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Paper

A Method of Important Player Extraction Based on Link Analysis in Soccer Videos

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Abstract In this paper, a method for extraction of important players in soccer videos based on link analysis is proposed. In a soccer match, players perform shoot tackles, assistance, and covering. Furthermore, the soccer tactics are defined the formation of players based on various relationships between players. The proposed method extracts the important players, in order to obtain information for understanding the soccer matches for various audiences. Specifically, our method notes that relationship between players, who cooperate with each other by the pass and the covering, is similar to relationship between web pages which are connected by links. First, the proposed method obtains player networks based on relationship between players in each team. The relationships are defined based on player positions and the possibility of the pass or the covering between players. Finally, in the proposed method, by applying the link analysis to the obtained player networks, important players are extracted. By realizing this approach, important players are extracted from the player networks based on the possibility of the pass or the covering between players. In the last of this paper, the above link analysis-based method was applied to actual soccer matches to show the reasonability of our method.

Key words: soccer videos, soccer tactics, first-arrival region, HITS algorithm, link analysis.

1. Introduction

In recent years, by using digital broadcasting and Hybridcast[1], audience can obtain not only video sequences but also various data such as information on the broadcasted contents. Furthermore, by the increase of the contents, improvement of the qualities of digital broadcasting is expected. However, generation of the various data in many broadcasted contents by manual operation is not realistic. Therefore, automatic extraction methods of information about the broadcasting contents from video sequences are very useful techniques. Particularly, in order to provide various data in soccer programs, various methods for automatic indexing are proposed[2]-[8].

In the field of video analysis about soccer contents, some methods create indexes of the game to extract the highlight scene such as used in the sports news program[6]-[8]. However, since many people are interested in not only general events such as set piece but also the various tactics, an analysis of soccer videos based on a tactical approach is necessary for support understanding of the broadcasted contents. Therefore, many traditional methods, which estimate positions of the players or pitch area for analysis of soccer videos[9]-[12], are proposed. Furthermore, in order to realize methods of analyzing soccer tactics from soccer videos, we previously proposed methods for pass region estimation[13] and players clustering[14].

By utilizing the methods for pass region estimation and players clustering, we can obtain newly information of soccer videos about pass of the ball and effective formation of player positions. However, since information of the players, who have an important role in the soccer tactics (important players), are very useful elements for understanding of team tactics, the extraction of important players is necessary. The important players are those who shoot, tackle, assist, and cover, and such players generally dominate the soccer match. Therefore, by visualizing the important players in soccer tactics, various audiences can easily understand the soccer match.

In this paper, we propose a method for extracting important players in order to obtain information for understanding the soccer match. In the soccer matches, the attack players and the defense players have the relationship of pass and covering, respectively. Furthermore, we note that this relationship between the players, which cooperate with each other by the pass and the covering, is similar to that between the web pages which is connected by links. Specifically, the proposed

Received September 9, 2016; Revised November 27, 2016; Accepted March 13, 2017

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method obtains the network of players based on relationship between players, which are possibilities of the pass or the covering. Moreover, the proposed method extract the important players from video sequences, by applying HITS algorithm[15] to the obtained networks of players. HITS algorithm[15] is generally utilized in link analysis of Web. By realizing this approach, important players are extracted based on the possibility of the pass or the covering between players.

This paper is organized as follows. An overview of the proposed method and a definition of important players and are shown in Section **2**. In Section **3**, the first-arrival region that is obtained based on the movement model of each player is explained. The first-arrival region is an element of the generation of player network. In Section **4**, HITS algorithm-based method for extraction of important players using the player network is proposed. In Section **5**, the reasonability of the link analysis-based method is shown by using actual data of soccer matches. Finally, concluding remarks are presented in Section **6**.

2. Overview of Proposed Method and Definition of Important Players

In this section, the important players are defined. The important players are target objects in our extraction method. In addition, an overview of the proposed method for extracting important players based on link analysis is shown in this section.

In the field of sports science, the feature of soccer players about the visual search behavior for understanding of the player positions is studied[16]. By the studies of sports science, the features of soccer players are indicated that the high skill players keep the good positions, which can communicate with many the other players by pass or covering. Therefore, the high skill players keep the good positions for achieve a same purpose, which is a realization of a tactics. Specifically, since the soccer tactics are decided by player formation, the good 2D positions in the soccer pitch that can communicate with many the other players by pass or covering is very important. On the other hand, web pages which describe about the same thing are linked with each other. Specifically, since many links with other pages of the same thing can increase traffic from the other linked pages, the links with the other pages is very important. From the above, the features of web links and relationships between players similar to each other. The relationships between players are defined from 2D positions in the soccer pitch. Thus, in the proposed method, important players are extracted by applying HITS algorithm, which is utilized for link analysis.

Especially, since authority pages of HITS algorithm are linked from other pages, authority players in the proposed method are defined as those who as ball receiver of attack team and attacker in defense team. On the other hand, since hub pages of HITS algorithm link to other pages, hub players in the proposed method are defined as those who as ball holder of attack team and cover player of attacker in defense team.

The details of the proposed method is explained in the following sections.

3. Generation of First-arrival Region

In this section, we explain the first-arrival region which are utilized for the generation of player networks. The first-arrival region is defined as regions that are each player firstly arrives to each position of the pitch[17]. Therefore, in order to generate the first-arrival region, a movement model of soccer players on the pitch must be defined. The movement model gives the minimum arrival time of each player to arbitrary points of the field based on the initial velocity and position of the player. The method of first-arrival region[17] formulates the movement model by assuming that each player's acceleration is constant. However, that movement model is not realistic because the speed of a player increases to infinity. Therefore, the proposed method utilizes the movement model that the force is generated against the velocity[18]. The details of movement model and calculation of the first-arrival region are explained in below.

3.1 Formulation of Movement Model

In this section, we firstly explain the definition of the movement model which is utilized for generating the first-arrival region. In the proposed method, we assume that a player can move equal distance to any direction and the force is generated against the direction of movement. Therefore, the movement model based on the above hypothesis is defined as follows:

$$m\frac{d}{dt}\overrightarrow{v} = \overrightarrow{F} - k\overrightarrow{v}, \tag{1}$$

where m is mass of the player, $\overrightarrow{F}$ is the maximum value of propulsion of the player, k is the resistance coefficient, and $\overrightarrow{v}$ is velocity of the player. In the above equation, the second term on the right-side represents the against force of the movement of the player. Furthermore, $\overrightarrow{F}$ is $F\overrightarrow{e}$, where $\overrightarrow{e}$ is an arbitrary unit vec-

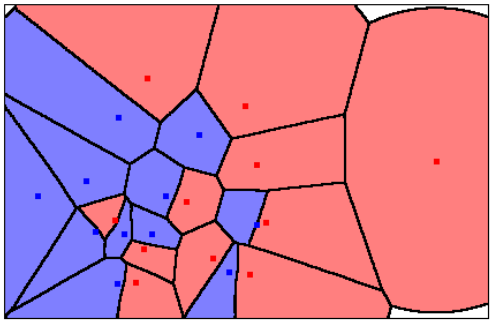


Fig. 1 The example of the first-arrival region of each player in the soccer pitch.

tor. Next, Equation (1) is rewritten as follows:

$$\overrightarrow{x} - \overrightarrow{x_0} = V_{max}\left(t - \frac{1-e^{-\alpha t}}{\alpha}\right) + \frac{1-e^{-\alpha t}}{\alpha}\overrightarrow{v_0}, \quad (2)$$

where Equation (2) is solution of a differential equation of Eq. (1), $\overrightarrow{v_0}$ is $\overrightarrow{v}$ at the time of $t = 0$ and α denotes the magnitude of the resistance. From Eq. (1), since $\overrightarrow{v} < \frac{\overrightarrow{F}}{k}$ is satisfied, Eq. (2) indicates that a player with initial velocity $\overrightarrow{v_0}$ at initial position $\overrightarrow{x_0}$ at $t = 0$ can reach the point $\overrightarrow{x}$ at time t.

3.2 Generation of First-arrival Region

In this section, we explain the generation of first-arrival regions. The movement model that gives the minimum arrival time to arbitrary points of the field based on the initial velocity and position of the player in the previous section were defined. The first-arrival region based on the minimum arrival time of each player is defined as follows:

$$D(p_k^{(t)}) = \{x \in R^2 | t_s(x, p_k^{(t)}) \leqq t_s(x, p_m^{(t)})), \\ m \neq k, m \in I_n\} (3)$$

where p_k represents each player, $I_n = \{1, 2, \ldots, n\}$, and $t_s(x, p_k)$ is the shortest time to arrival at position x. The first-arrival region D is the region where the player p_k can arrive earlier than any other players. Generation of the first-arrival region that is applied to an actual soccer video is shown in **Figure. 1**. In Fig. 1, the blue points and red points are attack team players and defense team players, respectively. Furthermore, blue area and red area are first-arrival region of the attack team player and the defense team player, respectively. By utilizing Fig. 1, we can obtain the relationship between players.

4. Extraction of Important Players based on HITS Algorithm

In this section, we propose HITS algorithm-based method for extracting important players from soccer videos. The proposed method notes that this relationship between the players, which cooperate with each other by the pass and the covering, is similar to that between the web pages which is connected by links. In the proposed method, we obtains the network of players based on relationship between players, which are possibilities of the pass or the covering. Since the obtained networks express the possibilities of the pass or the covering, we can analysis the relationship between players by utilizing the link analysis methods. Therefore, in order to obtain important players based on the relationship between players, we apply HITS algorithm to obtained player networks. HITS algorithm is generally utilized for extraction of the web pages which include important subjects. Therefore, in the proposed method, by applying HITS algorithm to the obtained player networks, the important players based on the relationship between players can be extracted.

In this section, Generation of the player network is explained in **4.1**, and a method for extraction of important players is proposed in **4.2**.

4.1 Generation of Player Network

In this subsection, we explain the generation of the player networks based on the first-arrival region. The possibility of the pass or the covering becomes high when the first-arrival regions are adjacent. Furthermore, when an opposite player does not exist and an own team player exist in the neighborhood, those possibilities becomes high. Thus, when the boundary line of the first-arrival regions is long and the distance between players is small, the possibilities becomes high. In the proposed method, the relation $[L_{ij}]$ of the players p_i and p_j $(i, j = \{1, \ldots, 22 | j \neq j\})$ is expressed by the player network using length of the boundary line of the first-arrival regions l_{ij} and the distance between the players d_{ij}. The adjacency matrix $\boldsymbol{L} = [L_{ij}]$ of the players is defined as follows:

$$[L_{ij}] = \begin{cases} \frac{l_{ij}}{d_{ij}} & (i \neq j) \\ 0.0 & (i = j). \end{cases} \quad (4)$$

Thus, we obtain an adjacency matrix $\boldsymbol{L}_o = [L_{o_{ij}}]$ * of the attack team players (attack team players' network) from the adjacency matrix $\boldsymbol{L}$. Similarly, we obtain an adjacency matrix $\boldsymbol{L}_d = [L_{d_{ij}}]$ ** of the defense team

* When the possibility of the pass between player p_i and player p_j is low, $[L_{o_{ij}}]$ is set to 0.0. Specifically, when the player p_j exists behind the player p_i, $[L_{o_{ij}}]$ is set to 0.0.

** When the possibility of the covering between player p_i and player

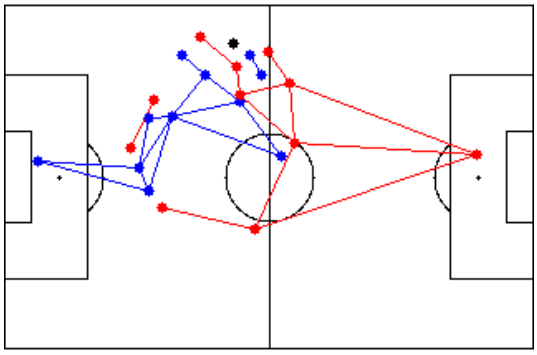


Fig. 2 The examples of player networks of both attack team and defense team players.

players (defense team players' network) from the adjacency matrix $\boldsymbol{L}$. Since the obtained network is generated based on the above process, the links of each player express the relationship between the players. The adjacency matrices $\boldsymbol{L}_o$ and $\boldsymbol{L}_d$ are asymmetric matrix. Thus, in the proposed method, directed graph $\boldsymbol{L}_o$ and $\boldsymbol{L}_d$ are analyzed by HITS algorithm. The example of a generated player network based on the first-arrival region is shown in **Fig. 2**. In Fig. 2, the blue points, red points, black point, edges are respectively attack team players, defense team players, ball, links. The links are expressed the relationship between the players which are the pass or the covering.

4.2 Extraction of Important Players based on HITS Algorithm

In this section, we explain a method for extraction of important players based on HITS algorithm. In the proposed method, important players are extracted from the obtained player networks by calculating weight of authority and hub in HITS algorithm. Specifically, by applying HITS algorithm to $\boldsymbol{L}_o$ and $\boldsymbol{L}_d$, the proposed method calculates an authority weight and a hub weight for each player based on $\boldsymbol{L}_o$ and $\boldsymbol{L}_d$. Furthermore, we extract important players by utilizing the obtained authority and hub weights. The details of the proposed method are shown in below.

(i) Update the weights

The authority weight a_{o_i} and the hub weight h_{o_i} are calculated by the following equations for the attack team players p_i and p_j $(i, j = 1, \ldots, 11)$:

$$a_{o_i} = \varepsilon \sum_{j=1}^{11} L_{o_{ji}} h_{o_j}, \tag{5}$$

$$h_{o_i} = \eta \sum_{j=1}^{11} L_{o_{ij}} a_{o_j}, \tag{6}$$

where ε and η are normalized constants, Both the authority weight and the hub weight are initially equal to 1. Similarly, the authority weight a_{d_i} and the hub weight h_{d_i} are calculated for the defense team player $i(i = 1, \ldots, 11)$.

(ii) Judgment of important players

In the proposed method, by iterating the calculation of the authority and hub weights in each player, converged authority and hub weights are obtained in all players. Furthermore, the proposed method extracts a player who have higher authority weight as important player, and extracts a player who have higher hub weight as important player too.

HITS algorithm is the authority and hub extraction method from networks based on link analysis. In the proposed method, since relationship between important players and relationship between important web pages are similar to each other, important players are extracted by utilizing the authority and hub weights based on HITS algorithm.

In recent years, the methods of web link analysis were reported[19)20)]. These analyze the huge networks such as web. However, in our method, the network of players, which are not huge network are analyzed. Therefore, we do not need the link analysis methods for the huge networks. Furthermore, we need extract authority players and hub players as important players from the player networks. Thus, we introduced HITS algorithm to the important player extraction.

5. Experimental Results

In this section, we show the effectiveness of the proposed method by experiments. In the first experiments, we used two frames captured from actual soccer videos at the beginning of the following events: (1) some players attack in cooperation with each other team mate, and an attack team player in the left side of the pitch succeeds the pass to a forward player, and (2) the attack team succeeds the left side attack, after that fails the right side attack. These scenes are shown in **Figs. 3** (a) and **4** (a), respectively. In these figures, blue points, red points, black points, yellow points, green points and edges are attack team players, defense team players, ball, authority, hub and link of players, respectively. The results of the important player extraction

p_j is low, $[L_{d_{ij}}]$ is set to 0.0. Specifically, when the player p_j exists behind the player p_i, $[L_{d_{ij}}]$ is set to 0.0.

are shown in Fig. 3 (b)-(d) and 4 (b)-(d).

In the proposed method, authority players in the proposed method are defined as those who as ball receiver of attack team and attacker in defense team. Furthermore, hub players in the proposed method are defined as those who as ball holder of attack team and cover player of attacker in defense team. Therefore, when the above authority and hub players are extracted, we judged the correct result in this experiment, where correct results are decided by manual configuration.

As shown in Fig. 3, correct extraction of the important players can be achieved by the proposed method. In the scene of Fig. 3, player A pass to the ball to player B, successfully. Furtheremore, player A' and player B' are very important players in defense team, since number of players in right side of the attack team is an advantage for the attack team. Therefore, in the scene of Fig. 3, player A(hub), player B(authority), player A'(authority) and player B'(hub) are need to extract. In Fig. 3, player A and player B were extracted in the network of the attack team. Furthermore, player A' and player B' were extracted in the network of the defense team. Thus, we verified the correct extraction by the proposed method from Fig. 3.

As shown in Fig. 4, the proposed method can also extract important players from the player network. In the scene of Fig. 4, first, player A pass to the ball to player B, successfully. After that, player A' and player B' successfully defense an attack by player C. Therefore, in the scene of Fig. 4, player A(hub), player B(authority), player A'(authority) and player B'(hub) are need to extract. In Fig. 4, player A and player B were extracted in the network of the attack team. Furthermore, player A' and player B' were extracted in the network of the defense team. Thus, we verified the correct extraction by the proposed method from Fig. 4. These experimental results verify that the proposed method appropriately generates the player network. Furthermore, we can verify the proposed method appropriately extracts the important players by using HITS algorithm.

Finally, we numerically evaluated the effectiveness of the proposed method. For the quantitative evaluation, 4,532 player networks *** generated from 2,266 frames in actual soccer videos. We applied the proposed method to each network and checked whether the result of extraction is correct or not. Correct extraction of important players was achieved in 2,886 networks, and the accuracy rate was 63.8% as shown in Table. 1. Furthermore, when we note only the player networks of the attack team, the accuracy rate is approximately 82.2%.

In order to confirm the reasonability of the link analysis-based method, we compared the performance of the important player extraction with a conventional method. The conventional method extracts two important players based on running speeds of each player from each network. Specifically, we extract players who are the highest speed in each team since the running speed is generally used for the player evaluation. The accuracy of the conventional method was 24.7%, when we note only the attack team, the accuracy of the conventional method 21.3%. From these results, since important players were more successfully extracted by introducing the link analysis into the soccer video analysis, we confirmed the reasonability of the proposed method.

In addition, when the audiences lack experience such as spectateor in studium and viewer of soccer videos, they can not understand the various game information such as important players and pass courses etc. Therefore, by indicating the important players on various information devices based on the proposed method, many audience will be encouraged to obtain better understanding of the various game information.

6. Conclusions

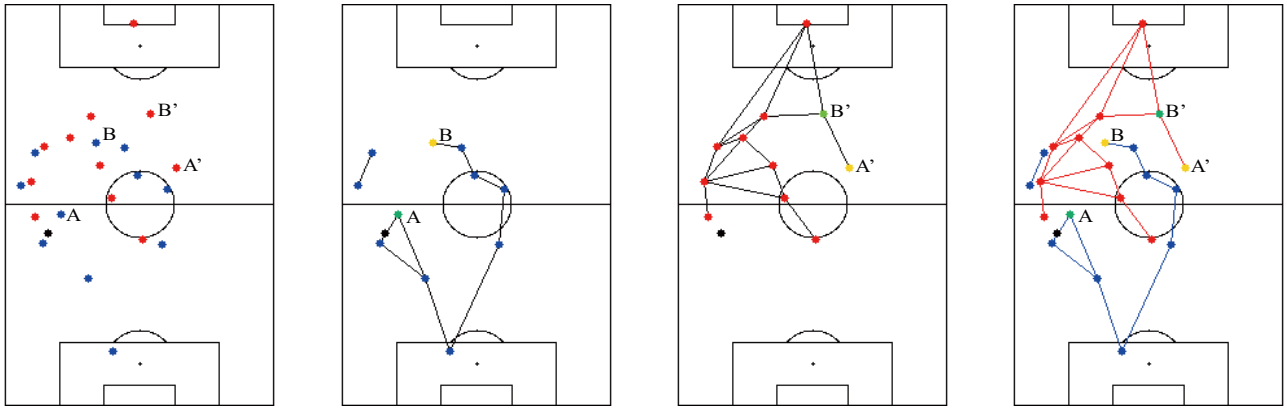
In order to obtain information for understanding soccer matches, we proposed a new extraction method of important players. We noted that relationship between the players is similar to relationship between the web pages which is connected by links. Thus, link analysis was introduced into the proposed method. By applying HITS algorithm to player networks, important players were extracted from soccer videos. The reasonability of the link analysis-based method was shown from the experimental results.

However, improvement of the proposed method which include the defense scenes is needed. The proposed method can currently be applied only to single frames. Since soccer tactics are defined by the formation which is player positions and there movement, by utilizing multiple frames in soccer videos, the improvement of the proposed method can be expected. Therefore, as the future work of this study, we should extend the proposed method to direct video processing for applications.

*** We generated the attack team player networks and the defense team player networks from each frame.

Table 1 Results of experiment for numerical evaluation.

	Total	Correct	Wrong	Accuracy rate	Accuracy rate in attack team
The number of player networks	4,532	2,886	1,646	63.8%	82.2%



(a) (b) (c) (d)

Fig. 3 Extraction results in scene 1: (a) player positions, (b) Extraction result in a network of the attack team, (c) Extraction result in a network of the defense team, (d) Extraction result in scene 1.

(a) (b) (c) (d)

Fig. 4 Extraction results in scene 2: (a) player positions, (b) Extraction result in a network of the attack team, (c) Extraction result in a network of the defense team, (d) Extraction result in scene 2.

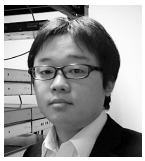
Acknowledgment

This research was partly supported by a Grant-in-Aid for Young Scientists (B) JP26730057, from the Japan Society for the Promotion of Science (JSPS).

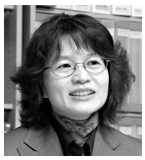
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