Development of Bio-mimetic Entertainment Dolphin Robots

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Abstract: - Development of bio-mimetic entertainment dolphin robots that act like real dolphins in terms of autonomous swimming and human-dolphin interactions are introduced. Body structures, sensors and actuators, governing microcontroller boards, swimming and interaction features are described for a typical entertainment dolphin robot. Actions of mouth-opening, tail splash or water blow through a spout hole are the typical responses of interaction when touch sensors on its body detect users' demand. A pair of microphones as the ears of a dolphin robot, in order to improve the entertainment dolphin robot's ability to interact with people, is used to estimate the peak sound directions from surrounding viewers. Dolphin robots should turn towards people who demand to interact with them, while swimming autonomously.

Key-Words: - Entertainment Dolphin Robot, Bio-mimetic, Interaction, Autonomous Dolphin System

1 Introduction

Recently one of the most rapidly growing areas of robot applications is the entertainment sector. Many kinds of toy/entertainment robots have been developed in the robot industry. A large portion of the products has a common feature: mimicry of animals. Several interesting and unique types of robots have been introduced and developed by the influence of bio-mimetics for the recent decades. Particularly, a fishlike underwater robot is one of these categories. Fish in nature move their bodies to generate propulsive power. It is also well known that fish achieve excellent power efficiency and maneuverability that have advantages over conventional propeller-based marine vehicles[1,2].

Our lab introduced a simple fishlike robot in 2005[3], and improved and added new functions in various manners shapes[4-7]. To confirm their effectiveness, our constructed fish robots have been tested in tanks and pools for user interactions as well as collision avoidance, maneuverability, control performance, posture maintenance, path design, and data communication.

In this paper, the development of a dolphin robot as a typical entertainment robot is described. Constructional parts such as body and chassis structures, several types of sensors and actuators, governing microcontroller boards and related interfacing circuits, swimming and interaction features are described as basic modules to construct a dolphin robot. Minimizing the degree of discrepancy compared to real dolphins and maximizing users' satisfaction are the most important two criteria in evaluation of the robot performance.

Actions of mouth-opening, tail splash or water blow through a spout hole are the typical responses of interaction when touch sensors on its body detect users' demand. In order to improve the entertainment dolphin robot's ability to interact with people, a pair of microphones as the ears of a dolphin robot is used to estimate the peak sound directions from surrounding people. The basic requirement for entertainment dolphin robots is the ability of turning towards people who want to interact with them, while swimming autonomously. It is assumed that the basic ways of communication are based on sound such as voice and claps.

It is required for a dolphin robot to swim in a given area naturally avoiding collision against obstacles while displaying its features of interaction when it detects viewers' interests. A dolphin robot uses three microcontrollers to reduce calculation loads for the required functions of motor operations for swimming and collision avoidance, analog sensor data acquisition including temperature and infrared distance sensors, decoding GPS information, counting the time of sonar in ultrasound sensors and directional sensor, and communications.

Functional modules of a dolphin robot are explained in section 2. The overall system for improved movements and interaction features are described in section 3. The experimental results of body movements and roll control are described in section 4, followed by conclusion in section 5.

2 Functional modules of an entertainment dolphin robot

Several building blocks such as body and chassis structures, many types of sensors and actuators, governing microcontroller boards and related interfacing circuits, swimming and interaction features are described as basic modules to construct a dolphin robot. They should be in harmony in capacities as well as in sizes to be a successful model of a real one.

2.1 Body and chassis structures

The sequence of forming outer FRP pieces of shells is as follows.

- 1. Shaping a dolphin model using styrofoam plates
- 2. Cut the model into proper number of pieces
- 3. Cover each piece with gypsum
- 4. Treat gypsum surface to be smooth
- 5. Mold using FRP on gypsum
- 6. Remove gypsum and styrofoam after FRP hardened

Figure 1 shows the results of above steps.

An internal chassis is necessary to connect all pieces into one though they can move horizontally. Also, it is the basic structure on which most of parts and components can be attached and fixed. Figure 2 shows one typical example of chassis connection. The first two joints move horizontally and the last one moves vertically.



(a) Styrofoam model



(b) Gypsum on styrofoam model



(c) FRP mold on gypsum

Fig. 1. Pieces of FRP shells of a dolphin robot



Fig. 2. Aluminum chassis of a dolphin robot

2.2 Sensors and actuators

There are several types of sensors and actuators attached on the robot's body or on the internal chassis as follows.

- IR distance sensors: measure nearby objects
- Laser ranger finders: measure medium to long range objects
- A direction sensor: measures direction using e-compass

- Acceleration sensors: measure force and inclination or detect collision to obstacles
- Four RC servo motors: moves three body joints and one for mouth opening
- Water pumps: propulsion, direction changes and water blowing

Also, there are several signal processing units which are water-proof by itself or kept in a water-proof box. A GPS receiver is used for navigation in a large area. A USN mote is installed for communication between pre-installed motes at known locations for exact localization. A Bluetooth unit is used for communication between a server PC. A Vernier LabPro water quality sensor board that has four sensor tips resides inside for pollution monitoring applications.

Table 1.	. Specification	of a laser	range finder
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Items of DISTO Pro ⁴ a	Specification	
Measurement range	0.3-100mm	
Resolution	1mm	
Maximum error	±2mm	
Measurement time	0.5–4sec	
Laser wavelength	635nm	
Weight	440g	
Dimensions	1818*70*47mm	
Communication port	RS-232C	
Baud rate	19200bps	



Fig. 3 Laser range finders

2.3 Microcontrollers

A dolphin robot has three microcontrollers, MSP430f140 by TI, to reduce the load of processing data. Also, multiple controllers are used due to ADC channel limits as the number of analog signals increases.



Fig. 4. Microcontrollers for a dolphin robot

The main microcontroller in Figure 5 reads data from several sensors: 1) reading data from potentiometers, ADXL accelerometers, temperature and IR sensors through ADC ports, 2) reading directional sensor to obtain directional information, and 3) communicating with a server using bidirectional Bluetooth modules to send commands or to get various data. Also, it sends commands for the control of several pumps by producing independent PWM signals to generate necessary actuating patterns: propulsion, waist control, roll control, mouth opening, water blow and tail movement.

The second microcontroller receives positional information from the GPS module and decodes data portion only for time, latitude, longitude, and GPS quality indicator from GPS data in GPGGA sentences by NMEA 0183 protocol. Also, it receives distance data from three laser range finders to the front, left and right sides. This microcontroller is also connected to a USN mote for sonar localization to get more precise positional information compared with the GPS-based method in specific and small areas.



Fig 5. Flowchart for main microprocessor



Fig 6. Flowchart for the second microprocessor

The third microcontroller is reserved for other applications such as water pollution monitoring and

ubiquitous sensor networks(USN) solutions. It communicates with the Vernier LabPro sensor board which has connections with four different sensor tips water quality monitoring. This microcontroller is also connected to a USN mote for sonar localization to get more precise positional information compared with the GPS-based method in specific and small areas.

The main microcontroller sends measured data to a server by Bluetooth modules. The server relays the information on the Internet by Ethernet modules. Therefore, any user can access all information on the Internet whenever the data are required.



Fig 7. Flowchart for dolphin robot system

2.4 Stereo microphone system

A pair of microphones as the ears of a dolphin robot is used to estimate the peak sound directions from surrounding viewers in order to improve the entertainment dolphin robot's ability to interact with people. While swimming autonomously entertainment dolphin robots should turn towards people who want to interact with them. It is assumed that the basic ways of communication are based on sound such as voice and claps.

A simple sound source localization method employing only microphones is used due to the restriction of computation time and resources in a dolphin robot system. A pair of left and right microphones is located to form the binaural ears of a dolphin robot. Also, a pair of microphones looking forward and backward, which is hidden at the head of the robot, can distinguish sound directions from either the front or the tail.



Fig. 8. Stereo microphone unit

Since the magnitudes of the measured microphone signals decrease as the difference between directions of the microphone and sounds increases, the magnitudes of the left and right signals of microphones are compared to find the sound direction relative to the robot's body line. The same rule applies to the second pair of microphones to determine the sound direction relative to the front.

Figure 8 shows a circuit diagram of a pair of stereo microphone system and its microcontroller interface.

2.5 Responses of interaction

An entertainment dolphin robot shows a few features in order to improve the robot's ability to interact with people other than the turning feature towards people who want to interact with them by detecting sound directions. Typical ones when touch sensors on its body detect users' demands are as follows:

- mouth opening/close
- tail splash
- water blow through a spout hole

As yet, much more powerful motors are necessary to mimic the features of real dolphins.

3 Construction of an entertainment dolphin robot

A set of water pumps inside its chassis frame is used for the main propulsion and direction changes of a dolphin robot. The propulsion unit is shown in Figure 9.



Fig. 9. Propulsion and direction control unit

The horizontal direction changes can be made by changing PWM ratios of the left or right set of pumps. When it turns to right, the set of left-side pumps has higher ratios compared to that of the right-side ones. Exactly the same method is used for minor depth control. When it goes down, the set of downward pumps has increased PWM ratios and the set of upward pumps stops its operation. The relative angles of the nozzles of water pumps are determined empirically to obtain the optimal results of the direction changes.

When direction changes are necessary in cases such as obstacle detection and avoidance, body and fin turns of the robot as well as proper pump operations determine the performance of swim patterns. Artificial muscle units consists of waters pumps and bellows proposed in [8] are applied in the actions of body turns of dolphin robots instead of conventional uses of motors and links. The artificial muscle unit is shown in Figure 10. Since dolphin robots try to mimic the patterns of behaviours of real animals, it is natural for actuators of robots to adopt the actuating mechanism and patterns of real muscle fibres.

The developed overall shape of dolphin robot's body which has four segments, fins and a tail is shown in Figure 11 without its skin.

Since an entertainment dolphin robot's actions of mouth-opening, tail splash or water blow through a spout hole are common expectations to most of viewers, they should be performed in exciting manners. However, they are quite easy tasks to be provided by a dolphin robot since the actions can be performed by using conventional motors or water pumps when the viewers' needs are sensed by a robot.





(a) Overall experimental setup





(b) Joint with artificial muscles (top view)



(c) Joint with bellows (side view) Fig. 10 Artificial muscle unit



Fig. 11. Dolphin robot without its skin

Item	Specification
Length	160Cm
Width (except pectoral fin)	28Cm
Height (except dorsal fin)	35Cm
Weight	30Kg
Minimum turning radius	2.5m
Main actuator (4 water pumps)	14 litre/min

Table 2. Specification of a dolphin robot

It is logical to assume that the viewers' basic ways of communication with entertainment robots are based on sound such as voice and claps since common guests have no special tools that sends commands to robots. Therefore, in order to improve the entertainment robot's ability to interact with people, a pair of microphones as the ears of a dolphin robot is used to estimate the peak sound directions from surrounding watchers. Entertainment dolphin robots should turn towards people who want to interact with them, while

swimming autonomously. A stereo microphone unit is shown in Figure 12.



Fig. 12. Stereo microphone unit

Figure 13 shows the results of an algorithm[7] for the estimation of the sound direction using only the side pair of microphones on the head of a dolphin robot. Since the magnitudes of the measured microphone signals decrease as the difference between directions of the microphone and sounds increases, the magnitudes of the left and right signals of microphones are compared to find the sound direction relative to the robot's body line. The same rule applies to the second pair of microphones to determine the sound direction relative to the front. It reveals a quite linear relationship between the sound direction and the calculated values based on the measured left and right microphone raw data. Based on this estimation, an entertainment robot can turn towards the direction of sound sources where people who want to interact with them exist.



Fig. 13. Estimation of sound direction

4 Experimental results of swim performance

The experimental results of body movements and roll control are described in this section.

4.1 Waist control for direction changes

It is required for a dolphin robot to swim in a given area naturally avoiding collision against obstacles while displaying its features of interaction when it detects viewers' interests. When direction changes are necessary such as the cases of detecting obstacles, a new destination is given or a viewer's attention is called, a set of water pumps control the waist angle so that the required direction can be achieved. The waist angle is measured by a potentiometer and the swim direction is measured through GPS data. The algorithm of the angle control routine is as follows.



(b) Step response with oscillation (three muscle units, additional weight: 2Kg) Fig. 14. Responses of direction changes

Figure 14 shows a typical result of the waist angle change during a cycle. The rotation ranges are given symmetrically as $-15^{\circ} \sim +15^{\circ}$ in degrees. The rise time from 10% to 90% of the given range is about 0.8 sec. Which changes depending on the number of water pumps.

4.2 Roll control

When a robot makes direction changes while swimming, the upper and lower parts of its body are flexed. Then, the roll action of the whole body appears due to its weight shift. Therefore, it is necessary to compensate the weight shift by a matching floating force which is made by moving air to either side of two bellows. When air flows into bellows at the right side of the body, a certain amount of floating force depending on the air flow appears at the right side. When the weight shift and floating force are cancelled out, a dolphin robot can maintain its balance even when it makes turns.



Fig. 15. Schematic diagram for roll control

Fig. 15 shows a schematic diagram of the control system for roll angle balance. An accelerometer chip ADXL is used to measure roll angles for a control loop. The closed-loop feedback control is described in the flowchart of Fig. 16. Also, typical roll angle responses are shown in Fig. 17 where the effects of weight shifts are cancelled out to keep body balance.

```
Roll angle control routine.

Start

While {

Input R(roll angle value).

If R>reference value, then operate air

pump counter clockwise.

Else if R<reference value, then operate

air pump clockwise.

Else if R=reference value, then stop

water pump.
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Fig. 16. Algorithm and flowchart of roll angle control



(b) Control response of roll balance for a cycle Fig. 17. Typical responses of roll balance

4.3 Autonomous swim performance

The performance of a bio-mimetic robot has been evaluated by the measure of closeness between the actual swim trajectories and reference ones. The muscle units replace conventional motor actuators. When direction changes are necessary, for example, a muscle unit can change the directions of a tail fin or its lower body just like real muscle does. The sequences of obstacle sensing and actuator commands for an autonomous swim are shown in flowcharts in Fig. 18.



(a) Flowchart of main processor for a dolphin robot



(b) Flowchart of sub processor for a dolphin robot Fig. 18 Flowchart of DSP for a dolphin robot Experiments of autonomous swim and balance control are done in a fountain on campus as shown in Fig. 19.



Fig. 19 Field test of a dolphin robot

5 Conclusions

We introduce an entertainment dolphin robot that acts like a dolphin in terms of autonomous swimming and human-dolphin interactions. Minimizing the degree of discrepancy compared to real dolphins and maximizing users' satisfaction are the most important two criteria in evaluation of the robot performance. In this respect, integration of several parts such as body sensors and actuators, governing structures. microcontroller boards, swimming and interaction features are described for a typical entertainment dolphin robot. Actions of mouth-opening, tail splash or water blow through a spout hole are the typical responses of interaction when touch sensors on its body detect users' demand. A pair of microphones as the ears of a dolphin robot, in order to improve the entertainment dolphin robot's ability to interact with people, is used to estimate sound directions from

surrounding viewers. Dolphin robots successfully turn towards people who demand to interact with them, while swimming autonomously.

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