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Gesture Recognition based Teleoperation Framework of Robotic Fish

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Abstract— **Robots attract strong interest from human beings, and ordinary people seriously expect to acquire intuitive understanding from the process of interacting with robots. In this paper, a teleoperation framework based on gesture recognition was developed and the recognized human gestures were mapped to corresponding swimming behaviors of underwater robotic fish. By this means, the robotic fish can be remotely controlled by hand gestures. Most significantly, the teleoperation framework offers the opportunity for onlookers to directly interact with the robotic fish, and the intuitive experience of onlookers about human-robot interaction can be augmented. Compared with traditional control structures of underwater robotic fish systems, the presented teleoperation framework can be built quickly, the influence of light condition can be eliminated entirely, and the onlookers can interact with robotic fish directly rather than need to learn about the system architecture and control strategy. Several tests were taken in a water pool to verify the performance of the presented teleoperation framework. The experimental results showed that the developed teleoperation framework is suitable for remote controlling underwater robotic fish, and the teleoperation framework can be widely applied to other application scenarios. The experiment setup was exhibited in IROS2015, Hamburg, the described teleoperation framework greatly attracted onlooker's interest.**

I. INTRODUCTION

Technology facilitates the research on underwater robots and the ordinary people's interest in robots. Because of the performance of teleoperation method, the teleoperation widely applied to different application scenarios, such as, mobile robots [1], service robots [2], surgical robots [3], [4], industrial robots [5], etc.. Teleoperation architecture can be regarded as the bridge that joins human beings and robots. Human beings can interact with robots through teleoperation. Meanwhile, human beings can find pleasure in the remote interaction.

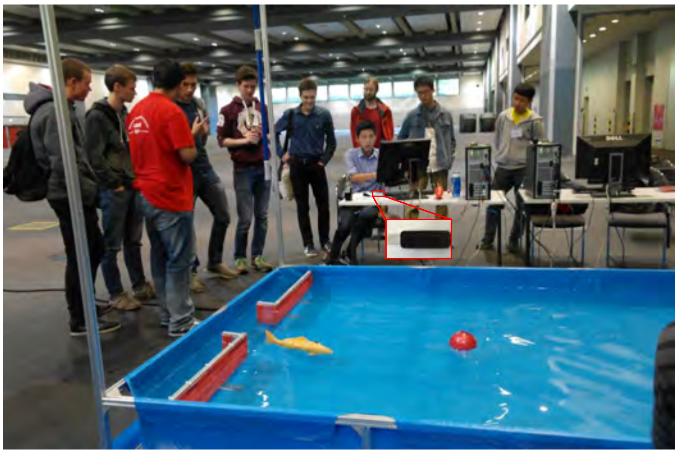

Fig. 1. The robotic fish setup at IROS 2015, a high school student is controlling the robotic fish through gesture recognition.

As a kind of underwater robot, bio-inspired robotic fish draw intense interest from roboticists and biologists. In [6], the authors developed the first biomimetic robotic fish propelled by an ionic polymer-metal composite actuator, and a passive plastic fin is attached to the ionic polymer-metal composite actuator. A 3D swimming robotic fish - MT1 is built in [7]. The proposed robotic fish has adopted a novel tail structure to generate a fish-like swimming motion. [8] developed a hybrid architecture for autonomous robotic fish which is able to swim and navigate in unknown or dynamically changing environments.

The aforementioned works presented multiple biomimetic robotic fish and adopted different methods to mimic the natural fish's swimming behavior. Also, in order to draw the attention from ordinary people and foster interest in science and technology, different methods and platforms have been proposed. [9] proposed a robotic fish platform to foster student interest in science, technology, engineering and mathematic subjects, through a series of lectures and practical activities that culminate with hand-on bioinspiration-based events to facilitate the understanding of the relationship between engineering and nature. [10] and [11] presented a biomimetic robotic fish which can be controlled remotely by an iDevice application (app) and the main purpose is for informal science education. Through the iDevice app, visitors can acquire unique learning experience and can interact with the robotic fish.

In order to enhance the user's intuitive experience, virtual reality was integrated with motion sensing technology to achieve a three-dimensional display and somatosensory interaction. Because of the practicability, high efficiency and low cost, the somatosensory apparatus has been widely applied in Human-Robot Interaction [12], [13]. [14] presented a teleoperation framework based on Leap Motion[1], which is used to recognize gestures and the recognized gestures have been applied to demonstrate a robot to perform tabletop object manipulation tasks.

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[1] http://www.leapmotion.com

In this paper, a teleoperation framework based on gesture recognition was developed to realize underwater robotic fish remote control. Gesture recognition method was introduced in detail and the presented teleoperation architecture was evaluated in several experimental scenarios. The experimental scenarios were exhibited in IROS 2015, Hamburg, Germany, is shown in Fig.1. The proposed teleoperation framework attracted enormous interest from onlookers and offered the channel for onlookers to interact with robotic fish directly, and onlookers acquired intuitive experience through this interaction mode.

The rest of the paper is organized as follows. The review of the prototype of robotic fish and experiment platform were introduced in section II. The main methodology for gesture recognition and action generating based on Leap Motion were described in section III, the experiments and evaluation were discussed in section IV. And finally the paper is concluded in section V.

II. SYSTEM SETUPS

A. Robotic Fish

The prototype of underwater robotic fish is made in the Intelligent Control Laboratory at Peking university according to carangiform fish [15], [16]. This prototype mimics natural ornamental carp and contains three functional structures: rigid head, flexible body and lunate fin, is shown in Fig.2.

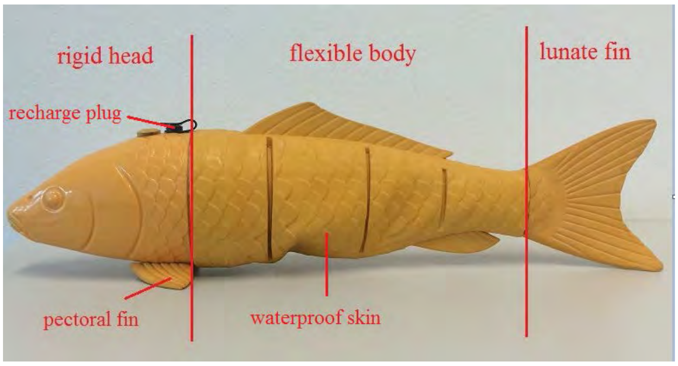


Fig. 2. Prototype of robotic fish.The robotic fish consists of the rigid head, flexible body and lunate fin.

Considering the balance and resistance during the process of swimming, biomimetics and streamline shape were applied to design and model the prototype. The rigid head as the engine contains a control module, a wireless module and battery to propel and steer the robotic fish. Three servomotors constitute the skeleton of robotic fish and waterproof soft rubber covered the servomotors to constitute the flexible body, and the lunate caudal fin imitates real carp's fin. The mechanical figuration is shown in Fig.3.

AVR micro-controller and CPG (Central Pattern Generator), inside the robotic fish, were adopted to achieve swimming mode control and body undulation to propel the robotic fish. Three servomotors receive PWM (Pulse-Width Modulation) signals from the AVR controller to achieve propulsion of the robotic fish. CPG generates rhythmic flapping angles and the generated angles parameters were converted to periodic angles values to adjust the direction of the robotic fish.

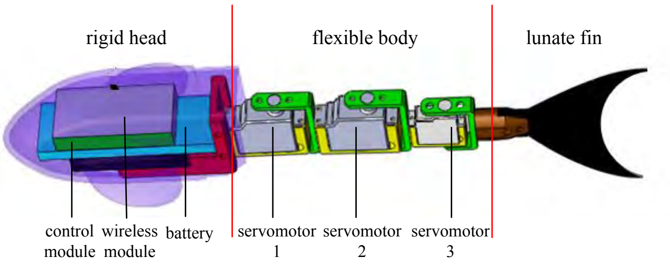


Fig. 3. Mechanical figuration of robotic fish.

B. Experiment Setup

The experiment platform also developed by Intelligent Control Laboratory at Peking university [17]. The experimental schematic is shown in Fig.4. The robotic fish swim in a $200cm \times 300cm \times 30cm$ pool. Two overview global cameras are fixed above the pool to monitor and record the swimming trajectory of the robotic fish, and through a USB port the recorded video was sent to the host computer to analyze the posture and location of robotic fish in real time.

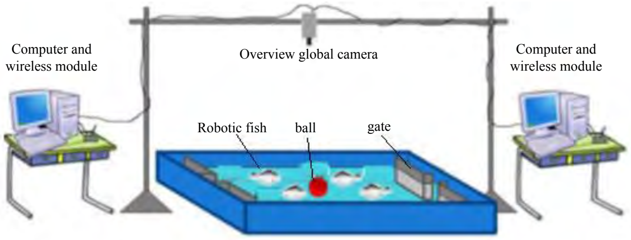


Fig. 4. Experiment platform of robotic fish

The 2.4GHz wireless communication module was adopted to realize the data communication between the robotic fish and host computer. The host computer analyzed the recorded data to identify the current state and position of robotic fish, and then, the corresponding control instruction is generated and sent to the robotic fish. The robotic fish responds to the control instruction and performs the designated swimming behavior.

III. TELEOPERATION METHODOLOGY BASED ON GESTURE RECOGNITION

A. Gesture Recognition

The Leap Motion controller is a USB peripheral device which adopts two monochromatic infrared cameras and three infrared LEDs to recognize human hand gestures. The hand gesture contains the orientation, direction and pose of palm and fingers. Leap Motion acquires the data of the palm's orientation and position, and each finger's extension status to identify a unique gesture. Most significantly, the open API can be used to recognize different gestures easily and applied to broad application scenarios. Considering the advantages and performances of Leap Motion, it was adopted to recognize the gestures and employed the recognized gestures to remotely control the robotic fish.

In automatic control mode, the corresponding commands, which contain speed and direction information, will be generated in the light of the recorded position and trajectory data of robotic fish, and programmed autonomous control strategy. The robotic fish receive the generated commands through a wireless module and perform the appropriate behaviors. Because of the characteristics of overview global camera, the capture effect is greatly susceptible to light condition and blind areas will be generated in the recognition region. If the robotic fish is in a blind area, the robotic fish and its current location cannot be tracked, and the fish will be stuck in the blind area that the programmed automatic strategy can not be executed.

The teleoperation based on gesture recognition can eliminate the influence of light conditions entirely, because the global camera is just employed to record the video and sent the video to the host computer through COM port. The relative coordinates of the robotic fish's current location can be calculated in programmed strategy, and the influence of blind area can be eliminated in this process. In the teleoperation mode, the recognized gestures were mapped to corresponding speed and direction instructions, and the gestures are adjusted according to the recorded video and acquired relative coordinates.

Leap Motion can recognize the orientation, movement speed and facing direction of the palm, the extension status of fingers, and the location and movement speed of fingertips. Leap Motion utilizes the recognized position and direction of the palm to identify whether the hand is in the identifiable space, which is a 150 field of view with roughly 8 cubic feet of interactive 3D space. The coordinates and Euler angles (α, β, γ along x, y, z axes) of the hand current location are applied to define the orientation of palm. In this paper, the direction and position of the palm as well as the finger extension status were integrated to define a specific gesture. The schematic diagram is shown in Fig.5.

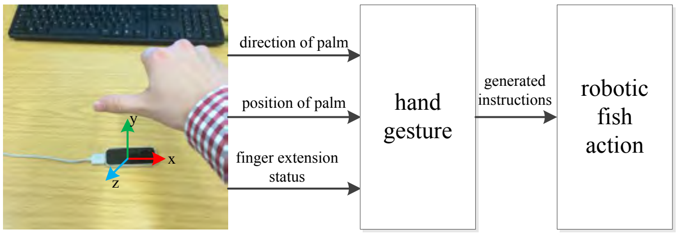


Fig. 5. Schematic diagram of gesture recognition

The sampling frequency of Leap Motion is 10 Hz, which ensures the response time is short enough to recognize the palm location variation in real time. Because Leap Motion cannot recognize the overlapped gesture precisely, to acquire high accuracy data of recognized gestures, the direction of the palm is in the opposite direction of y axis(represented in the algorithm is $\beta < 0$). A timer was set to update the current position data of palm every 30 ms. The finger's movement direction can be identified through the acquired variation of the palm position. The finger extension status can be represented by a binary number, 0 indicates the finger is non-extended, 1 indicates extended. The recognition algorithm is shown in Tab. I. The recognition method of right hand and left hand in the program is same, so just right hand's recognition method was listed in Tab. I.

TABLE I

RECOGNITION ALGORITHM

Algorithm 1 Gesture Recognition and Action Map

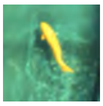
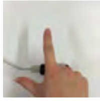
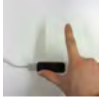
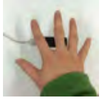
```
set the data update time 30ms
get the information of palm
    right palm information xPos, yPos, zPos and yDir
if $\beta < 0$ then
    identify the extension status of fingers
if right hand finger code == ”00000”
    set Text ”Stop”
    send fish command(id2, 0, 7)
else if finger code == ”11000”
    set $-7 < xPos < 7$, $-7 < zPos < 7$
    send fish command(id2, zPos + 8, xPos + 8)
else if finger code == ”10000”
    set $-7 < xPos < 7$
    if xPos == 0 then
        set Text ”Go Straight”
    send fish command(id2, -1, xPos + 8)
else if finger code == ”01000”
    set $-7 < zPos < 7$
    send fish command(id2, zPos + 8, 7)
else if finger code == ”11111”
    set Text ”Keep State”
    send fish command(id2, zPos, xPos)
```

B. *Gesture Mapping and Action Generating*

Through gesture recognition, the hand movement can be converted to robotic fish swimming action instructions which contain speed and direction data. The movement of the palm and fingers can be mapped to speed and direction adjust instruction of robotic fish. Through analyzing the swimming behavior of robotic fish and take into account the function realizability of gestures, the different gestures were defined to achieve the speed and direction adjustment of robotic fish. The defined gestures and the responding swimming actions are shown in Tab. II.

As mentioned above, hand movement can be converted to the robotic fish operation instructions through gesture recognition. The recorded video and acquired relative coordinates can be regarded as the feedback signal in the control loop. The recognized and recorded data of palm orientation ensured the hand in the identifiable space of Leap Motion. The movement of index finger has been converted to speed control command. The direction adjust is achieved by recognizing the movement of thumb. In real scenarios, the index finger and thumb need to move together to drive the robotic fish swimming in an expected status, because the robotic fish's speed in a certain range contributes to complete the direction adjustment action smoothly.

TABLE II
GESTURE LIST OF HUMAN HAND AND ROBOTIC FISH'S SWIMMING ACTIONS

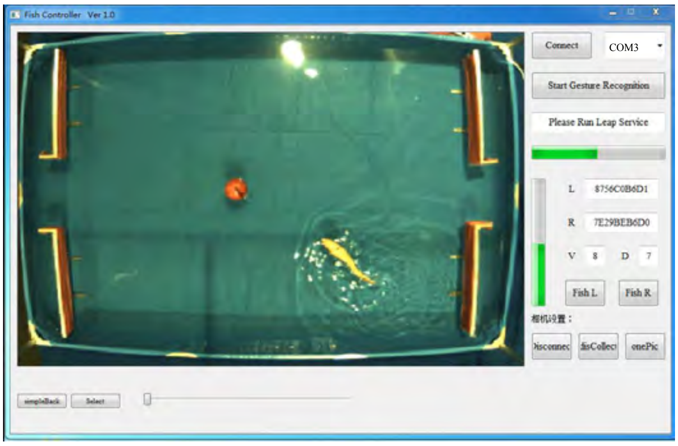
Hand Gesture	Position of palm	Extension Status of Fingers	Gesture Meaning	Robotic Fish's Swimming Action
	accelerate	$\beta < 0$, $\text{zPos}_{i+1} - \text{zPos}_i > 0$	B01000	
	decelerate	$\beta < 0$, $\text{zPos}_{i+1} - \text{zPos}_i < 0$	B01000	
	turn left with speed	$\beta < 0$, xPos < 0, -7 $<$ zPos < 7	B11000	
	turn right with speed	$\beta < 0$, xPos > 0, -7 $<$ zPos < 7	B11000	
	stop	$\beta < 0$	B00000	
	keep state	$\beta < 0$	B11111	

IV. EXPERIMENTS AND EVALUATION

A. Control Platform

We adopted QT, Visual Studio and OpenCV to complete programming and debugging, the developed control interface is shown in Fig.6. In the control interface, the correct serial port needs to be selected to connect with the robotic fish through a wireless module, and two robotic fish's ID need to be input into the matched EditText of left hand (L) and right hand (R). Then the left and right hand gestures will be recognized and mapped to control instructions. Because Leap Motion can not recognize two hands at the same time, so only one fish can be controlled through gesture recognition at one time. The speed control and direction adjustment were corresponded to the vertical scroll bar and horizontal scroll bar respectively. The current value of robotic fish speed and direction were displayed in EditText (V) and (D).

The overview global cameras were adopted to record and capture the trace of robotic fish. In the recorded graphic, the coordinates of pool's four vertices are (0, 0), (480,0), (0, 480) and (480, 750), the two gates' coordinates are (240, 0) and (240, 750). We adopted OpenCV to track the robotic fish during the swimming process to get the current location of fish, and the location data were integrated with the coordinates of vertices and gates to calculate the relative coordinates of robotic fish. The acquired relative coordinates are regarded as the guidance to adjust the finger gesture to achieve appropriate swimming action, for example, dribble the ball into the gate, swimming through the channel which was built by the gate framework, and so on.



COM3

Please Run Leap Service

L 8756C0B6D1

R 7E29BEB6D0

V 8 D 7

相机设置：

Fig. 6. Control interface.

B. Scenario Setups and Experiments

Several scenarios were built to verify the practicability of the developed teleoperation method. The goal framework was employed to build a channel, the robotic fish swam through the channel from the inlet and dribble to the goal. In the swimming course, the movement status in the start position, stop position, turn left and right location explicitly changed, and the speed and direction data are easier to record. So, these key points were selected to record the swimming behavior of robotic fish in the scenario, the sequence snapshots is shown in Fig.7.

The primary purpose of this scenario is to achieve robotic fish swimming with smooth trajectory and complete the

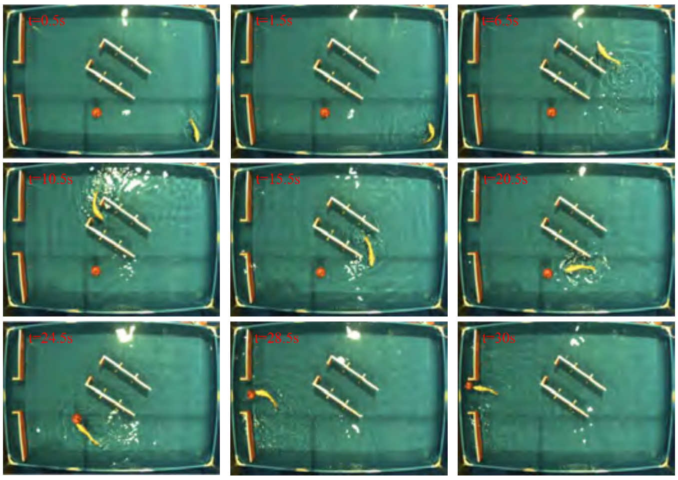


Fig. 7. Sequence of snapshots of the robotic fish during the scenario 1 test.

presupposed trajectory in the shortest time. The hardest part of the swimming course is to acquire smooth trajectory when rapidly switching between different swimming behaviors, for example, accelerate transform to turn left or turn right. To adjust the direction of robotic fish, the speed must be in a certain range to acquire a superlative trajectory, a high speed will cause large deviation between actual and expected trajectory. To obtain the harmony status between movement speed and trajectory, requires that the operator is able to use the gestures to control the robotic fish skillfully and adjust the gestures adroitly to complete the appropriate swimming behavior. To achieve the objective, the gesture control sequences have been repeated several times in the scenario. The trained move trajectory is shown in Fig.8.

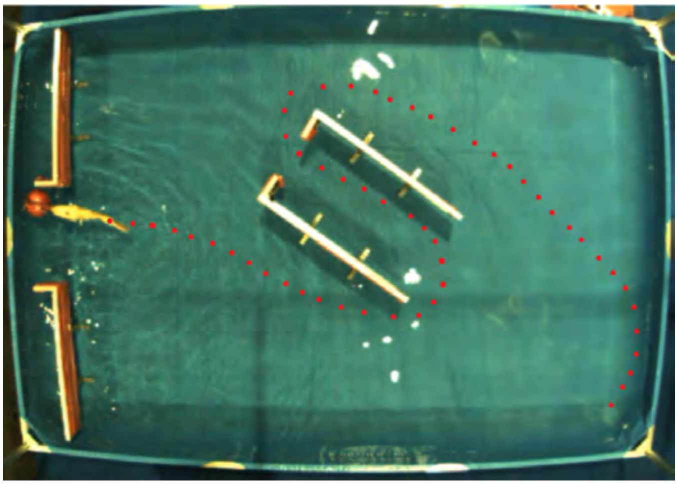


Fig. 8. Swim trajectory of robotic fish.

V. CONCLUSION

In this paper, a teleoperation method for robotic fish was presented, which adopted Leap Motion to recognize the hand gestures and the recognized gestures were applied to achieve robotic fish remote control. Typical gestures contain the palm's orientation, movement speed and facing direction, and fingers' extension status, location and movement speed. These recognized specific data were mapped to corresponding swimming actions of robotic fish, and the recorded video and acquired relative coordinates of the fish's current location were employed to adjust the gesture to generate appropriate instructions.

The proposed teleoperation control method of robotic fish offers the opportunities for onlookers to interact with robotic fish directly, and the onlookers do not need to be able to understand the principle of robotic fish control mechanism and autonomous control strategy. Through the described interaction mode, onlookers can acquire intuitive experience about Human-Robot Interaction and can facilitate their interest in robotics. The experimental scenarios were exhibited during the IROS 2015 and attracted enormous interest of onlookers, which include robotic experts, ordinary residents, high school students, pupils, and so on. In the case of the least affected by external environment, the gesture recognition based teleoperation method can be applied to search and probe tasks in underwater environment. It can also be used for informal education, popular science, entertainment and interactive scenarios.

VI. ACKNOWLEDGMENT

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