Design and Implementation of a Cluster Control System for Multi-Biomimetic Robotic Fish

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Abstract—**This paper addresses the problem of cluster control for multi-biomimetic robotic fish. First, the mechanical design and system configuration of the biomimetic robotic fish are briefly introduced. In order to deal with the challenging problem of cluster control, a cluster control system is proposed based on WiFi technology. Specifically, host computer can transmit wireless signals (IEEE 802.11 signal) to surrounding space as access point (AP), while multi-biomimetic robotic fish can connect to the wireless local area network as station (STA). Then multiple transmission control protocol (TCP) connections can be established with host computer as TCP client and multi-biomimetic robotic fish as TCP server. In this way, host computer can control the multi-biomimetic robotic fish cluster simultaneously. In the end, experimental results demonstrate the feasibility and effectiveness of the designed cluster control system.**

Index Terms—**Cluster Control, Biomimetic Robotic Fish, WiFi, TCP**

I. Introduction

With long-term natural selection, fish have excellent underwater sports ability. For example some fish can achieve high mobility in rally or explosive travel, or can maintain low energy consumption and high efficiency in long distance swimming [1]. By studying the propulsion mechanism of various fish swimming in nature, many researchers have developed biomimetic robotic fishes with excellent propulsion efficiency and high mobility, using mechanical components, electronic components and smart materials [2], [3].

Recently, the research on biomimetic robotic fish system has made great progress, a lot of work has been made in the BCF (Body and/or Caudal Fin) and the MPF (Median and/or Paired Fin), realizing three-dimensional (3-D) swimming, quick start, fast turn of biomimetic robotic fish in water [4], [5]. For example, Hu et al. developed the G9 robotic fish from 2006 to 2010, which is 52 cm long and consists of three joints at the tail. The center of gravity is moved inside the body to achieve floating and diving [6]. Between 2005 and 2014, Ijspeert et al. developed the Anguilliform robot, which has many degrees of freedom. The whole body participates in fluctuations, so the steering is more flexible [7]–[9]. In 2016, Bonnet et al. developed the single-joint biomimetic robotic fish, which is used to study the interaction behavior of the biological zebrafish. The biomimetic robotic fish is 8 cm long, driven by a micro stepping motor, whose maximum speed is 0.025 m/s [10]. In 2013-2014, Wu et al. developed a 3-D maneuverable robotic pike with a North American pike as a bionic object, having good performance of 3-D maneuverability [11], [12]. However, most researchers focus on the control of a single biomimetic robotic fish, but there is little research on cluster control systems for multi-biomimetic robotic fish.

The study of cluster control for biomimetic robotic fish is very meaningful. Through coordinated control of multiple biomimetic robotic fishes to form clusters, they can complete more complex tasks in a unstructured underwater environment [13]. In this paper, we design a cluster control system for multi-biomimetic robotic fish based on WiFi technology. First, we introduce the mechanical design and system configura-

tion of the biomimetic robotic fish briefly. Through WiFi module, the host computer can transmit wireless signals to surrounding space as access point (AP). Then a plurality of biomimetic robotic fishes act as stations (STAs), joining in the wireless local area network. After that, we establish multiple transmission control protocol (TCP) connections with host computer as client and multi-biomimetic robotic fish as server. Through host computer, we can control multi-biomimetic robotic fish to complete complex tasks, such as multi-fish chasing, synchronous movement, etc.

In the remainder of this paper, an overview of the biomimetic robotic fish is briefly introduced in Section II. The design of the cluster control system for multi-biomimetic robotic fish is elaborated in Section III. Experimental results are further provided in Section IV. Finally, the conclusion and future work are provided in Section V.

II. INTRODUCTION OF BIOMIMETIC ROBOTIC FISH

In this paper, the biomimetic robotic fish is mainly composed of head, body, tail and skin. Among them, the design of the head is an important aspect of bionics. The body is the main part of the whole robotic fish. It is placed with the power supply, hardware circuit and driving part, which is the brain and power source of the robotic fish. The tail is the actuator of the robotic fish swimming. The skin isolates the internal circuit from the external water environment, reduces the resistance during the swimming process and improves the propulsion efficiency [14]. Fig. 1 is physical map of the biomimetic robotic fish.

Fig. 1: Physical map of the biomimetic robotic fish

The configuration framework of the biomimetic robotic fish system is given by Fig. 2. It mainly includes six parts: micro controller unit (MCU), wireless communication, fish-tail position detection, motor drive, power management, and LED light control. Among them, the MCU can control and manage the whole robotic fish system. The WiFi module can send control commands received from the host computer to the MCU. Through three Hall sensors, the fishtail position detection system can acquire the fishtail position in real time and feed it back to the MCU. By processing control command and position information, the MCU can send two sets of pulse width modulation (PWM) waves to drive circuit of motor. The H-bridge drive circuit controls the motor speed and steering, thereby driving the biomimetic robotic fish to perform corresponding actions, such as forward, still, steering, etc. At the same time, the MCU can send control signals to three LED lights (red, green, blue) to control the biomimetic robotic fish

to emit multiple colors, which can display different states of the robotic fish intuitively and conveniently. The color of the robotic fish also provides a simple way for the subsequent fish to interact with each other. The robotic fish can obtain the color of other fish to judge the next action.
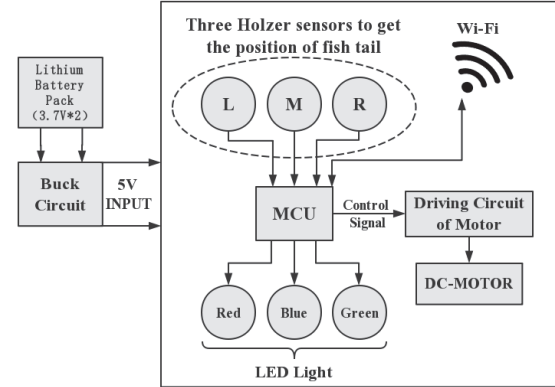

Fig. 2: The configuration framework of the biomimetic robotic fish system

III. DESIGN OF THE CLUSTER CONTROL SYSTEM FOR MULTI-BIOMIMETIC ROBOTIC FISH

The cluster control system for multi-biomimetic robotic fish needs to realize the information interaction between the decision-making layer and the biomimetic robotic fish. This paper uses WiFi to realize the wireless communication between the host computer and the biomimetic robotic fish cluster. In the whole communication process, the control command is sent by the host computer to the corresponding biomimetic robotic fish. The MCU parses the received command and controls the biomimetic robotic fish to perform the corresponding action. Next, the structural design, hardware design and software design of the cluster control system are introduced separately.

A. Structure Design of the Cluster Control System

Considering the range of activities of biomimetic robotic fish, WiFi is chosen as the way of wireless communication for the cluster control system. First, the infrastructure (Infra) based on the AP needs to be set up, and a number of STAs join the formed wireless network. The network topology is as shown in Fig. 3. The characteristic of the network is that the AP acts as the central node of the entire network and is responsible for forwarding all communication data in the network.

In this system, through WiFi module, the host computer transmits wireless signals as AP of the Infra, while a plurality of biomimetic robotic fishes are actively connected to the AP as STAs. They together form a Infra, so a wireless connection between the policy layer and the biomimetic robotic fish cluster is established.

The structural block diagram of the communication system is shown in Fig. 4. As a wireless transmitting unit, the WiFi
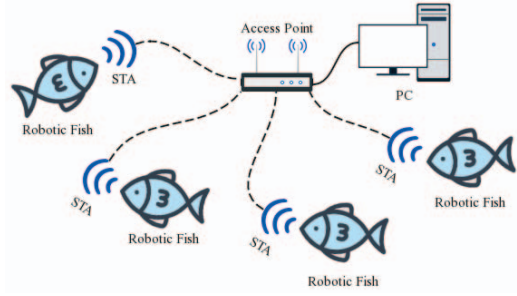
Fig. 3: The network topology of Infra

module (AP) exchanges information with the host computer through the serial port, acquires the command of the decision layer, and then sends it to the STA in the Infra through TCP protocol. As a wireless receiving unit, the WiFi module (STA) is connected with the MCU on the biomimetic robotic fish. It can receive the command of the decision-making layer through the Infra and realize the control of the robotic fish by using the MCU to implement various control actions.
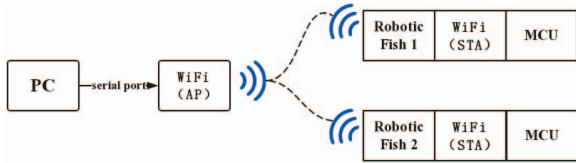

Fig. 4: The structural block diagram of the communication system

B. Hardware Design of the Cluster Control System

The wireless transmission unit of the cluster control system is connected to the host computer, and the UART-WiFi module based on the ESP8266 chip developed is used. The ESP8266 is a low-power, highly integrated WiFi chip that integrates the micro-processor Tensilica L106 to support the standard IEEE 802.11 b/g/n protocol, and has a complete TCP/IP stack [15]. By configuring the ESP8266 module as the AP mode, it can send information to all connecting STAs.

The control command is sent by the wireless transmitting unit to the Infra, the wireless receiving unit receives the control command and transmits the control command to the MCU. The wireless receiving module is connected to the biomimetic robotic fish, which adopts the ESP8285-M1 module [15]. The module can be easily integrated into the biomimetic robotic fish circuit board to reduce the volume of the circuit part.

C. Software Design of the Cluster Control System

TCP is a connection-oriented, reliable, byte-based transport layer communication protocol with reliable and stable advantages. Using TCP as the network communication protocol of the cluster control system ensures that each control command is accurately sent to corresponding biomimetic robotic fishes. In network communication, TCP/IP hierarchical model is divided into four layers: application layer, transport layer,

network layer, and data link layer. When using ESP8266 for TCP network communication, the design of transport layer and network layer must be implemented. The communication topology of the cluster control system is shown in Fig. 5.
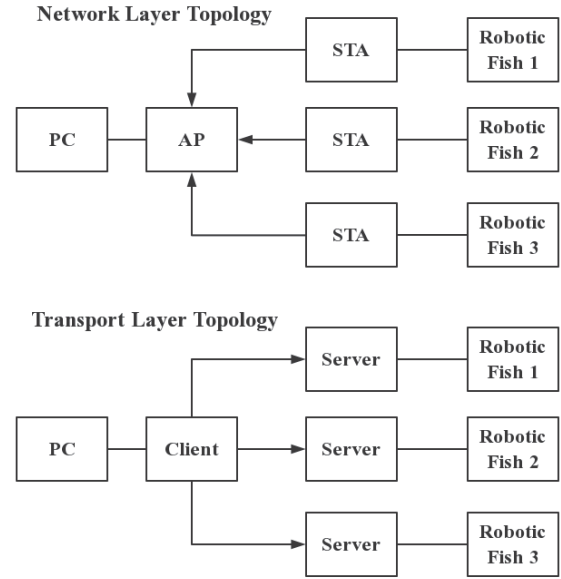

Fig. 5: The communication topology of cluster control system

The overall design ideas are as follows:
- At the network layer, the host computer acts as the AP and the biomimetic robotic fish acts as the STA. First, the host computer controls the WiFi module to establish a Infra. Then the WiFi module of each biomimetic robotic fish is controlled to automatically connect to the Infra and obtain an IP address. In this way, the Infra is established with host computer as the AP.
- At the transport layer, multiple TCP connections need to be established, the host computer acts as the client, and the biomimetic robotic fish acts as the server. First, the TCP server is set up by the biomimetic robotic fish, and the remote client information is monitored at the same time. Then, the host computer, as a TCP client, sends a request to multiple TCP servers, and establishes multiple TCP connections from the host computer to the robotic fish. This allows control commands to be sent to multiple biomimetic robotic fishs at the same time and avoids mutual interference.

The host computer program flow chart is shown in Fig. 6. First initialize the serial port parameters and open the serial port. After successfully opening the serial port, configure the WiFi module connected to the host computer as AP mode and set corresponding parameters: ssid (access point name), pwd (password), chl (channel number), etc. Then, query the STA information that has been connected to the AP. According to the accessed STA information addr (IP address) and port (port number), the host computer as TCP client sends multiple TCP connection requests to multiple STAs as TCP servers, and

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allocates each TCP connection an id number until the TCP connection is successfully established. After establishing TCP connection with each STA, the control command can be sent to each biomimetic robotic fish separately. The TCP communication is performed to the wireless transmitting module by transmitting an AT communication command, including the id number of the connection and the communication word length. Then send the communication content, when receiving the returned SEND OK, it means the packet is sent successfully.
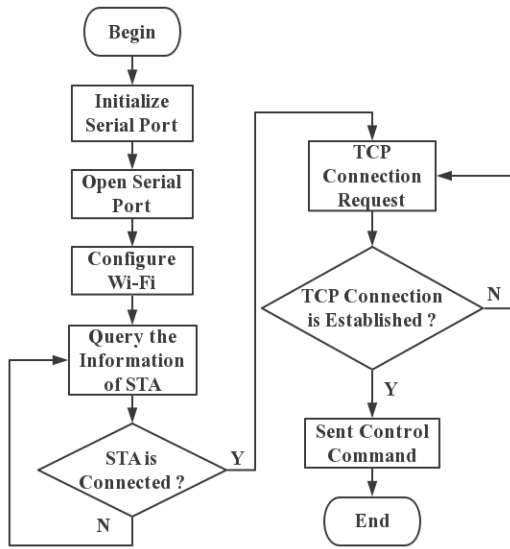
Fig. 6: The host computer program flow chart

Fig. 7: The biomimetic robotic fish program flow chart

| 0x55 0xAA 0x99 0x11 | Data | 0xFF |

Fig. 8: The design of data packet for control command

The biomimetic robotic fish program flow chart is shown in Fig. 7. First, the WiFi module is initialized and configured to STA mode. Then search for the AP signal and join the Infra. Next send a query command to the WiFi module to obtain the information currently connected to the AP and determine whether it is stably connected to the Infra with obtaining an IP address. If the connection is disconnected, re-send the command to join the Infra to ensure a stable connection at the data link layer. After successfully connecting to the Infra and obtaining an IP address, set the TCP server port, establish a TCP server, and monitor the server port. After receiving a TCP client request, establish a TCP connection with it. After the TCP connection is established, the robotic fish can receive the data sent by the host computer. Regularly check whether the TCP connection is stable. If the TCP connection is disconnected, check whether the WiFi connection is disconnected. If it is disconnected, reconnect the AP. If the connection is normal, re-monitor the TCP server.

In the cluster control system, communication using TCP protocol can ensure the integrity and accuracy of the data. At the same time, in order to make the MCU accurately obtain the control command, the design control command data packet includes three parts: the start bit, the data bit and the end bit, which are given by Fig. 8.

Among them, 0x55 0xAA 0x99 0x11 is used as the start bit to effectively and accurately identify the control commands
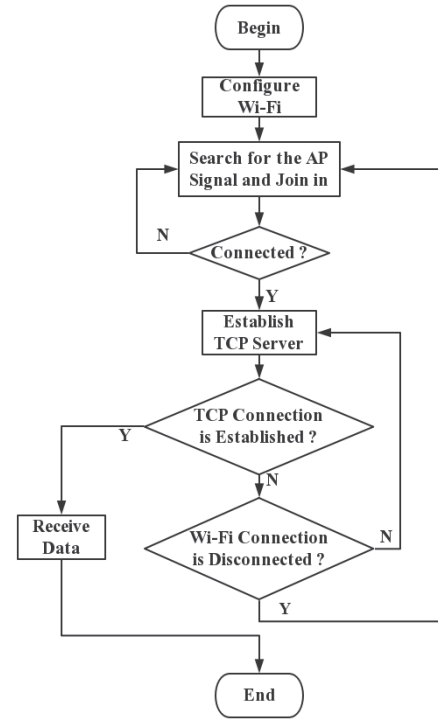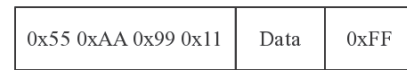
to avoid misidentification. The end bit is marked with 0xFF. The data bit function is given by the TABLE I, including the swimming direction, speed value, color value.

TABLE I: The data bit function

Function	First Bit	Second Bit	third Bit
Swim Control	0x00	Swim Direction	Speed
Color Control	0x01	Color Value	⌐
Reset	0x02	⌐	⌐

IV. Cluster Control Experiment for biomimetic robotic fish

A. Multi-modal Motion Control Experiment of biomimetic robotic fish

The following is a single biomimetic robotic fish multi-modal motion control experiment, including modal motions such as straight-forward, left turn, and right turn.

Firstly, the straight-forward experiment of the biomimetic robotic fish is carried out. The Fig. 9 is the video screenshot sequence of single fish straight-forward experiment. The six pictures are arranged in chronological order, showing the whole process of the biomimetic robotic fish moving forward for 6s. It can be seen that the cluster control system can control a single fish to swim towards a straight line.
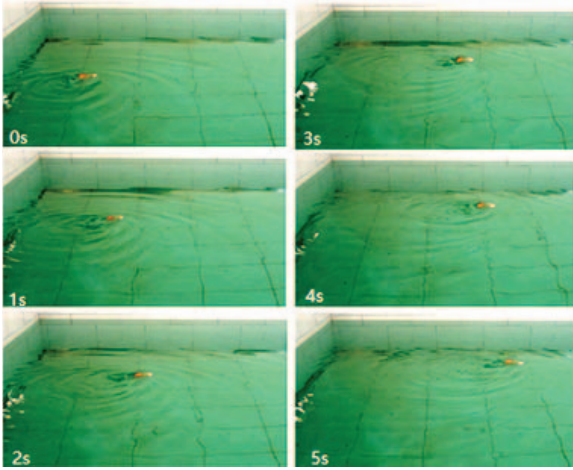
Fig. 9: The video screenshot sequence of single fish straight-forward experiment

Secondly, the right turn experiment of the biomimetic robotic fish is carried out. The Fig. 10 is the video screenshot sequence of single fish right turn experiment, showing the whole process of the biomimetic robotic fish turning right for 6s. It can be seen that the biomimetic robotic fish turns to the right about 90 angle, and the cluster control system can control a single fish to turn right.
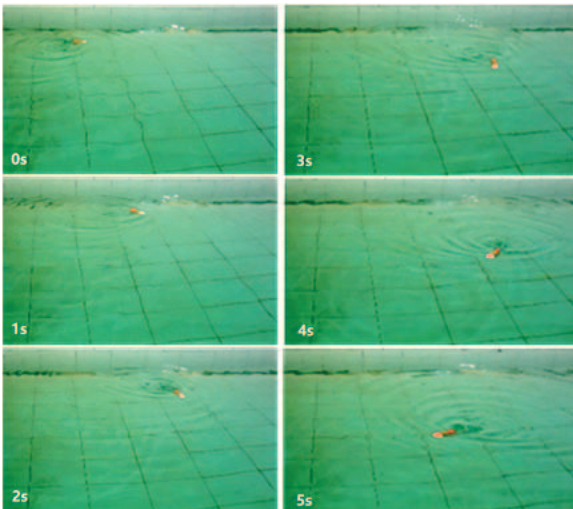

Fig. 10: The video screenshot sequence of single fish right turn experiment

Finally, the left turn experiment of the biomimetic robotic fish is carried out. The Fig. 11 is the video screenshot sequence of single fish left turn experiment, showing the whole process of the biomimetic robotic fish turning left for 6s. It can be seen that the biomimetic robotic fish turns to the left about 90 angle, and the cluster control system can control a single fish to turn left.

The experimental results show that the cluster control system designed in this paper can control the multi-modal motion of a single biomimetic robotic fish, and control the
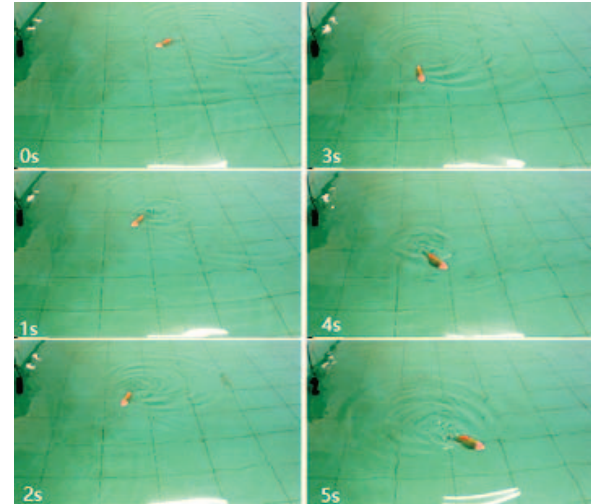

Fig. 11: The video screenshot sequence of single fish left turn experiment

modal movements of biomimetic robotic fishs such as straight-forward, right turn and left turn.

B. Chasing Motion Control Experiment for Multi-biomimetic robotic fish

This section introduces the multi-biomimetic robotic fish chasing motion control experiment. The Fig. 12 is the video screenshot sequence of multi-biomimetic robotic fish chasing motion experiment. At 0s, the two biomimetic robotic fish (red, blue) are basically in the same initial position. Then control the blue biomimetic robotic fish to move forward in advance, and at 1s the blue biomimetic robotic fish is in a leading position relative to the red biomimetic robotic fish. Then from the 2s to the 5s, the blue biomimetic robotic fish is controlled for multimodal movement, and the red biomimetic robotic fish is in the following position, chasing the blue biomimetic robotic fish.
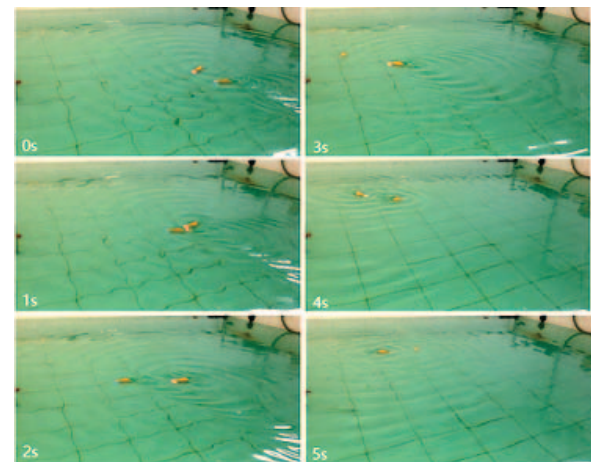

Fig. 12: The video screenshot sequence of multi-biomimetic robotic fish chasing motion experiment

The experimental results show that the cluster control system can stably control multi-biomimetic robotic fish in real time for chasing movement. When the blue biomimetic robotic fish is in the leading position, it can control the red biomimetic robotic fish to chase the blue biomimetic robotic fish.

C. Synchronous Motion Control Experiment for Multi-biomimetic robotic fish

This section introduces the multi-biomimetic robotic fish synchronous motion control experiment. The Fig. 13 is the video screenshot sequence of multi-biomimetic robotic fish synchronous motion experiment. At 0s, the two biomimetic robotic fish are basically at the same forward position. Then from 1s to 5s, the same control command is sent to the two biomimetic robotic fishes at the same time, and the two biomimetic robotic fishes are controlled to perform the same action, and the same multimodal motion is synchronized.
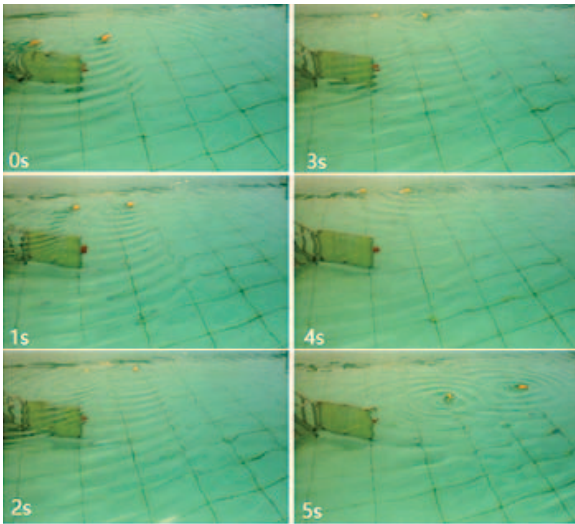

Fig. 13: The video screenshot sequence of multi-biomimetic robotic fish synchronous motion experiment

The experimental result shows that the cluster control system can stably control multi-biomimetic robotic fish in real time for synchronous movement, and can control two biomimetic robotic fishes to perform the same action at the same time. The two biomimetic robotic fishes maintain the initial relative position and perform the same multimodal motionat the same time .

The cluster control system for multi-biomimetic robotic fish can realize real-time and stable control of multiple biomimetic robotic fish and complete certain tasks.

V. CONCLUSION AND FUTURE WORK

In this paper, we have proposed a cluster control system for multi-biomimetic robotic fish based on WiFi technology. The Infra is consisted of host computer and multi-biomimetic robotic fish. Through WiFi module, the host computer acts as AP in this Infra, while a plurality of biomimetic robotic fishes act as STAs. Then, multiple TCP connections is established with host computer as client and multi-biomimetic robotic fish as server. With the help of the designed cluster control system, multi-biomimetic robotic fish can be real-time and stable controlled to complete complex tasks, such as multi-fish chasing, synchronous movement, etc.

However, due to the small size of the fish, it is greatly affected by the water flow, and are easily interfered by each other during the swimming process, resulting in a certain deviation of the swimming trajectory. In the next phase of research, the real-time performance and robustness of the cluster control system will continue to be improved, and the overall performance of the system will be further improved. At the same time, the light sensor is to be installed for the biomimetic robotic fish, so that the information between the robotic fish can be transmitted through the color change, and the robotic fish can make independent decisions to achieve group intelligence.

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