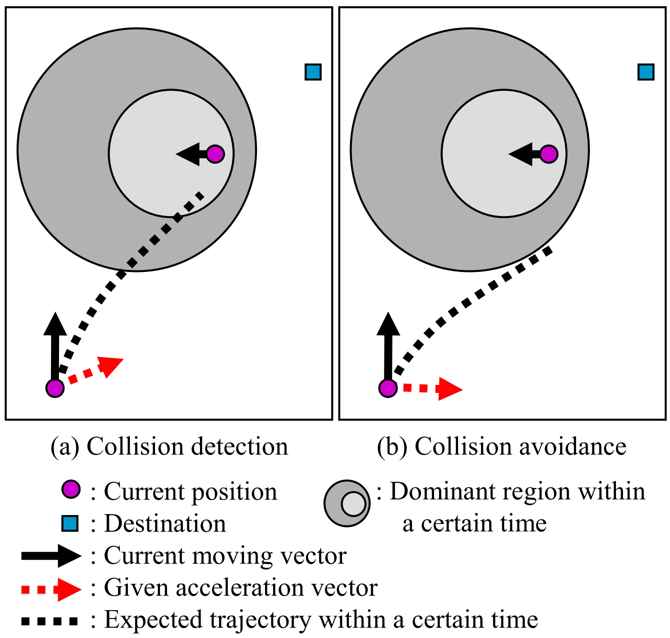

Fig.9 An example of avoidance action against other individuals

person moves from an initial point to a destination by avoiding an obstacle is performed. Fig.10 shows the simulation results. Three curved lines in the figure show the trajectories up to the destination, but the sensitivity of the collision detection, that is, the length of the antenna, is different, respectively. The sensitivity for curve (a) is high, curve (b) is middle and curve (c) is low. As the sensitivity became high, the timing of avoidance became early, and natural trajectories were generated.

In the second experiment, the simulation of a situation that a person and a group pass each other is performed. In the situation, P1 is moving from the right side to the left side, and a group which consists of P2, P3 and P4 is moving to the right side. Fig.11 shows the simulation results. The initial position of each person is indicated by a black small circle, and each trajectory is indicated by a curved line with an arrow. The right side figures in Fig.11 show the dominant region and the antenna of each person at the moment of collision avoidance.

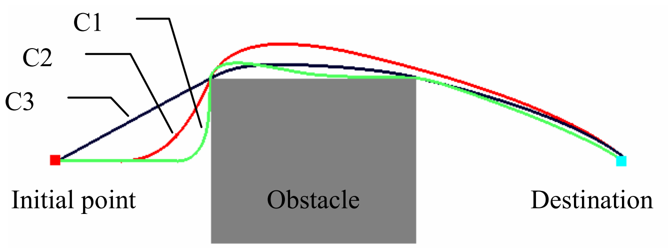

Fig.10 An example of avoidance of a static obstacle

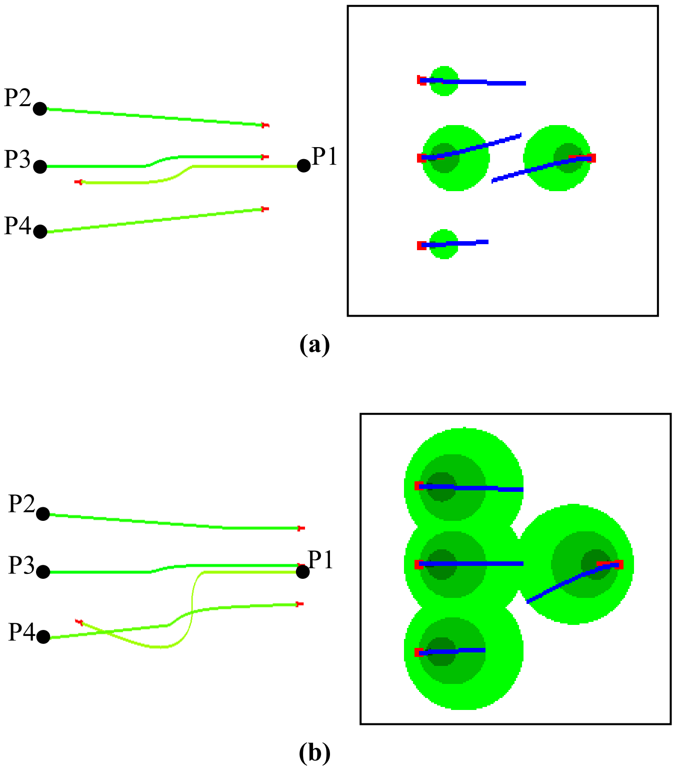

Fig.11 Example of the avoidance of some moving obstacles

In the figure (a), the sensitivity of P4 is lower than the others, and the size of dominant region of "P1 and P3" and that of "P2 and P4" are the same, respectively. In this situation, P1 can move through an opening between P3 and P4. However, in the figure (b), P1 takes a roundabout way to avoid the moving course of P4, because each dominant region is bigger than the above situation.

From the experiments, it found that various collision avoidance patterns were generable by changing the parameter such as the size of each individual's dominant region and the length of an antenna. Although there were some problems which should be improved, when applied our idea to the simulation of the stream of the man in a crossing or a passage, comparatively natural behavior was generable.

V. CONCLUSIONS

In the paper, a basic concept and calculating method of dominant region are described. Also, as its applications, teamwork evaluation in team sports game such as soccer and handball and a basic method for crowd behavior simulation are shown. From some experiments, it is suggested that the proposed feature is useful for evaluation and simulation of human behavior.

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