DESIGN AND DEVELOPMENT OF DECISION-MAKING AND CONTROL SYSTEM FOR VISION-BASED SOCCER ROBOTS

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Abstract: Centralized robot soccer becomes more and more popular project of science and technology. Because of its global vision, the decision-making and motion control becomes the keystone and the multilevel hierarchical structure is suitable. The robot controller is the 'Brain-less' executor, the motion controller includes all kinds of action functions and the organizing level can adopt different decision schemes. Various decision and control methods make the soccer robot a micro high-tech platform. This paper is a summary to the decision-making and control system of soccer robot according our years' research and experiments.

Keywords: robot soccer, control and decision-making, multilevel hierarchical control, reasoning model, reactive model, system simulation

1. INTRODUCTION

Centralized soccer robot is a soccer robot system with global vision and central decision-making, such as MiroSot and NaroSot in FIRA, F-180 in RoboCup. There are three to eleven robots in every team according to game category, but there is only one robot 'eye' which is above the field. The 'eye' is a CCD camera capturing the image and sending it to the computer to process it. When the image-processing sub-system has identified the positions and orientations of own (or opponent) robots and ball, it sends the information to the own robots(F-180), or to the decision-making sub-system(MiroSot, NaroSot, F-180). Because of the global vision and the full information obtained(if having a good vision system and situation), the centralized decision-making is convenient. Although there are many robots in every team, it is unsuitable to call it multi-robot system or multi-agent system for its only one 'eye' and 'brain'.

Centralized soccer robot is mainly composed of 5 sub-systems, which are vision, decision-making, wireless communication, robot hardware and management one(Wang Wenxue, 2001). Figure 1 describes the system architecture. Many documents did not separate the management sub-system from others(the functions of management system are mainly in vision system) which is not good to the modularization of system and exchange of various vision-modules.

The management sub-system is on the top of the system. It is charged with system initialization, data buffer creation, task scheduling, time assignment and system close. It is a program container and includes many sub-systems. To the management sub-system, all internal sub-systems are equal. There is much relationship between the

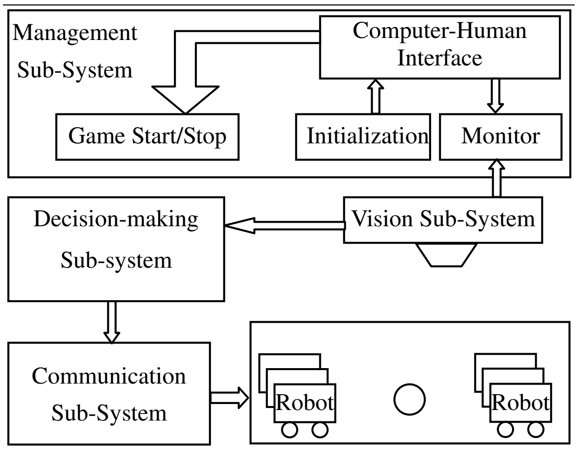

Fig. 1. The architecture of centralized soccer robot

management sub-system and the robot software architecture.

In soccer robot, the vision sub-system can be solved by some commercial image library and the communication sub-system, robot hardware have simple functions which can be bought too, so the main interest of soccer robot is the decision-making sub-system, or the implementation of the decision-making and control. It will express the coach's personal strategy and player's individual actions.

The task of the decision-making and control system of soccer robot(following we will call it the decision-making system)is to decide the left and right wheel velocity of own robots according the robots' and ball's position and orientation(position (x, y) and orientation θ) and make the robots to move according the planned trajectory, cooperate between team members. So the robot team can kick the ball into the opponent's goal and avoid into the own's goal in the intense competition. If we use a $(m + 1) \times 3$ matrix I(m is the number of identified robots) to denote the information sent by vision sub-system and use $n \times 2$ matrix O to denote velocities information sent by decision-making sub-system, we can use the following function to formalize the decision-making sub-system.

$$O = f(I) \tag{1}$$

We can see that equation 1 has the following character:

- the procedure which the function describes is dynamic but not static;
- there is many solutions for the variety of decision-making;
- there is no analytic solution because there is more rule knowledge and production reasoning beside some deduction reasoning;
- the solution is complex and difficult because there is more thinking even in mankind soccer, which is an unsolved difficult problem to describe and abstract.

This paper is a summarization of our soccer robot design and development according our years research and experiments. In the following sections, we will introduce the multilevel hierarchical architecture of intelligent robot, summarize the execution level, coordination level and organization level, introduce the development of the simulation system and the hot research problems recently.

2. MULTILEVEL HIERARCHICAL ARCHITECTURE OF INTELLIGENT ROBOT

Because the robots make the effector reach the desired trajectory or desired position, velocity, acceleration and force by multi-joint cooperation, the multilevel hierarchical architecture is suitable(Zixin, 1998). In general, there are there layers in intelligent robot(Saridis, 1997), which are organization level, coordination level and execution level. The organization level is the main part to control the system and it utilizes the artificial intelligence. As the rule generator of the reasoning machine, it processes high-level information and executes machine reasoning, planing, deciding, learning(feedback) and memory operating to give the best task queue.

The coordination level is the interface between the high level and the low level. It utilizes the artificial intelligence and operational research. The coordination level processes real-time information by generating a suitable sub-task queue. The coordination level is composed by some coordinators with definite structure and specified functions.

The Execution level is the bottom of the multilevel hierarchical architecture. It needs high precision and low intelligence. It controls the relative procedure suitably according the control theory. The centralized soccer robot also adopts the above multilevel hierarchical architecture. The organization level analyzes the situation in the field, decides the strategy and formation, and then assigns the roles. The coordination level decides the targets and actions of every robot and decomposes it to the instructions of every joint which are the left and right wheels of robot cars. The execution level control the robot's wheel velocities according the instructions send by the coordination level and make it go to the target. When there is an error, the low-level status can feed back to the high-level to affect and modify the result of high-level.

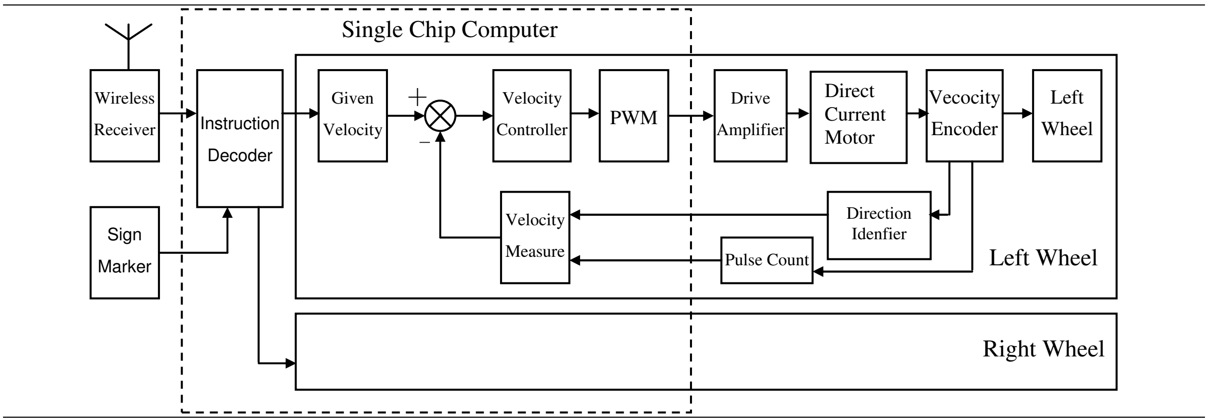

Fig. 2. robot single-chip control system

3. EXECUTION LEVEL — ROBOT CAR CONTROLLER

The robot cars are the players of the soccer team and the performers in the game. But they are the brainless and remote controlled robots for their lack of sensors to the outside environment and the ability to decide by themselves. They only execute the wheel velocity instructions sent by the host computer. To achieve high accuracy, quickness and robustness, robot has wheel velocity measure(generally the increment encoder) in every wheel and has digital feedback system composed of single-chip, DSP or FPGA. Figure 2 describes the classical robot velocity control system composed of single-chip. Obviously, it is the most basic and simple executor. To increase the quickness of robot, the electric current feedback can be added. To increase the performance of robot walk linearly, the balance adjustment of left-right wheel velocity(Cao Yang, 2003) can be added. To overcome the system uncertainty and increase the control performance, advanced algorithms such as adaptive control, fuzzy control (Hitchings M, 2001) (Hitchings M, 2000)can be used. To increase the operation speed and control frequency, the control chip can be changed.

Anyway, what the execution level do is to increase the control precision by control theory, so there is no intelligence.

As there is free space and time in robot control chip, some functions in motion control can be put to the robot controller such as saving and executing predefined open-loop control instruction series in penalty kick, with which a good performance has been achieved.

4. COORDINATION LEVEL — MOTION CONTROLLER

Since the execution level is to execute the robot left-right wheel velocity instructions accurately, the coordination level is to make the robot do various actions by the cooperation of robot left-right wheel velocity.

Action is the basic part of the game. Every excited game is composed of players' action series. The accurate and effective actions mean that the player has good basic skills. So the action is the output and the foundation of the decision-making sub-system.

Actions can be levelled too. We divides the actions into four types which are basic actions, skilled actions, combinatorial actions and tactical actions.

Basic action(BA) can be called the meta-action, such as turn(TurnAngle), goto a point(ToPosition) and move across a point(MoveAlong). They are the basic part of other actions and they translate other actions to the left-right wheel velocity.

Skilled action(SA) is the basic skill of robot player, such as kick ball(KickBall), shoot(ShootGoal), avoid to hit wall(AvoidBound), pass ball to a point(PassBall2Point) and block opponent(BlockMan), which are composed of several basic actions. For example, the shoot action is to make the robot cross the ball with some posture and velocity(assume ball is still), so it needs the basic actions such as turn and go to a point. As the same as the mankind soccer player, the shoot action of the robot can be various. Several different trajectory such as line-line and line-circle have been developed. Obstacle avoidance is also the important part of skilled actions(Wu Lijuan, 2001).

Combinatorial action(CA) is a action series to satisfy some requirement, such as penalty kick(PenaltyKick), free ball(FreeBall), goal kick(GoalKick) and free kick(FreeKick). They are the combination of basic actions and skilled actions, just like the batch action. When facing to different teams and opponents, we can change these actions through menus to suit different situation.

Tactical action(TA) is also based on the basic and skilled actions which need multi robots cooperation. It includes pass and shoot(PassToShoot), normal kickoff(NormalKickOff) and so on.

Because every action can be implemented by analytic algorithms, we can enlarge the 'granularity' of decision-making system and call the functions directly which make the decision-making system to a 'macro-thinking' level.

5. ORGANIZATION LEVEL — GLOBAL DECISION-MAKING

To the robot soccer, if the decision-making system is the coach, the coach is 'blind' who can not see the game situation and think with image. He must analyze the situation according the data of robot postures and ball position sent by vision sub-system and give the command of the players' actions of left and right legs(wheel velocity). It is a complex decision-making procedure and the main point of decision-making system which has been researched much(Messom, 1997) (Shim, 1997). The decision-making system should decide strategy as the blind coach, reason the every step abstractly and formalize the expert knowledge and decision procedure. (Xinhe, 2001)presents the Six-step reasoning model for robot-soccer:

(1) Pretreatment of input information(distance, velocity and relative angle calculation etc.).
(2) Judgement of offensive and defensive posture.
(3) Determination of battle formation and role assignment.
(4) Determination of the target position.
(5) Path planning.
(6) Calculation of the wheels' moving direction, velocity and displacement.

Generally speaking, step 1, 4, 5, 6 belong to the deductive reasoning , which can be performed through mathematical models. Step 2, 3 belong to the production reasoning, which can only be fulfilled with expert system. Above sections have made the deductive reasoning of step 4,5,6 form various action functions and the coordination level of intelligent control. In this section, we will discuss the functions of step 1,2,3.

5.1 From the information space to state space

The information of matrix I from vision subsystem is the posture of every object, including position (x, y) and orientation θ. Obviously, the matrix I information is limited. If we want to answer the questions in decision-making procedure, such as the situation of both sides or which player is the best for attack, we can only obtain the appended information such as relative angle, distance and velocity to deduce a series of judgement criteria without the thinking with image. So the information should be preprocessed and transferred to the state space. The state variables should be made in a state space which can be analyzed and clustered, and then the enough conditions can be given for the following reasoning.

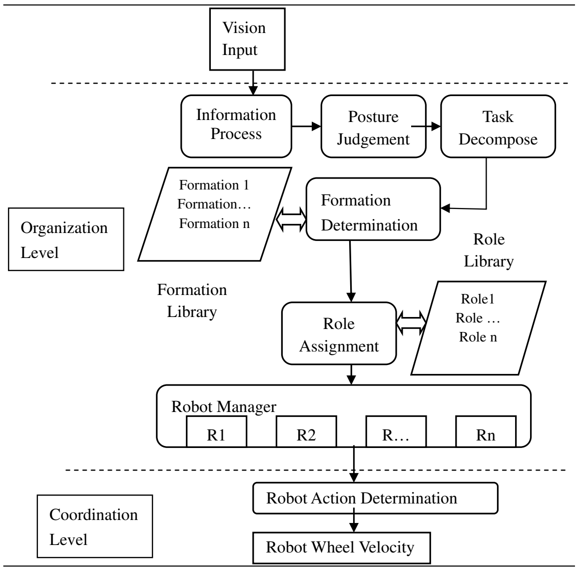

Fig. 3. Mapping-type decision-making

How to design and use the state space? It is a unsolved problem and obtains less attention.

Because the problems of algorithm complexity and criteria have not been solved properly,the following substitute method is used. The field can be divided into a number of regions. The judgement of offensive and defensive is based on the regions where the ball is in and where the ball moves to. The following state variables are defined:

$$State = (S1, S2, S3, S4) \quad (2)$$

$S1$ is the ball position, $S2$ is the ball movement direction, $S3$ is the ball velocity, $S4$ is the situation of which side controls the ball. Obviously, it is a relatively simple and extendable state space. As the competition becomes more active, a more complex state space should be used.

5.2 Mapping-type decision-making

Now the organization level should solve the important problem of how to get the mapping from the state space to the action space. One of the methods to solve it is to use the task space.

The method presented in the paper is to judge the offensive and defensive posture according the equation 2, bring forward the task which should be completed at present, decide the positions and roles of own robots with the form of formation.

The mapping rules are stored in the formation library and rule library.

Role is a logic robot which can fulfil some definite tasks. It finish the task by use the robot actions. Formation (Zhang Chunhui, 2000)is the global reflection of players' positions and roles. It is a definite combination. In essence, formation is an ordered arrangement of roles. It can be expressed with

$$F = (role1, role2, role3, ..., roleN) \quad (3)$$

F is the formation, $role1 \rightarrow roleN$ are roles. In formation, the roles are ordered according to their importance and the most important one is at the first. In the point of task schedule, formation is the 'unite actions' of multi robots. In the point of single robot, formation is the bridge to other robots.

We use the role assignment (Wu Lijuan, 2000)to relate the roles in the formation to the real robots. Role assignment is to choose the suitable robots for every role in the formation. The important roles should be assigned firstly.

To design the formation library and role library, the table model is used. By now, 3 classes of information are used, including formations, roles and role assignment parameters. To abstract, unifying and parameterizing the decision-making procedure, unified models with different parameters are used to store different formations and roles.

6. DEVELOPMENT OF THE SOCCER ROBOT SIMULATION SYSTEM AND ITS IMPLICATIONS

6.1 The implications of the soccer robot simulation system

The soccer robot simulation system affords a cheap and convenient tool for the development of the strategy and control system, since it provides a visual platform to test the algorithms, actions, functions and parameters of the decision-making system before the real system adopts them. The procedure of the development of the simulation system is the procedure that we analyze the real system, get the kinematic models and collision models of moving objects, test and correct the models by experiments. The models are the base of the development of the strategy and control system. The simulation system can also use its property of flexibility to make the soccer robot system have more functions and advantages. Most of the existing simulation systems are developed to be a game platform, and they can not satisfy all requirements in the development of the soccer robot strategy and control system. It is

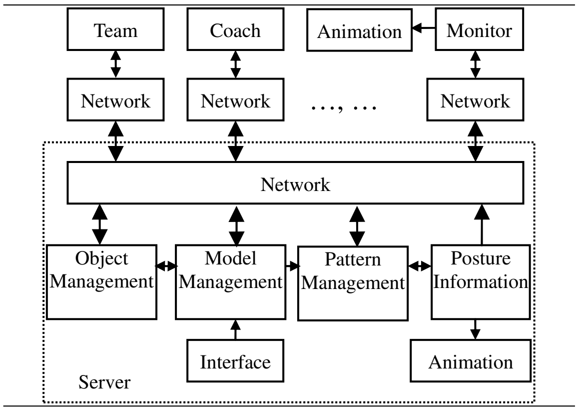

Fig. 4. Simulation system structure

necessary to develop a simulation system with open and flexible structures and can truly imitate the real system. The models of the soccer robot system were described in reference (Zhang Chunhui, 2001). The contents below mainly introduce the structure and operation mechanisms of our soccer robot simulation system NeuSim.

6.2 The NeuSim system

The NeuSim system adopts Client-Server model. It has network communication, object management, model management, mode management, man-machine interface and video display modules (described in fig.4).

Network communication module. The module makes the network communication using socket technique, whose tasks are to listen in the network, construct the connections, and transfer data.

Object management module. Here Objects are the programs to connect the simulation server from the clients. There are four kinds of objects according to the purpose of the objects, and different objects have different authorizations. The first kind of object is the strategy programs to play games called player, whose authorizations are to send velocity commands to the home robots and to accept the position information of all moving objects. The second kind of object is the programs to control and coordinate the players, control the rhythm of the game, such as referee and coach, whose authorizations are to change the velocity command and positions of the moving objects and interrupt, continue, reset and stop the game. The third kind of objects is the programs to debug robot actions or strategies, whose authorizations are to send velocity commands to home robots, accept position information of moving objects, and interrupt, continue, reset and stop the game. The forth kind of objects is the programs to monitor the video information of the game, namely remote monitor, whose authorizations are to accept position information of all moving objects. The function of the object management module is to manage the registration, connection, hanging and logout of the objects.

Mode management module. Different simulation services have different operation modes. Multiple modes are the set in the mode management module, such as normal game mode, uninterrupted game mode, step by step mode, debug mode, and so on.

Model management module. The models of moving objects are the base of the development of simulation system, including the kinematic model of the ball, the kinematic model and dynamic model of the robot, the collision model and collision detection model of moving objects, and so on.

We use a normal game to illustrate how to use the simulation system. First the network communication module is imported into the strategy sub-system of a real game system. After it the strategy system is given the position information of moving object by the network communication module instead of by vision system and the velocity commands are sent by the network communication module instead of by wireless communication system. Then two new strategy systems connect to the simulation server. When both strategy systems are connected successfully, they are registered by object management module, and the object management module rejects all but the remote monitor object after then. The mode management module selects the normal game mode and starts the simulation service. The latter operation of the strategy system is the same as the strategy system for a real game.

7. CONCLUSION

The paper summarizes recent researches on the centralized soccer robot strategy and control system, and there are also some problems to be solved. The control precision, velocity and reliability of the car-like robot in the execution layer need to be enhanced. More and more action functions are designed in the coordination layer, but the problem how to kick ball when the ball is moving has not been solved well. More effective and advanced algorithms need to be used to realize perfect tactical actions, such as one pass one shoot (namely, one robot pass the ball, another robot shoot the ball to the enemy goal), two beat one, and so on. The organization layer has most of the unresolved problems. At one side the strategy, formation and tactics of the soccer robots have not been well-regulated conclusions yet, at the other side there are few effective tools to discovery and use the knowledge of the game to model intelligence. The problem is closely relative to the development of the AI subject, which is the original intention of the organizer of the robot soccer subject. The researchers try to promote the researches in relative fields by the competition on the test-bed of soccer robot system and make the AI science developed.

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