Bio-Inspired Robot Launching System for a Mother-Son
Underwater Manipulation Task

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Abstract – To realize an underwater manipulation task, mother-son robot manipulation system is proposed. This paper
focuses on the design of the bio-inspired robot launching system which is for underwater manipulation. We designed the son
robot which is composed by 8 IPMC actuators and an ABS support frame. Due to the complicated structure, 3D printer was
employed to print the support frame. We also designed the launching system which can be fixed on the mother robot for
mother-son cooperation. And a stepped cylindrical shape was adopted to fit the son robot and make the launching and recovery
motion easily. To realize closed-loop control for the launching system and son robot, 3 proximity sensors were employed to
detect the main distance parameters and trigger the launching system. The control circuit and algorithm were proposed to
realize underwater manipulation. Finally, we used an underwater manipulation experiment to verify the feasibility for the
launching system. The experimental results showed that the launching system can realize underwater manipulation
successfully.

Index Terms – Bio-Inspired Robot, launching System, IPMC, Underwater manipulation.

I. INTRODUCTION

The development of robots has proceeded rapidly in recent
decades. So many kinds of underwater robots have been
developed to satisfy different requirement of underwater tasks.
According to control method, underwater robot can be divided
into two categories: ROV and AUV. According to the shape,
underwater robot can be divided into streamline shape and
special shape. The streamline shape is usually used in high
speed underwater robots and special shapes are always used in
remotely-operated vehicle (ROV) to carry out real time
underwater manipulation [1]-[3]. Generally, ROV operations
require an expensive mother ship, considerable deck support,
and special expertise. Moreover, the tether restricts the ROV’s
positioning and manipulation performance [4],[5]. Different
with ROV, AUV appears good performance on flexibility and
maneuverability, because AUVs do not require a tether and
continuous surface support.

In the Pohang University of Science And Technology (POSTECH), Son-Cheol Yu et al has designed and developed
a smart cable to drive an agent vehicle which takes a
manipulator. And the author employs an AUV as the mother
ship [6]. But the author just shows a conceptual design and we
do not know how to launch and recovery the agent vehicle.
Also in POSTECH, Jonghui Han et al focus on motion control
for an underwater vehicle-manipulator system by minimizing
restoring moments and. A nonlinear H∞ optimal control with
disturbance observer is proposed [7]. In the University of
Hawaii, Giacomo Marani et al developed an underwater autonomous manipulation for intervention missions AUVs.
This manipulator is used in a huge semi-AUV: SAUVIM [8].

In our laboratory, we developed a spherical underwater
robot with 3 vectored water-jet thrusters [9]-[14]. Due to the
water-jet thruster and special shape, the robot own low noise
and high flexibility[15]-[22]. We want to employ the robot to
realize underwater exploration, for example, monitoring
underwater creatures in a tight environment and collecting
samples. Because of the spherical shape and compact structure,
the robot is easy to cross dense water plant areas.

In order to realize complex underwater tasks, we employ a
bio-inspired robot as the son robot to carry out underwater
manipulation. The conceptual design of mother-son robot
manipulation system shows in Fig.1.

The paper is organized as follows. The section II
introduced the son robot which is actuated by ionic polymer
metal composite (IPMC). And then, the structure of launching
system is introduced in detail. The section III will introduce
the electrical system and control method for the launching

Fig.1. The conceptual design for mother-son robot manipulation system
system. A verification experiment is presented in section IV. Finally, the conclusions and future work are pointed in section V.

II. THE DESIGN OF THE UNDERWATER MANIPULATION SYSTEM

A. The design of the son-robot

The son robot is used for underwater manipulation. The essential design requirement of this robot is low noise. Therefore, we involve IPMC as the actuator of this bio-inspired robot. IPMC is a kind of smart material, it can generate bending force by adding voltage on the two sides. And the bending force is proportional to the voltage. The conceptual design and prototype shows in Fig.2. To realize grasping motion, we use 8 rectangular IPMC actuator to form a hand. The length-width ratio of the IPMC actuator also decide the output force and the payload. Generally, the bigger the length-width ratio, the smaller the bending force [23]. According to [24] and considering the size of target object, we select the length and width of each actuator is 25×8 mm. Based on the IPMC actuators, the son robot also can realize swimming motion, floating motion. After grasping the target, the IPMC actuators can generate a lot of bubbles, the bubbles will adhere to the actuators and provide buoyancy for the robot.

Because the size of son robot is small and the structure of support frame is complicated, a 3D printer is employed to print the support frame. The material is Acrylonitrile Butadiene Styrene (ABS). Because the density of ABS is 1.05 g/cm³, the robot can sink down freely. And the density of ABS is very close to water, the manipulator can be extended to maximum payload. And another important feature is hydrophobic, it is very suitable for this underwater task. To reduce the effect of underwater environments, this support frame adopts a circular. The maximum size of manipulation target is about 30×30×20mm.

B. Design of the robot launching structure

The launching system is designed to carry the son robot when the robot is in idle mode and launch the robot when the robot is in trigger mode. Considering the shape of son robot, the launching structure is designed as a stepped cylindrical shape. The 4 bars form a normal close door to hold the son robot. A water-proof servo motor is employed to control the door which is shown in Fig.3. 1 and 3 are connected by 7. 1 and 8 are connected by two springs in the axial direction. 1 is a key part to the launching system, when the servo motor is driven to 30 degrees, the sleeve will press the bars to keep the door closed. And when the servo motor is driven to 90 degrees, the servo motor will lift the sleeve, and the bars will turn 90 degrees to open the door. In the wall of 8, there are 4 magnets to provide attraction for the bars, therefore, the bars stick on the wall of stepped cylindrical support. The whole process is a screw motion for the sleeve. Fig.4 shows the open and close state for the launching system. The volume of the stepped cylindrical support is about (76+90)×100/2mm.
III. THE ELECTRICAL SYSTEM

A. Sensors and servo motor

To realize position detection for the son robot and target object, three proximity sensors are used in this research as shown in Fig.3. One is to detect the position of the target object which is fixed on the bottom of the son robot. Other two sensors are used to confirm the position of the son robot in the launching system. One is set in the middle of the stepped cylindrical support which can be used to check that whether the son robot is in the launching structure. Another is set on the bottom of the stepped cylindrical support. This sensor is used to confirm the robot has been launched successfully or not. If the son robot is launched and the third sensor has detected the robot, the robot is launched successfully, or else the son robot is still in the launching system.

Table I

<table>
<thead>
<tr>
<th>Feature</th>
<th>AT 4.8volt</th>
<th>AT 6volt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (°/sec)</td>
<td>0.18 60°</td>
<td>0.15 60°</td>
</tr>
<tr>
<td>Torque (kg·cm)</td>
<td>3.0</td>
<td>3.6</td>
</tr>
<tr>
<td>Weight (g)</td>
<td>28.5</td>
<td>28.5</td>
</tr>
<tr>
<td>Dimensions (mm)</td>
<td>31.0×15.2×31.0</td>
<td>31.0×15.2×31.0</td>
</tr>
</tbody>
</table>

The servo motor is an important actuator for the launching system. The prototype of the servo motor is shown in Fig.6. And the main feature is listed in Table I. The speed of the servo motor is about 0.15sec/60°, and the response time of the launching structure is mainly decided by the servo motor. Therefore, we can get the response time of the door, according to (1).

\[ T = \frac{\phi - \phi_0}{v} \]  

Where T is the response time, \( \phi \) is the target position of the servomotor. \( \phi_0 \) is the initial position of the servo motor. According to section II (b), we can know that, the \( \phi_0 \) is 30 degrees and the \( \phi \) is 90 degrees. And \( v \) is 60/0.15 degree per second. So, we can get T is 0.15s. Of course, this response time is also decided by \( v \). And \( v \) is controlled by the AVR processor. It is that means we can control the speed of the door.
Because the work condition is in water, a rapid open or close motion will cause turbulence. And the son robot is very small and light, it will be affected by turbulence easily.

B. Control circuit

In this research, we use an AVR processor to realize closed-loop control and motion control for son robot. The control circuit shows in Fig.7.

![Fig.7. The control circuit of the launching system](image)

The ATmega16 features a 10-bit successive approximation ADC. The ADC is connected to an 8-channel Analog Multiplexer which allows 8 single-ended voltage inputs. Both of the sampling precision and number of channels are suitable for this task. Three proximity sensors are converted by A/D converter. Furthermore, One of 4 PWM channels is used to control the servo motor. The motion of son robot is also controlled by the AVR processor.

C. Software design

The control algorithm is very important for the underwater tasks. This paper just considers the algorithm for underwater manipulation. The flow chart of underwater manipulation shows in Fig.8. In the initial state, the son robot is idle, and the mother robot cruises in a scheduled course. After finding a target, the mother robot stops at the right above of the target. And then the mother robot will detect the distance between the robot and the target to confirm the distance is smaller than the range of son robot, if not, the mother robot will sink down to a suitable position. After that, the servo motor is driven to open the door and launch the son robot. The son robot detects the distance between the target and proximity sensor 3. Proximity sensor 3 can guide the son robot to approach the target. Because the length of actuators is 25mm and 5mm is for installation, the length of leg is 20mm. If the distance between sensor 3 and target is less than 10mm, it is that means the target has been surrounded by the legs. The processor will drive the actuator to hold the target. After grasping the target, the son robot will float up and go back to the launching system. When the son robot return to the original position, the data of proximity sensor 1 will trigger the servo motor to close the door.

![Fig.8. Flow chart of the underwater manipulation](image)

Note: D is the distance between the mother robot and manipulation target. d1 is the distance between the son robot and the proximity sensor No.1. d2 is the distance between the son robot and proximity sensor No.2. d3 is the distance between the son robot and the target.

The threshold of D is decided by the manipulation range. The threshold of d1 and d2 are decided by the diameter of stepped cylindrical support. If the son robot is not in the upper part, the diameter of the support is 7 cm, the sensor almost has no output. But if the son robot is in the upper part, the output of sensor 1 and sensor 2 is bigger than 5cm, no matter where the son robot is.

IV. THE VERIFICATION EXPERIMENT

To confirm the performance of the launching system, a verification experiment is carried out. The experiment purpose is to test the cooperation between son robot and launching system. We set a target at the bottom of a water tank. And the launching system is set on the top of the tank. The launching system and son robot immerge in water. The launching system detects the target and then the processor calculate the distance between the target and launching system. Finally, the launching system sends the son robot to catch the target. The experimental setup is shown in Fig.9.

The manipulation target is a white cuboid, the size is 25×25×20 mm. Because the proximity sensor is sensitive to white color, the target and the frame of son robot is printed by white ABS.
This experiment has a strict experimental condition which is the manipulation target must be placed under the launching system accurately. This experimental condition depends on the accuracy of mother robot, so we do not discuss this problem in this paper. And the experiment is carried out in still water.

The experimental result shows in Fig.10. The experimental process can be divided into 9 parts. First, the target trigger the processor to open the door and launch the son robot, after launching the son robot successfully, it sinks down to the manipulation target and the son robot is driven by gravity. When the son robot touched the target, the distance between the son robot and the target is about 20mm, and then the son robot catches the target. If the son robot catches the target successfully, the distance between the son robot and the target is less than 10mm. And then the son robot holds the target tightly and generates bubbles to float up. After getting enough bubbles, the robot floats up and goes back to the launching system.

CONCLUSIONS AND FUTURE WORK

This paper presented a launching system for a bio-inspired micro robot. First of all, the conceptual design of mother-son manipulation robot system is presented to realize underwater sampling. For a manipulation task, a hand shape bio-inspired robot which is driven by 8 IPMC actuators is designed. The proximity sensor is employed to trigger the grasping motion. A water proof servo motor is to control the door for the launching system which is controlled by the ATmega16 MCU. The launching structure is designed as a stepped cylindrical shape to fit for the son robot. The control circuit is designed to drive the son robot and the launching system. Grasping motion strategy is proposed to realize underwater manipulation. Finally, an underwater manipulation experiment is carried out to verify the performance of launching system and the experimental result shows that the launching system delivery and receive the son robot successfully.

In the future, we will combine the son robot launching system and spherical mother robot together. To improve the adaptive capacity for complicated underwater environment, hybrid motion is also considered to add on the son robot.

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