2013 10th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI)
October 31-November 2, 2013 / Ramada Plaza Jeju Hotel, Jeju, Korea

# Design and Manufacturing a Robotic Dolphin to increase dynamic performance

Yong-Jai Park[1], Daegeun Park[1] and Kyu-Jin Cho[1]
[1] School of Mechanical and Aerospace Engineering/IAMD, Seoul National University, Seoul, 151-742, Korea
(Tel : +82-2-880-1663; E-mail: kjcho@snu.ac.kr)

***Abstract*** - Robotic fish and dolphin have been studied to increase their dynamic performance, especially the velocity of a robotic dolphin. There are lots of parameters to increase the velocity of the robotic dolphin such as increasing an oscillating frequency, the area of a caudal fin, or the oscillatory amplitude and so on. The efficient and easy way to increase the thrust is to use a compliant caudal fin. Using the flexible caudal fin, the velocity of the robotic dolphin can increase. Furthermore, using a novel variable stiffness mechanism, the stiffness of the caudal fin can be varied depending on an oscillating frequency to maximize the thrust. We introduce the design and manufacturing of a robotic dolphin which has a variable stiffness mechanism.

***Keywords*** – Robotic Dolphin, Thrust Maximization, Variable Stiffness, Robotic Fish, Underwater Robot

## 1. Introduction

The research of underwater robots is more important for exploring underwater environment, finding natural resources and applying for search and rescue mission than previously expected [1], [2]. In order to increase the performance of underwater robots, first of all, the dynamic performance of the robots is most important and it should be a fundamental characteristic of the underwater robot for swimming in the water. To increase the speed of underwater robots, the movement of the fish and aquatic mammal is considered especially dolphin. The speed of the underwater robots should reach a certain level for swimming at the fast moving flow.

To maximize the thrust of a robotic dolphin, flexible characteristic of a caudal fin is considered. For creating a traveling wave naturally, compliant materials are more useful than rigid materials. With rigid materials, large number of links and joints should be needed to create the traveling wave which is an important factor to generate the thrust of a robotic dolphin [3], [4]. Therefore, the dynamic performance of the robotic dolphin increases using a compliant caudal fin. However, the proper stiffness of the caudal fin is needed to maximize the thrust of the robotic fish. Therefore, a simple method has been presented to identify the condition for maximizing the thrust generated by a compliant fin propulsion system [5]. The stiffness of the caudal fin can be varied using a novel variable stiffness mechanism which is inspired by an endoskeleton structure, similar as a vertebral column [6].

In this paper, a design and manufacturing of the robotic dolphin which has a controllable stiffness caudal fin is presented. The goal of the robotic dolphin is to maximize the thrust when it swims at a certain frequency. Depending on the oscillating frequency, the stiffness of the caudal fin should be varied.

## 2. Prototype of Robotic Dolphin

A robotic fish is designed and it is inspired by dolphins. The dolphins swim by vertical oscillation of the fluke and the propulsive part of the dolphin consists of the vertebral column. For verifying the variable stiffness mechanism and the *half-pi phase delay condition*, the prototype of the robotic dolphin is designed and manufactured [5], [6].

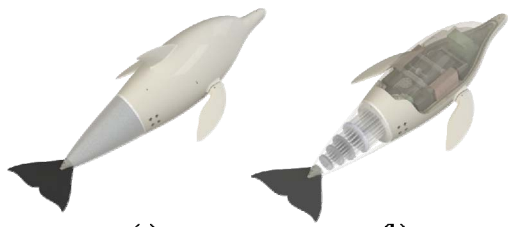


Fig. 1. (a) CAD model of the robotic dolphin, (b) CAD model of the inside of the robotic dolphin.

Total appearance is similar to the dolphin as shown in Fig. 1. Especially, the streamline of the robotic dolphin is considered to reduce drag effect when it swims at a speed. When a peduncle moves actively by tendons in a robotic dolphin, the rest of the part, which is typically a partial part of peduncle and a caudal fin, follows the motion of the driving part. It moves passively. Due to the passive motion, the robotic dolphin can reduce the drag and compensate the thrust due to the spring effect.

The robotic dolphin has three degrees of freedom. One is oscillating motion of the peduncle, the others are rotating motion of the pectoral fins. The pectoral fins were used for maneuvering (pitching and turning). A DC servo motor was chosen to drive the robotic fish, even though the DC servo motor has a limitation in terms of the response time. So, the tail cannot be oscillated over 3 Hz. However, in this prototype, we verify the effect of the variable stiffness mechanism, so the higher frequency condition is not a critical issue. Therefore, the DC servo motor was chosen instead of a DC motor with the Scotch-Yoke mechanism. The specifications of the robotic

978-1-4799-1197-4/13/$31.00 ©2013 IEEE

dolphin are listed in Table 1. For controlling the robotic fish, ARM based chip was used. Main actuator for driving was controlled with the rotating angle of the motor, which varies depending on a sine function.

Table 1 Specification of the robotic dolphin

| | |
|---|---|
| Mass | Approx. 2.3 kg |
| Dimension | 520 mm × 230 mm × 160 mm |
| Actuator for Driving | One Robotis MX106 (8.0 Nm at 11.1V) |
| Actuator for Pectoral fin | Two Hitec HS-7980TH (3.5 Nm at 6.0V) |
| Actuator of Changing Stiffness | One Robotis MX28 (2.3 Nm at 11.1V) |
| Controller | STM32F10x-64 (ARM based) |
| Network | RF 40 MHz |
| Power source | One LiPo 11.1V, One NiMH 4.8V |
| Materials | Polycarbonate, Aluminum, Acrylic Plastic |

Internal structure of a robotic dolphin shows in Figure 2. Outer dolphin form was manufactured using 3D printer in order to increase the compactness of the robotic dolphin. Outer cover was divided into two parts for easily assembling and disassembling the robot. In order to enhance waterproof performance, a silicone membrane was placed between a upper cover and a lower cover and they fasten with bolts. Pectoral fins were also made by 3D printer and they were connected with the Hitec servo motor through a rod. Silicone grease was filled between the rod and the outer cover for enhancing the waterproof performance. Actuation parts were fixed to the outer cover firmly.

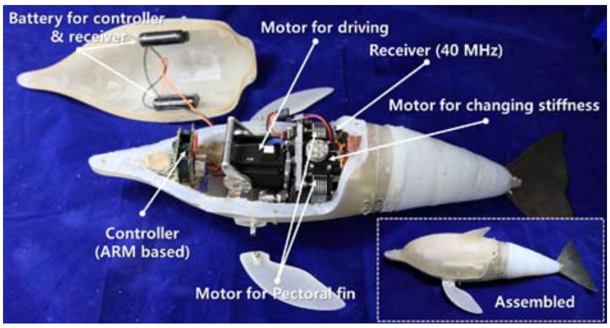


Fig. 2. Internal structure of the robotic dolphin and an assembled robotic dolphin

## 3. Basic Experiment of Robotic Dolphin

The robotic dolphin was tested in a water tank for verifying the effect of the variable stiffness mechanism as shown. When the stiffness of the peduncle increased, the speed of the robotic dolphin increased. The thrust of the robotic dolphin was calculated as:

$$Thrust = Drag\ Force = \frac{1}{2}\rho_w U_{robot}{}^2 C_d A_{ref} \qquad (1)$$

where, $\rho_w$ is the density of water, $U_{robot}$ is the speed of the robotic dolphin, $C_d$ is the drag coefficient of the robotic dolphin, and $A_{ref}$ is reference area of the robotic dolphin. When the robotic dolphin swim at a constant speed, the thrust and the drag force is the same. The Strouhal number was calculated as:

$$St = \frac{fA_{mp}}{U_{robot}} \qquad (2)$$

where, $f$ is the oscillating frequency and $A_{mp}$ is the amplitude of the peduncle. Using the Eq. (1) and (2) the dynamic performance of the robotic dolphin can be verified.


## Acknowledgement

This research was supported by the Converging Research Center Program and the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2009-0082824 and 2009-0087640).


## References


[1] D. T. Roper, S. Sharma, R. Sutton, and P. Culverhouse, "A review of developments towards biologically inspired propulsion systems for autonomous underwater vehicles," *Proc. Inst. Mech. Eng. Part M J. Eng. Marit. Environ.*, vol. 225, no. 2, pp. 77 –96, May 2011.

[2] United States. Naval Meteorology and Oceanography Command and Naval Research Laboratory (U. S.), *Review of autonomous underwater vehicle (AUV) developments*. Stennis Space Center, Miss.□: Naval Oceanographic and Atmospheric Research Laboratory, 2001.

[3] K. H. Low and C. W. Chong, "Parametric study of the swimming performance of a fish robot propelled by a flexible caudal fin," *Bioinspir. Biomim.*, vol. 5, no. 4, p. 046002, Dec. 2010.

[4] P. Valdivia y Alvarado and K. Youcef-Toumi, "Design of Machines With Compliant Bodies for Biomimetic Locomotion in Liquid Environments," *J. Dyn. Syst. Meas. Control*, vol. 128, no. 1, pp. 3–13, Mar. 2006.

[5] Y.-J. Park, U. Jeong, J. Lee, S.-R. Kwon, H.-Y. Kim, and K.-J. Cho, "Kinematic Condition for Maximizing the Thrust of a Robotic Fish Using a Compliant Caudal Fin," *IEEE Trans. Robot.*, vol. 28, no. 6, pp. 1216–1227, 2012.

[6] T. M. Huh, Y.-J. Park, and K.-J. Cho, "Design and analysis of a stiffness adjustable structure using an endoskeleton," *Int. J. Precis. Eng. Manuf.*, vol. 13, no. 7, pp. 1255–1258, 2012.