Game Theory-Based Research on Cooperative Behavior of Group Robots

Ping Yang
College of Mechanical and Electrical Engineering
Lanzhou University of Technology
Gansu, China

Cui-ming Li
College of Mechanical and Electrical Engineering
Lanzhou University of Technology
Gansu, China

Xiao-xing Shi
College of Mechanical and Electrical Engineering
Lanzhou University of Technology
Gansu, China

***Abstract*—This article researches the game theory and applies it in the cooperative behavior of group robots. This behavior is analyzed from the perspective of game theory. The gambling model of Cournot is used for group robots' modeling to find out the optimal solution. Controlling model is build and the cooperative behavior is simulated.**

Group robots; Game Theory; Cooperative; Strategies; Payoff;

I. INTRODUCTION

The robot's history has been developed since the first industrial robot has been made by Ingerborg and Devor from USA in 1959. As one of the greatest inventions, the robot experienced three generation, which from the original teaching and playback robot to 1970s when the robot basically owned the feelings, and then to today's robot which not only can judge and move by itself, but also memorize, infer and make decisions. The speedy development of robot exceeds our expectations far away. In areas such as industry, agriculture and commerce, and so on all fields, robot saved amount of labors, materials and brains, which liberate people from the amount, complicated, repeated and dangerous work. Nowadays, people's lives become more and more diversified, and the application of robot technical has gone in to the nearly every area. With its continually developing, the robot is facing more complicated work. If these complicated tasks want to be finished by a single robot, the requirement to the robot would be highly, not only the control program, circuit, but also the mechanical contracture, the parts and so on. The cost of the robot would be highly increased, and once something wrong with the some part of the robot, the whole work would be stopped.

Some people began to think that since some work couldn't be finished by a single robot, what about more? It would be fine if the robots could cooperate with each other efficiently like human beings, when problems come up, they could solve it by themselves. They cooperate to maximize their power and finally finish the job efficiently. Many problems would be solved if the robots could cooperate with each other. Basic on this idea, the group-robot comes up. In the group-robot system, every single robot is manufactured simply and low prices to product large quantity. The most important is that the group-robot is distributed controlled, but not the central controlled. So the best merit of the group-robot is even something wrong with some of the single robots when it is working, the whole work progress won't be affected. The system owns strong robustness. The group-robot's born and development widened its application in the modern manufacturing and will be the main direction of the modern robot technical. In working, the cooperation and competition showed up between the single robots, and a lot of problems of the robot technical have to be solved. Such as, the cooperation of the robots based on the communication technical, and once the information was blocked, what theory should we based to solve

978-1-4244-9439-2/11/$26.00 ©2011 IEEE

the problem to maximize the group's interest has

This paper researches the game theory and the relevant theory. *Cournot competition modeling*-based, model the group-robot and look for the best merit result of the cooperation between the single robots. Build the control model and simulate the progress.

II. Game Theory

Game theory is the theory which researches the reasonable decision-making behavior and the balance result of the decision-making body which rely and effect on each other. The combination of decision-making behavior and the result which relies and effects on each other is called Game. [1]

The research way of the Game Theory is the same as many other subjects that research the nature appearance with math tools. They all absorb the basic elements from the complicated phenomenon and analyze the math model constructed by these elements, put in other factors which effect the styles, then the results been worked out. Theory speaking, Game theory is the theory which researches the form of the interaction of the rational actors. Both competition and cooperation exist in the individuals of the group was known by the research of Game theory.

III. Game Model of Group robots

Assume a group robots system G= { $S_1, \dots, S_n$; $u_1, \dots u_n$ } is constituted by two robots, A and B, and the strategy space of the robots is the information election when they finished the job together. Each one chooses the strategies q_i (i=1, 2) from the feasible strategy aggregations Q_i= $[0,\infty)$ (i=1,2). When the job is finished, every robot's payoff is absolutely relevant with the result of the whole robot system, and is assumed as $p = p(q_1 + q_2)$.

When robots carry out some operation, and if the power and the control system are seemed as the been the a new lesion of the robot area.

cost of the robots, now $c_i(q_i)$ (i=1,2) is used to show robot i's cost on strategy q_i, which is meaningless to the result and will be $c_i(q_i)$=c=0, in the following calculation. So robot i's payoff function is

$$u_i(q_1,q_2) = q_i\, p(q_1+q_2) - c_i(q_i) \quad (i=1,2) \quad (1)$$

Mark robot A and B's Cournot reaction function with

$$r_1 : Q_2 \to Q_1 \qquad r_2 : Q_1 \to Q_2 .$$

If u_i (i=1,2) fulfills some ideal situation, the first derivative of payoff function can be solved and made to zero to impetrate the reaction function. For example, $r_2(\bullet)$ is the reflection of Q_1 to Q_2, which means robot B's best reaction function would be $q_2 = r_2(q_1)$ to the strategy q_1 of robot A. It should fulfill the following condition,

$$\frac{\partial u_2(q_1,q_2)}{\partial q_2}=0$$

Means

$$p(q_1+r_2(q_1))+r_2(q_1)p'(q_1+r_2(q_1))-c_2'(r_2(q_1))=0 \quad (2)$$

(q_1 is seen fixed.)

Analog to $r_1(q_2)$ and should fulfill the condition that

$$p(r_1(q_2)+q_2)+r_1(q_2)p'(r_1(q_2)+q_2)-c_1'(r_1(q_2))=0 \quad (3)$$

Solved $r_2(q_1)$ and $r_1(q_2)$, based on equations (1) and (2), and then find their crossing point. $p(q_1+q_2)$ is set to equal to max(0,12-(q_1+q_2)). The assumption to $p(q_1+q_2)$ has somewhat rationality. And if the cost of the two robots was seen as a constant c, which means,

$$c_1(q_1) = cq_1 \text{ and } c_2(q_2) = cq_2$$

Put $p(q_1+q_2)$, c_1 and c_2 into equations (1)and(2), then we obtain $r_2(q_1)$ and $r_1(q_2)$

$$r_2(q_1) = (12 - q_1 - c)/2;$$

$$r_1(q_2) = (12 - q_2 - c)/2;$$

Nash equilibrium q_1^* and q_2^* is the crossing point. So $q_2^* = r_2(q_1^*)$ and $q_2^* = r_1(q_2^*)$ is fulfilled.

Then, $q_1^* = q_2^* = 4 - c/3$ can be got through calculation.

Although in the Cournot competition model, the simple strategy space of the player owns continuum, the contradiction between the individual reason and the common reason exist in it just like the prisoner dilemma of the limit strategy space. [2] Might as well, set c=0, the Nash equilibrium of the game is $q_1^* = q_2^* = 4$ now. Both of the players' payoff is $u_1(4,4) = u_2(4,4) = 16$, if player i's payoff function is $u_i(q_1,q_2) = q_i(12-q_1-q_2)$ $(i=1,2)$

Set $q_1 = q_2 = 3$,

So, $u_1(3,3) = u_2(3,3) = 3\times 6 = 18$

Obviously, if the two robots sincerely cooperate each other and limit their owns' strategy as 3, they would got the satisfied payoff 18 is better than the Nash equilibrium (4,4) which is 16. So analyze from the strategy election of the single robot, Nash equilibrium didn't make the best. If every robot asks itself what result it wants to get from the game, some alternative ending seems unreasonable. Because some robots could do better than now, but the whole system s' payoff is the best. [3]

IV. CONTROL STRUCTURE OF GROUP ROBOTS SYSTEM

In group robots, every single structure should own many functions, such as perception, communication, mission decomposition and distribution, local planning, decision making, study and so on. [4] The individual robot's classic control structure contained the lamination hierarchical structure and the structure based on the behavior as well as the composite structure which is formed together by these two kinds of structures. The group robots' lamination type control structure is composed of three layers, which is system monitoring layer, coordination planning layer and the behavior control layer. Different control layer achieve the cooperation and coordination in different ways. Each layer has its planning task. The task decomposed layer by layer, and finally the robot got the executive action. Any layer of the structures is intelligent planning. This kind of structure has better concurrency and timeliness and can enforce robots' ability to the emergency of the changing environment.[5] The group robot system's controlling principle as shown in figure1.

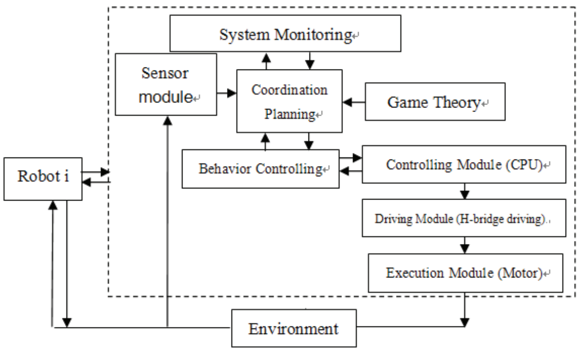

Figure1. Robot Control Structure

V. GROUP ROBOTS' COOPERATION BEHAVIOR SIMULATION

Take group robots' barrier-avoiding for example and simulate the effect of the cooperation of the robots. This simulation based on the Game Theory, and Microsoft Visual Basic was used to be the simulation platform.

The group robots system is constructed by three robots R1, R2 and R3. As shown in figure 2, three robots are required to move to point B from point A, R1 is initialized to be leader and R2, R3 to be followers. In the program when R1 is leader, the team keeps the triangle style, otherwise, keeps the straight line. When the three robots move to barrier C, the team wouldn't pass through in this triangle style. Robot R1 will give the leader position to robot R2 or R3, as shown in figure 3, the team will pass through the barrier C. This kind of way can not only save the system's source, but also let the team pass through the barrier in a simple way. When robot R3 finds all of the robots passed the barrier, R1 will be leader again, the team will get to point B in the triangle style, as shown in figure 4.

Figure2. Initial State

Figure3. Middle State

Figure4. End State

VI. CONCLUSION

When all of the robots work together, the competition about information, resources and so on, are existed in team, but more important is that they have to cooperate to each other to finish the whole work. The game theory researches about the relationship of competition and cooperation of the individuals in the same group, and any one's action affects the group. This paper based on the gambling model of Cournot to find out the optimal solution, in order to explain that only the robots cooperate to each other, the best solution can be found, but not any one of the do their best. Controlling model was also built, in this paper, the cooperative behavior was simulated and cooperation framework of the game theory was brought into the robot subject.

REFERENCES

[1] Fan Ru-guo, Han Min-chun, "Game Theory", WuHan University Press, 2006.3

[2] Rasmusen.E., "An Introduction to Game Theory", Peking University Press, 2003

[3] Tan Min, Wang Shuo, Cao Zhi-qiang, "Multi-robot Systems", Tsinghua University, 2005.4.

[4] Lan Ting, Liu Shi-rong, "Research on Multi-Robot System Inspired by Biological Swarm Intelligence" Robot, 29-3, 2007.5.

[5] Dennis Clark, Michael Owings, "The Design and Control of Robots", Science Press, 2004.5.