A dynamic sliding mode control method for multi-agent formation

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Abstract. In this article, we study the formation control problem of multiple agents. In the past studies on sliding mode control, when the state trajectory reaches the sliding mode surface, it is difficult to strictly slide along the sliding mode surface to the equilibrium point, but it travels back and forth on both sides to approach the equilibrium point, resulting in chattering. This is also the main obstacle in the practical application of sliding mode control, and in actual scenarios, the agent has a limited communication distance and perception distance. In order to solve this problem, we propose a dynamic sliding mode control method. First, we establish an agent motion model to determine the leader and follower. The trajectory of the formation is determined by the leader, and the follower agent maintains an ideal position in the leader coordinate system. Then, multiple agents conduct formation movement under the guidance of the leader. In this paper, two examples are used for simulation, and the simulation results show the effectiveness of the proposed formation control method.

1. Introduction
Due to the development of unmanned technology, formation control of agents has attracted widespread attention. Multi-agent formation control technology is widely used in high-risk environment, military, fire protection, agriculture and other fields. The early formation method was inspired by observing the behavior of birds, fish, etc. The formation maintaining strategy with low energy consumption and high stability is the advantage of the bionic formation method [1,2]. Agents use their own sensors to perceive the environment, and individuals communicate with each other to coordinate to complete target tasks [3]. The formation strategy must not only maintain a stable formation structure, but also have the ability to maintain and reconstruct the formation in the event of disturbances or changes.

In recent years, many literatures have studied the problem of agent formation control strategies. Literature [4] proposed a trajectory tracking control scheme for a three-wheeled mobile robot using a sliding mode control method. In order to improve the tracking accuracy, a sliding mode control algorithm based on the new approach law is proposed, which effectively reduces the jitter of sliding mode control input and improves the convergence speed and tracking accuracy. Literature [5] proposed a rolling time-domain method based on the idea of set theory to solve the formation problem. By calculating the final invariant state set of the agent and the one-step control set, the agent formation can be controlled. Literature [6] considered the delay problem on the basis of [5], and literature [7] considered the packet loss problem on the basis of [5]. Literature [8] studied the trajectory tracking of automated guided vehicles based on sliding mode variable structure control theory, and proposed a controller design method based on terminal sliding mode. In order to improve the traditional terminal sliding mode expression, a nonlinear sliding mode with fast convergence speed is designed, and
theoretical analysis proves that the sliding mode design is stable and converges quickly in a limited time. However, the chattering is still the main obstacle for sliding mode control applications.

The current four mainstream formation methods are Leader-Follower [9], Virtual-leader [10], Behavior-Based [11] and artificial potential field method [12]. The advantage of the leader-follower method is simple control. The formation movement plan is only determined by the leader’s movement trajectory, which avoids mutual interference between followers, requires less information and is easy to realize formation control [13].

In this article, we study a method based on the leader-follower structure and using distance and angle to control a multi-agent system. By using the sliding mode controller to calculate the control law, each agent can maintain an ideal distance and angle from the leader. In order to eliminate chattering during sliding to the sliding mode surface, we propose the concept of dynamic sliding mode surface and introduce the concepts of communication range and perception range to make the agent more realistic.

The structure of this article is as follows: In section 1, it mainly introduces the background and development of agent formation control technology, and the problems studied in this article; in section 2, the agent motion model is introduced; in section 3, the agent formation control method is shown; in section 4, the simulation results are shown; finally, conclusions are given in Section 5.

2. Agent Dynamic Model

For a system with one leader (labeled L) and N follower (labeled 1 to N), the dynamics of each agent in the global coordinate system are described as follows:

\[
\begin{align*}
\dot{x} &= V \cos \theta \\
\dot{y} &= V \sin \theta \\
\dot{u}_x &= \ddot{x} \\
\dot{u}_y &= \ddot{y}
\end{align*}
\]  

As shown in Figure 1, (x, y) is the position of the agent in the global coordinate system, \( \theta \) is the direction of motion, V is the speed of motion, and \((u_x, u_y)\) are the control of the agent in the x direction and y direction in the global coordinate system command. In order to maintain a certain distance and angle between the following agent and the leading agent, the expected position of the following agent in the global coordinate system is calculated as follows:

\[
\begin{bmatrix}
x_{id} \\
y_{id}
\end{bmatrix} = 
\begin{bmatrix}
x_i \\
y_i
\end{bmatrix} + 
\begin{bmatrix}
-\sin \theta_i & \cos \theta_i \\
\cos \theta_i & \sin \theta_i
\end{bmatrix}
\begin{bmatrix}
x_{il} \\
y_{il}
\end{bmatrix}
\]  

Among them, \( i \in \{1, 2, \ldots, N\} \), \((x_{id}, y_{id})\) is the expected position of the following agent in the coordinate system of the leading agent, and the calculation method is as follows:

\[
\begin{align*}
x_{id} &= d_{ii} \sin \theta_{ii} \\
y_{id} &= -d_{ii} \cos \theta_{ii}
\end{align*}
\]  

Fig 1. Agent dynamic model
3. Agent Formation Control Method

In this section, multiple agents are assembled to form a formation under the guidance of the leader to move in formation. In this process, the concept of dynamic sliding mode surface is introduced to eliminate chattering, and the concepts of communication range and perception range are introduced. Make decisions that need to be made in different areas. When the following agent is within the communication range of the leader, the following agent can obtain the movement state of the leader. When the following agent is within the perception range of the leader, the following agent can obtain the coordinates of the leader.

In order to make multiple agents gather to form a formation, we use the sliding mode controller to obtain the control input commands of each agent. The design method of the sliding membrane controller is as follows:

\[
\begin{align*}
\dot{e}_x &= x - x_d \\
\dot{e}_y &= y - y_d \\
s_x &= \dot{e}_x + \lambda e_x \\
s_y &= \dot{e}_y + \lambda e_y \\
\dot{s}_x &= \dot{e}_x + \lambda \dot{e}_x \\
\dot{s}_y &= \dot{e}_y + \lambda \dot{e}_y \\
u_{xd} &= -\lambda \dot{e}_x + s_x + \ddot{x}_d \\
u_{yd} &= -\lambda \dot{e}_y + s_y + \ddot{y}_d \\
\end{align*}
\]

(4)

Among them, \( \dot{s} \) is the law of approach:

\[
\dot{s} = -\varepsilon \text{sgn}(s) \quad \varepsilon > 0
\]

(5)

Where \( \lambda \) and \( \varepsilon \) are constants, \((u_{xd}, u_{yd})\) are ideal control input commands in the x direction and y direction of the agent. In order to eliminate the chattering phenomenon, the constant approach law, exponential approach law, power approach law and general approach law have been proposed in the past research. The idea of the general method is to use a larger speed when the agent is far from the sliding mode surface, and use a smaller speed when the agent is closer to the sliding mode surface. Here, when the agent is closer to the sliding mode surface, we change the parameters of the sliding mode surface to make the sliding mode surface fall on the agent to eliminate chattering.

\[
\lambda = \frac{-\varepsilon}{\varepsilon}
\]

(6)

In actual scenarios, the agent is limited by the communication distance and perception distance. Within the communication distance, the following agent can obtain the leader’s motion state information. The above-mentioned method can be used to achieve the agent formation movement, but when the follower agent is disturbed, causing the follower to leave the communication range of the leader and within the sensing range, the follower agent needs to rely only on the position information of the leader to return to the communication range of the leader to form a formation again.
When the following agent only has the position information of the leader, the method mentioned above cannot be used anymore, so it is necessary to use the position information of the leader to calculate the approximate motion state of the leader.

\[
V_{x_l}(t) = \frac{x_l(t) - x_l(t - \Delta t)}{\Delta t}
\]

\[
V_{y_l}(t) = \frac{y_l(t) - y_l(t - \Delta t)}{\Delta t}
\]

\[
u_{x_l}(t) = \frac{V_{x_l}(t) - V_{x_l(t-\Delta t)}}{\Delta t}
\]

\[
u_{y_l}(t) = \frac{V_{y_l}(t) - V_{y_l(t-\Delta t)}}{\Delta t}
\]

Among them, \((V_{x_l}(t), V_{y_l}(t), u_{x_l}(t), u_{y_l}(t))\) is the approximate motion state of the navigator, and \(\Delta t\) is the sampling time interval.

4. Simulation Results

In this section, we provide two simulation examples to verify the effectiveness of the formation control method. In the first simulation, the two agents are on the coordinate axis, their initial coordinates are both 5, the speed is 0, and the synovial plane parameter is \(\lambda = 1, \ \varepsilon = 2\). As shown in Figure 2, the abscissa in Figure 2 is time, and the ordinate is the position of the agent. From Figure 2, it can be seen that the dynamic sliding mode method converges faster than the ordinary synovial method. The abscissa of Figure 3 is time, and the ordinate is speed. It can be seen from Figure 3 that the dynamic sliding mode method effectively eliminates the chattering phenomenon.

Fig 2. The trajectory of the first simulation.
Fig 3. Speed change of the first simulation

In the second simulation, we used 11 agents, where agent 0 is the leader of agent 1 and agent 2, agent 1 is the leader of agent 3, agent 3 is the leader of agent 5, and so on; agent 2 is the leader of agent 4, agent 4 is the leader of agent 6, and so on. The communication distance of the agent is 3, the perception distance is 6, the speed of the leader in the x direction is 1, and the speed in the y direction is \( \cos 0.125\pi \). It can be seen from Figure 4, Figure 5, and Figure 6 that the agent can generally maintain formation move, but agent 1 and agent 2 can't stay in the ideal position well.

Fig 4. The trajectory of the second simulation.
Fig 5. The distance error between the position of the agent and its ideal position in the second simulation

Fig 6. The angular error between the position of the agent and its ideal position in the second simulation

5. Conclusion
In this article, we introduce the concept of dynamic synovial plane, and prove through simulation that this method is effective in weakening the chattering phenomenon. Compared with traditional methods, this method converges faster. By introducing the concepts of communication range and perception range, the actual scene is simulated more realistically. The second simulation result shows that multi-agents can roughly maintain the formation to move. In the simulation of Fig. 5, the error between agent1 and agent2 and the ideal position is too large, indicating that this method is still insufficient in terms of sensitivity, which will be studied in the future direction.

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