ZESZYTY NAUKOWE AKADEMII MARYNARKI WOJENNEJ
ROK XLIX NR 4 (175) 2008

Piotr Szymak
Polish Naval Academy

STRATEGY TO STEER OF UNDERWATER VEHICLE WITH TORPEDO-SHAPED BODY IN ENVIRONMENT WITH AFFECTING SEA CURRENTS

ABSTRACT

Steering of an underwater vehicle below surface of water is exposed to disturbances of its movement. Affecting sea currents are the main disturbance in an underwater environment. Another difficulty in this kind of operations is nonlinear dynamics of controlled object, especially in the case of its torpedo-shaped body. In the paper automatic control system of underwater vehicle 'Gluptak' has been presented, which can interact sea current influence in the case of lack of sea current measurement on the board of controlled object. Moreover two strategies of steering and selected results of numerical research have been inserted.

INTRODUCTION

The latest Polish implementation of the military underwater technology is Self-propelled Mine Counter Charge SMCC 'Głuptak'. It was designed in Underwater Technology Department from Gdańsk University Of Technology. It is a disposable, remotely operated and powered from board. It has shape like a torpedo. It carries mine disposal equipment to detected and classified target, which is usually an underwater mine [2].

SMCC 'Gluptak' has specific propulsion system, consisting of: four, 3 blade screw propellers in horizontal plane and single 3 blade screw propeller in a tunnel in vertical plane. Each thruster is electrically driven and has 50 W power. This propulsion system enables underwater vehicle to move in water with maximal speed 3 m/s and allows to control SMCC's movement in 4 degrees of freedom (2 translations motions: in longitudinal axis of symmetry x_o and vertical axis of symmetry z_o, and 2 rotations around lateral axis of symmetry y_o and around z_o axis).

Unfortunately underwater vehicle 'Gluptak' has not equipment on its board to measure parameters of sea current such as velocity and direction of affecting. Therefore control methods, which allow to counteract sea current in an underwater environment, were designed and examined. Selected results of their action in form of diagrams have been presented in the further part of the paper. In the next paragraph designed steering system has been described.

STEERING SYSTEM

Presented automatic steering system of underwater vehicle ‘Gluptak’ consists of:

— supervisory control unit, which is responsible for setting values of movement’s parameters, turning on and off individual controllers at proper moments;
— four controllers of: course, trim, translation and draught, which are generating adequate control signal (fig. 1).

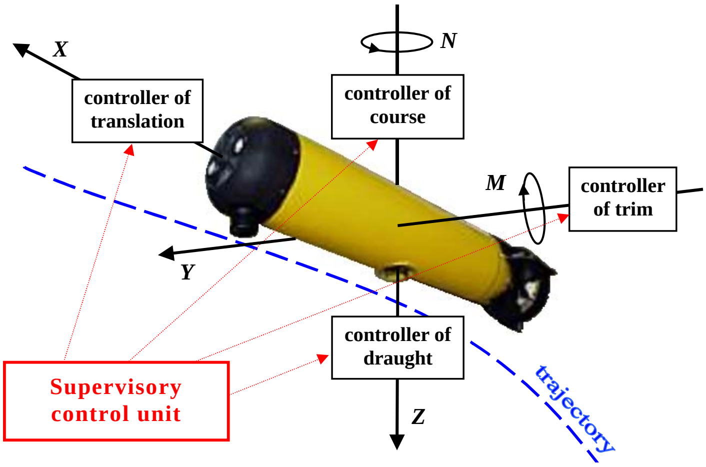

Fig. 1. Automatic steering system of underwater vehicle ‘Gluptak’

Because of almost 10 times bigger hydrodynamic damping in y_o and z_o axis than in x_o axis and about 4 times bigger thrust in x_o axis than in z_o axis, draught’s controller is useless in practise.

For the sake of lack of information about sea current influencing on underwater vehicle, it has been assumed that SMCC should approach to its aim with constant velocity 0,5 m/s. Therefore controller of translation controls translational velocity relative to a target of mission. Value of the velocity is obtained from underwater trackpoint system, which is used to navigate below surface of water.

For the purpose of movement in x_o axis steering classical proportional-derivative-integral action controller PID has been used, while for the aim of course and trim control proportional-derivative action controllers based on fuzzy data processing FPD have been used [3, 4].

STRATEGIES OF STEERING

During steering of underwater vehicle ‘Gluptak’, following factors should be taken into consideration:

- torpedo-shaped body, where the only efficient direction of moving is translational movement in x_o axis, because of almost 10 times bigger hydrodynamic damping in y_o and z_o axis than in x_o axis;
- potential possibility of control in 4 degrees of freedom reduced to 3 degrees of freedom (proper draught should be carried out by adequate trim and forward movement);
- specific construction of control cable called umbilical cord in form of thin optical waveguide unrolling from spool.

Automatic steering of movement of an underwater vehicle is usually based on moving along desired trajectory consisting of line segments connected by waypoints. In this case underwater vehicle moves forward along line close to straight line and its cable unrolls backwards, what will prevent eventual damages of cable by underwater vehicle's thrusters.

In the case of sea current action, effect of an underwater vehicle's pushing aside could be observed. When SMCC is equipped with sea current measuring device, there is no problem to interact. In this case contrary thrust should be calculated, which will take into consideration direction and velocity of sea current.

In the case of lack of sea current measurement on the board of SMCC correction of set value of controlled variables should be executed. For the purpose of interacting sea current two control methods have been developed:

- continuous updating of set value of controlled variable (if an underwater vehicle is pushed aside by sea current, then new set value of controlled variable is calculated);
- correction of set value of controlled variable on the base of bearing (after achieving set values of controlled variable bearing in horizontal or in vertical surface is calculated; changes of bearing in time indicate sea current action, what gives possibility to correct set value of controlled variable).

Second correction method was based on simple equation:

$$p_n = p_{n-1} + k_b \cdot \Delta b_n \,. \qquad (1)$$

Here p_n is a set value of controlled variable in n instant of time, p_{n-1} is a set value of controlled variable in n-1 instant of time, k_b is a gain factor and Δb_n is an error of bearing in n instant of time.

RESULTS OF NUMERICAL RESEARCHES

Numerical researches were carried out in the Windows/Matlab environment. Simulation was executed with influence of sea current with following parameters: specified velocity V_c and direction of affecting α_c.

For the purpose of 'Gluptak' movement simulation, non-linear model in six degree of freedom has been accepted [1]. Moreover following assumptions have been accepted: controlled object has 3 planes of symmetry, it moves with small speed in a viscous liquid and an origin of its movable coordinate system covers with vehicle's centre of gravity. For the aim of control methods' evaluation following indexes were applied:

— maximum deviation of trajectory d_{max} defined as the biggest value of trajectory's deviation;
— average deviation of trajectory d_{avg} defined in a form of:

$$d_{avg} = \frac{1}{k}\sum_{i=1}^{k}\left|d_i\right|. \tag{2}$$

Here $i = 1, 2, ..., k$ is a number of simulation step and d_i is a deviation of trajectory in i discrete time of simulation. Deviation d_i was calculated as the smallest distance from position of an underwater vehicle in i dis.crete time to the desired trajectory.

Selected results of executed researches in a form of motion diagrams in vertical plane have been inserted in fig. 2. Affecting of sea currents have been described with the aid of red arrows. Task of the underwater vehicle was to move from waypoint (0,0) to waypoint (40,40) with initial value of course equal to 0°.

As it can be observed, even in an underwater environment without sea current correction of set value of controlled variable is needed (fig. 2 a & b).

Comparison of two control methods has been executed in the presence of affecting sea currents from different directions (fig. 2 c, d, e, f). As it can be observed second method (correction of set value of controlled variable on the base of bearing) is better than the first one (continuous updating of set value of controlled variable). Using of added bearing signal gives possibility to move along trajectory closer to straight line, especially in the case the sea current acts on the underwater vehicle with more strength (table 1).

Table 1. Evaluation indexes of trajectory's deviation for automatic steered underwater vehicle 'Gluptak' in an environment with different sea currents

Control methods	**Parameters of sea current**	**d_{max} [m]**	**d_{avg} [m]**
without correction	V_c = 0 m/s	2,084	1,988
continuous updating of set value of controlled variable	V_c = 0 m/s	1,932	0,951
	V_c = 1 m/s, α_c = 60°	8,498	5,315
	V_c = 1 m/s, α_c = 90°	20,54	13,29
correction of set value of controlled variable on the base of bearing	V_c = 1 m/s, α_c = 60°	9,217	4,823
	V_c = 1 m/s, α_c = 90°	16,11	8,306

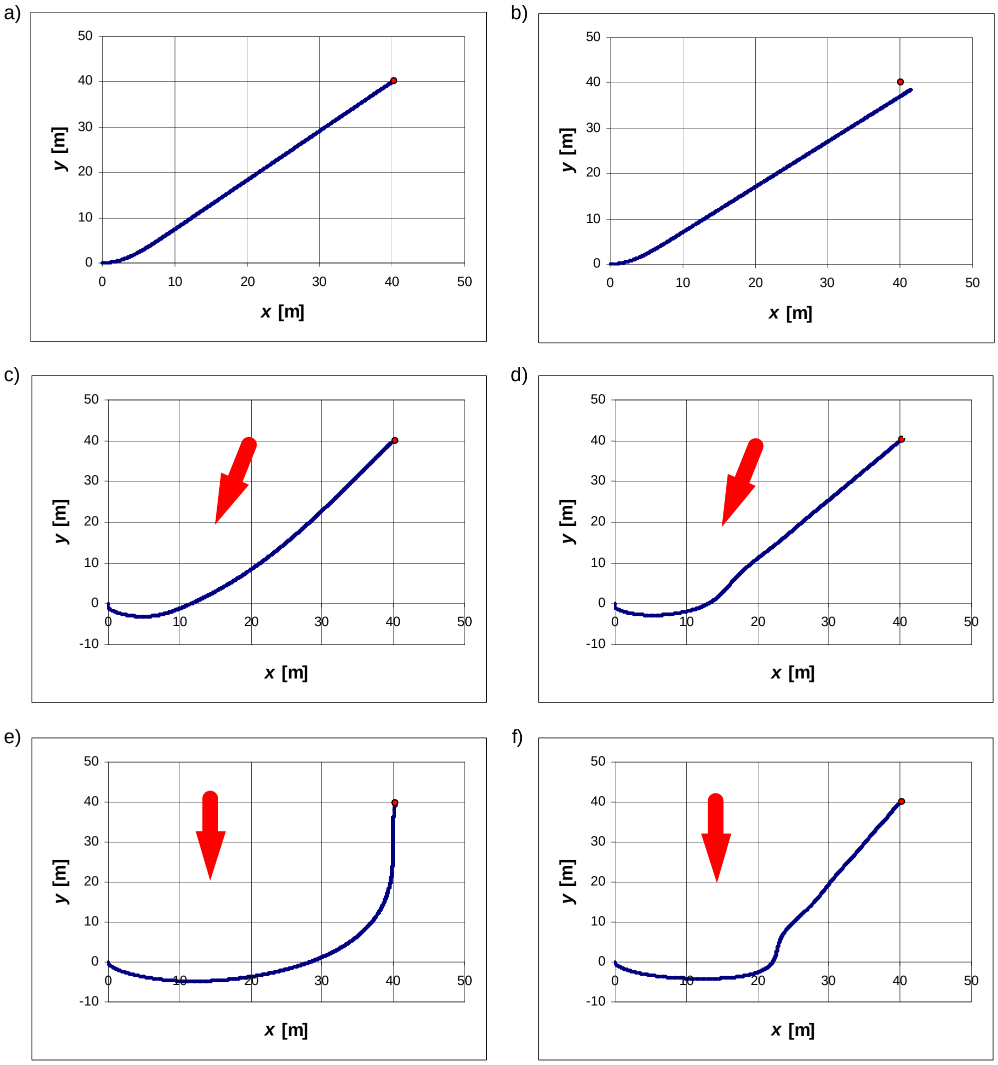

Fig. 2. Automatic steering of SMCC 'Gluptak' to a waypoint of trajectory on horizontal surface with using of following methods: a), c), e) continuous updating of set value; d), f) correction of set value on the base of bearing; b) without correction method; in environment with affecting sea current: c), d) $V_c = 1$ m/s, $\alpha_c = 60°$; e), f) $V_c = 1$m/s, $\alpha_c = 90°$

CONCLUSIONS

In general received results of executed numerical researches confirmed that automatic steering system of underwater vehicle 'Głuptak' can be successfully used to steer the underwater robot along desired trajectory.

In particular it should be underlined that introduction of added bearing signal in control system gives indirect information about affecting sea current, what is necessary in the case of lack of this type of information on board of an underwater vehicle. Correction of set value of controlled variable on the base of bearing enables moving to a next waypoint along safer trajectory (line closer to a straight line) than continuous updating of set value of controlled variable, especially in an underwater environment with strong affecting sea currents.

REFERENCES

[1] Fossen T. I., *Guidance and Control of Ocean Vehicles*, John Wiley & Sons Ltd., 1994.

[2] Kubaty T., Rowiński L., *Mine counter vehicles for Baltic navy*, Internet, http://www.underwater.pg.gda.pl/ publikacje.

[3] Szymak P., *Automatyczne sterowanie samobieżnym ładunkiem do zwalczania min podwodnych po zadanym torze*, 'Pomiary, Automatyka i Robotyka', 2008, No 2.

[4] Szymak P., *Using of fuzzy logic method to control of underwater vehicle in inspection of oceanotechnical objects*, 'Artificial Intelligence and Soft Computing', Polish Neural Network Society, Warsaw 2006, pp. 163–168.

STRESZCZENIE

Sterowanie pojazdem podwodnym pod powierzchnią wody narażone jest na zakłócenia jego ruchu. Oddziałujące prądy morskie stanowią główne źródło zakłóceń w środowisku podwodnym. Kolejnym utrudnieniem w tego typu operacjach jest nieliniowa dynamika sterowanego obiektu, zwłaszcza w przypadku torpedopodobnego kształtu kadłuba. W artykule zaprezentowano system automatycznego sterowania pojazdem podwodnym typu „Głuptak", który umożliwia przeciwdziałanie wpływowi prądu morskiego w przypadku braku pomiaru parametrów prądu morskiego na pokładzie sterowanego obiektu. Dodatkowo zamieszczono dwie strategie sterowania oraz wybrane wyniki badań symulacyjnych.

Recenzent prof. dr hab. inż. Andrzej E. Stateczny