Development of a Hydraulic Underwater Manipulator for Deep-Sea Survey AUV

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Abstract

We are developing a group of AUVs whose mission is to capture underwater creatures or acquire in-situ biological samples in the deep sea. The AUV under developing has a hydraulic manipulator to capture the target creature, and sends underwater images that provide biologists (operators) with information to determine which creatures should be targeted and captured during the operation. In this paper, the concept and design of hydraulic actuator for 5-axis manipulator, and the mechanics of manipulator is proposed, and the experimental results of manipulator control at 10 and 20 M Pa pressure are shown.

Keywords: Underwater Manipulator, Hydraulic Actuator, AUV

1. Introduction

New discoveries of mineral resources, energy resources and marine lives in the deep-sea have big potential to give deep impacts on our society. However, we are still unable to get detailed information about the mechanism of ecological system of dep-sea because of special features, high pressure, darkness and radio attenuation. Recently, underwater robots are employed to observe deep-sea floor as useful tools1,2, and they are

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mainly classified as Human Occupied Vehicle (HOV), Remotely Operated Vehicle (ROV) and Autonomous Underwater Vehicle (AUV) depending on the extent of autonomy and mounted facilities. We have been developing a group of AUV systems whose mission is to capture underwater creatures or acquire in-situ biological samples like DNA from various types of creatures in the deep sea. Although the final goal is to get the sample of wide variety of fish and marine creatures, considering the state of the arts of AUVs, our first target is to catch a creature, which moves slowly like a small crab or marine benthos.

The AUV under developing has a hydraulic manipulator to capture the target creature, and sends underwater images that provide biologists (operators) with information to determine which creatures should be targeted and captured during the operation. These images are to be sent from the AUV to the surface support vessel where the biologist are checking monitors to determine his/her desirable target creature and the transmission of image information data is carried out through an ultrasound communication.

The operation is illustrated in Fig.1. There exist a lot of issues to realize underwater sampling AUV such as navigation, control, image processing, actuators, sensory systems. In this paper, we introduce an underwater manipulator for a deep-sea survey and sampling AUV. Firstly, we introduce our project that aims to develop an observation and capturing system of marine creatures using multiple underwater robots composed of cruising and manipulator mounted AUVs. Next, we introduce the concept and design of hydraulic actuator for 5-axis manipulator, and the mechanics of manipulator to change the linear motion to rotational motion using cams, and the experimental results of manipulator control at 10 and 20 M Pa pressure.

![Fig.1 Concept of AUV sampling system](image)

2. Hydraulic Underwater Manipulator

The manipulator is supposed to have minimum 3 degrees of freedom (DOF) in the same plane for positioning (2 DOF) and orientation (1 DOF) of the arm tip, and 1 DOF for open-close of a gripper.

Basic requirements are:
- arm length ~ 600 mm
- payload ~ 0.5 kg (max)
- external pressure 20 MPa (max)

The manipulator should be able to operate in the salty water at neutral buoyancy, and is actuated by a set of stepping motors, ball screws and hydraulic cylinders that generates hydraulic pressure to move cylinders on the manipulator links. In order to convert the linear motion of cylinder into rotation, a special cam mechanism was introduced. The variation of linear motion is 50 mm and converted to 180 degree rotation. The criterion for the cam design is to achieve minimal, possibly small lateral force on the piston rod during the motion.

The problem to minimize lateral force on the piston rod is the same as to orient the hydraulic cylinder in the normal direction to the cam shape. We assume that the cylinders are aligned with the direction of the robotic arm length; therefore, the problem is translated into finding a cam shape \( r(\varphi) \), which satisfies the cylinder direction to be normal to the cam. For this we need to derive the equations that consider the offset angle between the cam shape angle parameter \( \varphi \) and the arm rotation angle \( \theta \), which is cause by the initial offset angle \( \theta_0 \) of the cylinder towards the cam radial direction.
The constraint to the solution here is linear motion of the piston $K\theta$ that is proportional to the rotational angle of the arm $\theta$. The parameters and obtained cam shape are shown in Fig. 2.

The developed manipulator is shown in Fig. 4. The structure is made of MC-nylon and the pressure hull is made aluminum with coating.

![Fig. 4 Underwater manipulator for deep-sea](image)

3. **Experiments in the Pressure Tank**

The experimental results at pressure 10 to 20 MPa in test tank are shown in Fig. 4. Pressure change (increase, decrease) was performed in 12 minutes, and the pressure was kept constant for 12 minutes to do the measurements. During the measurements, each joint was moved separately. Joint angles were measured by RLS 12bit absolute angle magnetic sensor RMD08. A video was also recorded during each measurement. Each main piston of each joint was moved for 4 mm: that is joint angles 23.59 degrees for DOF1, 36.86 degrees for DOF2, and 73.72 degrees for DOF3.

Although hysteresis of about 3 degrees (from 3 to 3.5 degrees) in DOF1, about 3 degrees (2.7 to 3 degrees) in DOF2, and about 9 degrees (8 to 9.5 degrees) in DOF3 can be observed in the results independently of the pressure, the manipulator showed good performance in deep-sea pressure.

4. **Conclusion**

In this paper, the concept and design of hydraulic actuator for 5-axis manipulator, and the mechanics of manipulator is proposed, and the experimental results of manipulator control at 10 and 20 MPa pressure are evaluated. It is shown that the developed manipulator is
enough small to be mounted on AUV, and can be actuated under the deep-sea pressure.

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References


Fig.4 Experimental results in the pressure tank.