Competition Analysis System for Soccer Robots Based on Global Vision and Trajectory Restrictions

Hong LIU, Hongbin ZHA, Fei LIN
National Lab. on Machine Perception, School of Electronics Engineering and Computer Science
Peking University, Beijing, China, 100871
{ liuhong, zha, linfei} @cis.pku.edu.cn

Abstract - *A novel system of automatic competition analysis based on global vision for practical robot soccer games is proposed in this paper to tentatively overcome gaps between simulation competitions and practical ones. Firstly, to improve performance of vision systems and to acquire more reliable competition data, several ideas including color space transformation, sensitivity object processing, local searching combined with global tracking are presented. Secondly, four trajectory restrictions of moving objects are introduced for acquiring more reasonable competition data. Finally, a competition analysis system to support technique statistics, data analysis and interested scenes retrieval is proposed and implemented. Experiments show that the system is compact and effective for quantitative analysis of practical robot soccer competitions.*

Keywords: Soccer robots, trajectory restriction, global vision, competition analysis

1 Introduction

Robot soccer games are more and more popular in recent years as new research and competition platforms. Related researches on learning and coordination among multiple robots are presented by K.Kostiadis and C. Castelpietr, et al[1,2]. Geometrical information and color features of playgrounds are utilized for robot localization and recognition in the researches of J.H. Kim and M.K. Sahota[3, 4]. Transforming color space from RGB to HSV for dealing with illuminative variations is implemented in the system designed by W.M. Shen, et al.[5]. Training methods with a series of special training uniforms have been presented in our system [6].

Robot soccer games are divided into practical competitions and simulation competitions. Simulation competitions are more suitable for dada analysis. Although more and more physical factors are considered in simulation competitions, many complex conditions only occur in practical ones. Analyses of practical competitions after the games mainly depend on researchers' subjective observations from video records, lacking of objective and quantitative evaluations. Until now, few automatic analysis systems are developed for practical competitions with the reason that it is very hard to track all the robots in real-time accurately and to replay the competitions with uncertain robots' trajectories.

Vision systems must work in real-time for the purpose of online collaborating and confronting among multiple moving robots, although there are many complex environmental factors, including variable illuminations, moving shadows, targets' rapid moving. To track robots with high accuracy in real-time, several ideas have been implemented. However, for the reason of limited time to process visual information in each period, many invalid data appear in the feedback from vision systems. These invalid data should be checked, substituted or given up. The main goals of this paper are to improve the global vision system, to introduce trajectory restrictions for acquiring more reasonable competition data and to analyze the practical competition by graphical user interface.

The remainder of this paper is organized as follows: Improvements of vision systems are presented in Section 2 and trajectory restrictions for global vision based competition data are given in Section 3. The competition analysis system and experimental results will be presented in Section 4. Finally, conclusions are given in Section 5.

2 Improvements of vision system

The task of global vision system is to recognize positions and orientations of all the objects. Here, objects include the moving ball and moving robots in the playground. Object recognition can be divided into several steps including feature extraction, object segmentation and configuration recognition. Color space is transformed from RBG to HSV firstly for extracting more reliable features of moving objects in complex vision environments. For a competition system with N robots in each team, configurations of all the objects at the moment of *i* are denoted as ITV(*i*):

$$ITV(i) = (FB^i, FH^i, FO^i), \qquad (1)$$

$$FB^i = (B_x^i, B_y^i), \qquad (2)$$

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$$FH^i=(H_{1x}^i, H_{1y}^i, H_{1\theta}^i, H_{2x}^i, H_{2y}^i, H_{2\theta}^i, \ldots, H_{jx}^i, H_{jy}^i H_{j\theta}^i, \ldots, H_{Nx}^i, H_{Ny}^i, H_{N\theta}^i), \quad (3)$$

$$FO^i=(O_{1x}^i, O_{1y}^i, O_{2x}^i, O_{2y}^i, \ldots, O_{jx}^i, O_{jy}^i, \ldots, O_{Nx}^i, O_{Ny}^i), \quad (4)$$

where, FB^i is for the position of the ball; FH^i is for the configurations of home robots; FO^i is for the position of opponent robots. All the *ITVs* feedback by global vision systems during the whole game are organized orderly and called Global Vision based Competition Data, denoted as *GVCD*. Theoretically, when the interval of vision feedback is small enough and recognition accuracy is high enough, the *GVCD* can determine the whole competition uniquely. Therefore, *GVCD* is the primary data structure for competition analysis in our proposed system.

From observations of *GVCD*, it is found that objects can be divided into two important states. In the first state, objects are moving continuously without disturbance from any other objects and their *ITVs* in adjacent periods are very correlative. In the second state, objects are moving along diverse and complex trajectories and their configurations must be updated in time. For different processing in the improved vision system, the first state is called object's sensitive state and the second state is called object's non-sensitive state. When objects are controlled by strategies for changing movements, very near to the ball, in very high speed or in crowded with other objects, their conditions are regarded as sensitive states.

For the reasons of complex environments and very limited processing time of vision systems, it is very hard to detect and recognize all the objects in single period. Wrong detection and fault recognition are rather popular even in important international competitions. These will be found in *GVCD* as invalid data and shown in competition as poor replay far from the practical competition. Therefore, detection and recognition should be scheduled according to objects' sensitive conditions. Objects in sensitive state should be processed in advance of non-sensitive ones. The non-sensitive ones will be considered when the processing time is allowed. The processing orders can be organized as follows: Sensitive objects are in advance of non-sensitive ones. The orders for objects in the same state are:(1) The ball in advance of robots; (2) Home robots in advance of opponent robots; (3) Position detection in advance of accurate recognition of configuration.

Experiments show that several milliseconds can be saved when the processing of one object is skipped. Several milliseconds are very important because the period of control loop is only about 16 milliseconds.

Therefore, a new problem is raised. When the processing of one object is skipped for several periods, whether it can be tracked later? One method to deal with this problem is to predict object positions according to the past periods. The other method is to combine local searching with global searching.

For the lowest computationally complexity, the predicted position of a object is computed by adding velocity to the current position. Then, object searching is organized as three phases: searching in the small circle with center of the predicted position and radius of predicted distance; searching in the middle circle with center of the last position and radius of biggest distance the object can move in five periods; searching in the global playground. Only if the searching in forgoing phase is failed, will next phase of searching be processed. In Figure 1, the white rectangular is the predicted position of its right robot, and the smaller and bigger circle with the thin white lines are corresponding to the searching areas for phase 1 and phase 2.

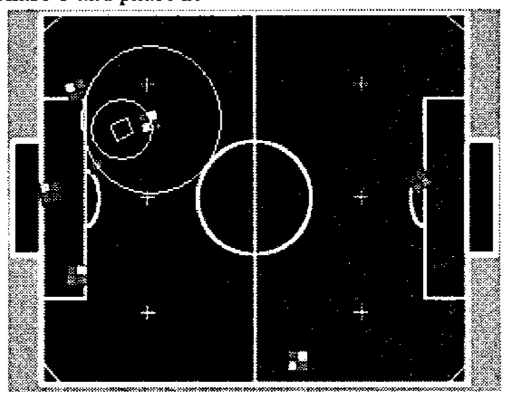

Fig.1. Prediction, local searching and global searching

Table 1. Comparative results for vision system

	Before improvements	After improvements
Preparation time	About 20 minutes	About 5 minutes
Processing time for vision	Average12 *ms*	Average 8 *ms*
Position accuracy	Less than 2*cm*	Less than 1*cm*
Orientation error	10 ° in average	7 ° in average
Invalid data in GVCD	Exist in About *15%* periods	Exist in About *5%* periods

Comparative results before and after improvement for vision system are given in Table 1. Practical competitions show that the global vision system is improved in multiple aspects.

3 Trajectory restrictions for *GVCD*

For the complex factors in vision system mentioned above and the limitations of targets tracking methods, some invalid data in *ITV* are unavoidable. They are corresponding to objects' wrong positions and orientations. From observations and analyses of *ITV*, we learn that many invalid data can be found by reasonable restrictions on trajectories of moving targets. Here, four basic trajectory restrictions for object j are introduced:

(1) Restriction of linear velocity: The maximum distance an object moved in one period is limited. It can be described as follows:

Assume that the position of object j in period of i is confirmed as valid. If the following formula is satisfied,

$$|H_{jx}^{i+1} - H_{jx}^{i}| > V_{xmax} \text{ or } |H_{jy}^{i+1} - H_{jy}^{i}| > V_{ymax}, \tag{5}$$

the position of this object in period of $i+1$ is regarded as invalid one. For the robots in our system, V_{xmax} and V_{ymax} are all set to be 3*cm*.

(2) Restriction of angular velocity: The maximum angle an object rotated in a period of T is limited. It can be described as follows:

Assume that the attitude angle of object j in period of i is confirmed. If the following formula is satisfied,

$$|H_{j\theta}^{i+1} - H_{j\theta}^{i}| > \theta_{max}, \tag{6}$$

the attitude angle of this object in period of i+1 is regarded as invalid one. For the robots in our system, θ_{max} is set to be 45°.

(3) Restriction of smoothness: Because the playground is a 2D plane, trajectories of a moving object are always continuous and smooth in most of cases. It can be found that positions between several periods are restricted each other. It can be described as follows:

Assume that the configuration of object j in period of i is confirmed, if one of the following formulas is satisfied,

$$|H_{jx}^{i+2} - H_{jx}^{i}| < X_1,\ |H_{jx}^{i+1} - H_{jx}^{i}| + |H_{jx}^{i+2} - H_{jx}^{i+1}| > X_2, \tag{7}$$

$$|H_{jy}^{i+2} - H_{jy}^{i}| < Y_1,\ |H_{jy}^{i+1} - H_{jy}^{i}| + |H_{jy}^{i+2} - H_{jy}^{i+1}| > Y_2, \tag{8}$$

$$|H_{j\theta}^{i+2} - H_{j\theta}^{i}| < \theta_1,\ |H_{j\theta}^{i+1} - H_{j\theta}^{i}| + |H_{j\theta}^{i+2} - H_{j\theta}^{i+1}| > \theta_2, \tag{9}$$

the position and the attitude angle of this object in period of i+1 are regarded as invalid ones.

The above rules can only deal with single invalid item among valid data. For several consecutive invalid items, two values of *NumofPos* and N*umofSignChange* for next M periods after period of i will be computed. *NumofPos* is defined as the number of different positions in the next M periods and *NumofSignChange* is defined as the times of different signs in differences of adjacent positions. If *NumofPos* $<a$ or *NumofSignChange* $> b$, these positions of are regarded as invalid ones from period of i to period of $i+M$. Where, M, a *and* b are determined by experiments.

(4) Restriction of overlap: In common cases, objects can't be overlapped each other in 2D playground. If the distances between two objects are too near, at least one object's position is invalid. This restriction can be described as follows:

For the positions of objects j and k in period of i, if the following formula is satisfied,

$$|H_{jx}^{i} - H_{kx}^{i}| < M_1 \text{ or } |H_{jy}^{i} - H_{ky}^{i}| < M_2, \tag{10}$$

the positions of these two objects in period of i are overlapped. Where, M_1 *and* M_2 are all determined by the size of robots. The overlaps between side wall and an object can also be checked by the above method.

Most of invalid data in *GVCD* can be detected by the above four restrictions. For the invalid data caused by influence among objects, they will be substituted by new positions from linear interpolation. Trajectories of all related objects should be continuous and smooth simultaneously. For the "invalid" items caused by lost recognition, several positions should be supplied by linear interpolation between former valid positions and the "invalid" positions. Based on the above processing for objects trajectories, more continuous, smooth and practical *GVCD* is acquired as the foundation of competition replay and analysis.

4 Competition analysis system

Based on the improvements of global vision system and trajectory restrictions, a competition analysis system for robot soccer games is proposed in this paper. The system is composed of following functions: *GVCD* data acquiring, trajectory restriction, graphics user interface, technique statistic, data analysis interface and video retrieval of interested scenes. The graphics user interface (GUI) of the system is shown in Figure 2.

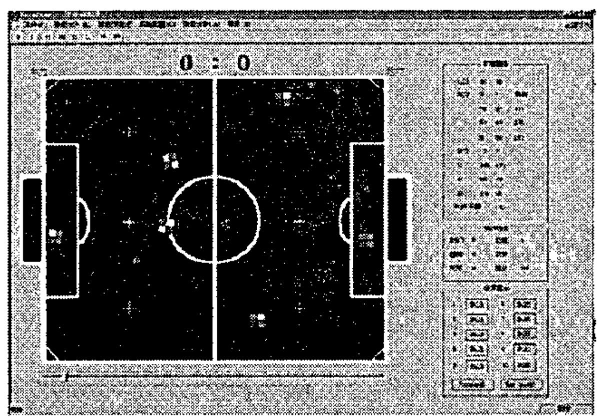

Fig.2. GUI of the competition analysis system

4.1 Data analysis interface

GVCD based competition analysis system can be used for researchers' subjective observations by graphical simulation and be used for quantitative analysis. Data mining technology is a promising research field for discovering implicit rules in a large spatio-temporal database. Strategies of opponent teams are unknown for us although they are very important for our future victories. Many implicit rules in opponent strategies, such as the relation between speed of goalkeeper and successful ratio of goal keeping, variations of attacking ability and defending ability for different robots during the whole competition, can only be mined by microcosmic data instead of qualitative observations

User defined interface for quantitative analysis is designed in our system by opening API. Users can edit and input their formula for data analysis functions. The functions will return results to graphical user interface for human evaluations.

4.2 Technique statistics

Technique statistics is often given after human soccer games as an important way for competition analysis. It is very helpful for audience to evaluate two teams. Therefore, automatic technique statistic is implemented in the competition analysis system composed of times of shooting, times of goal, total time of ball controlling and so on. Several special issues such as times of motion deadlock frequently occurred in robot soccer games rather than human soccer games are also considered.

Here, the computation method from *GVCD* for ball controlling time is given as an example. Total time of ball controlling is computed according to two times of consecutive ball kicking. If a robot of one team kicks the ball at the period of i, and the ball is kicked by a robot of the same team at the period of $i+m$, total time of ball controlling for this team will be added by m. If there is no robot kicking the ball for many periods and the ball stops in the left part of the playground, these periods will be added to the right team and vice versa.

4.3 Video retrieval of interested scenes

Retrieval of interested scenes in video records is a very important way for competition enjoyment and analysis. It is very hard to retrieve interested scenes in long-playing video records. *GVCD* just provide us a very easy way to retrieve interested scenes automatically in data level. When the retrieved scenes are represented by a function of components of *ITVs*, the corresponding period can be found in *GVCD* by similarity measurement. Many other scenes besides competition are often recorded in video records and *GVCD* data are acquired only during the formal competition. Therefore, time corresponding must be established before retrieval.

Shooting as a typical scene is given here for explaining retrieval methods. This retrieval method is also frequently used in technique statistics and other data analysis. Shooting action in practical games is defined as: After a robot kicking the ball, the ball goes forward straight to goals. Therefore, lines detection in ball's trajectories is needed. The retrieval method for shooting is follows:

(1) Restrictions are used for ball's trajectories in *GVCD*. Angular restriction is omitted for the ball.

(2) Finding a new piece of linear segment L by least square and distances from trajectory points to the detected linear segment.

(3) Computing the intersection P of L and the side wall B, if the point P is located just behind the goal, go to next step. Otherwise go back to step 2).

(4) Computing the distance between the ball and a robot j for the period of i and noted as *DistRobToBall (i)*. The moment of i is the starting point of the detected segment. Orientation and speed of the ball at that moment is computed and marked as $\theta_{ball}(i)$ and $V_{ball}(i)$, respectively.

(5) If $DistRobToBall(i) < D$, $|H_{j\theta}^{i} - \theta_{ball}(i)| < R$ and $V_{ball}(i+1) > V_{ball}(i)$, the segment is regarded as the results of robot j shooting. Then, i is used for detecting shooting action in *GVCD*. Where, thresholds D and R are determined from experiments according to different size of playgrounds and motion ability of robots. If the above formulas are not suitable, go to step 2).

(6) If all the trajectories are processed, this algorithm is finished. Otherwise, go back to step 2).

4.4 Experiments of interested scenes retrieval

For testing the proposed competition analysis system, video records and *GVCD* data are all acquired for five practical robot soccer competitions in MiroSot 3 vs. 3 playgrounds. The starting and ending points of time corresponding between video and *GVCD* are established manually after competitions. Because the period is about 16*ms* in competitions, the offset of the retrieved scene in video time should be (16*W*)/1000 seconds when the action is detected in period of *W* in *GVCD*. Shooting scenes (I and II) detected in *GVCD* are simulated in Figure 3(a) and Figure 4(a) and the corresponding scenes in video records as retrieved results are shown in Figure 3(b) and Figure 4(b). For the time corresponding is established for different game sections not frame by frame, scenes in *GVCD* may corresponding to several consecutive scenes in video records. Therefore, there are perceptible differences between the positions of objects in *GVCD* simulation and their practical competition video records. More similar scenes may be found in the adjacent frames before or after the exact corresponding time. Although there are small errors in the automatic retrieval results, the retrieved scenes can be used for competition analysis in most of conditions.

Two kinds of interested scenes, shooting and goal, are retrieved in *GVCD* and video records from the five acquired competitions. 202 shooting scenes and 77 goal scenes have been detected in *GVCD*. 233 shooting scenes and 80 goal scenes are retrieved in practical competition video records. Retrieval accuracy of two kinds of interested scenes is about 86% and 96%, respectively. If ball's trajectory after shooting is rather different from a linear segment, or the motion to the goal is caused by the ball's rebounding from the side walls, these shooting actions may not be retrieved in our system. It will be improved in our future works.

5 Conclusions

Based on the improved global vision systems and trajectory restrictions, an analysis system for robot soccer games is proposed in this paper. Performances of the vision systems are improved by color space transformation, tracking and recognizing sensitive objects with higher priority, combination of local searching and global searching. Most of invalid items in *GVCD* can be detected and substituted by four restrictions of objects. Functions of competition analysis interface, technique statistics, interested scenes retrieval are designed and implemented in the competition analysis system. Memory cost of *GVCD* data for 3 vs. 3 soccer robot games during ten minutes is only about $2M$ to $3M$ bytes. Experiments show that *GVCD* is very compact and useful in quantitative analyses for practical robot soccer games.

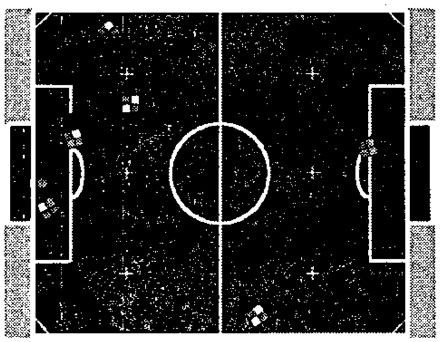

Fig.3(a). Detected shooting I in *GVCD*

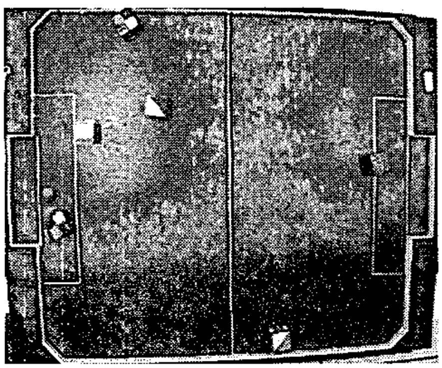

Fig.3(b). Retrieved shooting I in video records

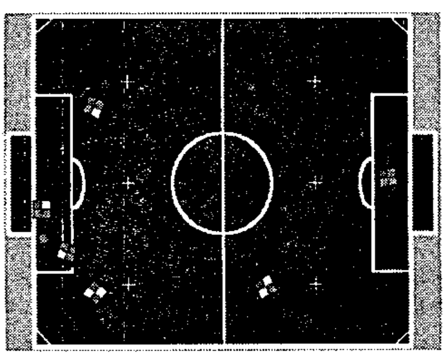

Fig.4(a). Detected shooting II in *GVCD*

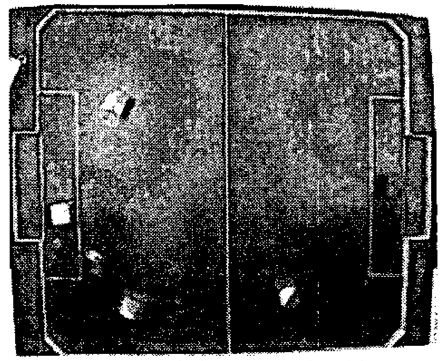

Fig.4(b). Retrieved shooting II in video records

Acknowledgments:

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