

Leader-follower Cooperative Movement Method for Multiple Amphibious Spherical Robots

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Abstract – Information exchanges and cooperative movements of multiple robots have become a hot topic in robotics. To increase the adaptability of robots in amphibious scenarios, an improved amphibious spherical robot was designed in this paper. However, the ability of single robot was limited. To further increase the sensing range and work efficiency of own amphibious spherical robots, a Leader-follower method, which could realize the coordinated movement and formation keeping for three or more robots, was adopted in this paper. The theoretical analysis show that the Leader-follower method could be easily applied in amphibious spherical robots for practical applications. And a simulation experiment platform named Player/Stage was used for verifying the effectiveness of this method. The construction of the experimental environment and the final simulation results were provided in this paper. Through the analysis of experimental results, the feasibility of the Leader-follower method was verified, and this method will be used to implement multiple amphibious spherical robots cooperative motion in future works.

Index Terms - Leader-follower; Amphibious Spherical Robot; Multi-robot cooperation; Player/Stage; Cooperative movement.

I. INTRODUCTION

The biologist and behavioral scientist by studying the biological behavior of groups, tried to seek inspirations and laws between subsistence and behavior. Social animal, like human, can achieve many unexpected things by group cooperation. Research showed that group cooperation could greatly improve the survivability of the biological, for example, the perceived threat, finding food, building, etc. Visible, if the group cooperation can be applied to the research on robot system, must enhance the feasibility and effectiveness of the practical application of robot [1].

In the study of multi-robot cooperation system, we can find that multiple robot system has more strong sensory ability and athletic ability than a single robot system [2]-[4]. Multiple robot system is one of the important topics in the field of artificial intelligence and mobile robot research, has strong demand in practical application. Especially in the complex task and the environment is volatile, like detection in deep sea, multi-robot collaboration much stronger than a single robot,

which has high research value in the field of intelligent robot research [5].

Since the late 80s, the first Cellular Robotic System (CEBOT) [6] based on multi-agent was building, dozens of years, multi-robot system both in theory and practical application research has made significant progress, and also set up some simulation system that applicable to multi-robot system study. Among them, the formation control problem has become a hot research problem of multi-robot systems, including through the appropriate formation control can improve system's ability to complete task efficiently. However, there are many difficult problems and challenges with the study of multi-robot, such as increasing the difficulty of the system management, and increasing the dependence of the system of communication, etc.

At present, the popular formation control technology are shown as follows. (1) Behavior-based method: through local control strategy and the behavior of robot itself, the method produced collective behavior when the robot need. The method of each behavior have their own independent goals and tasks, that belong to the category of distributed control, however, the biggest problem for this method is too difficult to achieve the overall behavior decision-making, so in the process of formation, the difficulty of keeping stable increase; (2) Virtual structure method: through calculating the path of the virtual leader robot as the robot's motion parameter, to achieve robot team formation; (3) Reinforcement learning method: through comparing the behavior of the robot and the factor of ambience, the method make an evaluation of incentives. If it was rewarded, the behavior would be strengthened, and on the other hand, the behavior would be reduced, until be eliminated. This method is also often used in path planning, but the learning process is too long, so does not favor the formation of the overall requirements; (4) Leader-follower method: it is mainly achieved by choose the lead robot, and the lead robot get the information of follow robot, such as distance, velocity, degree, and so on, to calculate the final condition of the follow robot, so as to realize keep following movement and formation in the end [7]-[8]. Compared with other methods, this method has higher applicability and availability, even there is a problem that the final computed result is difficult to choose the only one

(locally optimal solution), through improve the calculation mode of follower, and reduce the effects of local optimal solution, we can optimize this method to control robot. Considering amphibious spherical robots have special structures and application environment, Leader-follower method with concise and effective would be more suitable for achieving three amphibious robots' formation transformation and keeping.

The structure of this paper is organized as follows. Section II introduces three update structures for this robot. Details of Leader-follower method will be elaborated in Section III. The experimental method, to demonstrate Leader-follower method can be used for multi-robot control effectively, and experimental results will be carried out in Section IV. And Section V will be conclusion and follow-up relevant research work.

II. STRUCTURE OF IMPROVE AMPHIBIOUS SPHERICAL ROBOT

The amphibious spherical robot was developed in previous research [9]. The overall creative thinking mainly comes from the consideration of the following: Considering the wide range of work load and high strength, the robot adopts the traditional motor drive; Considering the internal space of the rich and flexible movement, the robot is the ball shape as the main body; Considering the high-speed cruise, streamlined fuselage structure may be the best choice [10]. This paper is mainly based on the amphibious spherical robots, as the requirement of the communication between the amphibious spherical robots, the structural of the robot need be improved, so these is the improved amphibious spherical robot in this paper.

They need more space to install the communication module and more stable motion structure to support multi-robot cooperation. So, we made some changes for this new robots, as follow.

Firstly, the robot is an amphibious robot, so need to work on the water in the future. We must ensure that the water proofing property of the robot and the robot is heavy enough to dive. Think about we will install some sensor on this robot, more spaces be needed, so we changed the size of the next amphibious spherical robots based on the micro-robot. The diameter of the robot is raised from 250mm to 350mm. those legs is bigger and stronger and can be used for supporting the whole body. The overall structure is shown in Fig.1 [11].

Secondly, the underwater sonar is mounted on the robotic body for communication in water. As ensure the water proofing property of the robot, we designed a new structure with sonar. The new structure is shown in Fig.2. The design inspiration comes from the observation of the submarine.

Thirdly, due to the bigger size and weight of the robot, the robot can't stand up when it begin to walk. We added a new structure as supporting platform to support the robot, as shown in Fig.3 below, and this supporting platform be shrink after it hold firmly. When the robot walk on the flat ground, this supporting platform can be used well for helping walking.

Those new structures were shown are just three, all of them would be introduced detailedly in later research.

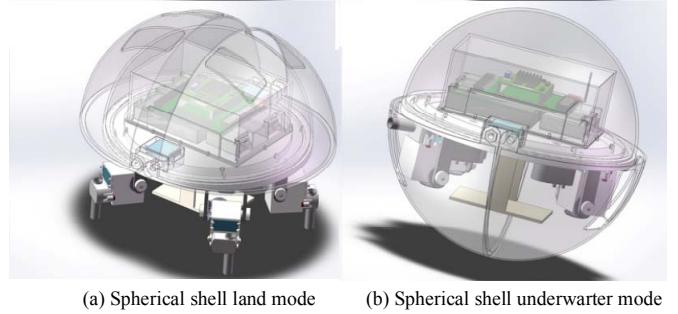


Fig.1 The overall structure of amphibious spherical robot [11]

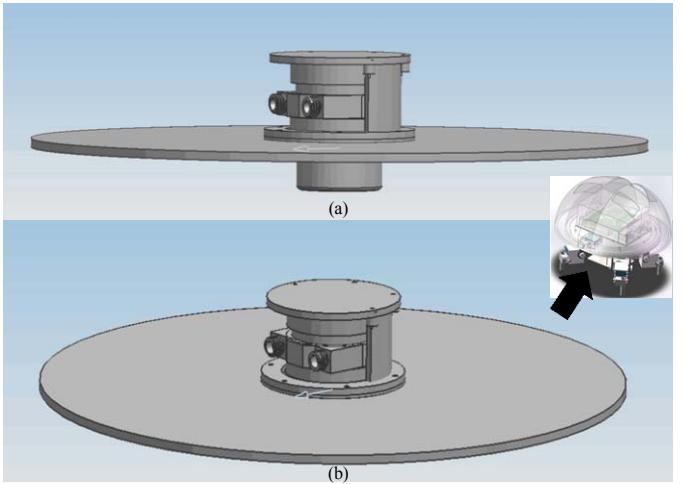


Fig.2 The sonar platform. (a) Front view. (b) Oblique view.

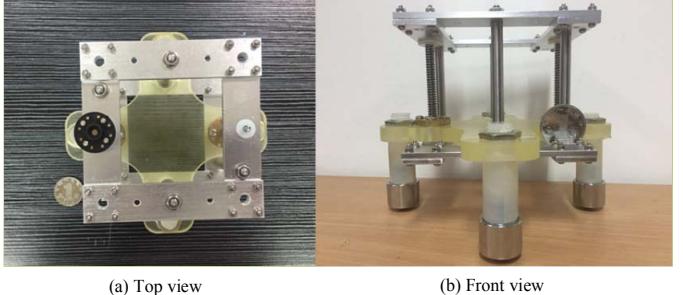


Fig.3 The supporting platform

III. LEADER-FOLLOWER ALGORITHM

In a word, formation control technology of multi-robot refers to the process of a few of robot move to the same direction or same objective. Each of them keeps a certain distance to achieve the difference formation, such as quadrilateral, triangular, linear and so on. And the technology can adopt to a wide variety of environments, and increase the possibility of practical application of robot.

Leader-follower method have many stretched form, such as $l-\varphi$ algorithm, $l-l$ algorithm, Tracking Algorithm. We use $l-\varphi$ algorithm in this paper, which has response rule to improve the stable of robotic motion, and has been widely applied today [7]. The basic control principle diagram is shown in Fig.4.

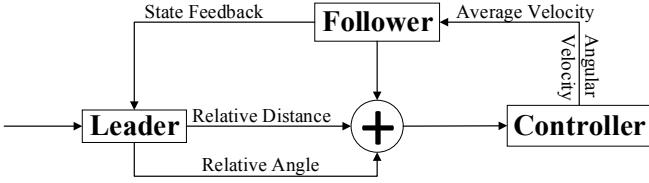


Fig.4 The basic control principle diagram of 1- algorithm

According to the topology structure of this system, formation can be divided into series formation and parallel formation. In series formation, each follower get the information of location from the near robot. In parallel formation, follower get the information from the leader, under the condition of a single leader, parallel formation is more stable than serial formation.

The location model of single robot is shown in Fig.5 [12].

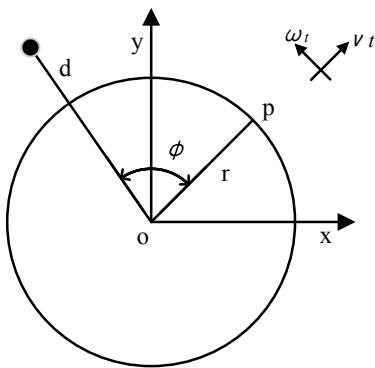


Fig.5 The location model of single robot

In Fig.5, \mathbf{o} is the center of spherical robot, \mathbf{p} is the front head of spherical robot, r is the radius of robot, d is the distance between robot and target, the current linear velocity and angular velocity is v_t and ω_t respectively, and ϕ is the angle between op and d .

According to the laws of the triangle and estimates, and can get the following formula:

$$d = r\omega_t \sin \phi - v_t \cos \phi \quad (1)$$

$$\phi = \frac{v_t \sin \phi}{d} - \omega_t + \frac{r\omega_t \cos \phi}{d} \quad (2)$$

If d and ϕ was zero in the end, the spherical robot could get to the destination, and the formation could complete.

Making an assumption:

$$\begin{aligned} d &= -\beta_1 d \\ \phi &= -\beta_2 \phi \end{aligned} \quad (3)$$

Among them, β_1 and β_2 are the parameters of the reservation, so the final equation is:

$$v_t = \frac{\beta_1(d - r \cos \phi) + r\phi\beta_2 \sin \phi}{d \cos \phi - r} d \quad (4)$$

$$\omega_t = \frac{\beta_1 \sin \phi + \phi\beta_2 \cos \phi}{d \cos \phi - r} d \quad (5)$$

Think about the physical constraints of the motors, the control variables should be:

$$\omega_t = \begin{cases} \omega_{\max}, \omega_t > \omega_{\max} \\ \omega_t, -\omega_{\max} < \omega_t < \omega_{\max} \\ -\omega_{\max}, \omega_t < -\omega_{\max} \end{cases} \quad (6)$$

$$v_t = \begin{cases} v_{\max}, v_t > v_{\max} \\ v_t, -v_{\max} < v_t < v_{\max} \\ -v_{\max}, v_t < -v_{\max} \end{cases} \quad (7)$$

The relation between leader and follower is shown in Fig.6 [13].

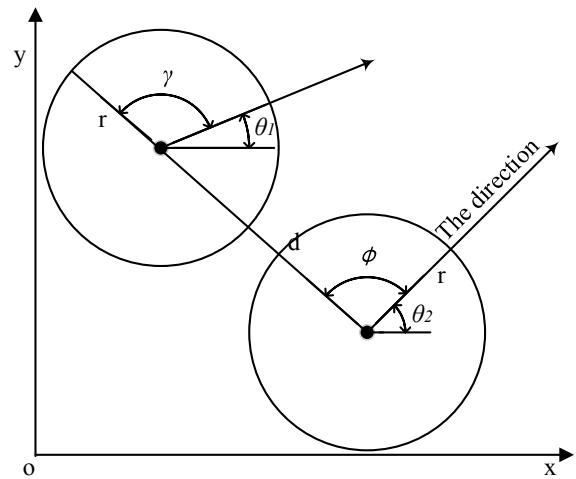


Fig.6 The location model of Leader-follower

Suppose each of spherical robot's location is (x_i, y_i, θ_i) , $i=1,2$. In the process of control, the status of leader is $R_1(x_1, y_1, \theta_1, \omega_1)$, the status of follower is $R_2(x_2, y_2, \theta_2, \omega_2)$. The positive direction of the robot's linear velocity is the direction of forward motion, the positive direction of angular velocity is counter clock wise.

Take $\gamma = \phi + \theta_1 - \theta_2$, d and ϕ can be expressed as:

$$d = v_2 \cos \gamma - r\omega_2 \sin \gamma - v_1 \cos \phi + r\omega_1 \sin \phi \quad (8)$$

$$\phi = \frac{1}{d} (v_1 \sin \phi - v_2 \sin \gamma - r\omega_2 \cos \gamma + r\omega_1 \cos \phi - d\omega_1) \quad (9)$$

In order to achieve formation, the final status is

As $t \rightarrow \infty$, So $(d_r - d) \rightarrow 0, (\phi_r - \phi) \rightarrow 0$.

Making an assumption:

$$d = \alpha_1(d_r - d) \quad (10)$$

$$\phi = \alpha_2(\phi_r - \phi)$$

Among them, α_1 and α_2 are integers. The final equations are shown below:

$$v_2 = \rho + r\omega_2 \tan \gamma \quad (11)$$

$$\omega_2 = -\frac{\cos \gamma}{r} [\alpha_2 d(\varphi - \varphi) - v_1 \sin \varphi + r\omega_1 \cos \varphi + d\omega_1 + \rho \sin \gamma] \quad (12)$$

$$\rho = \frac{v_1 \cos \varphi - r\omega_1 \sin \varphi + \alpha_1 (d_r - d)}{\cos \gamma} \quad (13)$$

Therefore, if the angular velocity, speed, position and direction of leader were defined beforehand, we could guarantee the follower move with a certain velocity and direction, to achieve the formation keeping in the end.

Compared with land situation, the underwater environment is more difficult to achieve formation keeping. We want to use altimetric compensation method in water like aircraft hover in air. As the new amphibious spherical robot is produced, we will make some experiments in water in the next study.

IV. THE EXPERIMENT OF LEADER-FOLLOWER METHOD

A. The experiment of Leader-follower method building

Due to the new amphibious spherical robot is being produced and quantitative, we cannot use Leader-follower in this robot, so we want to use a simulation experiment platform named player/stage, to demonstrate the effectiveness of this method, and provide the basis for algorithm of robot before algorithm transplantation [14].

Player/Stage is a platform for the simulation of the multi-robot system, and developed by Robotics Research Laboratory in University of Southern California in 1999. This platform can provide the corresponding internal interfaces for the robot system and simulation environment. Because of its open source resistance, flexibility and good portability, widely used in the development environment of the robot. Player provides the robot drive server, Stage provides multi-robot simulators, auxiliary tools and some commonly used library functions. Detail can be find in <http://playerstage.sourceforge.net> [12] [15]. Due to the Stage platform have multi-robot simulators, the simulation results of Stage could be more close to the real results, in the real situation, the conditions are changed a few or not in the real experiment.

The experiment building process is as follows: firstly, creating the file of ‘.world’, from this file, we could get the information of simulation scene, it includes the robotic information, barriers, and sensor and so on. The next step is creating the robot. In this expriment, we need three robots to simulate the robotic fomation, so we would set color, size, sensor, and serial port of robot, to build the file of ‘.inc’, adding the file to ‘.world’ call the robot. Thirdly, creating the file of ‘.cfg’, this is a kind of data file, it tell you which kind of drive device is Player needs to contect with the robot. If the user was using the real robot, then the drive equipment need to contect with Player; and if only was a simulation, all of job is working in Stage. The last part is code compilation, when Player is running, the structure diagram of Server/Client as shown in Fig.7.

The code go to the driver after proxy, and then control the related hardware. When performing a file of ‘.cfg’, the hardware will be replaced by Stage, as shown in Fig.8:

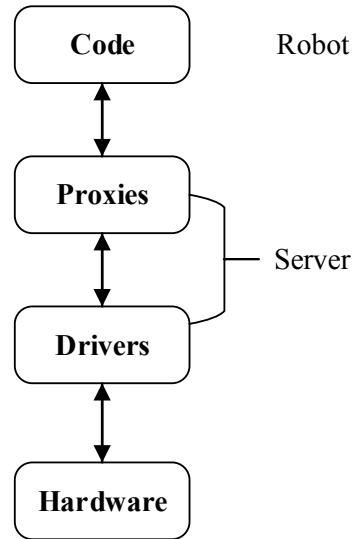


Fig.7 Control structure diagram when Player is running

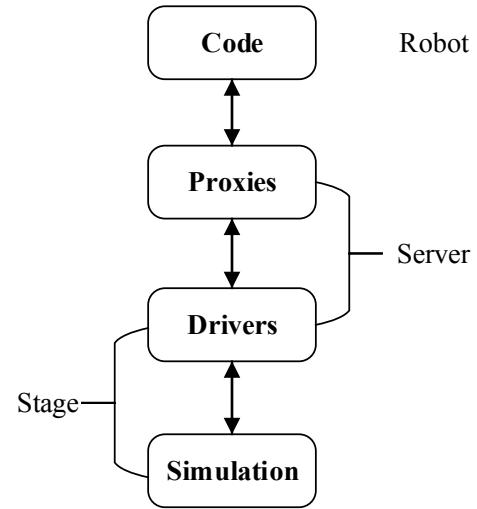


Fig.8 Control structure diagram when Stage is running

B. Experimental results

In Player/Stage platform, we create an environment with a 10m*10m field, and set up three robot, which is equipped with sonar, laser and position sensor. To control the lead robot, and let the follow robot to follow leader to achieve formation. The file of ‘control.world’ and ‘control.cfg’ be builded as the way described at the previous part. The control program is written with C programming language. Opening the terminal to execute the file of ‘player controL.cfg’, and then opening another terminal to execute the control command of ‘./control’. The result is shown as: (Fig.9)

We designed a virtual space and simulated the robot walk on the road. These are three robots be placed randomly.

Then using Leader-follower method, the controller get the act information, and control the three robots to get the triangle formation (a->b->c).

Then the three robots can keep formation when they move to the object, and also can change the formation during they walk on the ground (c->d).

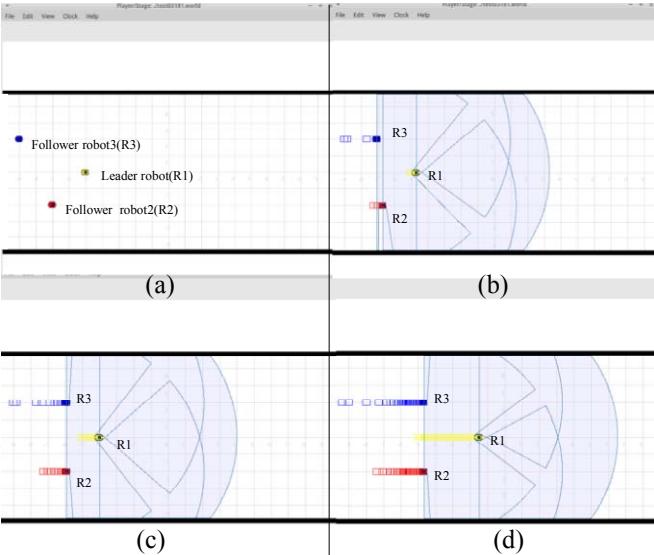
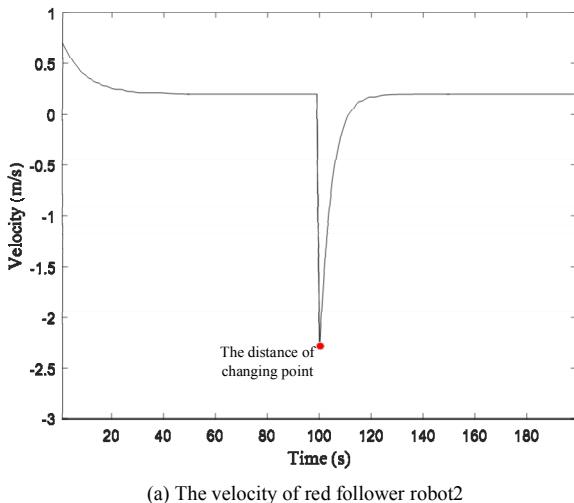
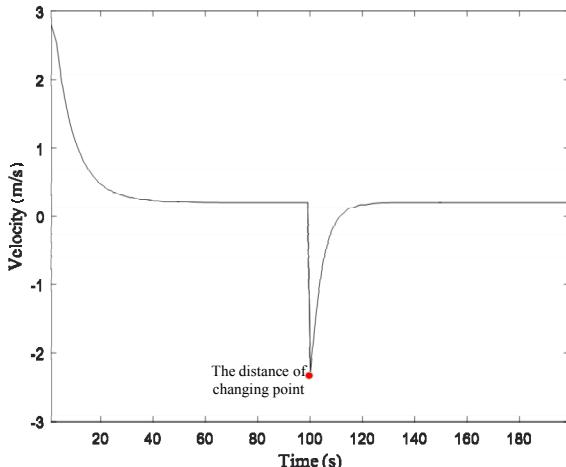


Fig.9 Control structure diagram when Stage is running. (a) Random initial state. (b) The process of following leader. (c) Formation keeping of three robots. (d) Changing the distance between leader and follower.



(a) The velocity of red follower robot2



(b) The velocity of blue follower robot3

Fig.10 The result of the robot's velocity

Fig.10 shows the results of two robots when they followed with leader robot. From this figure, we could find the robot could change the speed quickly and stably, and keep same speed to follow leader robot. However, when we changed the distance between leader and follower (The point shown in Fig.10), the speed of follower jumped negative value, and led to follower move back rapidly. This situation is not conform to the actual situation that we should consider.

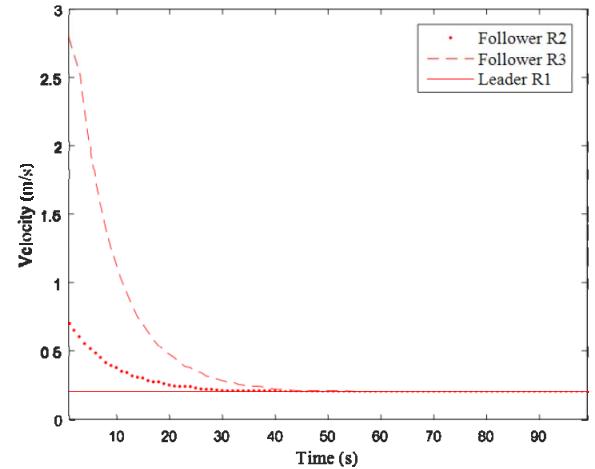


Fig.11 Velocity comparison of three robots

Fig.11 shows the process of how follower working to follow leader without changing the formation. Between 0s to 40s, acceleration decreased with time increased, and in the 50s, the speeds of followers became stable and were same as the leader. We used the different speed of leader to make the experiments, the results were almost similar.

All above the experiments demonstrated that Leader-follower method can be used for multi-robot control effectively.

V. CONCLUSIONS

The main research of this paper is multi-robot coordination for an improved amphibious spherical robot. In this multiple system, one leader and tow follower robots were used, by using a Leader-follower algorithm. The leader robot could check the position of follower robots in time, and calculate the speed and angular velocity of the follower robots, which could implement the coordinated movement and the formation of multiple robots. From the simulation experimental results, we find the Leader-follower algorithm can control the spherical robot easily. As the research object has a certain particularity, such as spherical body and crawl walking, the algorithm should be improved when it is applied to the robots in real time, we will carry out more experiments to evaluate it.

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