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Implementation of a distributed Control System for Autonomous Underwater Vehicle with VARIVEC Propeller

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Abstract

This paper presents the development of a control architecture for the autonomous underwater vehicle (AUV) with VARIVEC (variable vector) propeller. Moreover this paper also describes the new technique of controlling the servomotors using the Field Programmable Gate Array (FPGA). The AUVs are being currently used for various work assignments. For the daily measuring task, conventional AUV are too large and too heavy. A small AUV will be necessary for efficient exploration and investigation of a wide range of a sea. AUVs are in the phase of research and development at present and there are still many problems to be solved such as power resources and underwater data transmission. Further, another important task is to make them smaller and lighter for excellent maneuverability and low power. Our goal is to develop a compact and light AUV having the intelligent capabilities. We employed the VARIVEC propeller system utilizing the radio control helicopter elements, which are swash plate and DC servomotors. The VARIVEC propeller can generate six components including thrust, lateral force and moment by changing periodically the blade angle of the propeller during one revolution. It is possible to reduce the number of propellers, mechanism and hence power sources. Our control tests were carried out in an anechoic tank which suppress the reflecting effects of the wall surface. We tested the developed AUV with required performance. Experimental results indicate the effectiveness of our approach. Control of VARIVEC propeller was realized without any difficulty.

1. Introduction

Recently, the development in underwater robotics is aimed at providing solutions to the problems of environment, scientific and fisheries in the coastal ocean. During the last few years the use of AUV has rapidly increased, since such a vehicle can be operated in the deeper and riskier areas in which divers can not reach. The AUVs are being currently used for various work assignments [1-2]. However we are primarily concerned with daily marine environmental measurements in the closed sea areas For the daily measuring task, conventional AUV are too large and too heavy. Usually underwater vehicles are equipped with many thrusters. The thruster control mechanism is complicated and this takes a larger weight ratio, making the AUV larger and heavier. Our goal is to develop a compact and light AUV having intelligent capabilities. In this paper, we describe the development of an AUV with VARIVEC propeller [3-4] and its distributed control system, which is capable of performing several challenging, functions. We employed the VARIVEC propeller system utilizing the radio control helicopter elements, which are swash plate and DC servomotors. It is possible to reduce the number of propellers, mechanism and hence power sources. Our control tests were carried out in an anechoic tank. Experimental results indicate the effectiveness of our approach.

2. System Configuration

In this AUV system, we have implemented four modules, which includes:

(1) Acoustic transmitter control module.
(2) Acoustic receiver control module
(3) Data acquisition control module
(4) VARIVEC propeller control module

Each module utilizes one-chip microprocessor (Z84C015) for the distributed vehicle control system. The computer on the support vessel, which is modulated by Frequency Shift Keying (FSK) method, generates control signal command and then it is amplified and transmitted as an ultrasonic wave to the underwater vehicle. Microprocessor on underwater vehicle makes a decision about the control signal received, and depending upon it, generates the necessary control data for the FPGA, a sophisticated logic circuit, which in turns produces the PWM pulse to rotate the servomotors and hence control the VARIVEC propellers. Table 1 shows the dimensions of the underwater vehicle and the principal particulars of the VARVEC propeller. Developed AUV is shown in Fig.1 and block diagram of system configuration is shown in Fig. 2.

Underwater Vehicle		VARIVEC Propeller	
Over all Length	865 (mm)	Diameter	210 (mm)
Over all Width	350 (mm)	Propeller Extended Area Ratio	0.293
Overt all Height	520 (mm)	Boss Ratio	0.476
Dry Weight	75 (kg)	Blade Number	4
Operational Depth	50 m (max.)	Rake Angle	0

Table 1. Dimensions and principal particulars of underwater vehicle

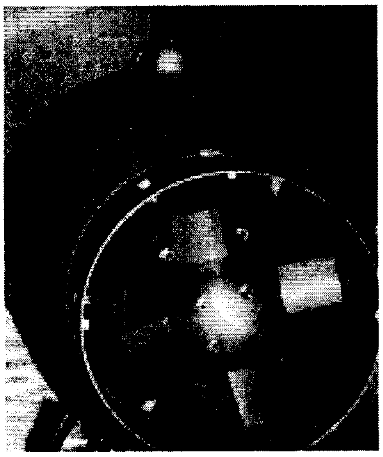


Fig. 1 Photograph of the AUV

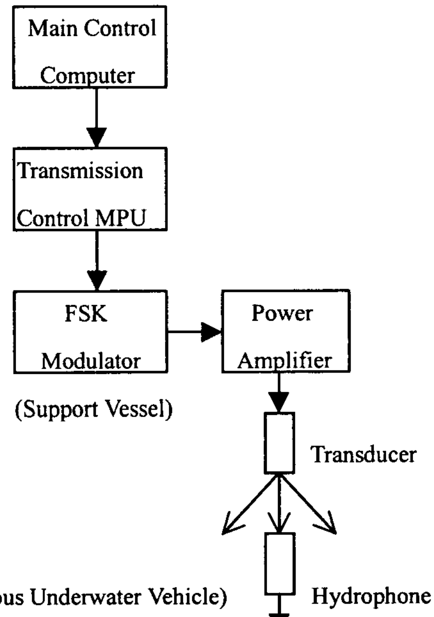
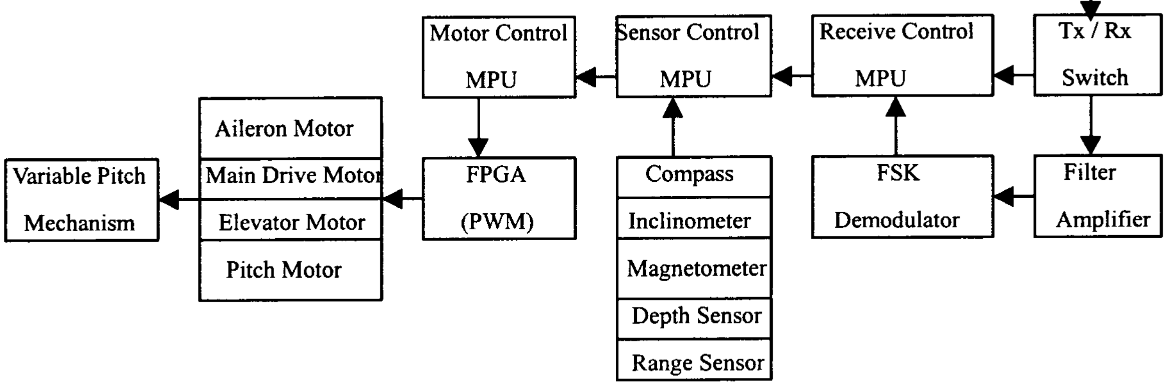
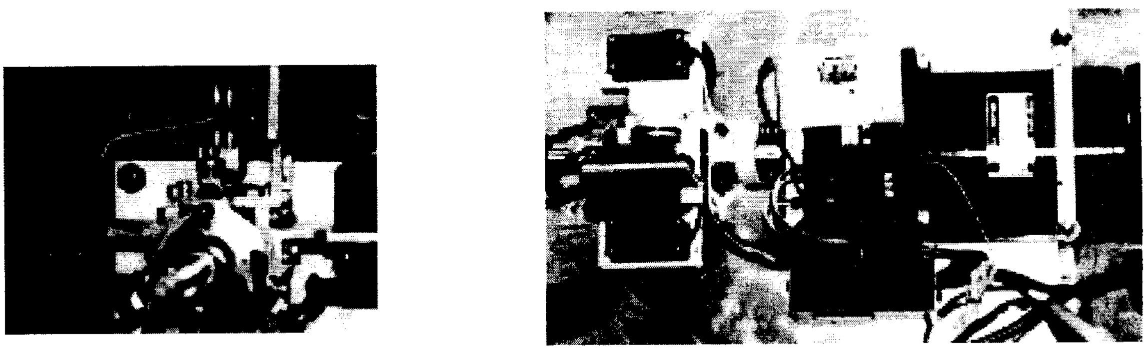



Fig. 2 Block diagram of System Configuration

3. Propulsion System

Usually, underwater vehicles are equipped with many thrusters to move forward or backward, upward or downward, rightward or leftward, or a combination of them, for three-dimensional maneuvering. In our research we have employed VARIVEC propeller as a propulsion system for the underwater vehicle. The advantage reason for using the VARIVEC propellers lies in their compactness, and in their capability to generate thrust and moment continuously in any of three-dimensional directions by controlling the collective pitch, cyclic pitch and combination of both. Moreover they have a fast response to the slightest position change of underwater vehicle. Mechanical realization of VARIVEC propeller system is very difficult to achieve. To solve this problem, we have used the mechanical assembly links and servomotors elements generally used in radio controlled helicopters. This approach has enabled us to build a very compact and effective mechanical mechanism, which is distinctly different from the present techniques being used. In our system, VARIVEC propeller is assembled to swash plate, which is linked to aileron motion, elevator motion and pitch motion control servomotors. There is another servomotor for the control of main drive motor. The FPGA chip controls the servomotors for VARIVEC propeller motion. Pulse Width Modulation (PWM) technique is used for control of servomotors. FPGA is generating the PWM pulses. Servomotors for their operation need a trigger pulse at intervals of about 14.2 milliseconds. Depending upon the width of the PWM pulse, servomotors rotate in clockwise or counter clockwise direction, controlling the movement of the blades of VARIVEC propellers. Main drive servomotor also operates on the same principle. If the pulse width is wide, it rotates slowly, and if it is narrow, it speeds up. The photograph of mechanical assembly of linkage between VARIVEC propeller and DC servomotors are shown in Fig. 3.



(a) Front view (b) Top view

Fig. 3 Photograph of mechanical assembly linkage

4. Experiments

(1)Free-running test

To evaluate the developed AUV system, we have conducted tests in an anechoic tank. For control of the vehicle, we have used one-chip microprocessor for the acoustic communication. The computer on the platform generates the control command signal, the signal is modulated by FSK, having a baud rate of 75bps. To increase the reliability of the acoustic communication system, we send command signal 5 times, and if the microprocessor on the underwater vehicle judges that the same command signal has been received more than 3 times, then it generates the necessary data for the FPGA to control the VARIVEC propeller. We have also taken the compass data, clinometer data, magnetometer data, and temperature data by using the electronic compass sensor (TCM2-50 Precision Navigation Inc), to evaluate the vehicle motion characteristics.

(2)Hydrodynamic characteristics of AUV

We have measured the hydrodynamic characteristics of our AUV by using circulating water channels with 0.15m/sec flow.

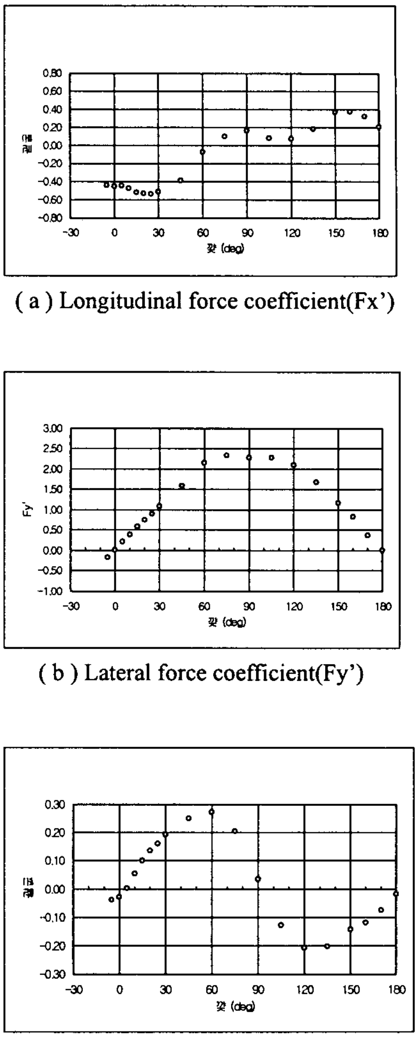
We have done the oblique towing test and propeller test. Measured data consist of the force on x-axis component (Fx), y-axis component (Fy) and moment of Z-axis (Mz). The data are evaluated by dimensionless form. Each coefficients are longitudinal force coefficient (Fx'), lateral force coefficient (Fy') and moment (Mz') respectively.

5. Experimental Results and Discussion

(1) For the control of AUV, we have used the acoustic communication system based on the algorithm, which achieves the satisfactorily results more than 90 percent of times, for vehicle moving forward or backward, turning left or right, or while submerging or surfacing. The communication error is rarely caused by the multi-path reflections of ultrasonic waves. The anechoic tank didn't mount the sound-absorbing rubbers in half area.

(2) We have acquired the azimuth data of rotating at spot by the use of electronic compass sensor, for confirming its ability to keep its position at some particular spot. We have also obtained the pitch and roll data by the use of above mentioned sensor. Since for now, we have conducted our tests in a tank, there was not so pitch or roll of the vehicle. Vehicle moved with great stability and according to the control command signals.

(3) Experimental results of oblique towing test are shown in Fig.4. The AUV motions with variable vector propeller approach to that of general one. The differences of characteristics are depended on the asymmetry of AUV shape. The results are conformed to the desired characteristics for control methods of variable vector propeller.



(a) Longitudinal force coefficient(Fx')

(b) Lateral force coefficient(Fy')

(c) Moment(Mz')

Fig.4 Experimental results of oblique towing test

6. Conclusion

We developed a compact AUV by employing VARIVEC propeller with distributed control system and sophisticated logic circuits. Experimental results indicated the effectiveness of our approach. Future works are measurement of the AUV performance in order to analyze in detail.

Acknowledgements

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