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 ‘Gluptak’. 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’](image)

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:

$$p_n = p_{n-1} + k_b \cdot \Delta b_n .$$  \hspace{1cm} (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 $\Delta b_n$ 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 $\alpha_c$.
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 trajec-
tory’s deviation;
— average deviation of trajectory $d_{avg}$ defined in a form of:

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

Here $i = 1, 2, ..., k$ is a number of simulation step and $d_i$ is a deviation of tra-
jectory 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 ver-
tical 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 way-
point $(0,0)$ to waypoint $(40,40)$ with initial value of course equal to $0^\circ$.

As it can be observed, even in an underwater environment without sea cur-
rent 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 af-
fecting 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

<table>
<thead>
<tr>
<th>Control methods</th>
<th>Parameters of sea current</th>
<th>$d_{max}$ [m]</th>
<th>$d_{avg}$ [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>without correction</td>
<td>$V_c = 0$ m/s</td>
<td>2.084</td>
<td>1.988</td>
</tr>
<tr>
<td>continuous updating of set value of controlled variable</td>
<td>$V_c = 0$ m/s</td>
<td>1.932</td>
<td>0.951</td>
</tr>
<tr>
<td></td>
<td>$V_c = 1$ m/s, $\alpha_c = 60^\circ$</td>
<td>8.498</td>
<td>5.315</td>
</tr>
<tr>
<td>correction of set value of controlled variable on the base of bearing</td>
<td>$V_c = 1$ m/s, $\alpha_c = 90^\circ$</td>
<td>20.54</td>
<td>13.29</td>
</tr>
<tr>
<td></td>
<td>$V_c = 1$ m/s, $\alpha_c = 60^\circ$</td>
<td>9.217</td>
<td>4.823</td>
</tr>
<tr>
<td></td>
<td>$V_c = 1$ m/s, $\alpha_c = 90^\circ$</td>
<td>16.11</td>
<td>8.306</td>
</tr>
</tbody>
</table>
CONCLUSIONS

In general received results of executed numerical researches confirmed that automatic steering system of underwater vehicle ‘Gluptak’ 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


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