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Multi-robot Formation Control Based on Leader-follower Method

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Abstract. Multi-robot coordination is one of the important issues for the research of mobile robot. Multi-robot formation, as a typical problem of multi-robot coordination, is suitable to some special situations where communication devices of mobile networks cannot be preinstalled. Thus it has attracted much attention. In this paper, a multi-robot formation control system for competition based on leader-follower method is present, which is divided into 4 parts: robot car, visual system, wireless communicating system and formation control. The multi-robot formation control system successfully achieved three kinds of formation control: line formation, column formation and cross formation, it is proven that the system is feasible and effective.

Keywords: formation, leader-follower method, multi-robot coordination

1 Introduction

Multi-robot system is cooperation to complete a task with the robot group [1] by the organization of multi-agent. Multi-robot system often deal with some of the tasks that is more difficult to be achieved by a single robot [2]. When the complex tasks such as reconnaissance, patrol, and space exploration are carried out, the advantages of multiple robots are more prominent. As the main research of multi-robot coordination control, multi-robot formation control has been paid much attention due to its robustness and efficiency, and can improve the system's ability of reconstruction and structural flexibility [3]. So it has a wide range of applications and broad prospects.

With the continuous development of multi-robot research, multi-robot system is widely used in military, aerospace and rescue search and other fields, for positioning technology, the literature [4] use UWB technology to build positioning system, through the measured data, realizing real-time positioning of robots. Lin et al. [5] proposed a multi-robot formation round-robin algorithm based on parallel guidance law to solve the problem of path redundancy caused by multi-robot planning path. Literature [6] achieved multi-robot formation control combining sliding mode control and fuzzy logic. But the model has uncertainty. Considering the delay problem of multi-robot formation control, Zhang [7] proposed a pulse control method based on predictive control, and compared the control results of time-delay systems under different sampling time intervals. The main research methods of multi-robot formation control are virtual structure method, behavior-based method and leader–follower method [8]. In virtual structure method, all the robots are regarded as a simulation structure, each robot has its own corresponding fixed-point and keeps track of the point in the process of formation. In behavior-based method, distributed control system with feedback is used and it is hard to ensure the stability of system due to unclear behaviors of multi-robot group. However, in leader–follower method, the followers are controlled to follow the leader, they usually maintain a line of sight toward the leader and the other robots whether they use visual sensors or not [9].

In this paper, using MiroSot 5:5 platform as hardware basis, a multi-robot formation control system for competition based on the leader–follower method was designed. The system presentin this paper mainly includes robot car, vision system, wireless communication system and formation control, which has

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successfully achieved three kinds of formation control: line formation, column formation and cross formation. Experimental results show that the multi-robot formation control system is effective and feasible.

2 Implementation Platform

The main standard for evaluation is whether the robots leave behind or deviate from the track during the competition time which is needed to complete the task. The determinant factor for a neat formation mainly depends on the cooperation and coordination between the robots. The competition scene is shown in Fig. 1.

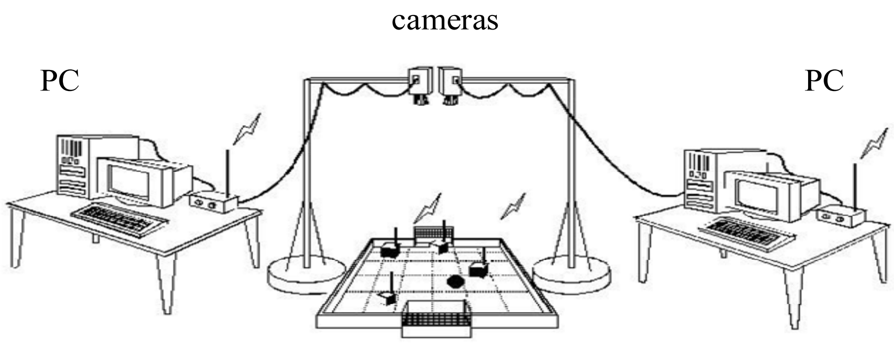


Fig. 1. Competition scene

The MiroSot 5:5 standard field used in formation control competition system is shown in Fig. 2, the field uses a non-reflective black wooden rectangular playground which is 220cm × 180cm × 5cm in size, and has 2.5cm thick black side-walls [10].

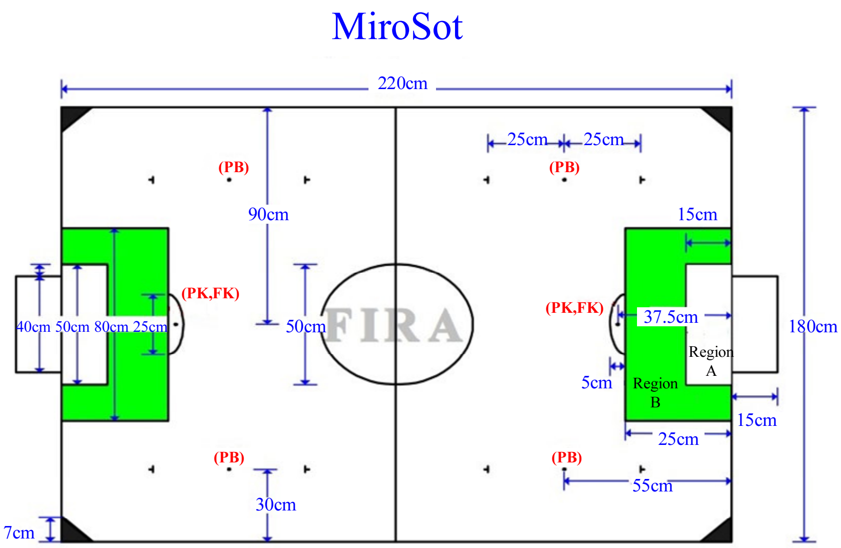


Fig. 2. MiroSot 5: 5 standard field for Formation control

Each robot is marked by the color code on the top of it. The real-time information of the site is obtained through the camera placed on top of the field, the camera is the only information source for formation control system. According to the site information sent by the visual system, formation control system makes decision. After decision-making process, the system can get coordinates corresponding to each robot, and then allocate motion control command for every robot through wireless communication. It makes the system more flexible by using wireless communication. The flowing chart of formation control system is shown in Fig. 3.

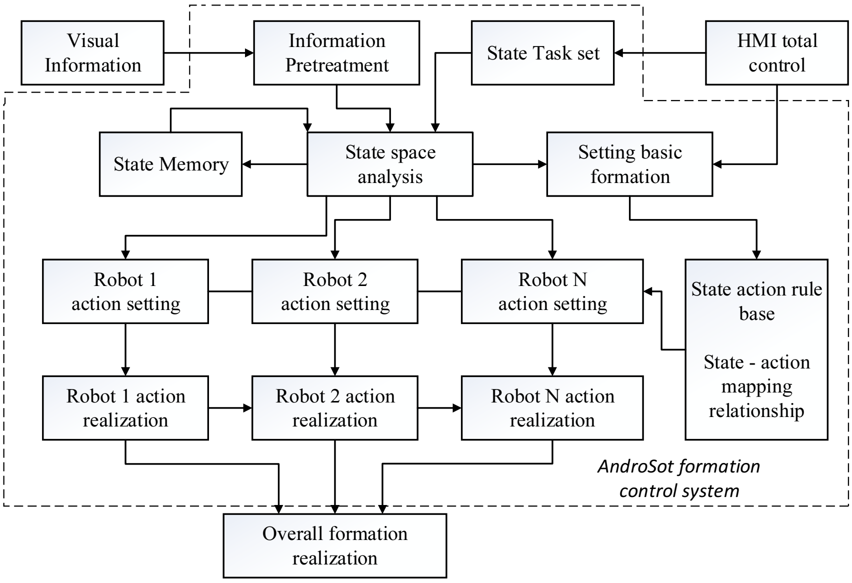


Fig. 3. Flowing chart of formation control system

2.1 Robot Car

The robot car mainly contains motors, retarder, velocity measurement encoder, driving source, CPU and wireless receiving module. Fig. 4 shows the body of robot car.

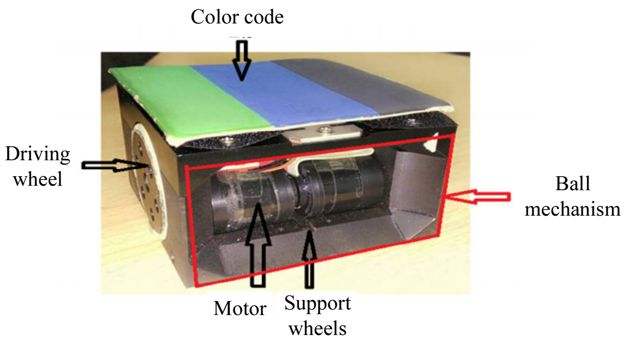


Fig. 4. Body of robot car

The developed robot car is 7.5cm × 7.5cm × 7.5cm in size, which uses two-wheel differential motion control structure. The motor uses Series 2224U006SR which is no heavier than 0.55g and with a maximum speed of 2.4m/s. The system can control its left and right wheel speed according to the command from host, to ensure it moves along the predetermined trajectory. The basic action mainly includes moving to a fixed point, rotating a certain angle etc.

Due to high precision, high transmission efficiency and high reliability, the gear reducer is used by robot car with the reduction ratio of 1:7.

L298 is used as the driving chip of formation control system. L298 is a double H-bridge high-voltage large-current integrated circuit, which can be used to drive the relay coil DC motor, stepping motor and other inductive loads.

C8051F019 chip produced by Sygnal Company is used for CPU, which has 25MHz clock and can generate PWM signals that makes it much easier to control motors. It also has such advantages as fast processing speed and fully compatible with instruction set of the MCS - 51 series microcontroller. Thus it is a suitable option as the core component of robot controller.

2.2 Visual System

The hardware of visual system mainly contains a CCD (Charge Coupled Device) camera and an image acquisition card. The location of the overhead camera should be at a height of 2m or higher from the playground [11].

The formation control system uses BASLERA312fc1394 digital camera to obtain real-time information, the main advantage is that the high quality image it provides can improve the results of recognition. It uses 1394 bus to transmit image etc.

The color code of robot car is shown in Fig. 5. The angle information of every robot is acquired through part A and part D, different combinations of part B and part C determine the serial numbers of robot cars.

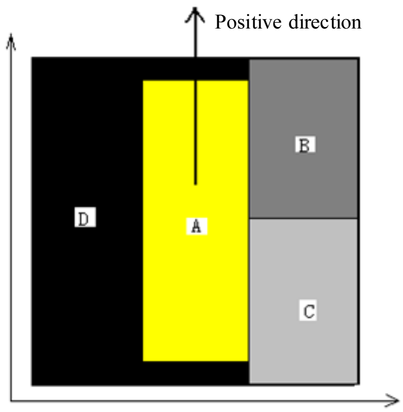


Fig. 5. Color code of robot car

The software of visual system mainly deals with the recognition of every robot car, which contains field calibration, image preprocessing, image segmentation and image recognition. The flow chart is shown in Fig. 6.

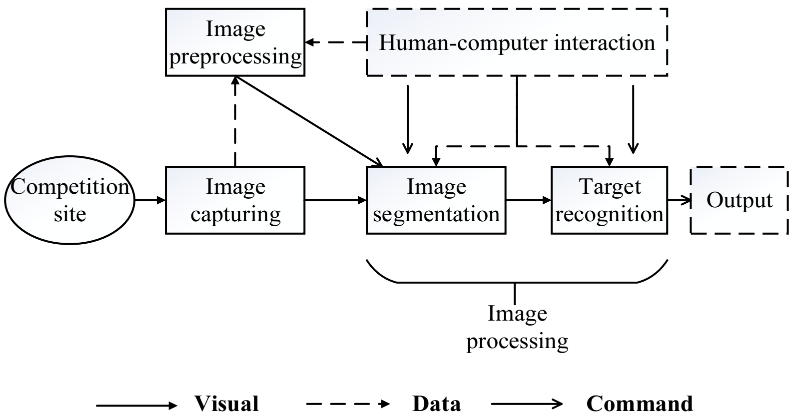


Fig. 6. Flowing chart of visual system

After field calibration, every single point on the field has a corresponding pixel in the image so that we can acquire the position information of each robot through the image. Image preprocessing ensures the follow-up process to work quickly and effectively. Image segmentation extracts the features of image and makes it possible to be recognized. All the coordinate and angle information is acquired after image processing, it is extremely important for robots to move precisely and keep the formation trimly.

2.3 Communication System

The communication system uses PTR4000 which based on nRF2401A as the wireless communication module. PTR4000 is a single-chip radio transceiver for the worldwide 2.4-2.5 GHz ISM band. The transceiver consists of a fully integrated frequency synthesizer, a power amplifier, a crystal oscillator and a modulator. Its main characteristics include high telecommunication speed, reliable capability, low supply current, and no requirement for external SAW filter [5].

3 Multi-robot Formation Control

In this paper, the leader–follower method is used for achieving formation control, the basic cogitation is as below: First of all, the system specify a certain robot as the leader, plan the path of the leader and control the leader to move along the exact trajectory. Afterwards, the system design the formation and determine the position between leader and followers, making the followers move as the leader's movement. The formation control system mainly focus on how to make the leader move along the trajectory and the followers keep the formation.

Move along the trajectory: Since only the leader in the entire formation control process moves in accordance with a predetermined trajectory, the followers are only responsible to keep the formation. So the formation control can be achieved as long as the system gets the movement parameters of the leader [6].

As it is shown in Fig. 7, the current coordinates of the leader is set as point P and the target location is set as point D.

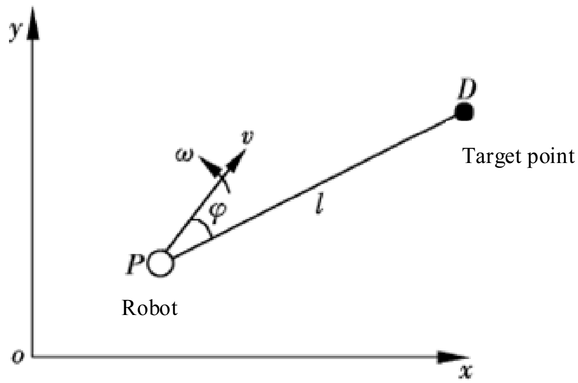


Fig. 7. Coordinates of the leader

Assume that the linear velocity of the robot is v, the angular velocity is ω, we can get the kinematical equation of the leader robot:

$$l = -v\cos\varphi \quad \textbf{(1)}$$

$$\varphi = \frac{v\sin\varphi}{l} + \omega \quad \textbf{(2)}$$

Thus we know the control parameters of leader robot.

Keep the formation: During the execution of formation control system, instantaneous pose and velocity information of every robot is acquired through the visual system [7]. The accurate coordinate of the leader is $[x_1, y_1]$, and the coordinate of the follower is $[x_2, y_2]$, then the relative position from the leader to the follower is $[d, \theta]$. The actual distance d and angle θ between the leader and the follower can be calculated through the formulas below:

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \quad \textbf{(3)}$$

$$\theta = \arctan\frac{y_1 - y_2}{x_1 - x_2} \quad \textbf{(4)}$$

Set the distance and the angle between the leader and the follower to be L and φ. Compare actual d and θ with given L and φ to obtain the control parameters for robots.

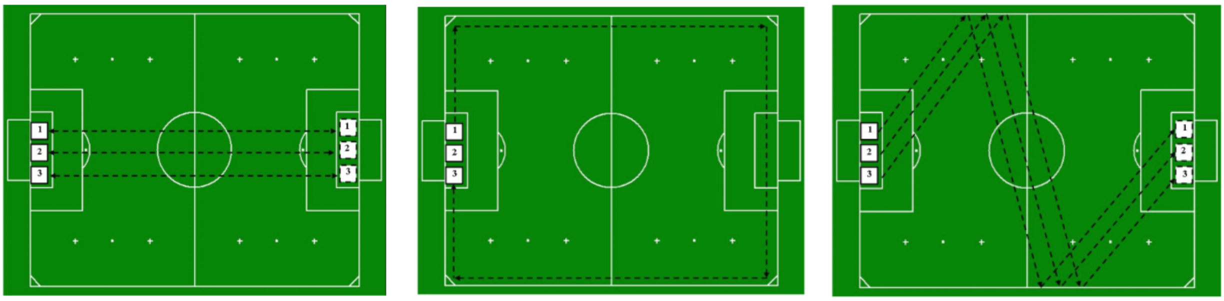
Calculate the relative positions and orientations between each robot and leader, compared them with pre-given threshold value L and φ, then constantly adjust their direction and speed. After starting the leader, the other robot will immediately follow and quickly move into formation.

4 Rules and Results

4.1 Rules of Formation Control

There are three kinds of formation previously mentioned according to the motion states of robots: line formation, column formation and cross formation.

Line formation is that robots move forward and back neatly in a parallel line form. Column formation is that robots make a circuit of the field in a serial line form. Cross formation is that robots move forward to the destination in a cross line form. Three kinds of formation are shown in Fig. 8.



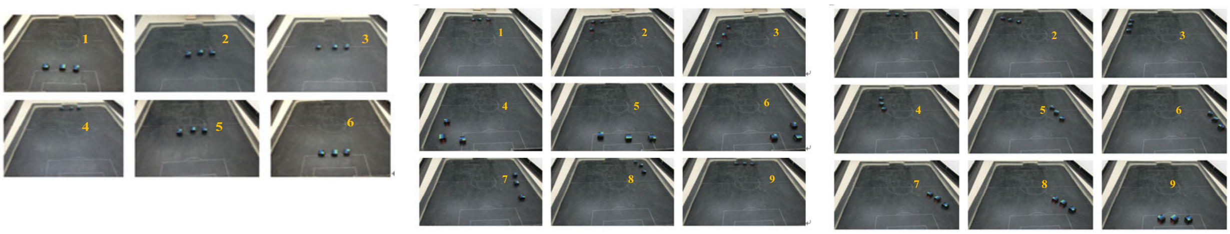
(a) Line formation (b) Column formation (c) Cross formation

Fig. 8. Representation of formation modes

The standard for evaluation is as follows: keep a neat formation and all robots should have the same direction and speed, points will be deducted as long as any robot was left behind or deviated from the trajectory.

4.2 Experiment Results

According to the above-mentioned experimental platform, we carry out the experiment in C++ development environment. The experiment results are shown in Fig. 9.



(a) Line formation (b) Column formation (c) Cross formation

Fig. 9. Formation mode in experiments

The motion states of robots in line formation, column formation and cross formation are respectively depicted in Fig. 9(a), Fig. 9(b) and Fig. 9(c). In every formation, a number of moment records corresponding to robots' positions and states are made, the number in each block is to explain the sequence of movement process. The whole records in each figure reflect the integral formation motion process. In line formation, three robots in a parallel line form neatly moved forward to the destination and then move back to the starting position. In column formation, three robots in a serial line form neatly moved forward, circling around the rectangle field and then returned to the starting position. In cross formation, three robots in a cross line form moved to the destination neatly.

We try to control the turning angle of robot car with the only coordinate method, but the effect is not good. So we define an angle function, the function is to make the car rotate to the desired angle location in the direction of specified clockwise or counterclockwise. After calculating the rotation angle, PD controller is used to control the speed of left and right wheels. If the speed of left wheel is not equal to the speed of right wheel, the car will rotate, the greater the speed difference between the left wheel and right wheel, the greater the rotation angle. Reasonable proportional and differential coefficients can make the robot go to desired angle location.

During the movement, the robot car is very low from the ground, it is difficult for it to overcome difficulties when meeting convex protrusions or obstacles, which will make the whole formation task uncompleted, so we should try to avoid convex protrusions or obstacles. In addition, the site calibration is also very important, if inaccurate, it will lead to a certain error between pose recognition results and actual pose, then result in irregular formation and poor results.

5 Conclusion

In this paper, a multi-robot formation control system for competition based on leader-follower method is present. MiroSot 5:5 platform was used as the hardware basis for the design and implementation of the system. The system consists of robot car, vision system, wireless communication system and formation control. The proposed formation control method mainly includes the leader moving along the trajectory and the follower keeping the formation. Experimental results show that the system successfully achieved three kinds of formation control: line formation, column formation and cross formation. It is proven that the multi-robot formation control system proposed in this paper is effective and feasible.

Based on the experiment results, it can be seen that the leader moves along the trajectory as planned and the followers can follow the leader effectively. However, robots may get lost sometime due to change of brightness and it is hard for robots to overcome convex protrusions from the field. Those two are the main reasons that lead to an irregular formation control. In future work, we should work on the visual system to improve robustness of the system and make it have the ability to avoid obstacles.

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