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Research Article

A Design of Multi-Agent System Simulation Platform for UGV and Research on its Formation Control Protocol

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ABSTRACT

Inspired by ants and fishes in nature, the multi-agent system plays a huge role in production and manufacturing in modern society. This paper takes UGV as the object and designs a multi-UGV test platform. The platform composes of UGVs, ultra-wideband, and Bluetooth Mesh. At the same time, the UGV can achieve different control objectives by changing the code of main controller. The formation control protocol of UGVs is designed and its stability is analyzed. The effectiveness of the protocol is verified by numerical simulation. Finally, the designed control protocol is applied to the designed hardware simulation platform to verify the effectiveness of the simulation platform.

1. Introduction

Multi-agent system (MAS) technology plays a huge role in industry and manufacturing. The technology of the multi-agent system is mainly inspired by ants, fishes, birds in nature, etc. Theoretically, the agent can be anything, such as UGV (unmanned ground vehicle), UAV (unmanned aerial vehicle), sensor, robotic arm, etc.

At present, the theoretical research on multi-agent systems is gradually becoming mature, such as the consensus control[1], rendezvous control[2], and formation control[3]. But at the application level, there are still many areas that need to be improved.

This paper designs a physical simulation platform of a multi-agent system to verify its application in actual scenarios. This platform adopts a layered structure design, which includes a communication layer, an agent layer, and a positioning layer. The communication layer is to establish communication channels between agents so that any agent can communicate with all other agents. The agent layer contains all the individual agent that makes up the system. The positioning layer provides positions for each agent.

A UGV with Arduino or STM32 as the main controller was designed. Then, the principle of Bluetooth Mesh communication technology and the principle of UWB (ultra-wideband) positioning were explained.

The dynamic consensus and static consensus of the multi-agent system are analyzed, and the static formation control protocol of the system is designed based on the static consensus. Finally, a numerical simulation is performed to verify the validity of the static formation control protocol designed. After that, the static formation control protocol is applied to the physical simulation

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platform to verify the effectiveness of the physical simulation platform.

2. Multi-agent System Simulation Platform

The multi-agent system simulation platform, which is shown in Fig.1, consists of three parts: 1) Agents. Agents could be anything, such as UGVs, UAVs, sensors, manipulators, etc. This paper takes the UGV as an example. 2) Communication network. The agent needs to know the status information of other agents when it is working. The purpose of Bluetooth Mesh is to establish the communication channel between agents. 3) UWB positioning system. The position states of all agents come from this system.

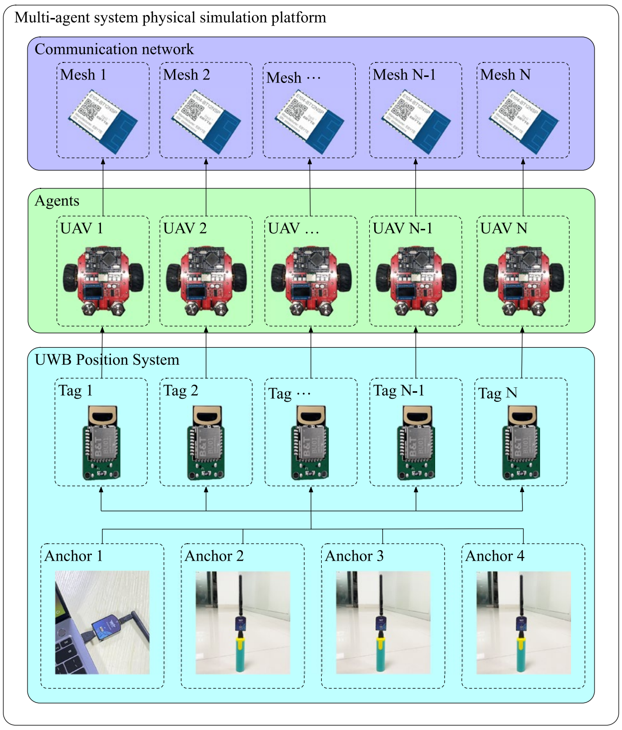


Fig.1. Multi-agent system physical simulation platform

2.1. *UGV architecture*

This article uses UGV as the research object as shown in Fig.2. The main controller of UGV could be Arduino, STM32, or Raspberry Pi. To achieve precise control, the motor pulse must be in a precise and controllable state, so the PWM (pulse-width modulation) signals combined the motor pulse and the PID (proportional-integral-derivative) control algorithm. To adjust the PID parameters more conveniently, the screen is used to display the return value of the encoder and the battery voltage. The main purpose of real-time voltage acquisition is to keep the motor regulation within a fixed voltage range and avoid the influence of current differences.

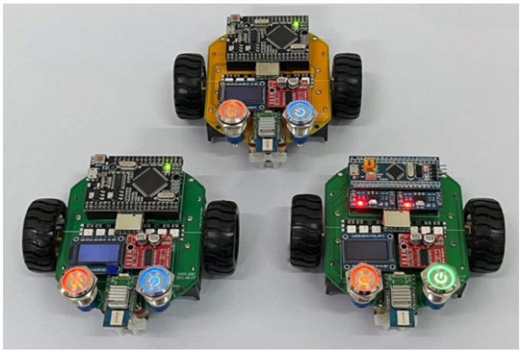


Fig.2. UGV agents

2.2. *Communication network*

The communication network uses Bluetooth Mesh technology as shown in Fig.3, and the chip model is E104-BT12NSP. The module supports the Sig Mesh and 2.4Ghz Bluetooth band. In the Mesh networking, the maximum communication distance between two neighboring nodes in a network is 50 meters. If two nodes have a common neighboring node, then the maximum distance between them can be up to 100 meters.

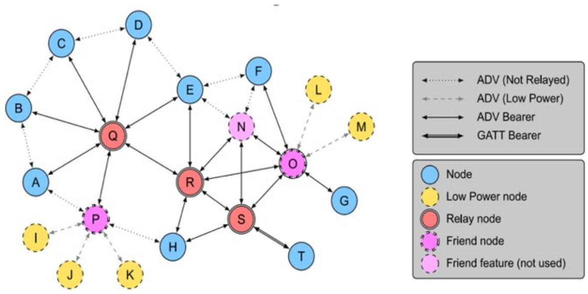


Fig.3. Bluetooth Mesh networking diagram

2.3. *UWB Positioning system*

UWB positioning technology can be applied to the positioning, tracking, and navigation, and can provide very accurate positioning information.

UWB positioning technology uses TOF (time of flight) ranging method. The TOF ranging method is a two-way ranging technology. It mainly uses the flight time of the signal between two transceivers to measure the distance between nodes. The module will generate an independent timestamp from the start. As shown in Fig.4, the transmitter of module A transmits a requested pulse signal at A1 of its time stamp, and module B transmits a responsive signal at time B2, which is received by module A at time A2 of its timestamp. The flight time of the pulse signal between the two modules can be calculated to determine the flight distance. Because in the line-of-sight environment, the TOF-based ranging method has a linear relationship with the distance, so the measurement results will be more accurate.

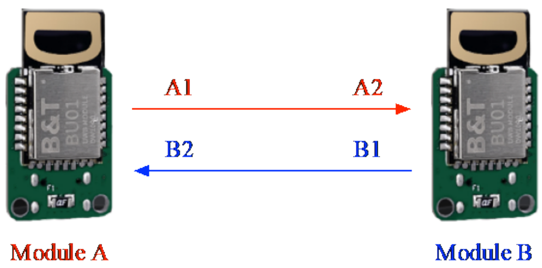


Fig.4. UWB ranging principle diagram

3. Formation Algorithm

In this part, we first elaborated the dynamic model of UGV, then introduced the consensus protocol of common second-order systems, and finally constructed the formation control protocol based on the consensus protocol.

We assumed that UGV satisfies the second-order dynamics model. Then the system dynamics model can be expressed as

$$\begin{aligned} \dot{p}_i &= v_i \\ \dot{v}_i &= u_i \end{aligned} \tag{1}$$

where $p_i = [p^x \quad p^y]^{\mathrm{T}}, v_i = [v^x \quad v^y]^{\mathrm{T}}$ represent the position and velocity of UGV, respectively. $u_i = [u^x \quad u^y]^{\mathrm{T}}$ is the control input.

3.1. *Consensus protocol*

The dynamic consensus protocol and static consensus protocol of the second-order system as formula (2) and formula (3) respectively.

$$u_i = \alpha \sum_{j\in N_i}(p_j - p_i) + \beta \sum_{j\in N_i}(v_j - v_i) \tag{2}$$

$$u_i = \alpha \sum_{j\in N_i}(p_j - p_i) - \beta v_i \tag{3}$$

where α, β are positive gain, N_i represent the neighbors of the node i [4].

The difference between dynamic consensus protocol and static consensus protocol is whether the final state of the velocity v_i is static, that is, the final velocity state of dynamic consensus is equal but not necessarily 0, the position is in a constantly changing state, but the final velocity state of static consensus equal 0, the position remains stationary.

3.2. *Formation protocol*

Based on the static consensus protocol (3) of the system, this paper designs the following static formation control protocol (4)[5,6].

$$u_i = \alpha \sum_{j\in N_i}\big((p_j - h_j) - (p_i - h_i)\big) - \beta v_i \tag{4}$$

where $h_i = [h^x \quad h^y]^{\mathrm{T}}$ is the desired formation states of agent i.

The protocol (4) can ensure that the system completes the formation within a limited time and remains stationary. Formula (2) can also be changed to a dynamic formation protocol, but it will become another type of time-varying formation problem, and we will not discuss it here for the time being.

4. Simulations

In this part, we conducted the numerical simulation experiment and the experiment of the simulation platform respectively. The numerical experiment was used to verity the effectiveness of formation control protocol (4). The simulation platform was used to extend the value of engineering. The simulation experiment is set as the system has three agents and the communication relationship is shown in Fig.5. The ultimate goal of simulations is to complete the triangular formation.

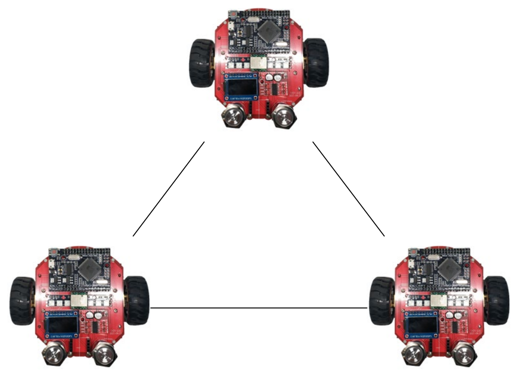


Fig.5. Multi-UGV system communication topology

4.1. *Experiment 1*

Set the initial states of the three UGVs as follows

$$p_1(0) = [20 \quad 15]^{\mathrm{T}}, v_1(0) = [1 \quad 1]^{\mathrm{T}},$$
$$p_2(0) = [20 \quad 10]^{\mathrm{T}}, v_2(0) = [1 \quad -2]^{\mathrm{T}},$$
$$p_3(0) = [20 \quad 20]^{\mathrm{T}}, v_3(0) = [-2 \quad 1]^{\mathrm{T}}.$$

The positive gains are $\alpha = 0.3, \beta = 1.5$. The formation control protocol is equation (4). Fig.6 and Fig.7 show the simulation results on X-axis and Y-axis respectively.

Through observing the experimental results, each agent can reach the specified position in a limited time, that is to say, the system has completed the set formation requirements.

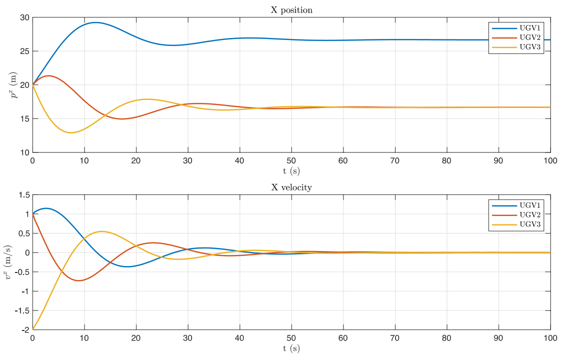


Fig.6. The states of UGVs along X-axis

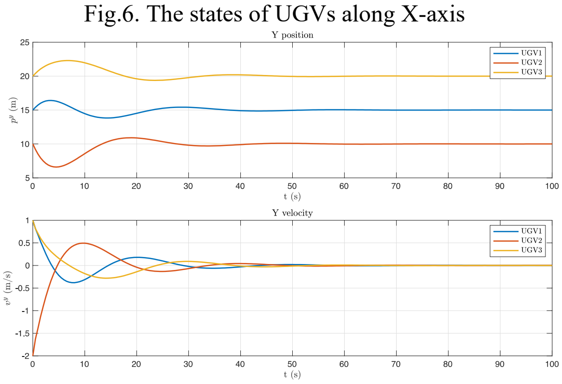


Fig.7. The states of UGVs along Y-axis

4.2. *Experiment 2*

After the correctness of the formation protocol is verified by numerical simulation, the formation control protocol (4) is applied to the designed physical simulation platform.

The experimental platform is shown in Fig.8. Four UWB as anchors is distributed at four corners of the experimental site to provide auxiliary location information. There are also three UWB modules mounted on the UGV to provide position coordinates. The Bluetooth module on the UGV assists communication, enabling an agent to obtain information such as position, speed, and control input of other agents.

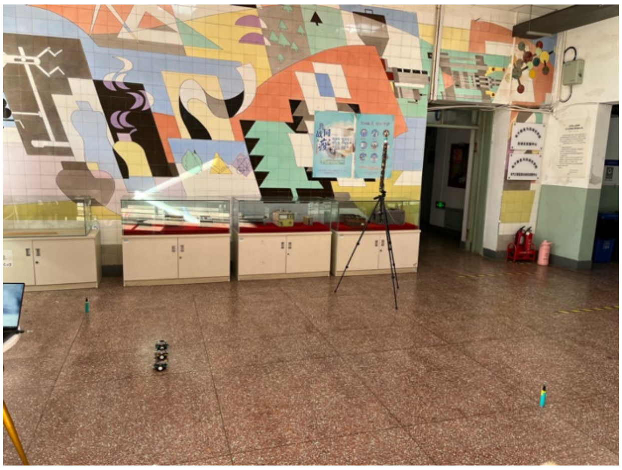
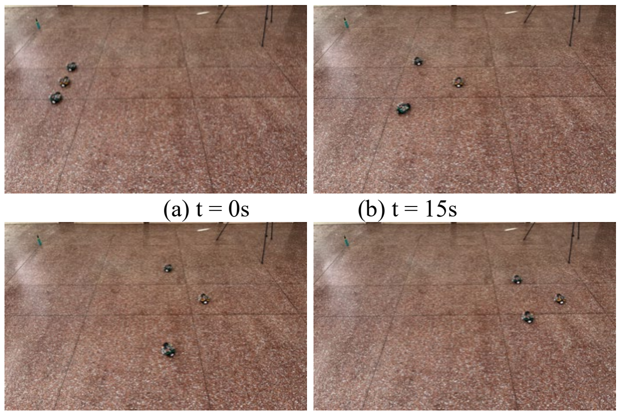


Fig.8. Experimental scene diagram

The running effect of the simulation platform is shown in Fig.9, showing the different positions of the three UGVs at different time instants. At the beginning of the experiment, the three UGVs were lined as the line (t=0s) and then began to move away (t=15s) gradually due to the effect of the control protocol. Due to the influence of the speed, the distance would be large (t=30s), and then returned to the predetermined formation position (t=45s) to complete the triangular formation.



(a) t = 0s (b) t = 15s

(c) t = 30s (d) t = 45s

Fig.9. The operating positions of the three UGVs at different time instants

5. Conclusions

This paper designed a multi-agent system simulation platform and introduced the simulation platform in details.

The platform composed of three layers which including the agent layer, the communication layer, and the positioning layer. A type of UGV is designed, which is used as an agent to verify the effectiveness of the simulation platform. The consensus control protocol is analyzed, and the formation control protocol is designed based on the consensus protocol and applied to the simulation platform.

In the next step, we will design different types of agents and integrate them into our simulation platform to expand the scope of the platform.

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