

The intelligent underwater laboratory

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Abstract. The intelligent underwater laboratory is designed to study the properties of water, polluting factors with the determination of the source of pollution. The laboratory consists of a self-propelled autonomous vehicle with a three-propulsion system and a static immersion and ascent system. The multi-propulsion control system enables maneuverability of the device. The solution of the positioning problem by adjusting the coefficients and obtaining new maneuverable capabilities of the device provides performing inspection on the bottom of the vessel, the screw part, and taking water samples.

Keywords: remote-controlled uninhabited underwater vehicle, thrusters, increased maneuverability, intelligent underwater laboratory, propulsion system, positioning, bottom inspection of the vessel

1. Introduction

It is noted that pollution of the marine environment by a sea transport is one of the main environmental problems. Marine pollution is divided into natural and anthropogenic, which represents the bulk of all pollution. Pollution is distinguished by the sources associated with maritime transport: warships, various vessels, underwater installations used for the exploration of the seabed.

Pollution associated with marine transport operations are:

- leaks;
- loading and unloading operations;
- discharge of flushing and ballast water;
- docking;
- sewage from ships;
- dumping of solid waste;
- losses at oil spillage in tankers;
- emergency situations.

The large number of tanker ships in the Novorossiysk port indicates the main danger of oil pollution and raises the question of studying the marine environment.

The study of the vessel bottom for pollution and destruction, related operational activities is one of the main tasks. Structural failure and repair works not only incur large costs, but also contributes devastating consequences for the environment.



The current and future increase in the number of sea vessels causes enormous damage to the environment. Thus, shipping represents a significant share in the global pollution of the marine environment.

Despite the consideration of risks and damage, resolutions adopted by the governments of many countries to protect the marine environment, we consider it necessary to organize the work of underwater devices that enable timely provision of information about possible violations in the design of ships and to assess the water environment when organizing work on detected violations.

Inspection or operational works at the vessels involves remote-controlled uninhabited underwater vehicles (RCUUV) that collect video information. The RCUUV during the study of the object design should be moved by maneuvering the device at a sufficiently close distance to the object. The mode of movement of the RCUUV sets a number of tasks: movement along a given trajectory; circulation; joining an object; mooring; keeping the device on the set course; etc.

The control of such objects takes into account some difficulties associated with external factors (disturbances and noise of measurements, flows, wave interaction) and some inaccuracies or uncertainties for the application of numerical methods in varying different situations. Therefore, the most rational method presents artificial intelligence.

2. Materials and Methods

RCUUV is a rather complex dynamic apparatus operating on the basis of control algorithms under conditions of constantly changing external factors. The use of fuzzy set theory provides the reduce in inaccuracies and uncertainties associated with incoming input information.

At the same time, the general structure of the RCUUV operation system can be represented in the form of a diagram:

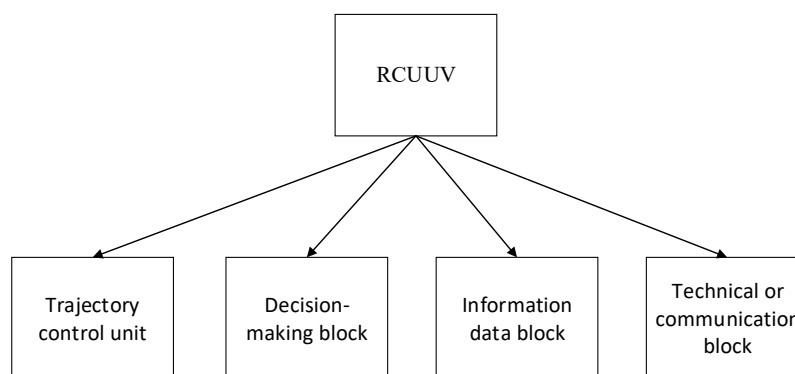


Figure 1. Module of the RCUUV control system

Characteristic features of using such a RCUUV design is presented in Table 1.

Table 1. Advantages and disadvantages of using RCUUV

Advantages of using RCUUV	Disadvantages of using RCUUV
The ability to work in difficult conditions, characterized by strong currents	Required engineering preparation of works
Production of works in the absence of visibility	Provision from the carrier vessel
Possibility of automation of underwater operations	High probability of catching the cable for underwater objects
Working for a long time	The high cost of assembly and maintenance of the device

The model that reflects the formal nature of the transformations of the input signals in control systems into the output is called a descriptive mathematical control model. The scientific approach to the development of control actions on RCUUV is based precisely on the mathematical model of the system. At the same time, a mathematical model is supposed as a set of mathematical expressions and equations logically related to each other and combining the input and output values of the system.

The works of Lukomskono Yu.A., Lewis F., Makhin N. N., Pantov E. N., Polovitsky A. S., Haskind M. D., Chugunov V. S., Sheremetov B. B., etc. are devoted to the construction of the mathematical model of mobile devices and calculations of various characteristics.

Based on the basic mathematical model described in [1, 5], we describe the movement of the RCUUV underwater vehicle using a system of 4 blocks of differential equations in projections along three coordinates, as a controlled object immersed in the marine environment based on the law of dynamics and kinematics:

$$\left\{ \begin{array}{l} \omega_x = \theta' + \varphi' \cdot \sin\psi \\ \omega_y = \varphi' \cdot \cos\psi \cos\theta + \psi' \cdot \sin\psi \\ \omega_z = -\varphi' \cdot \cos\psi \sin\theta + \psi' \cdot \cos\psi \\ \begin{cases} x'(t) = V_x \cos\psi \cos\varphi + V_y (\sin\varphi \sin\theta - \sin\psi \cos\varphi \cos\theta) + V_z (\sin\varphi \cos\theta + \sin\psi \cos\varphi \sin\theta) \\ y'(t) = V_x \sin\psi + V_y \cos\psi \cos\theta - V_z \cos\psi \sin\theta \\ z'(t) = -V_x \cos\psi \sin\varphi + V_y (\cos\varphi \sin\theta + \sin\psi \sin\varphi \cos\theta) + V_z (\cos\varphi \cos\theta - \sin\psi \sin\varphi \sin\theta) \end{cases} \\ \begin{cases} R_x = K'_x + \omega_y K_z - \omega_z K_y \\ R_y = K'_y + \omega_z K_x - \omega_x K_z \\ R_z = K'_z + \omega_x K_y - \omega_y K_x \end{cases} \\ \begin{cases} M_x = L'_x + \omega_y L_z - \omega_z L_y + V_y K_z - V_z K_y \\ M_y = L'_y + \omega_z L_x - \omega_x L_z + V_z K_x - V_x K_z \\ M_z = L'_z + \omega_x L_y - \omega_y L_x + V_x K_y - V_y K_x \end{cases} \end{array} \right. \quad (1)$$

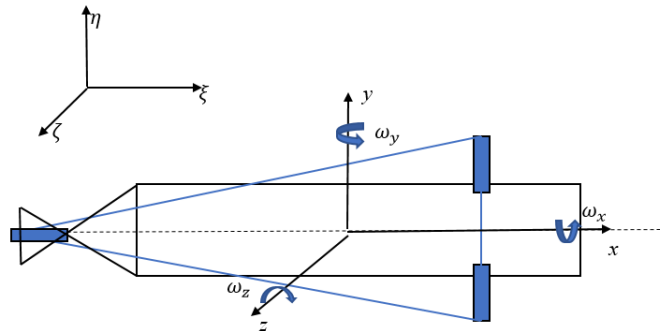


Figure 2. RCUUV model in three-dimensional space

In this case, the coordinate system $Oxyz$ is connected to the body of the underwater vehicle and moves (rotates) together with it (called mobile or connected), and $O\xi\eta\zeta$ is an earth or semi-connected coordinate system. The yaw angle φ , the trim angle ψ and the roll angle θ enables to translate a connected coordinate system from the initial state, when combined with a semi-connected system (Figure 2). The vectors $\vec{V} = (V_x \ V_y \ V_z)^T$ and $\vec{\Omega} = (\omega_x \ \omega_y \ \omega_z)^T$ of the linear and angular velocities, respectively, are expressed in terms of projections on the coordinate axes. The coordinates of the vectors \vec{R} and \vec{M} present projections of the external forces of their moments acting on the RCUUV, relative to the origin of the associated coordinate system. The main vector of the amount of motion RCUUV \vec{K} and the moment of the motion amount \vec{L} when the RCUUV is rotated around the origin coordinates $Oxyz$ are related to the angular velocity $\vec{\Omega}$ by the equations [1]:

$$\begin{cases} \vec{R} = \vec{K}' + \vec{\Omega} \times \vec{K} \\ \vec{M} = \vec{L}' + \vec{\Omega} \times \vec{L} + \vec{V} \times \vec{K} \end{cases} \quad (2)$$

3. Results

To control marine mobile objects with high accuracy, it is advisable to use modern methods that do not require the use of complex mathematical models of control objects. Such methods apply fuzzy logic and neural networks when implementing individual controllers or control systems for moving objects as a whole [8].

Therefore, we suggest installing active control tools in the underwater vehicle:

- in the front part, we will place two additional propellers consisting of angle reducers and electric drive motors;
- the control drive is compatible with the depth rudders, so that when installing the rudders, the device buries or surfaces;
- turn control with shifting the steering wheel, is also provided by turning "on the opposite" propellers, when turning to the left – left backward, right forward; if circulation is required, then additionally the main propulsor, reverse directions contribute the opposite.

The RCUUV movement system must have a sufficient number of propellers for stable movement. At the same time, the direction of their traction can change depending on the desired direction of movement.

Let us define the following five principle modes of propeller operation:

- all four propellers work at an emphasis in the forward direction;
- two propellers of the thruster operate in opposite directions with a left turn (left backward, right forward);
- two propellers of the thruster operate in opposite directions with a right turn (left forward, right backward);
- two propellers of the thruster operate in opposite directions with a left or right turn and the main marching forward;
- two propellers of the thruster work in opposite directions with a left or right turn and the main marching back.

To synthesize the control controller, we use a set of logical rules for controlling three propellers according to experimentally determined characteristics.

Taking into account the calibration characteristic, it is necessary to obtain the output characteristics of the stops and moments of the propellers in the adopted control scheme of the vehicles on the basis of the above logical rules and the operating voltage levels set during the control of the device on the propellers.

Let us choose the Sugeno algorithm for the synthesis of a fuzzy propulsion control controller. The synthesis of the propulsion control controller is performed in the Matlab computer mathematics system in the Fuzzy Logic application [15, 16].

The input parameter is the voltage on the thrusters set by the joystick, the output parameters are the thrust force of the thruster and the moment of turning the device.

Synthesis by the values of the input sets of forces, depending on the voltage on the collectors of the engines, is provided by the logical operations "AND", "OR", at the intersection of the graphs of the values of the membership functions.

Changing the voltage on the collectors of the propellers in accordance with the calibration characteristic shown in Figure 3, by means of control from the joystick, provides calculation the values of the output parameters and create control tables for the on-board controller of the device.

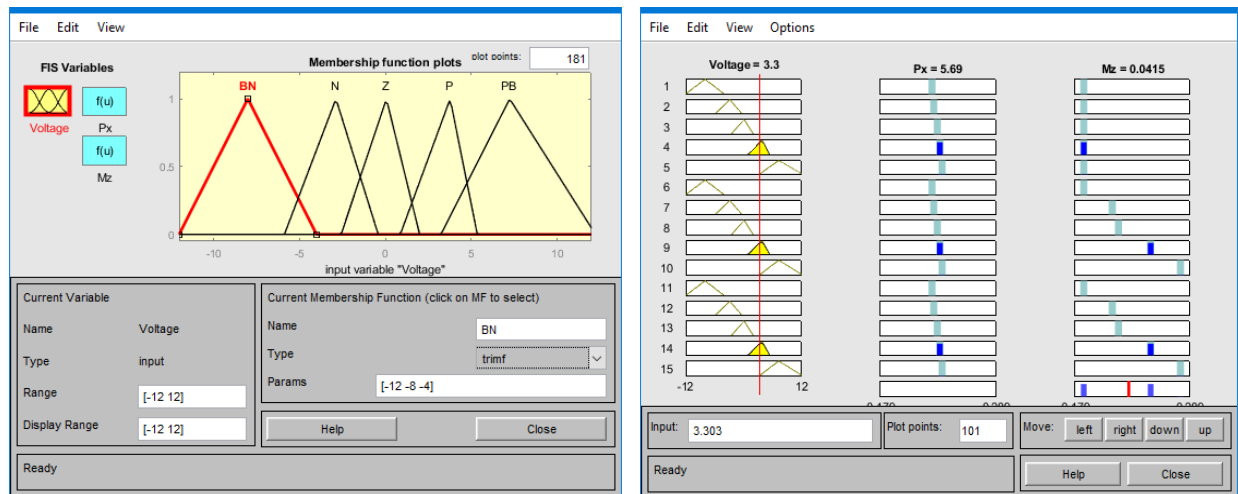


Figure 3. Setting the stop of the propellers and moments at different voltage values on the collectors and the logic for selecting the output values of the stops and moments

The second input parameter converts the dependences of the output values of the propellers stops and moments into the surfaces of the parameter levels, as shown in Figure 4.

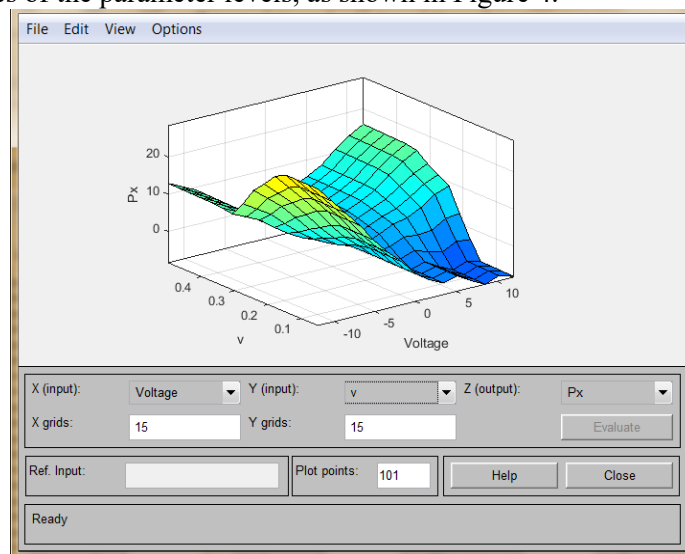


Figure 4. Output parameters of the fuzzy control controller for voltage and flow rate parameters

As follows from Figure 4, the device has a certain inertia when the supply voltage changes on the collector of the propellers. The magnitude of the moment affects the initial section of the voltage change from -12 to +12 volts (backward and forward, respectively).

The current also contributes to the value of the moment when the device moves, which explains the change in the steepness of the characteristics when moving against the current [11].

The synthesis of the control signal based on the observed parameters in the fuzzy controller is performed for each data set and the signal coming from the control joystick.

4. Discussion and Conclusions

This approach complicates the usual method of using a control system on the table, since it requires several timers implementing control functions, since, parameters are selected at fixed points in time in the fuzzy logic editor.

The considered object control systems were tested at different values of input parameters. The Sugeno type model is more accurate, however, it is complicated to find suitable conclusions of the rules.

The controller based on fuzzy logic can provide a higher quality of the transient process for controlling the vehicles. Adjustment of the controller based on fuzzy logic can be carried out by optimization means. The fuzzy logic controller provides greater flexibility in configuration and better quality of the transition process, but requires configuring a large number of parameters.

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