Simulation of Spatial Motion of Self-propelled Mine Counter Charge

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Abstract: - In the paper a semiautomatic control system to steering of unmanned underwater vessel is considered. The fuzzy logic is incorporated for the keeping of desired orientation and two independent controllers are used to generate command signals. Input variables fuzzification, fuzzy rules and output set defuzzification are described. Quality of control is concerned for different surge speeds. Some computer simulations are provided to demonstrate the effectiveness, correctness and robustness of the approach.

Key-Words: - Mine counter measure, Underwater vehicle, Modelling, Autopilot

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 operated in 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 2m/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.

2 Equations of motion

The general motion of marine vessels of 6 DOF describes the following vectors [1, 3, 4, 6]:

$$\begin{aligned} \boldsymbol{\eta} &= [x, y, z, \phi, \theta, \psi]^T \\ \mathbf{v} &= [u, v, w, p, q, r]^T \\ \boldsymbol{\tau} &= [X, Y, Z, K, M, N]^T \end{aligned} \qquad (1)$$

where:

- $\boldsymbol{\eta}$ – the position and orientation vector in the inertial frame;
- x, y, z – coordinates of position;
- ϕ, θ, ψ – coordinates of orientation (Euler angles);
- $\mathbf{v}$ – the linear and angular velocity vector with coordinates 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;
- $\boldsymbol{\tau}$ – vector of forces and moments acting on the robot 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.

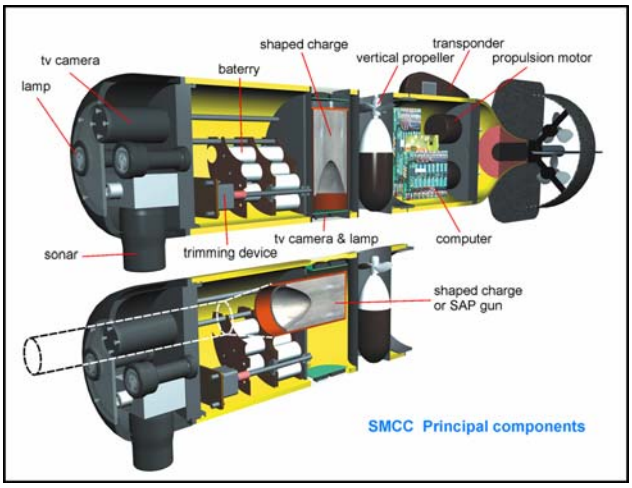

Fig. 1. Main parts of the SMCC

The nonlinear dynamical and kinematical equations of motion in body-fixed frame can be expressed as [3, 4,]:

$$\begin{aligned} &\mathbf{M}\dot{\mathbf{v}} + \mathbf{C}(\mathbf{v})\mathbf{v} + \mathbf{D}(\mathbf{v})\mathbf{v} + \mathbf{g}(\boldsymbol{\eta}) = \boldsymbol{\tau} \\ &\dot{\boldsymbol{\eta}} = \mathbf{J}(\boldsymbol{\eta})\mathbf{v} \end{aligned} \tag{2}$$

where:

- $\mathbf{M}$ – inertia matrix (including added mass);
- $\mathbf{C}(\mathbf{v})$ – matrix of Coriolis and centripetal terms (including added mass);
- $\mathbf{D}(\mathbf{v})$ – hydrodynamic damping and lift matrix;
- $\mathbf{g}(\boldsymbol{\eta})$ – vector of gravitational forces and moments;
- $\mathbf{J}(\boldsymbol{\eta})$ – velocity transformation matrix between the body fixed and the inertial frames.

3 Fuzzy control law

Adopted from [2, 9] a fuzzy proportional derivative controller (FPDC) working in the configuration presented in Fig. 2 has been designed for keeping of a desired orientation.

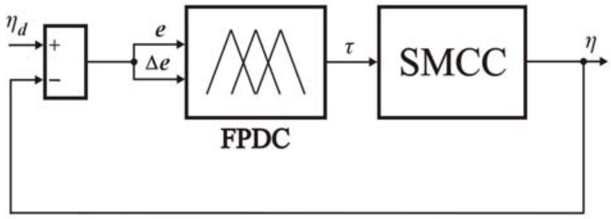

Fig. 2. A structure of the fuzzy controller

Membership functions of fuzzy sets of input variables, i.e. an error signal $e = \eta_{di} - \eta_i$ and a derived change in error $\Delta e = \eta_i - \eta_{i-1}$ as well as an output one (a command signal) τ_i, are shown respectively in Fig. 3. 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].

Table 1. The fuzzy controller's base of rules

		Error signal e						
		NB	NM	NS	Z	PS	PM	PB
Derived change in error Δe	NB	NB	NB	NB	NM	Z	PS	PB
	NM	NB	NB	NM	NS	PS	PM	PB
	Z	NB	NM	NM	Z	PM	PM	PB
	PM	NB	NM	NS	PS	PM	PB	PB
	PB	NB	NS	Z	PM	PB	PB	PB
		Command signal τ						

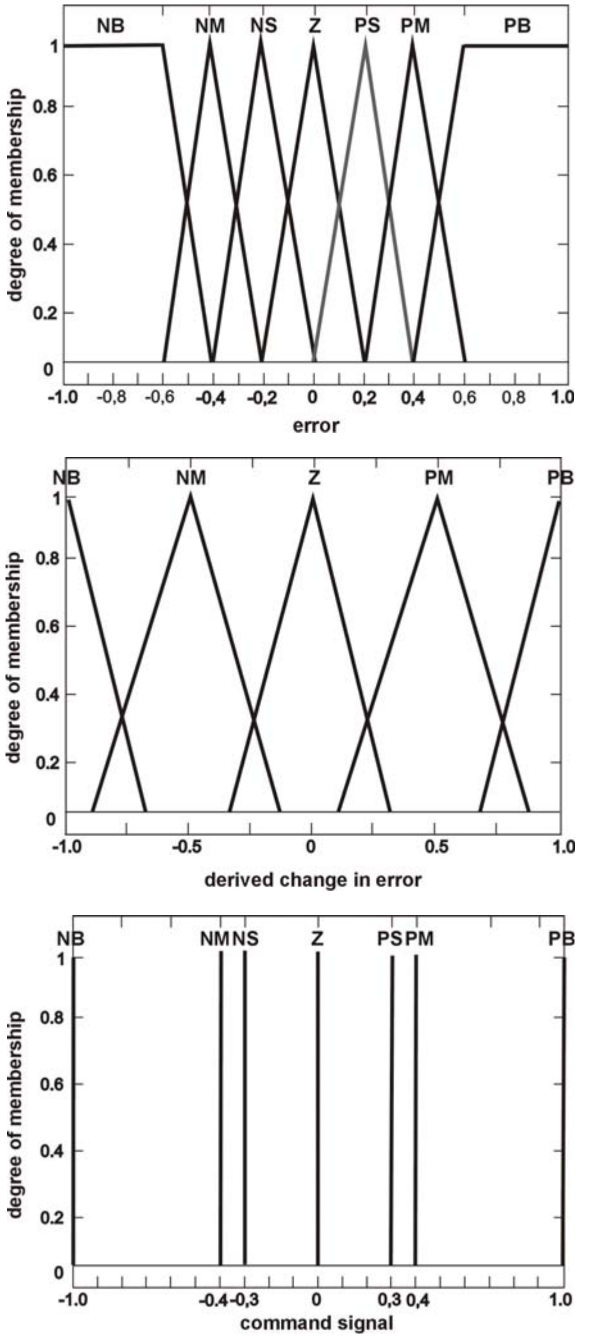

Fig. 3. Fuzzifier membership functions of error signal e, derived change in error Δe and command signal τ

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 control object has to follow the desired path starting from the point $P_b = (x_b, y_b, z_b, \phi_b, \theta_b, \psi_b)$ and ending at the point $P_f = (x_f, y_f, z_f, \phi_f, \theta_f, \psi_f)$ with constant speed u,
4. vector of position and orientation is measurable,
5. travel time is not fixed, thus the navigation between two points is not constrained by time.

A structure of the proposed control system is drawn in Fig. 4.

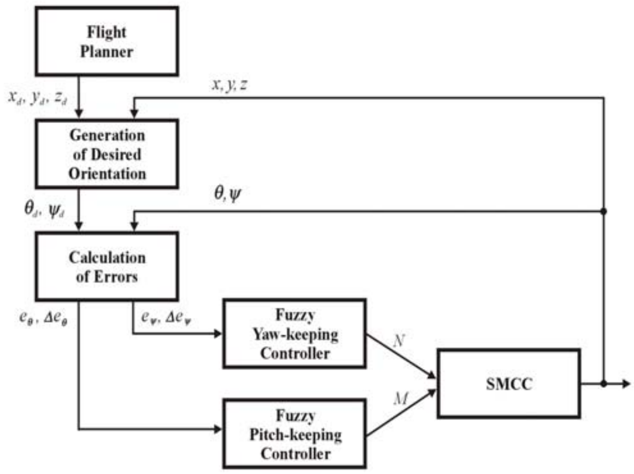

Fig. 4. A block-diagram of the control system

Some results of simulations for constant speed in surge motion are depicted in Figures 5 and 6. The case study showed that the proposed autopilot enhanced good pitch and 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 robust and having good performance. Another advantage of the discussed auto heading and auto pitch control system is its flexibility with regard to the change of dynamic properties of the vessel.

Further works are needed to identify the best fuzzy structure of the autopilot and test the robustness of this approach in the presence of environmental disturbances.

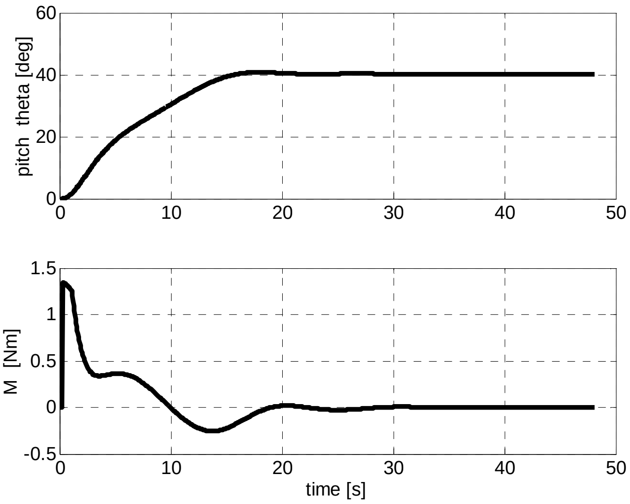

Fig. 5. Time histories of pitch θ and moment about transversal axis M for surge velocity u = 1.5 m/s

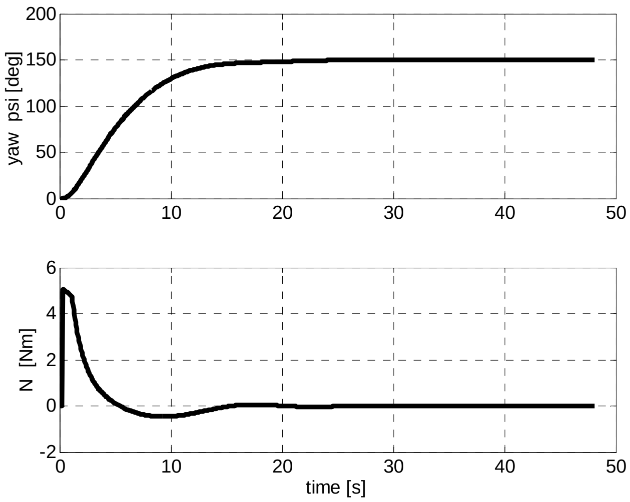

Fig. 6. Time histories of yaw ψ and moment about vertical axis N for surge velocity u = 1.5 m/s

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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;

Mine disposal device:

1. the shaped charge with 2 kg of explosive, vertically or horizontally mounted;
2. the SAP projectile gun;
3. other devices up to 8 kg mass.

Appendix B

The SMCC model

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

$$\mathbf{M} = diag\{49.5 \quad 104.0 \quad 104.0 \quad 0.8 \quad 18.9 \quad 18.9\}$$
;

$$\mathbf{D}(\mathbf{v}) = diag\{0.15 \quad 1.9 \quad 1.9 \quad 0.0 \quad 0.8 \quad 0.7\};$$

$$\mathbf{C}(\mathbf{v}) = \mathbf{0};$$

$$\mathbf{g}(\boldsymbol{\eta}) = \begin{bmatrix} -\sin(\theta) \\ \cos(\theta)\sin(\phi) \\ \cos(\theta)\cos(\phi) \\ 0 \\ 0 \\ 0 \end{bmatrix}.$$