Semiautomatic Control of Self-propelled Mine Counter Charge in Plane Motion

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Abstract: - In the paper a semiautomatic control system to steering of unmanned underwater vehicle is considered. Underwater objects, which operate beneath surface of water, very often are exposed to disturbances of its movement from a sea current. In case of lack of sea current measurement devices on the board they can not counteract it by generating contrary thrust. A method of evaluation of influence of environmental disturbances for vehicle’s motion is presented. The method allows partly eliminating negative influence of the sea current for vehicle’s motion along predefined path. Some computer simulations are provided to demonstrate effectiveness and correctness of the approach.

Key-Words: - Mine counter measure, Underwater vehicle, Fuzzy control

1 Introduction
A Self-propelled Mine Counter Charge (SMCC) is used to identify and destroy naval mines located up to 300 m from a launch point. It is a disposable, torpedo like, small remotely operated vehicle of four degrees of freedom.

To achieve high navigation accuracy, the SMCC system uses comprehensive set of navigation equipment. Different devices are of prime importance during mission phases defined below. USBL hydroacoustic navigation system leads vehicle during transition to a target area. Diving depth and altitude are measured simultaneously. While in the area, scanning sonar and TV camera provide required information. Complete set mounted on the vehicle consists of (see Fig. 1): 2 B&W TV cameras, 3 lamps, a scanning sonar, 2 laser aiming devices, a magnetic compass with pitch and roll sensors, an echosounder as altitude meter, a pressure sensor as depth meter and a transponder/responder for hydroacoustic navigation. Main technical parameters are given in the Appendix A.

The SMCC is prepared to carry two types of mine disposal devices. They are located in vehicle bow section. Less expensive is shaped charge. It is metal lined to increase capability to initiate mine explosive charge. Depending on target specification, shaped charge is pointed horizontally or vertically. Vertical charges are used against moored and partly buried mines. A SAP projectile gun is installed as alternative due to its effectiveness against non sensitive explosives and mines buried in sediments. The charge type should be selected according to local conditions.

Mine counter mission consists of two periods. The first phase is movement to the target area. The tracking is accomplished by means of the acoustic transponder/responder fixed to the vehicle body and responds to the ultra short base line navigation system or ships mine hunting sonar. During transition at relative speed of 2 m/s to 3 m/s is obtained by means of changes of speed of propellers. Reaching the target area takes the SMCC from several minutes in friendly environment to 15 minutes while struggling with a strong current. During the second phase the target is found using vehicle sonar and TV camera.

The SMCC is controlled by trained operator. He uses navigation data, sonar and television image. His work is supported by navigation computer that integrates data from the hydroacoustic navigation system and platform's (ship) navigation sensors. The SMCC can be controlled manually using two types of consoles. To facilitate the operator's work in the transient phase, an automatic control procedure presented below is going to be implemented.

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2 Equations of motion
The general motion of marine vessels of six degrees of freedom DOF describes the following vectors \([1, 3, 4, 6]\):
\[
\eta = [x, y, z, \phi, \theta, \psi]^T \\
v = [u, v, w, p, q, r]^T \\
\tau = [X, Y, Z, K, M, N]^T
\] (1)
where:
- \(\eta\) – vector of position and orientation in the inertial frame;
- \(x, y, z\) – coordinates of position;
- \(\phi, \theta, \psi\) – coordinates of orientation (Euler angles);
- \(v\) – vector of linear and angular velocities in the body-fixed frame;
- \(u, v, w\) – linear velocities along longitudinal, transversal and vertical axes;
- \(p, q, r\) – angular velocities about longitudinal, transversal and vertical axes;
- \(\tau\) – vector of forces and moments acting on the vehicle in the body-fixed frame;
- \(X, Y, Z\) – forces along longitudinal, transversal and vertical axes;
- \(K, M, N\) – moments about longitudinal, transversal and vertical axes.

3 Control law
Used in numerical researches control system of the SMCC consists of (see Fig.2):
1) supervisory control unit, which is responsible for setting values of movement’s parameters, turning on and off individual controllers at proper moments,
2) three controllers of: course, trim and translation, which are generating adequate control signal.

Every controller has been designed basis on adopted from [2, 9] a fuzzy proportional derivative (FPDC) working in the configuration presented in Fig. 3.
Membership functions of fuzzy sets of input variables, i.e. an error signal $e = \eta_d - \eta$ and a derived change in error $\Delta e = \eta_t - \eta_{t-1}$ as well as an output one (a command signal $\tau$), are shown respectively in Fig. 4. The following notation has been taken: N – negative, Z – zero, P – positive, S – small, M – medium and B – big.

Presented in Table 1 rules from the Mac Vicar-Whelan’s standard base of rules have been chosen as the control rules [7, 10].

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<th>Error signal $e$</th>
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<th>Z</th>
<th>PS</th>
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<th>Derived change in error $\Delta e$</th>
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4 Simulation study

Numerical simulations have been made to confirm validity of the proposed control algorithm for the following assumptions:

1. the nonlinear dynamical model (2) is used to simulate the SMCC behaviour (see the Appendix B),
2. the fuzzy control law is used with membership functions presented in Fig. 3 to steer the SMCC,
3. the vehicle has to follow the desired path in horizontal motion starting from the point $P_i = (x_i, y_i)$ and ending at the point $P_f = (x_f, y_f)$ with constant speed $u$,
4. vector of positions and orientations is measurable,
5. environmental disturbances are present in underwater space,
6. the vehicle is not equipped with sea current measuring device,
7. travel time is not fixed, thus the navigation between two points is not constrained by time.

Taking above in consideration, it has been assumed that the SMCC should take starting position relative to a target of mission in the way that the sea current can act on it in its longitudinal axis and on the contrary of its translational velocity vector. In such situation the vehicle is able to move forward along a line close to the straight line (see Fig. 5).
In case of sea current action, effect of an underwater vehicle’s pushing aside could be observed. Since the SMCC is not equipped with sea current measuring device, there is a real problem to interact producing contrary thrust.

For the purpose of interacting sea current two control methods have been developed:
1) continuous updating of controlled variable (if the vehicle is pushed aside by sea current, then new value of controlled variable is calculated),
2) correction of controlled variable on the base of bearing (changes of bearing in time indicate sea current action, what gives possibility to correct set value of controlled variable).

Numerical simulations have showed that for analysis of motion in the horizontal plane the second method seems to be more effective. In the method the correction is based on a simple equation:

\[ \psi_{dn} = \psi_{dn-1} + k_b \cdot \Delta \psi_n \]  

(3)

Here \( \psi_{dn} \) is a desired value of controlled variable (heading) in \( n \) instant of time, \( k_b \) is a gain factor and \( \Delta \psi_n \) is a error of bearing in \( n \) instant of time.

Simulations have been executed starting from the point \( P_0 = (0 \text{ m}, 0 \text{ m}) \) and ending in \( P_f = (40 \text{ m}, 40 \text{ m}) \) with influence of the sea current with the following parameters: specified velocity \( V_c = 1 \text{ m/s} \) and different directions of affecting \( \alpha_c \).

Some results of simulations for constant speed in surge motion are depicted in Figure 6. The case study showed that the proposed autopilot enhanced good yaw control along of the desired route. The main advantage of the approach is its simplicity and satisfactory performance.

The quality of control can be improved by adequate choosing of parameters of membership functions of input and output variables. Tuning of their values can be done i.e. by the Genetic Algorithms [5, 8]. Therefore further investigations are required, especially in case of using described approach to control the vehicle behaviour in more degrees of freedom.

5 Conclusions

This paper has described the using of the fuzzy autopilot for control of orientation of the Self-propelled Mine Counter Charge. From the obtained results it can be concluded that the proposed approach provides the semi-automatic control
system being effective and having good performance.

Another advantage of the discussed auto heading system is its possibility to counteract unknown parameters of environmental disturbances and keep real route very close to desired path being a straight line.

Further works are needed to identify the best fuzzy structure of the autopilot and test the robustness of this approach in motion of more degrees of freedom.

References:

Appendix A

Technical specification of the SMCC

External dimensions:
1. length – 1.40 m;
2. width with stabilizers – 0.36 m;
3. height with stabilizers – 0.36 m;
Mass – 45.0 kg;
Buoyancy – 1.0 N to 2.0 N;
Operating depth – 200 m;
Maximum speed – 3 m/s;
Range – 500 m;
Propulsion:
1. horizontal plane – four thrusters, 3 blade screw propellers, electrically driven, each 50 W power;
2. vertical plane – single thruster, electrically driven 3 blade screw propeller in a tunnel, 50 W power;
Mission duration time – 30 minutes;
Energy source – lithium ion accumulator battery;
Control – remote, computer aided, using single optical fibre of 2000 m length;

Appendix B

Model of the SMCC

The following parameters of the vehicle’s dynamics have been used in the computer simulations:

\[
M = \text{diag}\{49.5, 104.0, 104.0, 0.8, 18.9, 18.9\};
\]

\[
D(\mathbf{v}) = \text{diag}\{0.15, 1.9, 1.9, 0.0, 0.8, 0.7\};
\]

\[
C(\mathbf{v}) = \mathbf{0};
\]

\[
g(\mathbf{\eta}) = \begin{bmatrix}
-\sin(\theta) \\
\cos(\theta)\sin(\phi) \\
\cos(\theta)\cos(\phi)
\end{bmatrix}.
\]