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Dynamics and Control of a Towed Vehicle in Transient Mode

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ABSTRACT

The dynamics and control of a towed vehicle when it changes depth and course were studied theoretically and experimentally. A mathematical model of motions of the vehicle is described in 6-degree-freedom motion equations and that of the towing cable is done using the lumped mass model. Control systems based on an optimal control theory (LQI synthesis) were developed to control the vehicle safely during the depth change. In the course change experiment the PID controller was used. The performance of the controller and the accuracy of the mathematical model of motions have been evaluated by field experiments. The towing tension was also measured in field experiments to confirm the safety of the towing cable.

INTRODUCTION

A towed vehicle system is very useful for obtaining the horizontal distribution of ocean features such as salinity and temperature. A vertical profile is also important for the study of the ocean-atmosphere interaction. To obtain the vertical profiles of physical and chemical properties over a broad area of the sea, the depth of the vehicle must change automatically for efficient observation. Even with steady towing at a constant depth the mother ship must often change course rapidly — for example, to avoid collision with another ship — and then return to the observation line. An ocean observation usually continues for several days, and it is hard for the operator of the towed vehicle system to have to strain to concentrate throughout the experimental term. A reliable motion control system of a towed vehicle is therefore needed. Sometimes the vehicle is required to go very close to the sea surface or to the bottom to investigate the physical and chemical properties in the boundary layer. An overshoot in depth control is dangerous in this case because it results in the vehicle emerging from the water or colliding with the sea bottom. The accuracy of the control system should thus be very high. Stability of a towed vehicle system has been studied in the past, but control accuracy has not been researched. In this paper the dynamics and control system of the towed vehicle were studied to develop a more accurate control method.

CONCEPTUAL VIEW OF FLYING FISH SYSTEM

The principal features of the Flying Fish system and towing cable are given in Table 1, and Fig. 1 shows a vertical view of the vehicle. The sensors for the conductivity, temperature, depth, dissolved oxygen, turbidity, chlorophyll, pH and acoustic Doppler current profiler are contained in each small pressure vessel. The large pressure vessel contains the CO_2 analyzer and its support system. The roll-sensor, pitch-sensor and telemeter system are also housed in the large pressure vessel. The vehicle has a large main wing and 2 horizontal wings to control depth, pitch and roll. These wings are actuated by brushless DC servo motors with a rack-pinion and timing-belt mechanism.

The strength member of the towing cable is Kevlar, which has a breaking strength of 9 tons. The towing cable is jacketed with

Flying Fish	
Operating depth	0~200m
Dimensions(L×B×H)	3.84m×2.26m×1.40m
Weight in air	1300kg
Weight in water	-20kg
Instrumentation	ADCP, CO_2, CTD, DO Turbidity, PH, Chlorophyll
Towing velocity	0~12knot
Motion control	Heave, Pitch, Roll
Towing Cable	
Length	400m
Diameter	22.5mm
Weight/m in water	0.063kg
Strength member	Kevlar
Lines	One pair power line Ten signal lines

Table 1 Principal features of Flying Fish

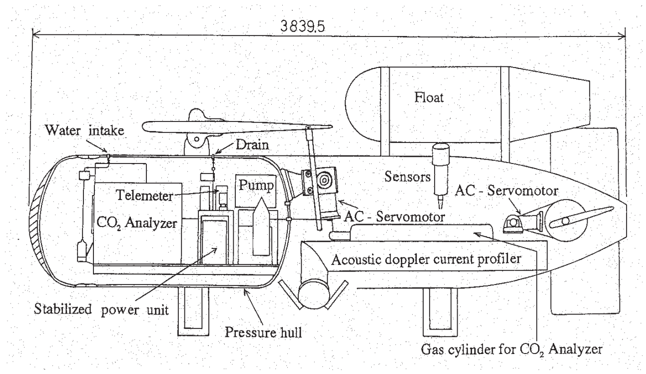

Fig. 1 Vertical profile of Flying Fish

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KEY WORDS: Towed vehicle, dynamics, unsteady motion.