INSTRUMENT-MAKING
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ПРИЛАДОБУДУВАННЯ
ТА ІНФОРМАЦІЙНО-ВИМІРЮВАЛЬНІ СИСТЕМИ

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METHOD OF CONSTRUCTING THE NAVIGATION SYSTEM OF AUTONOMOUS MOBILE ROBOTS USING FUZZY LOGIC ELEMENTS

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Summary. *Fuzzy logic is used to drive complex process that is difficult to formalize and describe mathematically. To navigate, the information from distance sensors which work in the infrared spectrum radiation is used. Fuzzy system makes decisions based on the output value depending on the input data. Making decision by fuzzy system is due to the conversion of distinct input values to fuzzy, and determining the extent of input relevance to any of fuzzy sets. Calculation of fuzzy operators based on framework built rules is made. The paper contains structural diagram of motion control of autonomous mobile robot based on fuzzy logic. The system is based on artificial neural network, which consists of input, two hidden and output layer. The simulation of autonomous mobile robot control algorithm.*

Key words: *synergy, navigation system, fuzzy logic, multilayer artificial neural network, fuzzification.*

Problem setting. The problem of control of robotic devices has covered a wide range of researches, associated with the creation of an artificial analog of human intelligence, development of navigation systems; modeling of individual functions and structures of robotics control system; the researches of the impact of current and the potential factors on the autonomous system and so on. The research results in the fields of computing, cybernetics, synergy, bio- and nanotechnology make it possible to make predictions for the near future of robotics intensive development as an applied science, creation and widespread adoption of intelligent technical systems. The emphasis in theoretical and practical researches is put on the opportunities of decision-making by the robots without human intervention.

Analysis of recent researches and publications. Fuzzy logic is widely used in the management of complex technological processes, electronics devices [1], in diagnostic and in expert systems [2]. A well-known class of adaptive automatic control systems which include machinery and vehicle subsystems such as engine, transmission, brake system, steering, which require a creation of comprehensive management action. The complete mathematical model of the movement of autonomous mobile robot is very difficult to synthesize since a large number of real technical solutions is based on the expert experience that is difficult to formalize.

The work objective is to build a research the navigation systems of autonomous robot on the basis of fuzzy logic algorithm in the control system.

The object of the research is the control system of autonomous robot equipped with the navigation system that includes the system of sensors determining the distance to surrounding objects.

Forward sensor determines the distance to an obstacle that gets in the corner of its perception, left and right are placed at an angle 45 ° relative to the forward. This placement provides maximum use of the information on accommodation of the nearby objects. The signals from the sensors in the form of analog signals are received by the control unit, which must calculate the direction of motion of the model (Figure 1).

Structure and functions of the navigation system of autonomous mobile robot based on fuzzy logic. Let fuzzy system makes a choice of the variants of the solutions based on the dependence of the output value on several input values.

Let us assume that the mathematical model of dependence of output on inputs is absent and instead of it the base of expert rules in a fuzzy expressions «*if –then*» is used in terms of linguistic variables and fuzzy sets.
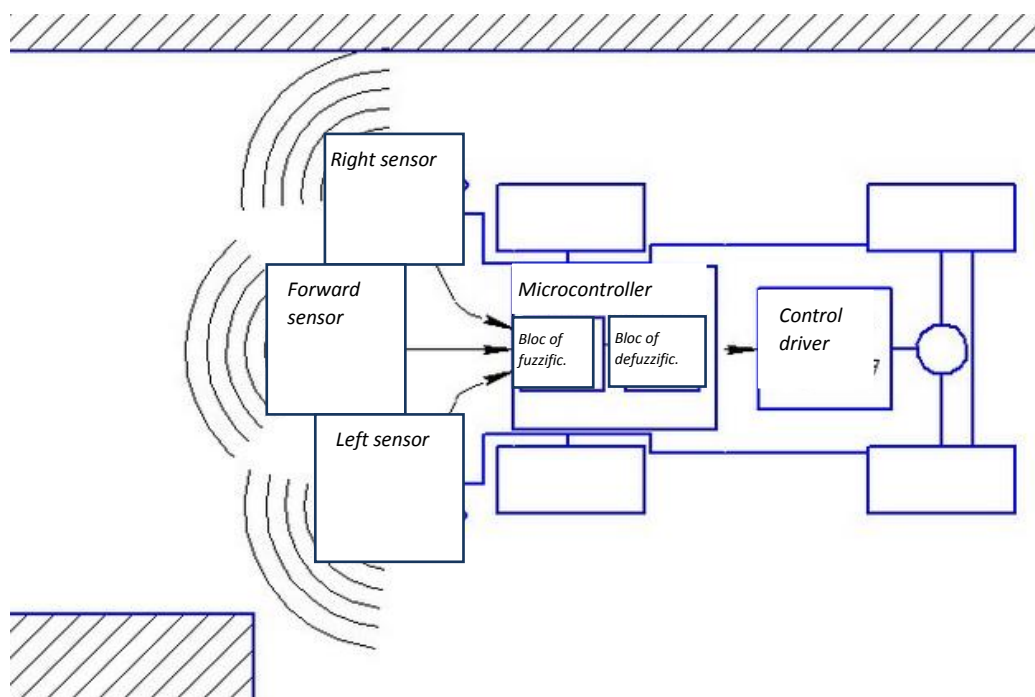

Figure 1. Diagram of the navigation system of autonomous mobile robot

Then the functionality of fuzzy decision-making system is determined by the following steps [3]:

1) conversion of distinct input variables to the fuzzy, that is determination of degree of compliance of inputs with each of the fuzzy sets;

2) calculation of the rules based on the use of fuzzy operators and the use of implication to obtain output values of the rules;

3) aggregating of fuzzy outputs of the rules into general output value;

4) converting of fuzzy output of the rules into distinct value.

The structure of the system with the fuzzy logic is shown in fig. 2. This scheme consists of input, of two hidden and of output layer.

The first layer shows a system inputs, the second layer – fuzzy linguistic variables, the third layer – the rules on fuzzy variables, the fourth layer – outputs of the rules. Scales of all

the layers except the last are equal to 1. Scales of the ties between the layer of the rules and the output layer are defined by the learning algorithm.

Inputs $\bar{x} = (x_i/i=1..n)$ and the output y are distinct controlled values. Each parameter x_i, $i=1..n$ has fuzzy equivalent in the firm of a linguistic variable $\tilde{X}_i = \{A_{i,j} \mid j = 1..m_i\}$. Linguistic variable i $\tilde{X}_i$ consists of m_i terms $A_{i,j}$, each of which is a fuzzy set.

The rules R_k, $k = 1..N$ check the meanings of each linguistic variable, so the maximum possible number of rules is equal to $N_{\max} = \prod_{i=1}^{n} m_i$. The real number of the rules we will denote by $N < N_{\max}$. The output of the rule – is the linguistic variable, which takes the value of one of the terms Bj. To summarize the rules we will conduct the aggregation of their fuzzy outputs into a single fuzzy set with its subsequent conversion to a distinct output value y.

Phasing deals with the clear converting of distinct input values to fuzzy sets. For this we will use the singleton model [4].

While phasing the clear input x_i the degrees of its compliance with every linguistic term $A_{i,j}$ with respective membership functions are determined.

Let us formulate the rules for fuzzy logic conclusion. Fuzzy input values of the system are converted to output on the basis of the rules of fuzzy logic, which is typical for expert decision-making systems. As the decision-making system performs conversion of values n of input linguistic variables $\tilde{X} = \{\tilde{X}_i \mid j = 1..n\}$ into linguistic output. The rules R accumulate the knowledge of experts in the form of fuzzy $R = A \rightarrow B$, which can be regarded as a fuzzy set on the Cartesian product media of input and output fuzzy sets. The process of obtaining the fuzzy result from the fuzzy input sets based on knowledge $A \rightarrow B$ we will depict in this form

$$B' = A' \bullet R = A' \bullet (A \rightarrow B), \tag{1}$$

where $\bullet$ – is a composite rule of fuzzy inference.

We will use maximum of composition for fuzzy inference and we will realize fuzzy implication by means of finding a minimum of the membership functions.

To simulate the work of an expert system according to the scheme of implication we will use a set of fuzzy rules, each of which is constructed as a conditional operator:
if – is logical expression, then – is an operator, where *logical expression* – is the statement which is built on the bases of basic logic operations on fuzzy values; operator – is a resulting decision. The rules can determine the ratio of compliance (is) between the input linguistic variables $\tilde{X}$ and their fuzzy terms $\{A_{i,j} \mid j = 1,...,n; j = 1,..m_i\}$. The use of conditional fuzzy rules is natural for knowledge representation by the experts and simplifies its mechanical processing.

In general, the rule may include all possible combinations of linguistic terms for each input variables, combined by the logical operations. It should be noted that by means of conversions of fuzzy sets any rule containing in the left part a conjunction and disjunction, can be transformed into a system of rules in the left part of which will be only just conjunctions, or just disjunctions. To determine the fuzzy conjunction the finding of the minimum can be used, and for fuzzy disjunction – the finding of the maximum of two membership functions. Not reducing generality, we will consider the rules that are based on the basis of conjunction. Let us consider the model of Mamdani (Mamdani) [5]. Mamdani model operates only with linguistic variables and with the fuzzy sets and transforms fuzzy inputs into fuzzy outputs unclear [6]. For Mamdani model the rules will look like

$$R_k : if \ \tilde{X}_1 \ is \ A_{1,k} \ and...and \ \tilde{X}_n \ is \ A_{n,k} \ then \ \tilde{Y} \ is \ B_k \ , \tag{2}$$

where $A_{i,k} \in \tilde{X}_i$ – are the fuzzy sets for inputs and $B_k \in B$ – are fuzzy sets for the output linguistic variable that are used in k-th rule (k = 1..N). Operation *and* is interpreted as t – a norm of fuzzy sets.

       Fuzzy logic is introduced into the algorithm control by the elements of human thinking. In this connection, the usual mathematical model of the process is not the basis for the design of the models based on fuzzy logic. Controllers that are designed by this method for the realization of human thinking are «programmed» using the language of fuzzy logic, realized through the membership functions, rules and their interpretation. Modeling of the control algorithm of this autonomous system is achieved through a package MATLAB FUZZY Toolbox. Which includes the algorithm (mamdani), which operates the knowledge bases that are transparent and are intuitively clear are shown in fig. 2.
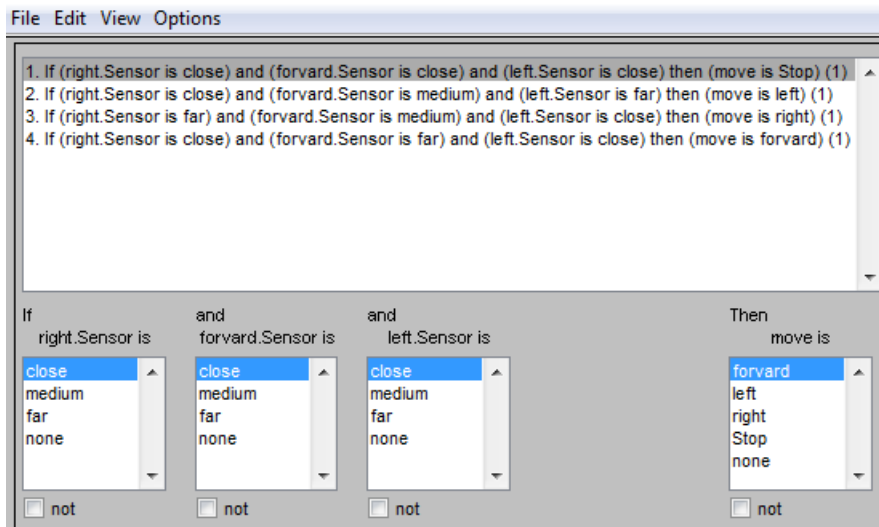

Figure 2. Base rules simulated in MATLAB

Setting the direction of the motion depending on the input value:
– 0..100, motion is carried to the left;
– 100..150, motion is carried to the left;
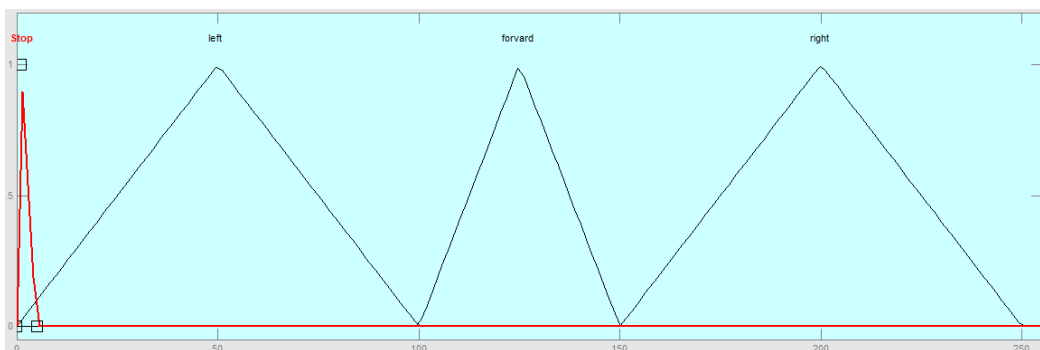– 150..250, motion is carried to the right;
– 0..15 stop.

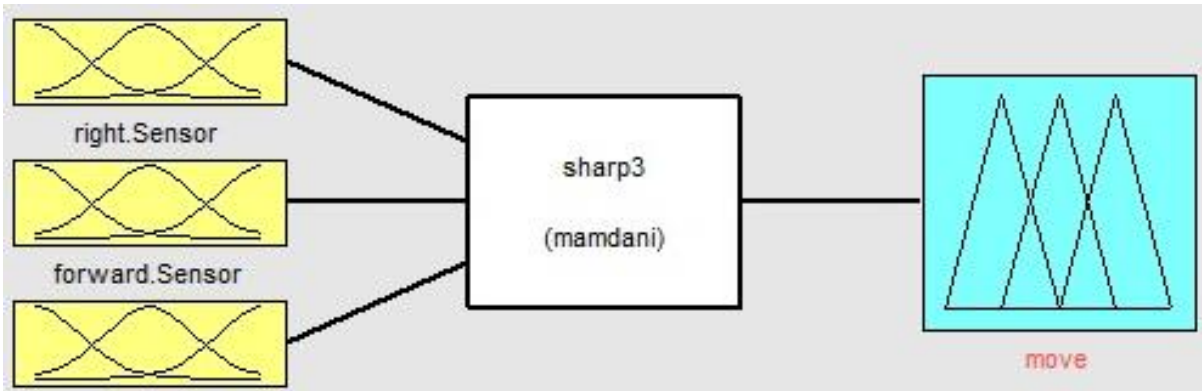**Figure 3.** Structure of distinct output values MATLAB

Figure 4. Structure of the control algorithm in the environment MATLAB

Fuzzy output for navigation system of autonomous mobile robot

Let the base of fuzzy rules of decisions-making includes determined by the experts dependencies of the change of direction of autonomous model on the indicators of the interference sensors.

We will introduce linguistic variables: signals of the left, forward and right sensors (low, medium, high); motion of the model (stop, to the right, straight, to the left).

Here are a few of the possible rules:

R1: if the left sensor has high level and low forward and low right then the motion of the model is to the left;

R2: if the left sensor has a low level and low forward and low right then the motion of the model is straight;

R3: if the left sensor has a low level and high forward and high right then the motion of the model is to the right;

R4: if the left sensor has a low level and low forward and right low then the model stops.
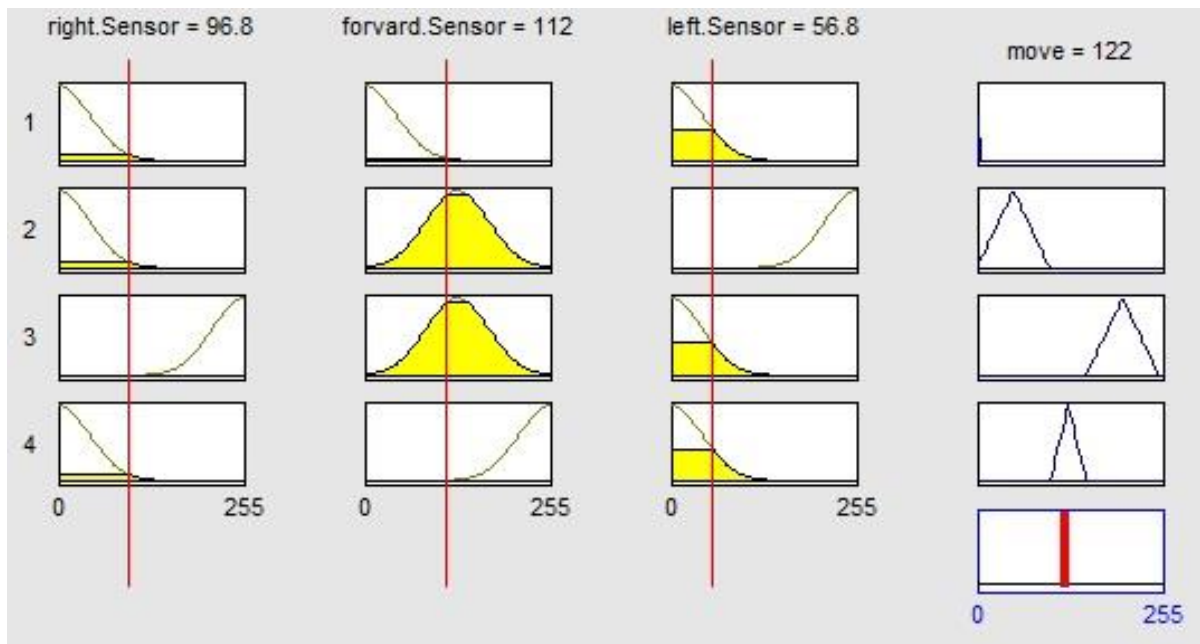

Figure 5. Structure of the input values and sensor output AMR

Conclusions. The designed model makes it possible to choose the optimal control of the motion of robot for a given route based on data from the sensors and the use of the base of

formation rules of the output signal of control. Apparatus of fuzzy logic has several advantages, such as flexible response to variable dynamic processes; improvement of the accuracy of processing of the inputs; reduction in time to make decisions through the system of simple flexible linguistic rules that affect directly the accuracy and speed of decision making in rapidly changing environment where the studied model is situated.

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МЕТОД ПОБУДОВИ СИСТЕМИ НАВІГАЦІЇ АВТОНОМНОГО МОБІЛЬНОГО РОБОТА ІЗ ВИКОРИСТАННЯМ ЕЛЕМЕНТІВ НЕЧІТКОЇ ЛОГІКИ

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Резюме. Використання нечіткої логіки знаходить застосування у керуванні складними технологічними процесами, який складно формалізувати та описати математично. Для навігації використовується інформація від давачів відстані, які працюють в інфрачервоному спектрі випромінювання. Нечітка система приймає рішення на основі залежності вихідної величини від вхідних даних. Прийняття рішення нечіткою системою відбувається за рахунок перетворення чітких вхідних значень у нечіткі, та визначення ступеня відповідності входів кожній із нечітких множин. Проводиться обчислення нечітких операторів на основі бази побудованих правил. Наведено структурну схему системи керування рухом автономного мобільного робота на основі нечіткої логіки. Система побудована на основі штучної нейронної мережі, яка складається з вхідного, двох прихованих та вихідного шару. Проведено моделювання алгоритму керування автономного мобільного робота.

Ключові слова: синергетика, система навігації, нечітка логіка, багатошарова штучна нейромережа, фазифікація.