Research on Multi-agent Vision Location and Coordination Formation Control Strategy Based on Wireless Sensor Network Technology

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Keywords: Multi-agent; Formation control; Two-dimensional space

Abstract: For a long time, people have noticed a lot of group behavior in nature, and carried out more detailed analysis and research. Many individuals with certain intelligence are combined to form a multi-agent system which has both independent control performance and mutual coordination characteristics. Formation control is the most typical problem in the Multi-Cooperative control of these complex tasks. With the development of multi-agent system research, the coordinated control of intelligent groups has become a hot topic in the field of control. Based on the introduction theory, this paper focuses on the formation control of typical formations such as node expansion, assembly and dispersion. Formal modeling in two-dimensional space and giving theoretical proof of maintaining formation rigidity. In actual research, the sensors carried by robots have certain perceptual limitations, and there are often noises and delays. The actual multi-agent system tends to be in a three-dimensional space with a strong nonlinear dynamics model.

1. Introduction

For a long time, people have noticed a lot of group behavior in nature, and carried out more detailed analysis and research. For example, the cooperative predation of insects, birds and fish in the biological world, and the common defense against invaders, etc. [1]. For example, the self-organization and self-excitation of particles in physics show some group characteristics. Many individuals with certain intelligence are combined to form a multi-agent system with both independent control performance and mutual coordination characteristics [2]. It is increasingly recognized that the cooperation of multi-agent systems can accomplish more complex tasks at a lower cost. Compared with single agent, multi-agent system, especially distributed multi-agent system, has many obvious advantages [3]. In the multi-cooperative control of these complex tasks, formation control is the most typical problem, which is of great significance for enhancing the robustness of the system and improving the system efficiency [4]. Multi-agent system formation control refers to the design of a suiTable control protocol, so that multiple networked agent nodes reach the desired speed and position, and maintain the formation formation [5]. Communication topology changes due to unexpected situations such as communication interference and control failure [6]. In order to ensure the information transmission, it is necessary to reconstruct the communication link between multiple agents, which is also a problem that the formation control needs to solve.

With the deepening of research on multi-agent systems, the problem of coordinated control of intelligent groups has become a hot topic in the field of control [7]. Its application research in disaster rescue and search, collection and treatment of toxic and hazardous substances, battlefield reconnaissance and attack has aroused great concern of relevant researchers. Since it is quite difficult for an agent to obtain global information, agents need to communicate with each other to collaborate to accomplish a common task [8]. In addition, each autonomous agent needs to work, etc., which consumes a lot of energy. If the external resources and their own energy are limited, it is more necessary for the agent to save energy consumption. Multi-agent completing the same task is generally inexpensive [9]. It is more economical than a single agent with good performance but high cost. Formation control is a hot issue in multi-agent system research [10]. It refers to the

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control problem of multi-agent team which keeps the predefined geometric shape while adapting to the environmental constraints in the process of formation toward a specific goal or direction. A networked control system with medium access constraints and bit rate constraints is designed for multiple controlled objects [11]. The system nodes are scheduled based on the average dwell time method, and the network bandwidth is allocated online by using linear programming optimization algorithm.

The advantages of multi-agent system are bound to make it play an important role in the environment, military, industrial and other fields. Making use of multiple cheapnesses may be easier and cheaper, and as some tasks become more complex [12]. Using multiple collaborations can often accomplish some single difficult tasks. The wheel model with nonholonomic constraints is transformed into two second-order integral models by dynamic feedback linearization, and the formation control problem of wheel type is studied [13]. The decision-making and actions of each individual in the group are independent, but there are a wide range of altruistic cooperative behaviors within the group. Since 2013, a variety of UAV integrated optimization formation controls have been studied [14]. In 2014, directed alignment of formation control and network positioning was proposed [15]. Then, the system's distributed formation control: dynamic interactions and absolute/relative damping were published in the Journal of Systems and Control Letters [16]. In 2016, distributed formation recovery control based on network switching and diagnostic defects was proposed [17]. In the past 2018, some scholars have studied the formation control and trajectory tracking of non-complete mobile robots [18]. Multi-agent formation control can effectively shorten task execution time, reduce task execution cost, and improve multi-agent work efficiency [19]. Based on the introduction theory, this paper focuses on the formation control of typical formations such as node expansion, assembly and dispersion. Formal modeling in two-dimensional space and giving theoretical proof of maintaining formation rigidity. It has laid the foundation for in-depth research on formation control and stability analysis.

2. Materials and Methods

Formation control and formation control have always been the focus and difficulty of multi-agent cluster formation. Through the wireless local area network, the communication between the upper computer and the communication between the upper and the lower is realized. Firstly, the image information is collected by the global positioning camera and sent to the upper computer positioning algorithm for processing [20]. In the intelligent group, there is a relative formation between the individual and the individual, and the cluster has a macro formation relative to the external environment. With the rapid development of sensor networks, intelligent groups can work together to complete some complex tasks [21]. In actual network transmission, the interaction weight of the communication topology tends to change dynamically as the effective distance between the receiver and the transmitter changes. Adding a new join edge and changing its topology will not affect the rigidity of the graph. Therefore, if the number of edges in the graph satisfies certain conditions, the rigidity of the graph can be guaranteed. Behavior-based controllers consist of a series of actions, i.e. simple basic actions. The accuracy and real-time of information are very important, so the design of multi-agent positioning system is the key problem.

The location range is mainly affected by the wide angle of the camera and the height of the distance between the camera and the platform. Limited by the indoor height and camera parameters, only a limited number of agents can be expanded in a certain range. When the number of agents increases, a single camera can not satisfy the coverage of the robot's motion space. Aiming at medium access constraints in wireless communication networks, an agent node scheduling protocol is designed by using binary sequence. The scheduling protocol is used to schedule the access network of agent nodes satisfying the conditions at sampling time. Figure 1 shows the structure of the agent node.

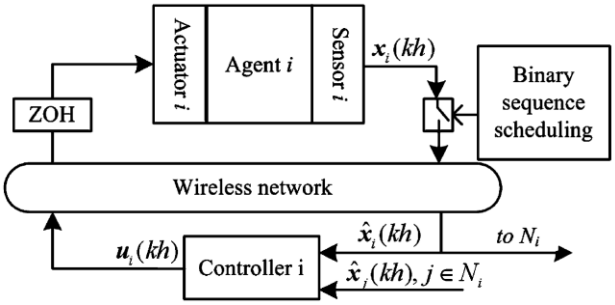

Figure 1 Structure of the agent node

The basic idea of virtual structure method is to regard the formation of multi-agent system as a virtual rigid structure, and each agent as a fixed point on the relative position of the rigid structure. In the positioning process, firstly, multi-agent formation image information is collected by camera. Then the image is inputted into the host computer. The image is positioned by image information acquisition, image color recognition, dynamic tracking, data communication and other steps of the positioning software. It is assumed that the formation objects are driven by two invisible forces to avoid obstacles and continue to move towards the target point. Therefore, the repulsive force field of obstacle to agent and the gravitational field of target point to agent can be constructed. The superposition of these two potential fields is artificial potential field. The rigid frame can be used to represent a rigid formation, that is, the multi-agent formation during the formation process, the distance between the nodes is kept constant, and the formation formation is unchanged. The types of multi-agent formation formation changes include node changes, formation assembly, and formation separation. Low-priority actions are partially executed when they are met, taking full advantage of the redundancy features of multi-agent systems. Various forms of formation and formation experiments were carried out in actual systems such as omnidirectional and underwater, and good experimental results were obtained.

The idle frequency band and the cognition are randomly generated within the range of the base station, and the probability of occurrence of each corresponding idle frequency band is subject to the Poisson distribution. When the free frequency band is allocated and not occupied, the simulation result is shown in Figure 2.

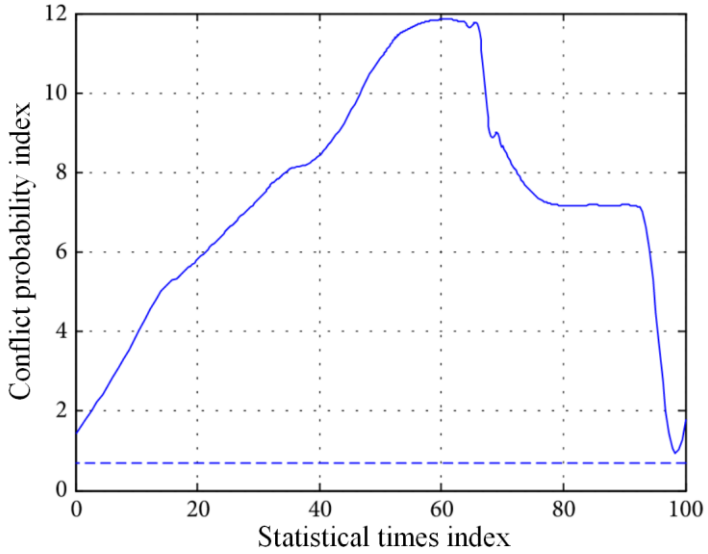

Figure 2 Simulation results of cognitive access conflict probability

Each behavior has its own goal or task, and its input can be used as the sensor's sensory information or the output of other behaviors in the system. Accordingly, the output of each agent is sent to its actuator to control the formation of the agent. Because of its particularity, multi-agent vision positioning must be able to transmit information anytime and anywhere, monitor and analyze data accurately, and achieve efficient interaction through the network. Data acquisition, visual

positioning and data receiving module transmit data through interface. The data format is shown in Table 1.

Table 1 Data format

Name	Length
Start sign	3
Data length	5
Command word	8
Data part	11
Stop code	8

For each type of formation change, based on the theory, new constraints are added to ensure the rigidity of the reconstructed formation. For the first-order integrator model, the common continuous-time consistency protocols are:

$$w(x,y,d)=\exp(-(\frac{d_g}{r_g}+\frac{d_c}{r_c})) \tag{1}$$

For first-order discrete systems, common discrete-time consistency protocols are:

$$C(x,y,d^{(i)})=\sum_{(x,y)\in N(x,y)} w(x,y,d^{(i)})\cdot SelfAd(x,y,d^{(i)}) \tag{2}$$

The multi-agent formation control model can be implemented as follows:

$$E(x)=\sum_{j=1}^{n} E_j \tag{3}$$

$$\begin{aligned} E_{LR}^{ij} &= \sqrt{\sum_{u=1}^{U}\phi_u^{ij}}\,,\ j\in(1,M),i\in(1,H) \\ \phi_u^{ij} &= (S_{Lu}^{i}-S_{Ru}^{i})^2 \end{aligned} \tag{4}$$

In the multi-agent positioning experiment system, the function of the controller module is to receive the location and environment information of the agent, make information decisions and issue control commands. The main controller first receives various sensor data acquired from the co-controller and locates the location information of the movement obtained by the computer. The controller processes the information and gives instructions to guide the formation. For the individual agent, the optimal path to be searched is along the negative gradient direction of the artificial potential field, which is the direction in which the function declines the fastest [22]. Considering that wireless communication is affected by factors such as multipath failure, shadowing, and the distance between the transmitter and the receiver, it is different from the traditional fixed connection weight topology model [23]. A new interactive weight communication topology model is established by introducing the receiving probability to make the connection weight change with the distance between agents. The master controller synthetically analyses the position information and sensor information, and transmits the information of the moving control speed and angular speed to the formation system. In this way, many complex tasks such as formation, gathering and formation can be accomplished. Compared with the following navigator method, the virtual structure method generally does not need explicit navigator. Formation error can be introduced into the design of control law as feedback, thus achieving higher control accuracy.

The model is used to simulate the formation control risk assessment, and the risk degree of the project is obtained. As shown in Table 2. The results of comparison between recommended value and evaluation value are shown in Figure 3.

Table 2 Recommended values and evaluation data for sample risk

Sample	1	2	3	4	5	6
Evaluation value	5.86	5.89	5.65	5.86	5.25	5.75
Recommended value	5.85	5.81	5.68	5.77	5.17	5.79

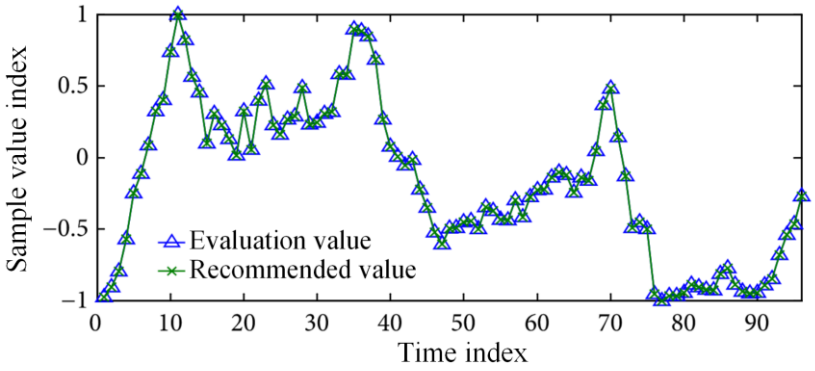

Figure 3 Comparisons of recommended and evaluated values

The initial version of Smart Mobility contains only a few basic sensors. Such as embedded camera, motor, laser ranging, etc. Limited perception and range. So the second development is carried out, which extends the ultrasonic sensor, infrared ranging sensor, tracking module and so on. According to the existence of limit cycles on the phase plane, the two-dimensional formation space where the agent is located is divided into safety area and dangerous area. The occlusion obstacles in the system are placed at the center of the limit cycle. Under the guidance of the potential field of the obstacles, the agents form curves along the path of the limit cycle. This ensures that the agent nodes can smoothly bypass all kinds of obstacles. By introducing information update error and formation error, and designing an effective formation control strategy. The second-order multi-agent system formation control problem is transformed into a stability problem of closed-loop system with time-varying delay. The limit cycle theory is applied to the real-time formation of the agent, which can overcome the limitations of the artificial potential field method which is easy to fall into the local extremum and cannot reach the target point.

The above control algorithm is also applicable when each agent is required to maintain a certain desired distance in position. Image stitching is to splicing multiple images with spatial overlapping areas in the same scene captured by different cameras and different cameras. For larger fields of view, higher resolution images [24]. It mainly includes image feature extraction, image matching, camera parameter estimation, image fusion and mosaic. Fast and accurate registration is the key to the success of stitching. Only for a given relative position expectation, it needs to be implemented as input deviation in the control law. The experimental simulation considers two factors of the total bandwidth gain and the system conflict probability of the spectrum allocation system, and carries on the simulation analysis, and compares the two methods of the fuzzy spectrum allocation and the random spectrum allocation. Specific parameter settings are shown in Table 3.

Table 3 Settings of simulation parameters

Parameter	Parameter value
Cognitive quantity	20
Number of idle bands	20
Distance	0-30km
Channel bandwidth	200KHz
Mobility	0-90km/h
Discount factor	1.5
Initial weight	3
Learning rate	0.9
SNR	20-85dB

The main advantage of the virtual structure method is that it is easy to describe the behavior of

the group as a whole. The formation feedback can be naturally applied to design the control law to achieve higher formation control accuracy. However, the disadvantage is that the formation must be rigidly formed, which limits the scope of application of the method. Figure 4 shows the formation trajectory of the agent when it is a single obstacle.

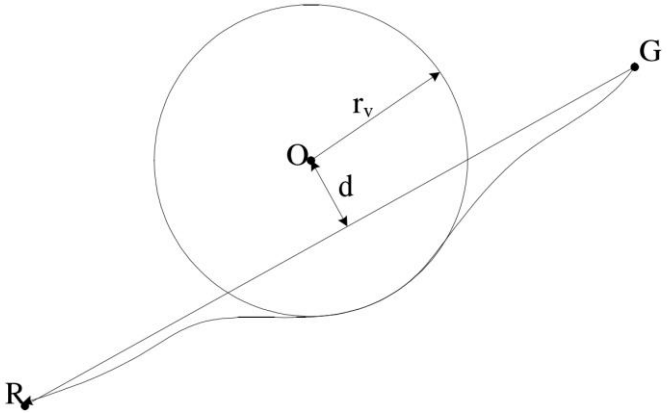

Figure 4 Formation trajectory of the agent when a single obstacle

When multiple obstacles are superimposed on each other and agents are in formation, it is necessary to treat the superimposed obstacles as a large virtual obstacle. As shown in Figure 5.

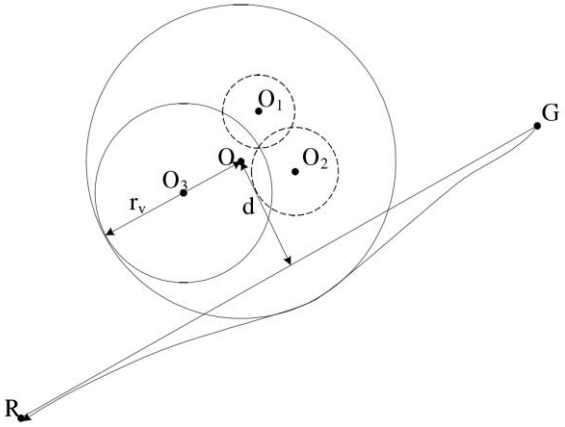

Figure 5 Formation trajectory of the agent when the obstacle is superimposed

3. Result Analysis and Discussion

In order to display the sensor information of intelligent mobile in real time and monitor the intelligent mobile in real time, the monitoring software of the agent experimental platform is designed. Judging whether there are obstacles crossing a straight line, if there are obstacles, it will be regarded as an obstacle that has a negative effect on the formation of agents. In order to establish a more realistic network communication model, the performance indicators used to measure wireless connections have been studied in mobile networks. Graph theory can be used to design multi-agent formation and formation control strategy based on design formation. Embedded camera video display module displays real-time image information in front of the car body. The sensor information display module displays the sensor information carried [25]. Such as battery capacity, ultrasonic ranging, infrared ranging, and so on. The agent will make a formation in the counterclockwise direction around the obstacles within the set formation range.

As the position of the agent changes continuously within the formation space, the line and the obstruction obstacles it passes through will also change. The multi-agent system following the pilot method is switched between any two formations by enumerating all possible control charts. The availability of the channel is degraded, so the bandwidth gain of the system decreases as the arrival rate increases. As shown in Figure 6.

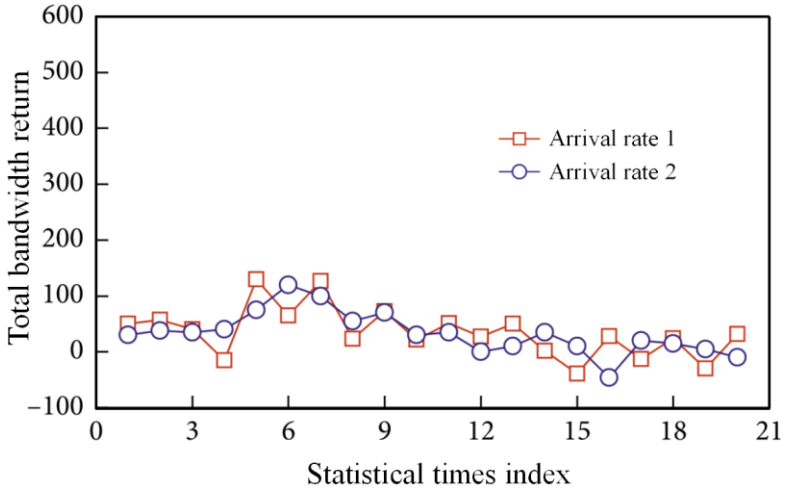

Figure 6 System bandwidth gain at different arrival rates

Without being affected by occlusion obstacles, agents will form in the direction of the target point under the guidance of the target point. Select repulsion potential function between agent and obstacle:

$$w_j^i = \frac{\frac{1}{(EP_{LR}^{ij})^2}}{\sum_{j=1}^{k}\frac{1}{(EP_{LR}^{ij})^2}}, j \in (1,k) \tag{5}$$

The potential field function between agents can be defined as:

$$HWt = \frac{\sum_{i=1}^{N} D_i(x)}{N} \tag{6}$$

Therefore, the agent is subjected to the potential field control:

$$V_{id} = wV_{id} + c_1 r_1 (P_{id} - X_{id}) + c_2 r_2 (P_{gd} - X_{id}) \tag{7}$$

$$D_i = a + \sum_{j=1}^{n} b_j p_j + r_i Y + u \tag{8}$$

A zero-order keeper is used to maintain the controller input value at the last sampling instant. Then the information update of the controller is expressed as follows:

$$D_i = a + \sum_{j=1}^{n} b_j \ln(p_j) + r_i \ln(Y) + u \tag{9}$$

Due to the medium access constraints of wireless network communication channels, at most multiple agent nodes are allowed to access the wireless network at any time. Behavior-based method and virtual structure method have their own advantages and disadvantages. The provided network selective access scheme is compared with the random access method. The blocking rate and average power consumption of the two schemes under different service arrival rates are compared. The traffic blocking rate situation is shown in Figure 7.

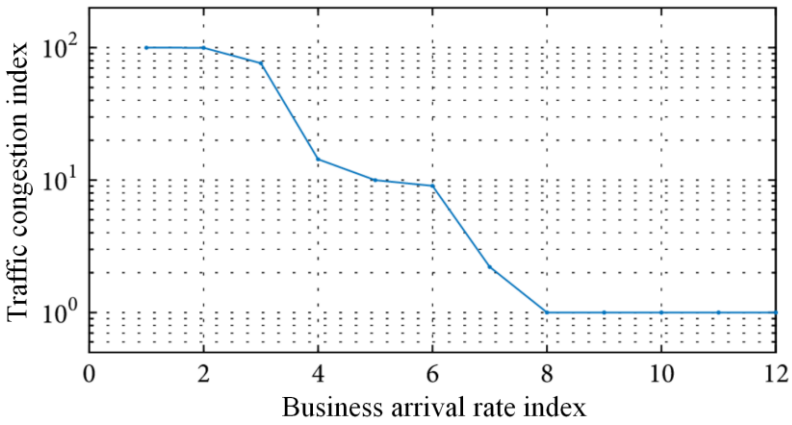

Figure 7 Business blocking rate change

The advantage of following the pilot law is that the behavior of the group can be determined by a single agent, the leader. The disadvantage is that the robustness of the formation is highly dependent on the robustness of the leader. Once the pilot is destroyed, the formation will be destroyed. The basic instruction control module contains some basic formation instructions, such as forward, backward, left drift, right drift, and stop [26]. Assuming that the adjacency map corresponding to the group is connected, then all individuals in the group will avoid environmental obstacles to reach the destination and eventually form a sTable cluster formation [27]. Generally, in behavior-based methods, a single agent only needs the information of the neighbor agent, which is essentially a distributed control method and is not affected by the size of the agent. When there are no obstacles on the path of the agent formation, the agent forms directly to the target position. In order to meet different target needs, the form of utility function selection is also different. Spectrum resources are not fully utilized, which brings great interest to engineering, economic and management organizations to find better spectrum management strategies and technologies. The parameters used in the simulation are shown in Table 4.

Table 4 Main simulation parameters

η1	0.69	μ1	0.092
η2	0.057	μ2	0.075
η3	0.18	μ3	0.172

When obstacles appear on the formation trajectory, the agent can avoid obstacles according to the set formation strategy. At the same time, the speed of each agent gradually becomes uniform over time. When the agent crosses the obstacle area, it is clustered in the vicinity of the target location. Figure 8 shows the virtual spring between the agents.

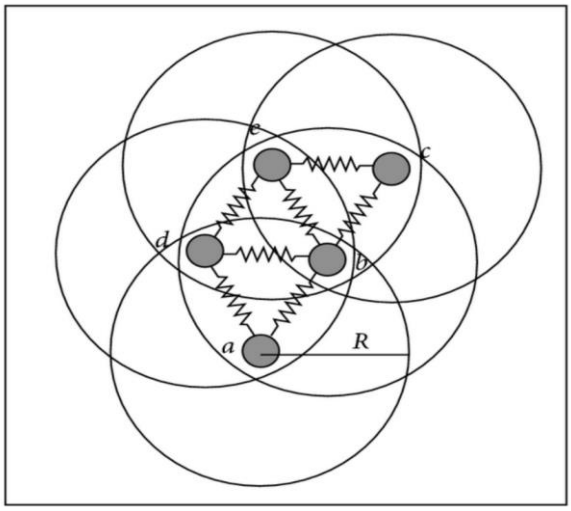

Figure 8 Virtual spring between agents

Considering the uncertainty of the wireless network and the relationship between the topological connection weight and the distance between the agent nodes, the traditional fixed connection weight topology obviously cannot reflect the communication quality. Figure 9 shows the consistent formation state of the agent.

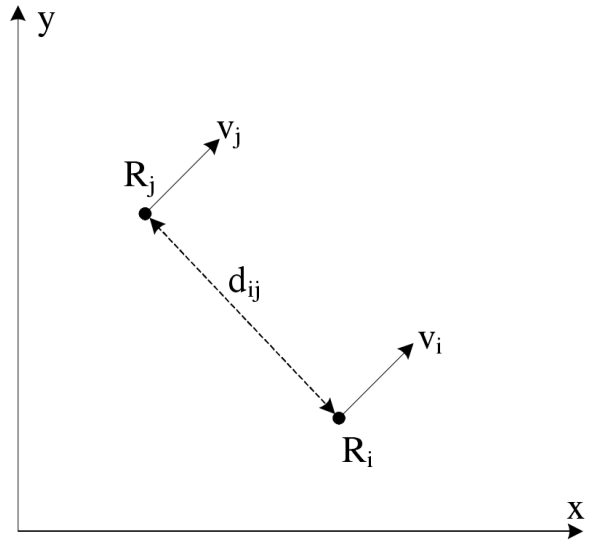

Figure 9 Consistent formation state of the agent

In order to verify the consistency control protocol proposed in the paper, two formations in the horizontal plane are taken as an example. The target requires a straight line for each tracking level. Another disadvantage of following the pilot law is that following the agent generally cannot affect the formation of the leader. If the leader is flying too fast, it may cause the following agent to fail to follow the leader's trajectory. In the research of vision-based positioning, the influence of illumination on the positioning accuracy is the most serious, which often causes serious deviation or even failure of positioning. In the behavior-based formation control algorithm, this method does not need to model the dynamic, complex, unstructured environment [28]. It has strong adaptability to the environment, can realize distributed control, and can simply expand the number of mobile robots. But this method can not define group behavior, and it is difficult to analyze and quantitatively describe the convergence and convergence speed of formation by mathematical method.

When each agent is required to maintain a desired distance in position, the above control algorithm is also applicable, but for a given relative position expectation, it needs to be implemented as input deviation in the control law. Through many iterations, the optimal model with the most effective data is finally obtained. This method is a process of repeated testing and iteration. Video mosaic module in the algorithm processing module is used to mosaic image information. Firstly, feature points are extracted from several acquired images, and common features are extracted from two images with common parts. The anti-jamming capability of an algorithm is often a key factor in determining the feasibility and accuracy of positioning. As the formation of the agent continues, its formation status will be adjusted and changed accordingly. The occurrence of this kind of situation is the result of the consistency control law in the formation algorithm.

According to the proposed simulation hypothesis, it can be concluded that the stability of the path corresponding to the spectrum used on all links in the path is better. The degree of path stability corresponding to the combination of Link values is obtained, as shown in Table 5.

Table 5 Path stability

Link	0.06	0.07
0.05	0.621	0.852
0.06	0.478	0.765

It is difficult to quantitatively describe and analyze many characteristics of formations

mathematically, such as stability and convergence speed. Under the joint action of the agent formation control law and the multi-agent formation control law, the multi-agent system successfully realized the formation processing and formation control in the formation process. There are two ways to share spectrum between master and cognitive: spectrum underlying and spectrum coverage. There are many cognitive and existing cognitive radio networks, and each cognitive spectrum allocation depends on the cognitive base station for unified allocation. The success rate varies with the number of cycles as shown in Table 6.

Table 6 Success rate changes with the number of cycles

Number of calculations	Prompt function success rate (%)
2000	81.86
2700	82.22
6000	82.69
9000	88.54

A uniquely determined formation formation is obtained by designing a graph with the smallest sum of edges of the edges. The reception probability is used to characterize the communication quality of the wireless network channel, and the reception probability can be defined as:

$$D(p_1) = A \cdot \frac{m(1-r)}{p_1^b} \tag{10}$$

The adjacent nodes may be different at different times, and the topological structure of multi-agent system may also be changed. The following formation control protocols are designed:

$$R_t(p_{1t}, Q_t) = p_{1t} \cdot \min(I_t + Q_t, D_t) - (p_{0t} \cdot Q_t + C_t \cdot AI_t) + R_{t-1} \tag{11}$$

Define the information update error as:

$$I_{t+1} = I_t + Q_t - \min(I_t + Q_t, D_t) = \max(I_t + Q_t - D_t, 0) \tag{12}$$

The adjacent nodes of the agent node are:

$$AI_t = \frac{(I_t + Q_t) + (I_t + Q_t - D_t)}{2} = I_t + Q_t - \frac{D_t}{2} \tag{13}$$

Consider the following linear consistency protocol as the control input:

$$AI_t = \frac{(I_t + Q_t)}{2} \cdot \frac{(I_t + Q_t)}{D_t} \tag{14}$$

In order to establish a more practical wireless network channel model and to characterize the influence of the distance between agents on the connection weight, the receiving probability is used to represent the connection weight. Figure 10 shows formation tracking.

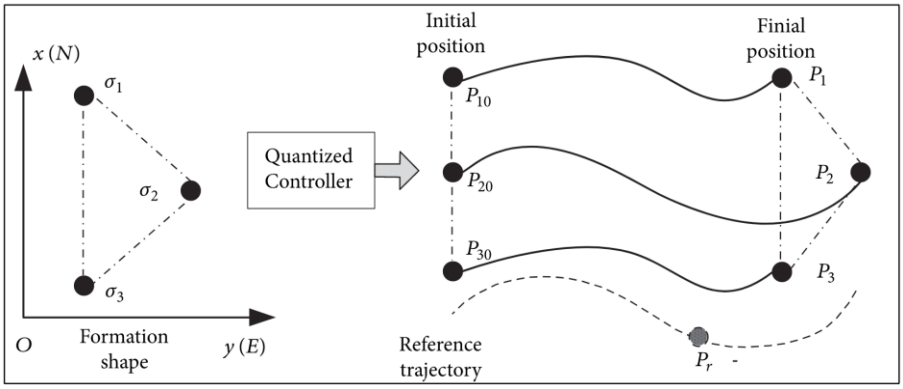

Figure 10 Formation tracking map

Researchers in the field of control have published several monographs of algebraic graph theory

on multi-agent formation-related issues. The concepts of algebraic graph theory commonly used in formation control include adjacency matrix and Laplacian matrix of graphs. "Video Display Window" displays the video information of the positioning camera above the multi-agent platform, and can save any video clips and pictures in the formation process. At the same time, an image edge detection module is added to display each frame captured by the camera in the detection window after edge detection. It is precisely because the behavioral characteristics of the two control laws are not the same, so in the simulation experiment, the agent group realizes the dual control of formation and formation. To integrate the various technical components of a multi-agent formation system into an organic and complete system, first of all, these technical means must meet the specific requirements of the system. The test data of the existing system, the system simulation data of the added convolutional code, and the system simulation data of the added code are compared, and the results are shown in Table 7.

Table 7 System wireless transmission mode optimization simulation data

Test label	1	2	3	4	5
Error frame number	4	2	9	8	4

In order to realize the information exchange between the host computer and the agent, the communication module is designed in the software. Multi-agent formation control generally has a large-scale, decentralized perception, communication and control structure. And a network structure is formed among the agents. So multi-agent system can be modeled as graph naturally. In the graph representing multi-agent system, the neighbor vertex of a vertex of the graph represents the set of agents with topological relations such as perception. Therefore, from the Laplacian matrix of the graph, a local, distributed and scalable multi-agent formation control law can be designed. Therefore, the stability of the formation control law can be proved by the eigenvalues of the Laplacian matrix.

4. Conclusions

Multi-agent system related research has achieved many remarkable results, but mainly stays in the theoretical and simulation stages. The research of application systems based on multi-agent systems is both the premise and the ultimate goal of theoretical research. Based on the multi-agent cluster theory, based on the artificial potential field method, the limit loop method is used to improve the intelligent obstacle avoidance algorithm. Using algebraic graph theory as a research tool, introduce the concept of rigid graphs and minimum rigid graphs. Based on this, a rigid graph theory is proposed to describe the multi-agent formation operation. At the same time, the consistency algorithm is applied to the multi-agent formation control, and the formation avoidance formation control model for the agent group is formed. Finally, the feasibility and reliability of the proposed algorithm are verified by stability analysis and simulation experiments. Agent systems usually consider ideal perception. However, in practical research, sensors carried by robots have certain perception limitations, and often have noise and time delay. Therefore, formation control under communication and perception constraints is also a problem worthy of attention. Actual multi-agent systems often exist in three-dimensional space and have strong non-linear dynamic models. Therefore, how to extend the existing research methods to three-dimensional space has become an urgent problem to be solved.

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