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ABSTRACT

of the dissertation for the degree of doctor of philosophy

DEVELOPMENT OF FUZZY AGGERGATION MODEL OF DISTANCE SENSORS

Specialty: 3337.01 – Information-measurement and control systems (Technique)

Field of science: Technical sciences

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Dissertation work was performed at the "Equipment engineering" department of Azerbaijan State Oil and Industry University, Ministry of Science and Education of the Republic of Azerbaijan.

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GENERAL DESCRIPTION OF THE DISSERTATION

The actuality of the topic. Solution of different problems requires the aggregation of fuzzy information gathered from different sources. Formally, aggregation is a collection of data, linguistic terms, and the process of combining into common result. Aggregation problems are used in many scientific studies, such as decision making under uncertainty, multi-criteria decision making, data processing, widely used in the problems of linguistic data aggregation of information done on fuzzy sets. In this dissertation work the problems of the fuzzy aggregation model of distance sensors based on fuzzy conditions or initial conditions are widely covered. This process covers all the basic concepts of fuzzy set theory - membership functions, linguistic variables, fuzzy implication methods, etc. The development and application of fuzzy decision-making systems consists of diferent stages implemented on the basis of fuzzy logic. Aggregation is a procedure that determines the degree of truth of conditions for each rule of a fuzzy decision-making system.

Goal of the dissertation. The goal of the dissertation work is to develop a fuzzy aggregation model of distance sensors. Taking this into account, the following problems were solved:

- the main characteristics of existing distance sensors were determined, and a comparative analysis was carried out;
- the issue of measuring the distance under conditions of uncertainty by means of an ultrasonic sensor was considered;
- application of fuzzy logic for data aggregation and processing in distance sensors was considered;
- various types of fuzzy data modeling and aggregation, type-2 fuzzy logic and data aggregation based on *Z*-decision making were considered.

Main clauses defended. The following provisions are submitted for defense in the dissertation work:

- the main characteristics of distance sensors were determined, and a comparative analysis was carried out;
- data aggregation and processing based on fuzzy logic in distance sensors was reviewed;

- application of type-2 fuzzy sets and aggregation of information through these sets for decision-making in conditions of deeper uncertainties in distance sensors were considered;

- Z-decision-making tools were applied to the issues of information aggregation in distance sensors.

Research methods. Fuzzy set theory methods, operations on fuzzy sets, aggregation of information based on Z-numbers and type 2 fuzzy numbers are used in the dissertation work. Computer experiments are conducted in MS Excel and Matlab environment.

Scientific value of the thesis. The main scientific innovations of the study are follows:

- information aggregation and processing in distance sensors based on fuzzy logic;

- fuzzy numbers and their aggregation, modeling;

- type-2 fuzzy sets were applied for information processing under conditions of uncertainty in distance sensors and the issue of information aggregation through these sets was considered;

-Z-decision-making tools have been applied to information aggregation issues.

Theoretical and practical significance of research. The issue of developing a fuzzy aggregation model of distance sensors can be applied to various fields of economy, production, and business. This dissertation examines the differences and similarities between several methods and approaches.

Application of the results obtained in the dissertation work. The obtained results and probabilities can be applied in decision-making issues related to various fields.

Approbation of dissertation. Main results of dissertation were presented and discussed at seminars of the department of "Instrument Engineering" of Azerbaijan State Oil and Industry University and International conferences.

Organization where dissertation was realized. Dissertation was realized in Azerbaijan State Oil and Industry University, department of "Instrument Engineering".

Structure of dissertation. Manuscript of dissertation includes introduction, 4 chapters, conclusion, and references.

Publications. In total, 15 scientific works were published. Of the 14 scientific works published on the study, 8 are articles and 6 are conference materials, 1 methodological tool.

MAIN CONTENT OF THE WORK

The introduction highlights the relevance of the topic, the goals and objectives of the research, the main provisions to be defended, research methods, the theoretical and practical significance of the research.

Chapter 1 deals with the main characteristics of distance sensors, that are defined and their comparative analysis is carried out, and distance measurement by ultrasonic sensors, adjustment of input and output parameters of the ultrasonic sensor, simulation of temperature and pressure measuring information switching systems in the Proteus software environment, structural schemes, working algorithms are shown, measuring transducers are shown problems of approximation methods of non-linear output signals were considered.

Sensors are a device, module, machine, or subsystem that aims to detect events or changes in the environment and send information to other electronic devices, usually a computer processor. The sensor is always used in conjunction with other electronic devices. With developments in micromachines and easy-to-use microcontroller platforms, the use of sensors has expanded beyond traditional temperature, pressure, or flow measurement sensor fields, such as MARG (magnetic, angular rate, and gravity) sensors, which are widely used in mechatronics. Sensors are measuring transducers that perform a one-valued functional dependence of one quantity on another. Input quantities can be electrical, non-electrical, magnetic, mechanical, optical, etc. The natural input quantity of the sensor is the physical quantity to which it reacts to any of the quantities characterizing it in the object of measurement. Sensors can be divided into two categories, passive and active.

Passive sensors do not need an additional power source, and according to the change of the external influence, an electrical signal is always generated at its output. They are also called generator transmitters. Generator type transmitters are small powerful measuring devices. Examples of passive sensors are thermoelectric and piezoelectric transmitters.

Active sensors are transmitters that require external energy, called an actuation signal, to operate. These transmitters are also called parametric transmitters.

In addition, analog sensors such as potentiometers and force sensing resistors are still widely used. Applications include production equipment, machinery, aircraft and aerospace equipment, automobiles, medical, robotics and technological tools used in our daily lives. The number of sensors in complex technological processes, information-measurement and management systems of scientific research and testing works is hundreds, sometimes even thousands. Transmitters and their measuring circuits are the main means of systems that measure temperature, force, pressure, flow parameters, spatial position parameters, light intensity, and other physical quantities. They do not operate in isolation and usually perform primary converter functions in the structure of information-measurement and management systems. Therefore, it is necessary to acquire certain knowledge about the primary transmitters of physical quantities, i.e., sensors and their connection methods to information systems. In modern information-measurement systems, many different sensors are used, which differ in their physical principle, the nature of the output signal, and their dynamic range and power. When connecting the sensors with other devices of the system, their output signal should be made to meet the requirements of the level, power, information carrier set by the relevant state standards. Such transformations are called unification. The level of constant current in the system is 0.5 mA; -0.5÷0÷5 mA; 0÷20mA; -20÷0÷20 mA; 4÷20mA; it should be within the limits of -100÷0÷100 mA. 0÷1V in distance measurements; 0÷5V; it is recommended to use 1÷5V signals. There are many other sensors that measure the chemical and physical properties of materials, such as optical sensors to measure refractive index, vibrational sensors to measure liquid viscosity, and electrochemical sensors to monitor the pH of liquids. The sensitivity of a sensor indicates how much the sensor output changes when the measured input quantity changes. Some sensors can also affect the object they are measuring. For example, a thermometer placed in a container of hot liquid is affected by room temperature. Sensors should be designed in such a way that they can have very little impact on the object being measured. Shrinking the sensor can overcome this and provide other benefits. As a result of technological progress, microscopic scale sensors such as microsensors have been developed using the technology of microelectro-mechanical systems. In most cases, microsensors achieve faster, shorter measurement times and higher sensitivity than macroscopic approaches (Table 1).

Table 1

Use of sensors in research

Sensor Name	Quantitative	Use
Ultrasonic Sensors	1	Distance measurement
Light Sensors	2	Light detection
Heat Sensors	1	Temperature detection
Rotation sensors	3	Robot rotation angle

An ultrasonic sensor consists of an ultrasonic transmitter, an ultrasonic receiver, a control circuit, and a power source. The frequency of dances is between 17-20 Hertz and 20,000 Hertz, and our ear perceives the longitudinal elastic wave as sound. Such dances are called acoustic dances. Vibrations with a frequency less than 17 Hertz are infrasound, and vibrations with a frequency greater than 20,000 Hertz are ultrasound. Ultrasound is a sound pressure wave that vibrates at a frequency far above the upper limit of the human hearing range. The upper limit of sound that humans can hear is about 20,000 Hertz. If the frequency of sound is higher than 20000 Hertz, it is called ultrasound. An ultrasonic sensor with a frequency greater than 20,000 Hertz allows the robot to see and detect objects. It is typically used by a robot to avoid obstacles, measure distance, and detect motion.

Ultrasonic sensors use this principle: they measure distance by calculating the time it takes for a sound wave to hit an object and return. It works just like an echo. Ultrasonic measurements and ultrasonic sensor are shown in figure 1(a) and figure 1(b)

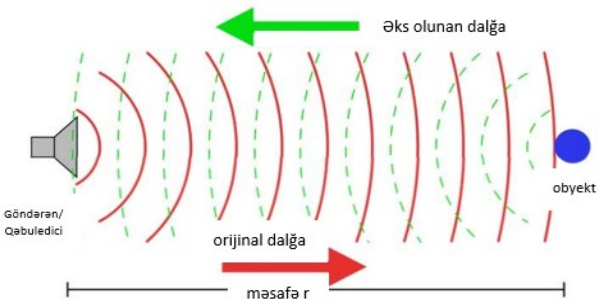

Figure 1(a). The principle of ultrasonic transformation

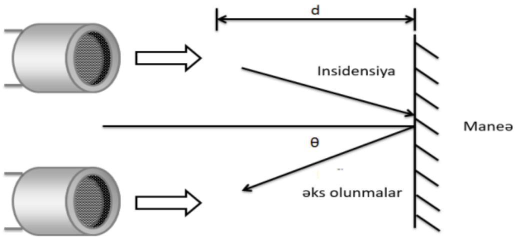

Figure 1(b). The principle of ultrasonic change with a sensor

Figure 2 show the principle of ultrasound change and how the information is obtained by the ultrasound sensor.

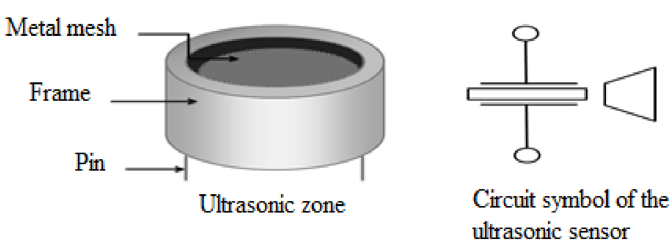

Figure 2. The principle of ultrasonic change with a sensor

The ultrasonic transmitter starts the ultrasonic wave in a certain direction and at the same time the timer (counter) starts to count. When the ultrasound wave hits a wall or obstacle, it echoes and is transmitted back to the ultrasound receiver. Once the ultrasound receiver catches the reflected wave, the timer (counter) will stop counting immediately.

Ultrasonic sensors are commonly used in automation tasks to measure distance, position changes, level, for example as presence detectors or to measure the cleanliness of transparent material in special applications. They are based on the principle of measuring the propagation time of ultrasonic waves. This principle ensures reliable detection regardless of the object's color rendering or design, or its surface type. This principle ensures reliable detection of liquids, transparent objects, glass, etc., regardless of the color or design of the object or the type of its surface. Another advantage of these sensors to use is that they are not very sensitive to spots but can measure distance even in harsh environments. Ultrasonic sensors are manufactured in many designs. In laboratory use, a simple enclosure is used for the transmitter and receiver in a separate or single space, while for industrial use, robust metal enclosures are usually constructed. Several types of sensors allow to adjust the sensitivity using a potentiometer or digitally. Also, the output can be available in analog signal directly in single version or in digital form. In the case of sensors that can be connected to a computer via a communication interface, it is possible to set detailed parameters of the entire sensor operating range and measured distances. Ultrasound has similar propagation characteristics to auditory sound in the environment. This is the mechanical vibration of the environment. Ultrasonic propagation can occur in gases, liquids, and solids. Active ultrasound has a physical or chemical effect when applied. The result obtained obtains higher values. Ultrasound is used in cleaning, welding, drilling and the like. Passive ultrasound output is the contrast generated at smaller values. Its main application areas are distance measurement, material flaw and material thickness detection, liquid and gas flow measurement, and healthcare diagnostics. Speed of sound depends on the type of medium it travels through and the current temperature of the environment. The speed of sound in some materials is shown in table 2.

Table 2

The speed of sound in some materials

Gas (m / s) Solids (m / s)		Gas (m / s) Solids (m / s)		Gas (m / s) Solids (m / s)	
Weather (0 ° C) 331 Al	Weather (0 ° C) 331 Al	Weather (0 ° C) 331 Al	5100	Water (20 ° C)	1481
Air (20 ° C) 343 Steel	Air (20 ° C) 343 Steel	Air (20 ° C) 343 Steel	5000	Water (25 ° C)	1497
He (25 ° C) 965 Concrete	He (25 ° C) 965 Concrete	He (25 ° C) 965 Concrete	1700	Gasoline (20 ° C)	1170
H (25 ° C) 1284 Cu	H (25 ° C) 1284 Cu	H (25 ° C) 1284 Cu	3500	Hg (25 ° C)	1450
He-Helium H-Hydrogen			He-Helium H- Hydrogen		

Ultrasonic sensor SRF08 is sometimes called sonar. It is an ultrasonic obstacle detector and is capable of measuring distances up to 11 m. The block diagram of the ultrasonic sensor is shown in figure 3.

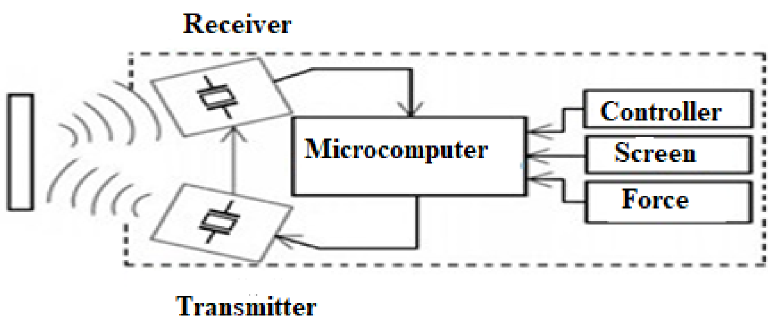

Figure 3. Block diagram of the ultrasonic sensor

The measuring principle of the sensor is an ultrasonic signal in octave cycles and a frequency of 40 kHz. Sonar measures the time between sending a test signal and receiving its reflection. It is possible to read the measured values as a data management system. According to this principle, one of the biggest advantages of the sensor is the ability to measure objects only at desired distances. The sensor communicates via the I2C communication bus. This fact allows for sensor addressing and creation of sensor matrices at the same time. In addition to changing the factory-set base address, the sensor allows selection of ambient light measurement units and output variables. Sonar sensors are also suitable for use in neural networks. The main features of SRF08 distance sensor are power supply voltage 5V, current consumption 12mA, standby frequency 40kHz, measuring range 43mm-11000mm, communication bus - I2C, main address - 0xE0 (adjustable 16 addresses), measurement mode multiple echoes, unit inch, cm, microsecond, dimensions are 43x20x17 mm. Primary registers only allow writing in the range (0-2), the others read and write. The SFR08 sensors have a total of 36 records.

An example of traces during a typical test is shown in figure 4. The thick line is the current output of the ultrasonic sensor, and the thin line is the calculated, predicted output. D is the height of the measuring head.

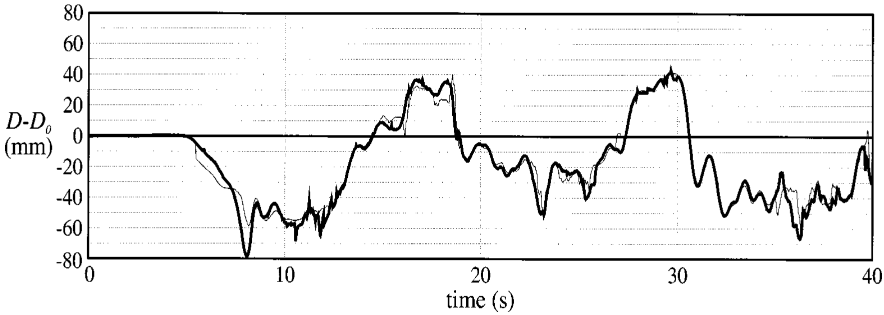

Figure 4. Example of traces during a typical test

The temperature measuring information system consists of 3 TCM-277-01 type temperature transmitters (thermoresistance), 1 Kp590KH6 type 8-input switch, Sh79 type unification (normalizing) converter, K11113PV1 type 10-level analog-to-digital converter (ADC), K1816VE51 type programmable universal It consists of a controller, a digital display device (K9Q), a RAVI-800 type alphanumeric printing device. The structural scheme of the temperature measurement information system is shown in figure 5.

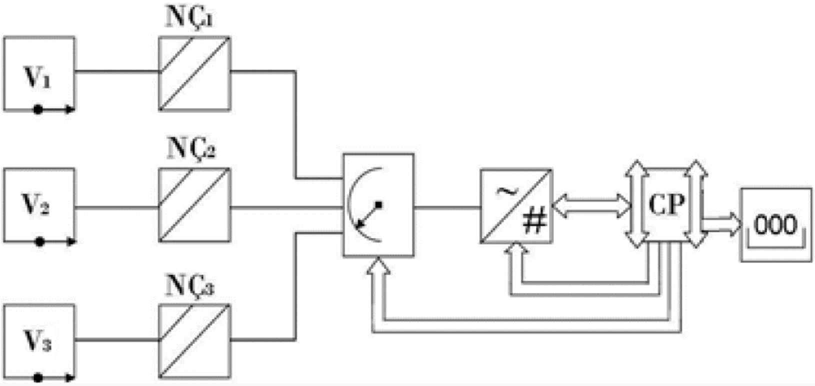

Figure 5. The structure of the temperature measuring information system

The thermoresistance is connected to the electrical circuit and exchanges heat with the environment. Requirements such as a temperature coefficient of resistance as large as possible, chemical resistance to environmental influences, sufficient strength, and high specific electrical resistance are imposed on the material of thermoresistance. Thermoresistors are non-preheated and superheated types. In non-preheated converters, the current flowing through the resistor does not heat it, and the temperature of the thermistor is determined by the ambient temperature. Such thermoresistances are used to measure temperature. In superheated converters, the heating caused by the current depends on the properties of the environment.

The operation scheme of the temperature measurement information system in the Proteus software environment is shown in figure 6.

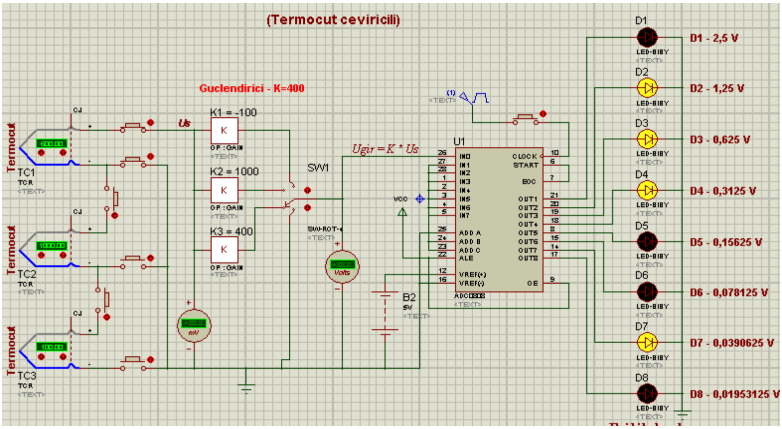

Figure 6. Operating scheme of the temperature measurement information system in the Proteus software environment (simulation)

Such converters measure the speed, density, composition of the medium, etc. used to measure. In most cases, pure metals are used as the material of conducting thermoresistors, because the temperature coefficients of electrical resistance of alloys are small. In addition, the temperature dependence of the resistance of pure materials is well known, which makes it possible to standardize the devices in which they are used. Copper, platinum, and nickel are mainly used for thermoresistors. Platinum thermoresistors allow heating up to 1200°C. The conversion equation is nonlinear. The main drawback of platinum thermoresistors is the non-linearity of the conversion function. However, the high recovery property of Rt = f(t), stability and plasticity of platinum make it indispensable in many cases. Nickel thermoresistors from +250°C

It is applied up to a temperature of + 300°C. At higher temperatures, the dependence Rt=f(t) is not single-valued. The electrical properties of nickel depend on the alloy and thermal treatment. The main advantages of nickel are its high specific resistance and temperature coefficient of resistance. As you can see, the system works on the principle of separation of signals by time.

According to the code from the microcontroller, the TV1 temperature sensor, then TV2 and then TV3 temperature sensors are connected to the input of the system in a certain order. The resistance generated in the thermocouple is converted into an electrical signal (voltage or current) through a normalizer. The electrical signal is converted into a code through an analog-to-digital converter and enters the microcontroller. The received code is processed by a certain algorithm in the microcontroller and the temperature of the environment where the thermoresistance is located is calculated. The temperature value is displayed on the digital display and documented by printing on the printer. The operation scheme of the pressure measuring information system in the Proteus software environment is shown in figure 7.

The working principle of the pressure-measuring information system was developed accordingly. The pressure measuring information system consists of 3 Sapfir-22DH type sensors, 1 KP590KH6 type 8-input switch, K1113PV1 type 10-level analog-to-digital converter, K1816VE51 type programmable universal microcontroller, digital unification, and alphanumeric printing for presenting the measurement result consists of devices. The operation of the system is controlled by a microcontroller.

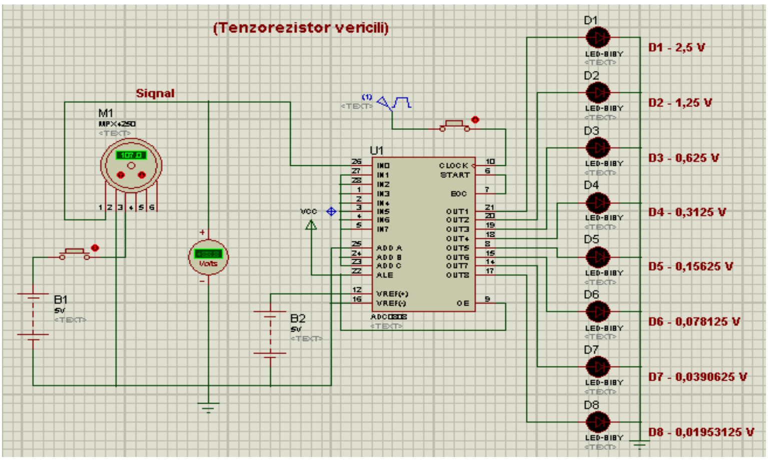

Figure 7. Operation scheme of the pressure measuring information system in the Proteus software environment

The digital-to-analog conversion block is defined to convert information given in digital form into analog information that affects the executive mechanisms of the controlled object. The output signal of the module is a unified constant current signal varying in the range of 0-5mA.

The operation scheme of the information system that measures various parameters in the Proteus software environment is shown in figure 8.

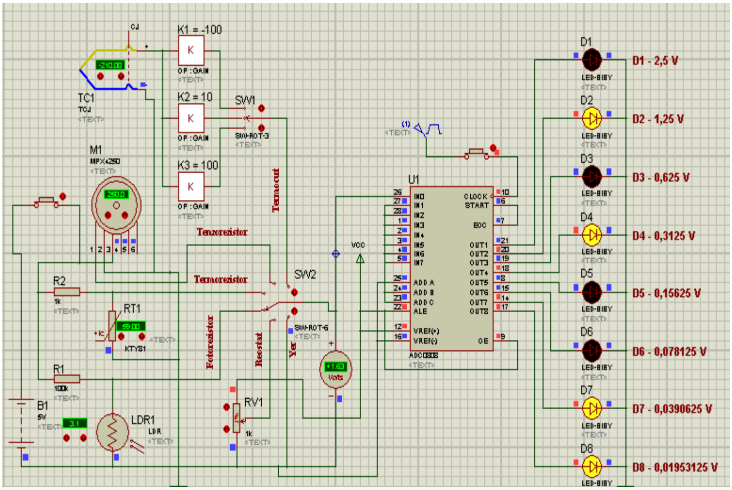

Figure 8. Operating scheme of the information system that measures various parameters in the Proteus software environment

The wide application of microprocessors and microcontrollers in measuring systems has made it possible to abandon the centralized principle of technological process management and move to a more flexible and reliable distributed control and management principle. In this case, the calculation, logical decision-making, and similar issues that the measurement system should perform are distributed among their separate organizers. The functions performed by different measurement and calculation tools are also different. Examples of such functions include automatic selection of the measurement threshold, selection of operating mode, acceleration, self-test and selfdiagnosis operations, linearization of the conversion function, etc. can be shown.

Advances in sensor technology have increased the applications of sensor networks in many fields such as industrial monitoring, building and home automation, medicine, environmental monitoring, urban sensor networks, intelligent transportation. These networks are used for security, military defense, disaster prevention, etc. can also be used for Indoor environmental monitoring includes two main applications of wireless sensor networks: collecting information on physical parameters of the environment and fire and smoke detection to better control environmental systems such as heating, ventilation, and air conditioning. Critical events such as fire can cause severe structural damage to an enclosed space and life-threatening conditions, so early fire detection in residential areas is essential to immediately reduce damage and loss of life. The main purpose of sensor networks for fire detection is to collect controlled original data and provide basic information and decision support for the monitoring center. Also, the data extraction algorithm must be fast enough to process high-speed incoming data. Sensor circuitry may often require in-network processing, where data is processed at a higher level before further processing. In this way, individual nodes acquire and process local information and must communicate with neighboring nodes, send local and partial models, and make an overall decision to obtain a collective decision. In this case, it becomes difficult to store all the data and it must be processed immediately with compression and filtering for more effective extraction and analysis to create real-time moving images from massive, heterogeneous, and dynamic data. This reduces transmission costs and reduces data storage overhead. Sensor data collection (acquisition) is a relatively new field, but it has already reached a certain level of maturity. Data mining in sensor networks is the process of extracting application-based models and patterns from a continuous, rapid, and possibly infinite stream of data from sensor networks with reasonable accuracy. However, extracting useful knowledge from raw, i.e., unprocessed sensor data is a difficult process, and sensor networks are not directly applicable due to traditional data mining methods, distributed nature, and characteristics of sensor data (massive amount and high dimension), limitations of sensor networks and sensor nodes. This is a reason to explore new data mining techniques that deal with the extraction of information from the large volumes of data continuously coming from sensor networks. The main purpose of data mining techniques is to find and describe structural patterns in the data to attempt to explain the relationships between the data and create predictive models based on them. For these reasons, in recent years, there has been great interest in applying data mining techniques to large volumes of sensor data in the research field. On the other hand, when observing a system or process through measurements, the measured quantity is almost always subject to various types of uncertainty. For example, if we consider a sensor to measure a physical quantity of interest, the output of the sensor is likely not directly proportional to the actual physical quantity, depending on the principle of the sensor and its implementation, but instead is the result of a non-linear dependence.

Similar readings from two sensors with different nonlinear characteristics can lead to values of the actual physical quantity with different uncertainty intervals. Also, the characteristics can vary even for one sensor under different measurement conditions. The graph of two sensors with different nonlinear characteristics is shown in figure 9.

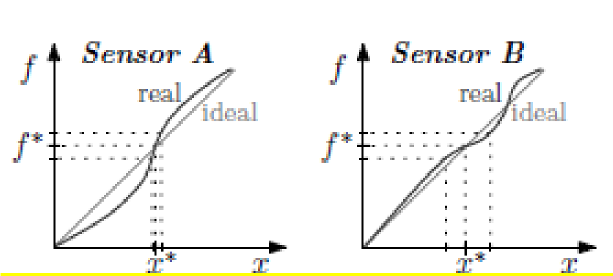

Figure 9. Graph of two sensors with different nonlinear characteristics

In measurement information systems used in various fields, when a non-linear sensor is used in the conversion function, it is necessary to perform non-linear functional conversion operations on numbers in micropossessors in all cases during straight measurements, indirect and joint measurements. The issues of approximation of functional dependencies during transformations performed in intelligent measurement tools and information measurement systems are considered relevant. For this purpose, various approximation methods are used. The purpose of approximation is to describe nonlinear functions in a simpler, more convenient way for use and calculations with negligible loss of accuracy.

Chapter 2 deals with information on fuzzy sets, basic elements of fuzzy system, fuzzy aggregation operators, application of fuzzy logic in data aggregation and processing in distance sensors were considered.

There are three main elements in a fuzzy system. They are fuzzy sets, membership functions and rules. Fuzzy sets are the basis of fuzzy logic system, and membership functions are used to represent fuzzy sets graphically. Rules work like the human brain, helping a fuzzy logic system to make decisions.

Fuzzy sets are generalizations of classical sets represented by characteristic functions. Unlike classical sets, in fuzzy sets different degrees of membership are allowed. The membership function of a fuzzy set is a generalization of the indicator function in classical sets. In fuzzy logic, the membership function represents the degree of truth. Membership functions allow us to describe a fuzzy set using a diagram. Since fuzzy concepts are defined, simple functions are generally chosen to construct membership functions for fuzzy sets. Using more complex functions does not add much precision. The most used membership functions are the triangular membership function, the trapezoidal membership function, and the Gaussian membership function. Figure 10 shows a triangular membership function.

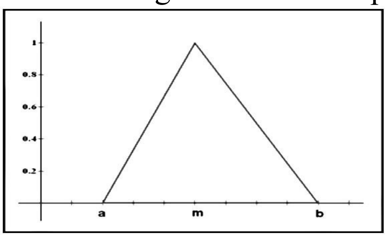

Figure 10. Triangle membership function

The equation of the triangular membership function is shown as follows.

$$\mu(x)=\begin{cases} 0, & x\le a \\ \dfrac{x-a}{m-a}, & a<x\le m \\ \dfrac{x-b}{b-m}, & m<x<b \\ 0, & x\ge b \end{cases}. \quad (1)$$

Here, a is defined as the lower bound, b as the upper bound, and m as the mean value of the fuzzy number in the triangular membership function.

Figure 11 shows a trapezoidal membership function.

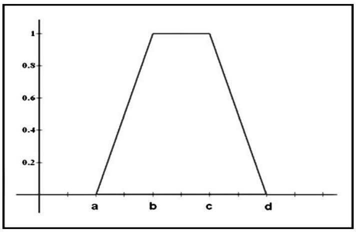

Figure 11. Trapezoidal membership functions

The equation of the trapezoidal membership function is shown as follows:

$$\mu_A(x)=\begin{cases} 0, & (\mathrm{x}<\mathrm{a}),(\mathrm{x}>\mathrm{d}) \\ \dfrac{x-a}{b-a}, & a\le x\le b \\ 1, & b<x<c \\ \dfrac{d-x}{d-c}, & c\le x\le d \end{cases}. \quad (2)$$

Here, μ_L:[a,b] $\rightarrow$[0,1] and μ_R:[c,d] $\rightarrow$[0,1] are the left and right membership functions of the fuzzy number and are expressed as $a<b<c<d$.

In figure 12, the membership function is determined by means of the Gaussian curve:

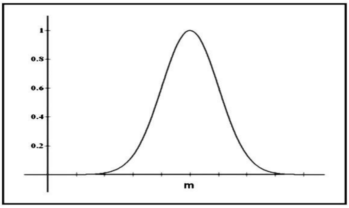

Figure 12. Gaussian membership function

The equation of the Gaussian membership function is shown as follows:

$$\mu_A(x) = \mathrm{e}^{\frac{(x-m)^2}{2k^2}} \tag{3}$$

Here, the Gaussian membership function is defined by m-mean and k-standard deviation ($k > 0$) , and the smaller k is the narrower the bell curve will be.

The microcontroller is based on fuzzification blocks, solutions, defuzzification and a database. The fuzzification block transforms fuzzy quantities into fuzzy quantities whose values are predefined in the knowledge base as linguistic terms. The decision block is designed to match fuzzy condition rules defined in the database to transform fuzzy input data into fuzzy control signals. The defuzzification block is designed to convert the fuzzy quantities from the decision block into the fuzzy quantity used to control the object. According to the technical characteristics, we define the input linguistic variable "Distance to the obstacle" with a permissible value range between 30 and 350 mm. There is no absolute certainty that a failure will occur up to 35 mm, and it should be noted that, for example, 110 mm corresponds to the category of "failure" with a degree of 0.9. However, 1 rank can be assigned from 40 mm to 100 mm, that is, failure at these values will be unambiguous. After values of 120 mm, failure is considered to have been measured, but not yet occurred, as the distance corresponding to the term "failure" should be in the range of 0 to 1 degree. This fact creates a signal to record the "pre-failure condition". The larger the distance quantity, the less relevant the corresponding period, as the degree tends to 0, the frequency of recording the sensor's output signals increases. As a result, a fuzzy set is defined that represents the concept of failure in the entire measurement range of the sensor. Remote sensors use multiple sensor networks that continuously collect data from a specific area and send it to a database. Cluster-based data collection and aggregation is one of the main procedures for distance sensors.

The measured value of the distance in terms of linguistic terms (very close, close, accident) is shown in figure 13. The degree of relevance of fuzzy rules is defined by the name of relevance function. In our case, a distance 120 mm is considered very close, and 240 mm is considered close.

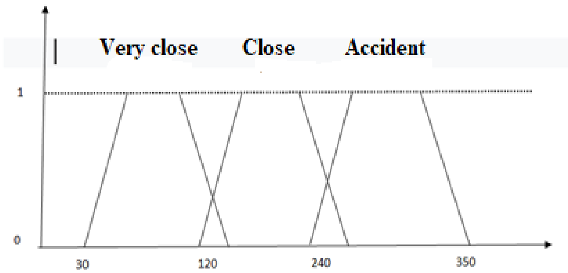

Figure 13. Graph for determining the fuzzy set of distance sensors

Clustering is an important procedure to extend the lifetime of a distance sensor network. The cluster head combines the data received from the corresponding cluster nodes and sends it to the base station. The main problem of distance sensor network is the selection of suitable node heads. Properly selected hubs reduce power consumption because there are short paths between sensors. For this, the development of a fuzzy aggregation model of distance sensors is one of the important issues. Existing methodologies in distance sensor technology allow researchers to reduce the security problems in distance sensor network by calculating aggregated data, energy consumption of sensor nodes, application of shortest path search algorithm. Energy consumption can be reduced by applying data collection and aggregation methodology. Data aggregation is a set of information that needs to be collected at the right time to use the energy of sensor nodes more effectively. For more effective data aggregation, temperature sensors, humidity sensors, etc. with the same characteristics. The information received from various sensors is collected once and sent for further processing. Clustering is the best option to reduce energy consumption and communication load, increase network lifetime by minimizing redundant data. Here, the development of a proposed fuzzy aggregation model for aggregating data from distance sensors at the receiver node is considered.

Chapter 3 deals with various types of fuzzy data modeling and aggregation, fuzzy object aggregation methods. As an example, the simulation of the motion sensor of the robot in the Matlab environment was considered. In these robots, the relationship between the input and output parameters is determined in the microcontroller built in the fuzzy logic system. The robot tries to avoid obstacles with fuzzy logic. Obstacles are in front, left and right of the robot. Therefore, there are three input parameters, quantities. At the output, a sound signal from the left is sent to the object and the distance is measured by calculating the time it takes to return. There is an output quantity corresponding to this distance. The sum of all outputs appears at the end, the aggregation is performed. The processing of the result begins with the processing of rules organized by If-Then statements. The antecedent or condition block of a rule is defined by an If statement, and the result or result block is defined by a Then statement. The value assigned to the result block is equal to the logical sum of the activation values of the previous membership functions characterizing the boundaries of fuzzy sets. The activation value is equal to the value of the membership function where the input variables intersect at the time of evaluation. A defuzzification operation is performed to transform the fuzzy values represented by logical inference and sequential membership functions into a stable and accurate result. In the Matlab environment, we can show the general interface of the fuzzy controller as shown in figure 14.

In the most common If-Then fuzzy relationships in soft computing technologies, dependencies between fuzzy sets are performed and explored based on rules developed by experts. The aggregated result is obtained after determining the truth for each rule specified in the rule form. Dependencies between fuzzy sets in If-Then fuzzy relations in Matlab environment are shown in figure 15.

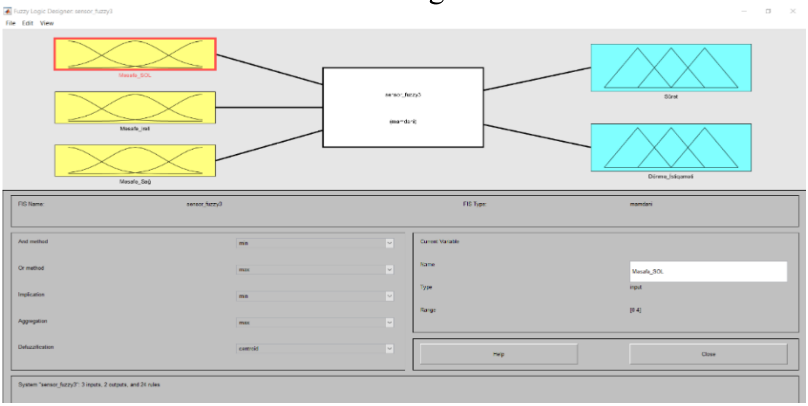

Figure 14. General interface of fuzzy controllers built in MATLAB

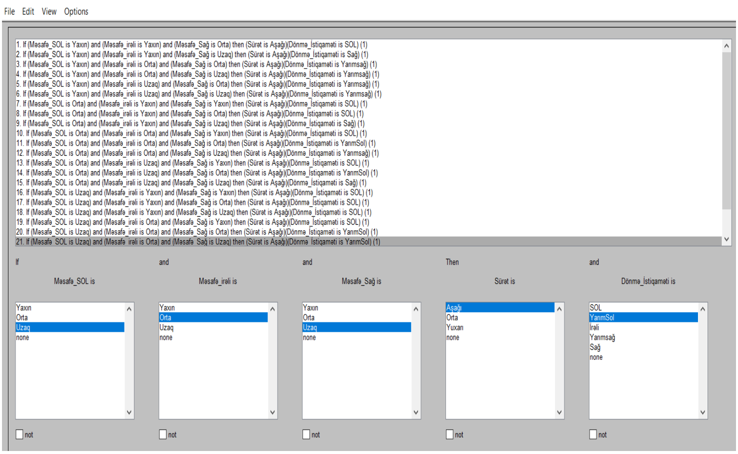

Figure 15. Dependencies between fuzzy sets in IF-THEN fuzzy relations.

The rules showing the simulation of the motion sensor of the robot in the MATLAB environment are put forward by the experts. The 25 rules showing the robot's motion sensor simulation are organized as follows:

1. If (Distance Left is Close) and (Distance Forward is Close) and (Distance Right is Medium) then (Speed is Down) (Rotation Direction is Left)
2. If (Distance Left is Close) and (Distance Forward is Close) and (Distance Right is Far) then (Speed is Down) (Rotation Direction is Right)
3. If (Distance Left is Close) and (Distance Forward is Middle) and (Distance Right is Medium) then (Speed is Downhill (direction is Semicircle)
4. If (Distance Left is Close) and (Distance Forward is Middle) and (Distance Right is Far) then (Speed is Down) (Rotation Direction is Semi-Right)
5. If (Distance Left is Close) and (Distance Forward is Far) and (Distance Right is Medium) then (Speed is Down) (Rotation Direction is Semi-Right)
6. If (Distance Left is Close) and (Distance Forward is Far) and (Distance Right is Far) then (Speed is Downhill Direction is Semi-Right)
7. If (Distance Left is Middle) and (Distance Forward is Close) and (Distance Right is Close) then (Speed is Downhill Direction is Left)
8. If (Distance Left is Middle) and (Distance Forward is Close) and (Distance Right is Middle) then (Speed is Low) (Rotation is Left)
9. If (Distance Left is Middle) and (Distance Forward is Close) and (Distance Right is Far) then (Speed is Down) (Rotation Direction is Right)
10. If (Distance Left is Medium) and (Distance Forward is Medium) and (Distance Right is Close) then (Speed is Down) (Rotation Direction is Left)
11. If (Distance Left is Medium) and (Distance Forward is Medium) and (Distance Right is Medium) then (Speed is Low (Rotation Direction is Half Left) Rotation direction is Halfway)

12. If (Distance Left is Middle) and (Distance Forward is Medium) and (Distance Right is Far) then (Speed is Low) (Rotation direction is Semi-Right)

13. If (Distance Left is Middle) and (Distance Forward is Far) and (Distance Right is Close) then (Speed is Down) (Rotation Direction is Left)
14. If (Distance Left is Middle) and (Distance Forward is Far) and (Distance Right is Medium) then (Speed is Down (Rotation Direction is Half Left)
15. If (Distance Left is Medium) and (Distance Forward is Far) and (Distance Right is Far) then (Speed is Down) (Rotation Direction is Right) 16. If (Distance Left Far is Far)) and (Distance Right is Close) then (Speed is Down) (Rotaion direction is Left)
17. If (Distance Left is Far) and (Distance Forward is Close) and (Distance Right is Medium) then (Speed is Downhill Rotation Direction is Left)
18. If (Distance Left is Far) and (Distance Forward is Close) and (Distance Right is Far) then (Speed is Down) (Rotation Direction is Left)
19. If (Distance Left is Far) and (Distance Forward is Middle) and (Distance Right is Close) then (Speed is Down) (Rotation Direction is Left)
20. If (Distance Left is Far) and (Distance Forward is Middle) and (Distance Right is Medium) then (Speed is Low)
21. If (Distance Left is Far) and (Distance Forward is Middle) and (Distance Right is Far) then (Speed is Down) Rotation Direction is is Half Left)
22. If (Distance Left is Far) and (Distance forward is Far) and (Distance Right is Close) then (Speed is Down) (Rotation direction is Left)
23. If (Distance Left is Far) and (Distance Forward is Far) and (Distance Right is Medium) then (Speed is Down) (Rotation Direction is Half Left)
24. If (Distance Left is Far) and (Distance Forward is Far) and (Distance Right is Far) then (Speed is Up) (Rotation direction is Forward)

25.If (Distance Left is Far) and (Distance Forward is Close) and (Distance Right is Far) then (Speed is Down) (Rotation Direction is Left)

Let's look at the fuzzification of input and output quantities in the MATLAB environment using these rules.

The fuzzification of the input quantity "Distance Forward" is shown in figure 16.

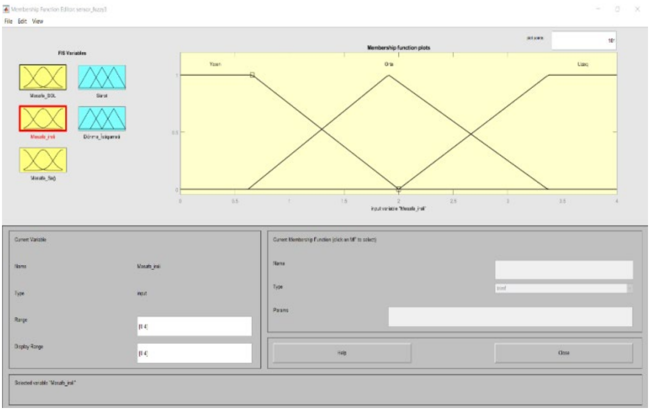

Figure 16. Fuzzification of the input quantity "Distance Forward"

The fuzzification of the input quantity "Distance Right" is shown in figure 17.

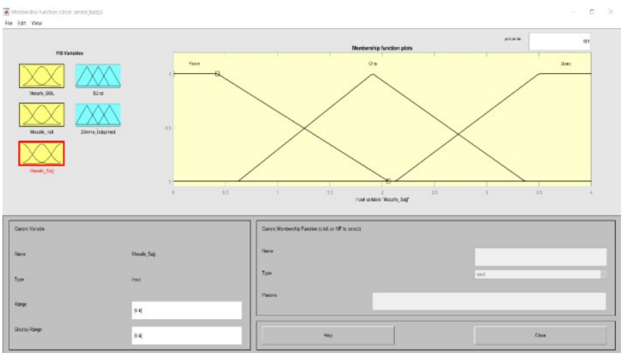

Figure 17. Fuzzification of the input quantity "Distance Right"

The fuzzification of the output quantity "Velocity" is shown in figure 18.

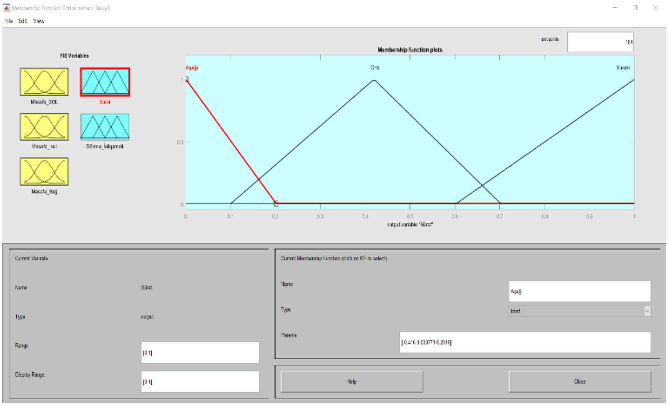

Figure 18. Fuzzification of the output quantity "Speed"

The fuzzification of the output quantity "Rotation angle" is shown in figure 19.

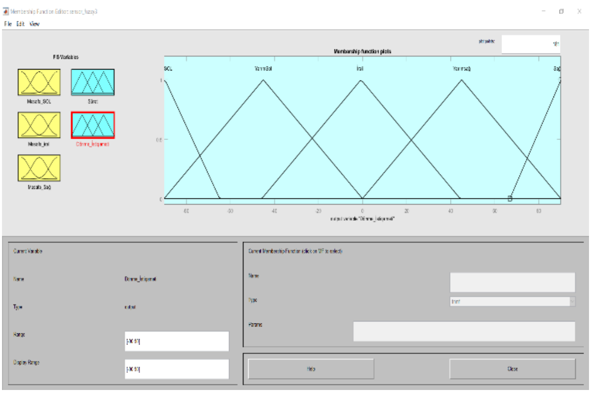

Figure 19. Fuzzification of the output quantity "Rotation angle"

In the MATLAB environment, the result of the activation of the rules using the rule table of the dependencies between the fuzzy sets in the If-Then fuzzy relations is as shown in figure 20.

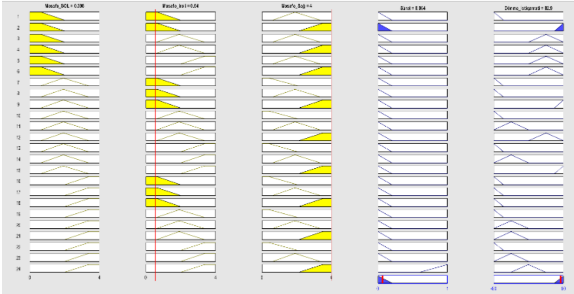

Figure 20. Fuzzy rules activation window

The activation window of fuzzy rules in MATLAB environment is shown in figure 21. Figure 22 shows the obstacle avoidance of the fuzzy controller robot. The result of the simulation shows that the robot with fuzzy controller effectively avoids the obstacles placed in the direction of movement of this robot.

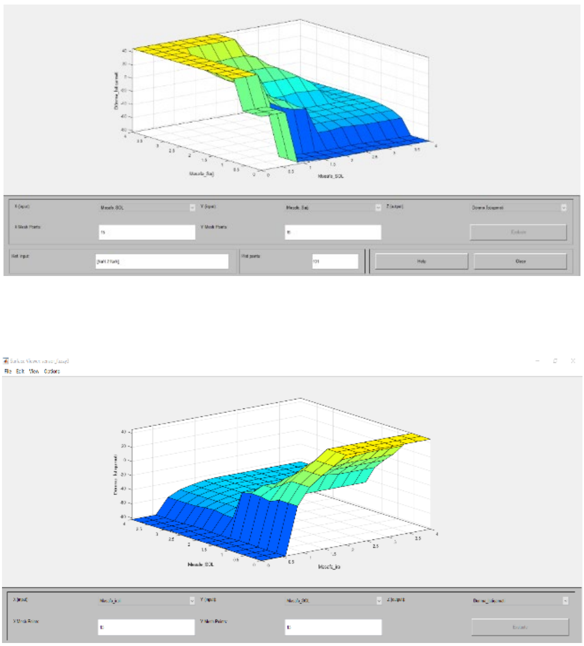

Figure 21. Fuzzy rules activation window

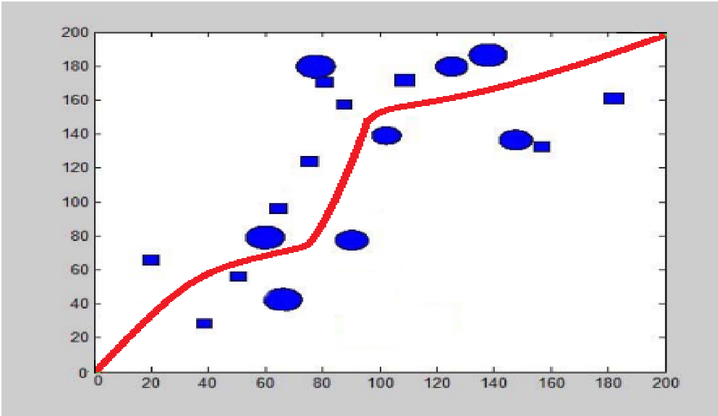

Figure 22. Obstacle avoidance of a fuzzy controller robot

In the most common If-Then fuzzy relations in software computing technologies, dependencies between fuzzy sets are performed and learned based on rules developed by experts. The overall result is obtained after determining the accuracy for each rule specified in the rule table. Based on the table of rules showing the simulation of the robot's motion sensor in MATLAB environment and 25 rules proposed by experts, a fuzzy controller was constructed and simulated based on these rules. The results of the simulation show that the fuzzy controller robot has a high control ability under uncertainty conditions.

Chapter 4 deals with the data aggregation in sensor networks, data aggregation in distance sensors based on type-2 fuzzy logic, and Z-information aggregation.

By studying and analyzing data collected from multiple simulations, experts can gain the expertise needed to build, for example, a fuzzy logic system for fire detection and assessment. The number of fuzzy sets should be chosen for both input and output. Results may change based on how data is analyzed by experts.

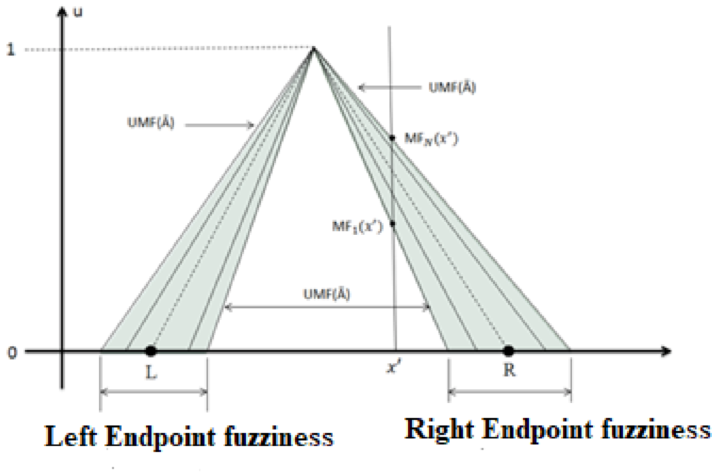

Figure 23. Value of membership function in type-2 fuzzy set

If the expert can classify the temperature value as high, medium, and low, it is reasonable to have a three-input fuzzy set for the temperature value. In another case, if the expert classifies the light value only as high and low, the input fuzzy sets for the light value should be two. In type-2 fuzzy logic approach (figure 23), four different language terms are used by experts to describe different temperature intensity and light intensity for fuzzy inputs. The terms high, medium, low, and very low are chosen to describe four different fuzzy sets for both input temperature and light in the proposed fuzzy logic system. The output of fire intensity is described in four other language terms, related to fire, small fire, medium fire, and large fire. The membership function is one of the most important parts of a fuzzy logic system. It decides how the input variables are transformed into fuzzy sets. An example of the data analyzed by the expert for the temperature value is shown in table 3.

Table 3

Data analyzing the temperature value by an expert example

dis(m)\temp	Great fire °C	Medium fire °C	Small fire °C	There is no fire °C
close	high temperature	average temperature	average temperature	very low temperature
average	average temperature	average temperature	down temperature	very low temperature
Far	down temperature	down temperature	very low temperature	very low temperature

Table 4

Example of data analyzed by an expert on the value of light

dis(m)\ light	Large fire (lm)	Medium fire (lm)	Small fire (lm)	No fire (lm)
Close	High light value	Medim light value	Medium light value	Very low light value
Medium	Medium light value	Medim light value	Down light value	Very low light value
Far	Down light value	Down light value	Very low light value	Very low light value

Table 5

Fundamentals of fuzzy inference rules

Approximate fire intensity	Light value Very low	light cost Low	Light Cost Average	Light Value High
Temperature Very low	Very low	Very low	Very low	Very low
Temperature low	Very low	Low	Low	Medium
Temperature Medium	Very low	Low	Medium	High
Temperature High	Very low	Medium	High	High

An example of data analyzing light value by experts is shown in table 4. The basis of fuzzy inference rules (table 5) should be developed by experts using their experience or new information that can be gathered for a specific solution.

Z-aggregation of information. Aggregation problems are used in many scientific studies, such as decision making under uncertainty, multi-criteria decision making, data processing. The problem of aggregation of information in the case of linguistic data is performed on fuzzy sets.

In various applications, the aggregation process becomes complicated due to the fuzzy nature of the data. On the other hand, the linguistic representation of data contains uncertainty, in many cases human knowledge is partially reliable. This partial reliability is also usually fuzzy and is formulated as a fuzzy constraint on probability distributions. Z-numbers are widely used to solve this type of uncertainty-bearing problems. This chapter also represents the problem of partially reliability of data aggregation based on discrete -numbers and the t-norm and -conorm operators on them. The t-norm and t-conorm operators are successfully used for handling uncertainty in systems analysis, decision analysis, management, modeling, and forecasting. Application of t-norm and t-conorm aggregation of experts' opinions described by Z-numbers is shown in the following example.

Suppose that three experts want to make a common decision for the selection of sensors. Because of uncertainty and fuzziness, each expert expresses his opinion in Z-numbers:

$$A_{Q_1} = 0/1 + 0.3/1 + 0.4/2 + 0.7/3 + 1/4 + 0.8/5 + 0.6/6 + 0/7$$

$$B_{Q_1} = 0/0.4 + 0.01/0.5 + 0.14/0.6 + 0.6/0.7 + 1/0.8 + 0.6/0.9$$

$$A_{Q_2} = 0.2/0 + 0.4/1 + 1/2 + 0.4/3 + 0.2/4 + 0/5$$

$$B_{Q_2} = 0/0.4 + 0.01/0.5 + 0.14/0.6 + 0.6/0.7 + 1/0.8 + 0.6/0/9$$

$$A_{Q_3} = 0/1 + 0.5/2 + 0.6/3 + 0.7/4 + 1/5 + 0.7/6 + 0/7$$

$$B_{Q_3} = 0/0.4 + 0.01/0.5 + 0.14/0.6 + 0.6/0.7 + 1/0.8 + 0.6/0.9$$

In addition, experts' degrees of certainty are also different. Confidence levels of experts are also expressed in discrete numbers $Z_{w_i} = (A_{w_1}, B_{w_1})$:

$$A_{w_1} = 0/0 + 0.6/1 + 0.8/2 + 1/3 + 0.7/4 + 0/5 \ ,$$

$$B_{w_1} = 0/0.4 + 0.01/0.5 + 0.14/0.6 + 0.6/0.7 + 1/0.8 + 0.6/0.9$$

$$A_{w_2} = 0/1 + 0.4/2 + 0.6/3 + 1/4 + 0.8/5 + 0/6$$

$$B_{w_2} = 0/0.4 + 0.01/0.5 + 0.14/0.6 + 0.6/0.7 + 1/0.8 + 0.6/0.9$$

$$A_{w_3} = 0/2 + 0.4/3 + 0.6/4 + 1/5 + 0.8/6 + 0/7$$

$$B_{w_3} = 0/0.4 + 0.01/0.5 + 0.14/0.6 + 0.6/0.7 + 1/0.8 + 0.6/0.9$$

The problem is to determine the final opinion of the expert group on the considered decision based on aggregation with t-norm and t-conorm operators:

$$Aggreg(Z_1, Z_2) = Z_{agr}$$

The problem is solved as follows. In step 1, the experts' (Q) total weight estimate $Z_{Q_{w_1}} = \left(A_{Q_{w_1}}, B_{Qw_1}\right)$, $i = \overline{1,3}$ is determined using the t-norm operator. Consider the calculation of Z_{agr} for three experts:

$$A_{Qw_1} = 0.2/0 + 0.4/1 + 1/2 + 0.4/3 + 0.2/4 + 0/0$$

$$B_{Qw_1} = 0/0.80 + 0.01/0.82 + 0.14/0.85 + 0.6/0.87 + 1/0.89 + 0.6/0.9$$

$$A_{Qw_2} = 0/0 + 0.6/1 + 0.8/2 + 1/3 + 0.7/4 + 0/1$$

$$B_{Qw_2} = 0/0.64 + 0.01/0.68 + 0.14/0.73 + 0.6/0.77 + 1/0.82 + 0.6/0.90$$

$$A_{Qw_3} = 0/1 + 0.5/2 + 0.6/3 + 0.7/4 + 1/5 + 0.7/6 + 0/1$$

$$B_{Qw_3} = 0/0.77 + 0.01/0.79 + 0.14/0.81 + 0.6/0.84 + 1/0.86 + 0.6/0.9$$

In the second step, the estimations calculated based on t-conorm are aggregated. For $Z_{Qw_1} = \left(A_{Qw_1}, B_{Qw_1}\right)$ and $Z_{Qw_2} = \left(A_{Qw_2}, B_{Qw_2}\right)$ (for first and second experts) t-conorm is calculated. $S\left(Z_{Qw_1}, Z_{Qw_2}\right) = \max\left(Z_{Qw_1}, Z_{Qw_2}\right)$ is used as the t-conorm. The result is obtained as follows:

$$A_{12}=0/1+0.5/2+0.6/3+0.7/4+1/5+0.7/6+0/1$$

$$B_{12}=0/0.46+0.01/0.55+0.14/0.63+0.61/0.72+1/0.81+0.6/0.9$$

To obtain the final estimate, the t-conorm of $S(Z_{12},Z_{Qw_3})=(A,B)$ is calculated:

$$A=0/0+0.5/2+0.6/3+0.7/4+1/5+0.7/6+0/0$$

$$B=0/0.73+0.01/0.76+0.14/0.78+0.61/0.82+1/0.85+0.6/0.91$$

Thus, on the basis of t-norm and t-conorm operations, the final expert group assessment $Z(A,B)$ is obtained.

Results

The main **scientific results** obtained in the dissertation are as follows:

1. The main characteristics of distance sensors were investigated, a comparative analysis was carried out and the expression of the values of the variables in the conditions of uncertainty in linguistic terms was determined.
2. Issues of data aggregation and processing in distance sensors based on fuzzy logic were considered. Using fuzzy aggregation operators, the problems of summarizing and processing information and variable values in distance sensors in conditions of deep uncertainty according to their weights, first fuzzification of the information entering the system, and then defuzzification and smoothing after processing have been worked out.
3. Different types of aggregation issues were considered. Problems of modeling and aggregation of fuzzy data while taking measurements in distance sensors were worked out.
4. Various forms of fuzzy logic have been developed for information aggregation in distance sensors. Type-1 fuzzy logic and aggregation

operators are used when it is possible to express the value of the variable with a fuzzy number, and the degree of membership with fuzzy numbers. In order to aggregate information in conditions of deeper uncertainty, type-2 fuzzy logic and aggregation operators are used, in which the values of the variables are expressed by fuzzy numbers, and the degrees of belonging of these values are fuzzy. On the other hand, if the values of the variables are expressed by fuzzy numbers and the reliability of these values by certain numbers, the evaluation of the final expert group is carried out as a result of the aggregation of individual expert opinions based on the t-norm and t-conorm operations using the concept of Z-numbers.

The main results of the dissertation are published in the following works:

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8. Xudaverdiyeva M.Ə., İbrahimova A.V., Əliyeva S.Ç., Kərimova S.İ. Karbon nanoborularının tətbiq sahələri / "Müasir informasiya ölçmə və idarəetmə sistemləri: Problemlər və perspektivlər- 2019" (MİÖİS-2019), Bakı, İyul 01-02, 2019, s. 184-185
9. Xudaverdiyeva M.Ə., Ultrasəs sensorun köməyi ilə məsafənin təyin olunmasında qeyri-səlis məlumatların fazzifikasiya və defazzifikasiyası / Birinci Beynəlxalq Elmi-Praktiki Konfrans: Müasir İnformasiya, Ölçmə və İdarəetmə Sistemləri: Problemlər və Perspektivləri, - Bakı: - 2019, s.184-185.
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11. Khudaverdıyeva M.A., Distance measuring by ultrasonic sensor // The Southern Caucasus Scientific Journals, - Georgıa: - 2022, pp. 36-44.
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14. Xudaverdiyeva M.Ə., Qeyri-Müəyyənlik şəraitində Qeyri-Səlis Kontrollerli Robotun Simulyasiyası / Internatıonal Eastern Conference On Human-Computer Interactıon Naxçıvan-2022.

15. Azərbaycan Respublikasının Təhsil Nazirliyi “Sistemli analiz” fənnindən laboratoriya işlərini yerinə yetirmək üçün Metodik Göstərişlər, Bakı.

The personal role of the author in the work with co-authors:
[1,2,3,5] - Methods of approximation of functional dependencies with correction, linearization and solution of problems of correction of integral errors;
[7,8,10,11]- application of fuzzy logic to information measurement systems, setting of the problem, computer simulation
[4,6]- setting the problem, computer simulation.
[9]- Fuzzification and defuzzification of fuzzy data in determining the distance using an ultrasonic sensor
[13]- problem statement, linearization of output function by multiplicative approximation method.
[12,14]- Processing the simulation of a robot with a fuzzy controller under uncertainty in MATLAB, drawing up a table of rules, and aggregating data.

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