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MATHEMATICAL MODELING OF THE AUTOMATIC CONTROL SYSTEM FOR AN AUTONOMOUS UNDERWATER VEHICLE AS A GROUP AGENT

МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ СИСТЕМИ АВТОМАТИЧНОГО КЕРУВАННЯ АВТОНОМНИМ НЕНАСЕЛЕНИМ ПІДВОДНИМ АПАРАТОМ ЯК АГЕНТОМ ГРУПИ

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Abstract. A mathematical model of the automatic control system for an autonomous unmanned underwater vehicle operating as a group agent has been developed. The ACS was modeled in the MATLAB Simulink software. There has been carried out the simulation of the maneuvering motion of the AUUV, in which the device maintained at a safe distance from the given agent (object of the group) in the specified distance range: the adhesion mode, or the cohesion mode. The proposed control system contains two major control units: the distance control unit and the course control unit. For the implementation of the task, fuzzy controllers of the Mamdani-type were chosen, with defuzzification via the Center of Gravity method.
Keywords: mathematical modeling, automatic control system, group control, adhesion and cohesion, fuzzy controller, maneuvering motion.

Анотація. Представлено розробку математичної моделі системи автоматичного керування автономним ненаселеним підводним апаратом, що працює як об’єкт групи. Моделювання роботи САК проводилось в системі Simulink середовища MATLAB. Проведено симуляцію роботи маневрового руху АНПА, при якому апарат утримував безпечну дистанцію із заданим об’єктом (агентом групи) у заданому діапазоні відстаней: режим адгезії, режим когезії. Запропонована система керування містить два основних блоки регулювання: блок контролю дистанції та регулятор курсу. Для реалізації поставленої задачі було обрано нечіткі регулятори типу Мамдані, з дефазифікацією по методу центра ваги.
Ключові слова: математичне моделювання, система автоматичного керування, групове керування, адгезія й когезія, нечіткий регулятор, маневровий рух.

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Problem statement. Within the framework of the task of control of a group of autonomous unmanned underwater vehicles (AUUVs), there is a relevant issue of the synthesis of automatic control systems (ACSs) of their coordinated movement. During the movement, it is necessary for each AUUV to maintain a safe distance to the neighboring vehicles in a given range of distances: when the minimum distance between them does not pose a risk of an emergency collision (adhesion mode), and the maximum distance guarantees sustaining the group and does not pose a threat of an individual vehicle leaving the range of the sensors of other members of the group (cohesion mode) [3]. During the development of data management systems for these objects, one often faces the problem of the ambiguity of the decision when forming a control signal.

Therefore, the use of fuzzy logic provides an approach to designing the necessary control system (fuzzy control) and ensures the possibility of solution to a wide range of problems in which the data, goals and constraints are either too complex or ambiguously defined and, therefore, are not subject to precise mathematical description.

By fuzzy control we mean a control strategy based on the empirically acquired knowledge of the functioning of the object (process) presented in a linguistic form as a set of rules [1].

A generalized procedure for the synthesis of fuzzy control algorithms can be formulated as follows:

– identifying the set of goals to be addressed by the system;

– specifying the sets of input and output variables of the controller;

– listing possible situations in the system operation;

– forming a base of rules;

– choosing the fuzzification methods;

– specifying the output mechanism and defuzzification methods.

When controlling the maneuvering motion of an AUUV, especially if it operates in a group that performs a joint mission, application of regular control methods will not ensure the adequate level of accuracy. It is also necessary to consider the substantial non-linearity of the parameters to be monitored. The use of fuzzy logic allows solving a number of problems without applying the regular linearization.

A linear continuous PD controller $y(t) = K_p\varepsilon(t) + K_d\frac{d\varepsilon(t)}{dt}$ can be replaced with a fuzzy controller (similar in control strategy and logic) if the value of the control action $y(t)$ is considered its output variable:

$$y(k) = K_p\varepsilon(k) + K_d\Delta\varepsilon(k)\,.$$

Thus, for the input variables $\varepsilon(t)$, $\Delta\varepsilon(t)$ and the output variable $y(t)$, a fuzzy controller can be synthesized; it would implement the nonlinear law $y(t) = \mathrm{F}[\varepsilon(t), \Delta\varepsilon(t)]$ and would be equivalent to a PD controller [2].

Currently, the development of a mathematical model of the control system for the AUUV maneuvering motion, which is implemented in accordance with the principles of fuzzy algorithms, is quite a relevant task.

Latest research and publications analysis. In the modern world, the range of intelligent means used in the study of deep sea missions employing AUUVs is expanding due to the development of robotics in general [1]. The reference book [2] proposes a new methodological framework for the development of distributed intelligence systems for collective control of moving AUUV groups. This framework helps solve the essential tasks of the coordinated operation of the AUUV group.

At present, the scale of AUUV systems is being expanded and their deployment is being enhanced, which leads to an increase in the complexity of AUUV missions and, consequently, to the continuous improvement of motion control laws [6]. One of the stages of this process is incorporation of the artificial intelligence and fuzzy logic elements, in particular, into the laws of the AUUV motion control and the creation of combined control structures. The key problem of including the artificial intelligence elements into AUUV autopilot (self-guided mechanisms) is the distribution of control functions between the classical and fuzzy components of the combined autopilot.

Several techniques applied to control underwater vehicles are explained in [13], including control via PID controllers, linear quadratic Gaussian control, fuzzy logic control (FLC), adaptive control, slide control (SMC), static state control, prognostic control, and neural network based control. They manifested a high reliability and convenient settings. Since almost all of the control methods have some advantages and disadvantages, an appropriate controller can be made by combining the classical and the modern intellectual methods.

Publication [11] proposes the ACS for an AUUV group which takes into account the constraints of communication in the underwater environment. A special feature of the system is the possibility for all the vehicles to share the computing resources of the group.

The MORPH project offers the concept of an underwater robotic system that is formed through integration of various mobile robotic modules with additional resources [12, 13]. Each node of the MORPH units (a set of small and inexpensive robotic marine vehicles) is an AUUV capable of performing particular tasks.

One of the main problems of group control of a swarm of robots is to provide a mode of coordinated movement of the vehicles along a predetermined trajectory or route. Thereat, it is important to keep the robots not far from their groups and to avoid merging individual groups, that is, the cohesion and segregation modes [10].

THE ARTICLE AIM is to develop a mathematical model of the control system for an autonomous unmanned underwater vehicle operating as an agent within a set of other objects.

Basic material. To coordinate the work of agents (underwater vehicles or objects that perform a joint mission), a control system has been developed that has the following structure (fig. 1).

This system consists of two main controllers: the distance controller and the course controller.

If a vehicle changes its course and starts moving away or approaching another agent, the sensors capture the change of parameters, and the controllers produce a new trajectory.

The unit of distance sensors forms a vector of distances to the nearest target $\vec{d}_s = [d_1\ d_2\ d_3\ d_4]$. The distance to the target is calculated according the expression (1):

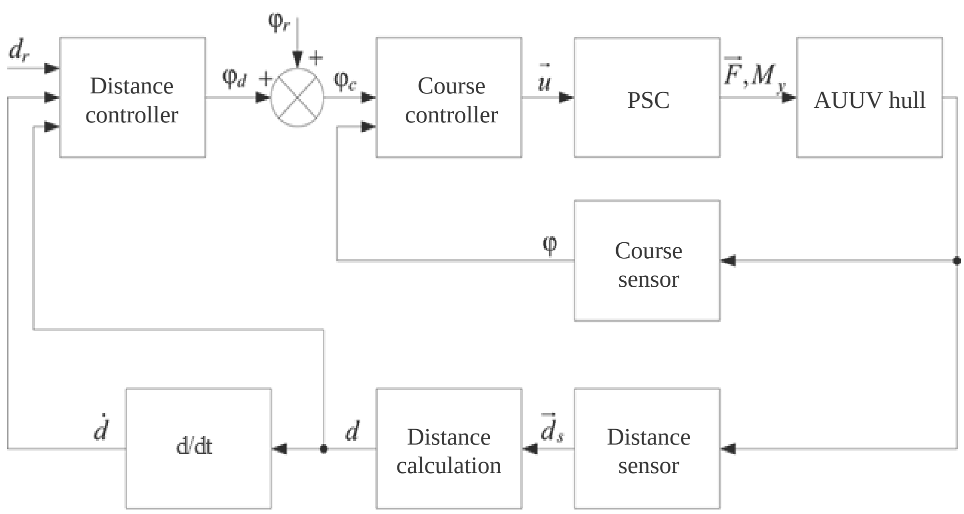

Fig. 1. Structural diagram of an AUUV ACS

$$\begin{cases} d = (d_{\min 1} + d_{\min 2}) / 2; \\ d_{\min 1} = d_i \,|_{|d_i - d_{i+1}| \to \min}; \\ d_{\min 2} = d_{i+1} \,|_{|d_i - d_{i+1}| \to \min}, \end{cases} \quad (1)$$

where $d_{\min1}$, $d_{\min2}$ are the parameters of a pair of distance sensors with the minimal difference of values, m; $i = 1..3$.

Fuzzy controllers are used to solve this problem. The distance (course) controller is a fuzzy Mamdani-type PD controller with defuzzification of the control variable via the center of gravity method.

The input parameters for the distance controller are the deviation $\varepsilon_d = d_r - d$ and the deviation derivative $\dot{\varepsilon}_d = \dot{d}_r - \dot{d}$.

The variable is represented by the following linguistic terms: Out of Range, Missing, Track, Object Approximation (Danger). The variable $\dot{\varepsilon}_d$ is represented by the following terms: negative (N), zero (Z), positive (P). The controller output is the deviation φ_d from the given course, which is represented by the following terms: negative large (NL), negative small (NS), zero (Z), positive small (PS), positive large (PL). The base of rules of the controller is presented in Table 1 [11].

Table 1. Base of rules for the distance controller

$\dot{\varepsilon}_d$ \ ε_d	Out Of Range	Miss	Track	Danger
N	Z	PL	PS	NS
Z	Z	PL	Z	NL
P	Z	PS	NS	NL

The course controller, in turn, receives the input comprising the control signal and the signal from the course sensor. At the output, the course controller generates the control signal for the propulsion and steering complex (PSC), which consists of a separately excited DC motor and a steerable shrouded propeller [12, 13].

The mathematical modeling of the developed control system has been performed in the Matlab Simulink system.

Fig. 2 shows the structural diagram of the ACS, which allows studying the operation of the underwater vehicle together with the agent deviating from the given course.

The developed mathematical model allows maintaining the control object at a certain distance from the given agent. At that, the distance controller monitors the agent approaching or moving away with a specified control accuracy (in this case, 0.5 m.) The course controller forms a new AUUV trajectory. Fig. 3 shows the structure of the fuzzy course controller implemented in the Simulink system.

The signal coming from the distance controller is determined by the following terms: OB is a negative large angle (the object is rapidly moving away over long distances); OM is a negative small angle (the object is gradually moving away); Track is the object moving along the given trajectory; PM is a positive small angle; PB is a positive large angle (see Fig. 4).

The next step is to compare this signal with the signal from the course sensor, which, in turn, determines the error between the nearest agent and the angle of rotation of the AUUV steering nozzle (see Fig. 5).

At the output, there is a vector that determines the voltage applied to the motor (setting the vehicle's speed) and the angle of rotation of the nozzle, which allows for the formation of a new motion trajectory (see Fig. 6).

Modeling results. Let us simulate a situation in which a given object (for example, another underwater vehicle) will move along a sinusoidal trajectory, and the controlled AUUV will maintain a set distance from it.

Fig. 7 presents the signal coming to the distance controller from the sensor which records that the target changes its motion trajectory.

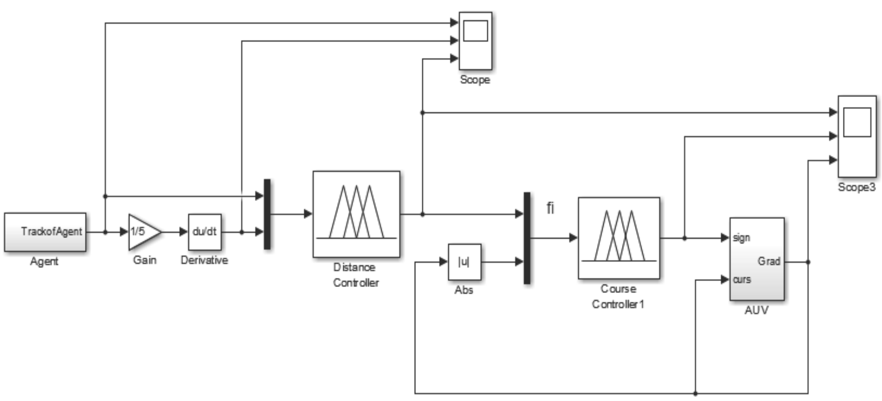

Fig. 2. Structural diagram of the AUUV ACS implemented in the Simulink system

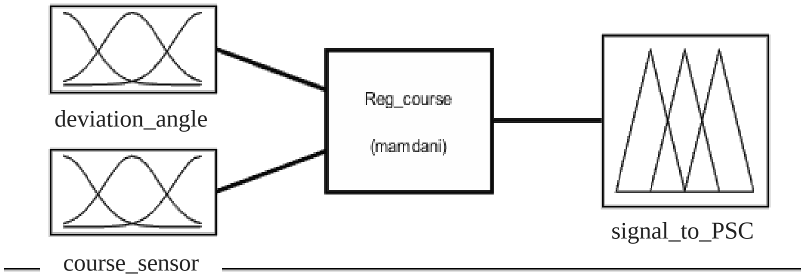

Fig. 3. Structure of a fuzzy course controller

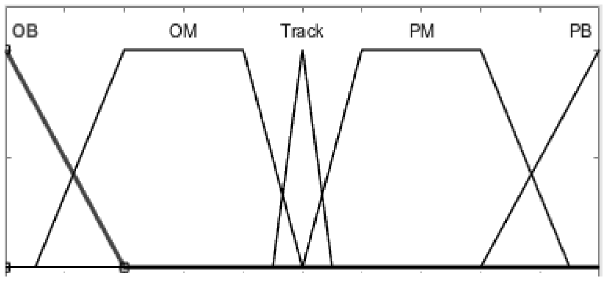

Fig. 4. Terms of the deviation angle signal

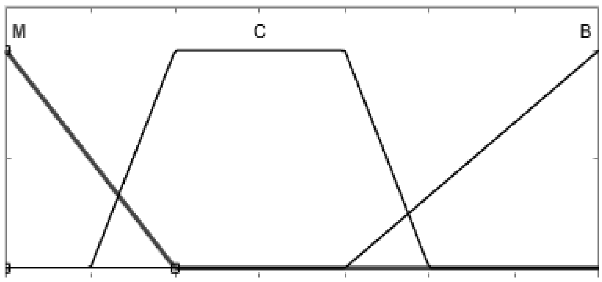

Fig. 5. Terms of the control error

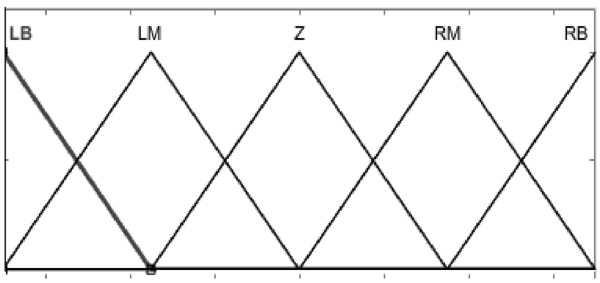

Fig. 6. Setting the input control signal

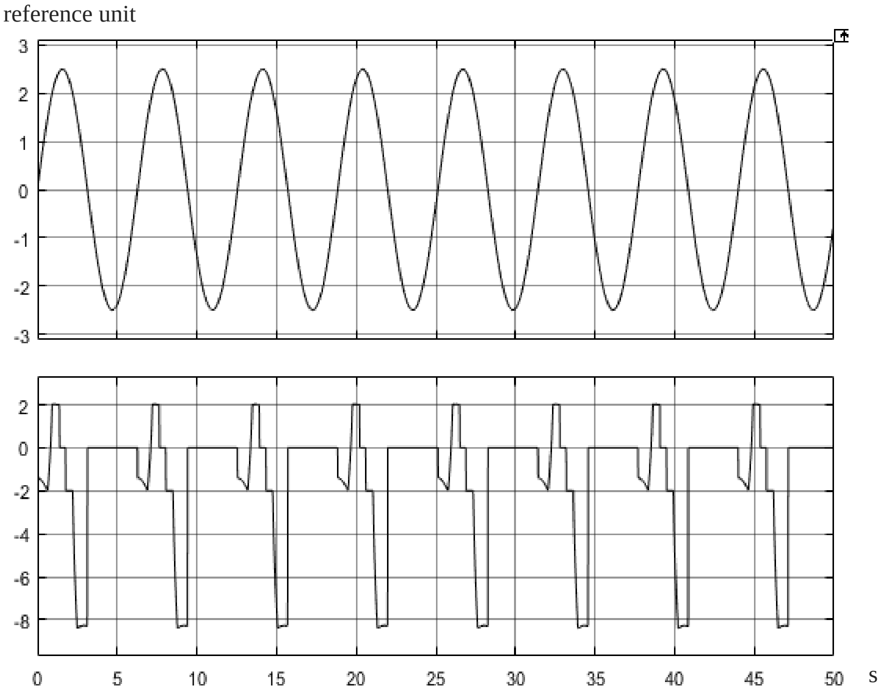

Fig. 7. Input signal from the distance controller

Fig. 8 and 9 represent the result of operation of the course controller, which forms the vector of signals for the propulsion and steering complex.

Fig. 8 shows the signal that forms the angle of rotation of the steering nozzle. The second signal (Fig. 9) accounts for changing the speed of the vehicle. The combination of these signals forms a controlling action on the PSC, which changes the trajectory of the AUUV.

It is clear from the simulation results that the vehicle changes the motion trajectory when the agent operating together with it violates the set range of deviation.

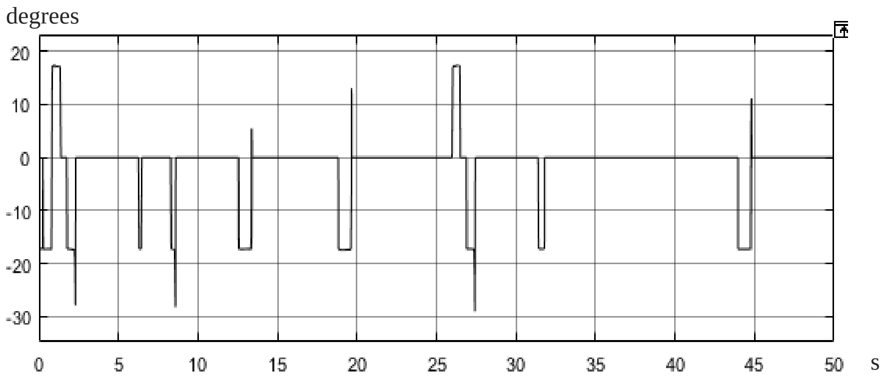

Fig. 8. Signal about the change in the steering nozzle's angle of rotation

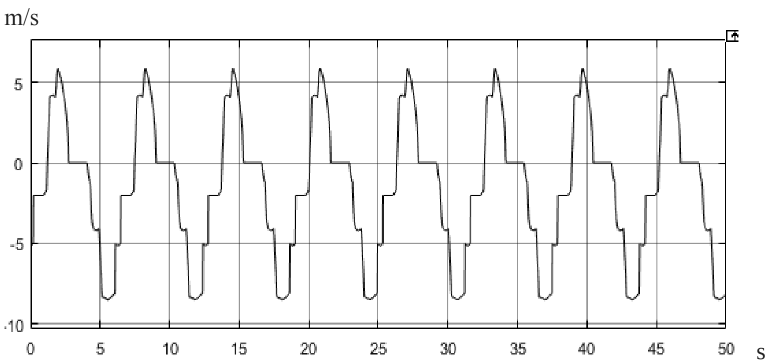

Fig. 9. Signal about the change in the vehicle's speed

CONCLUSIONS.

1. There has been developed a mathematical model of the automatic control system for an autonomous unmanned underwater vehicle operating as an agent within a set of other objects.

2. The developed control system consists of two main control units: distance control and course control, which were implemented on the basis of Mamdani-type fuzzy controllers with defuzzification of the control variable via the center of gravity method.

3. The Simulink system was employed to simulate the operation of the AUUV with a task to control the set range of motion deviation from a given object moving along a sinusoidal trajectory. It is important to note that the AUUV cannot exactly repeat the motion trajectory of the controlled object, since it takes time to change the course and speed of movement.

4. The obtained results allow improving the quality of control of a group of remotely operated unmanned underwater vehicles at their maneuvering motion.

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