Intelligent Motion Control System for the Mobile Robotic Platform

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Abstract

Most of the modern mobile robotic platforms use interactive management using computing and artificial intelligence technologies. A feature of mobile robotic platform is the ability to adapt to the external environment, which requires the inclusion of intelligent sensors and control systems. In this paper it is proposed to develop intelligent motion control system for the a mobile robotic platform on the basis of an integrated approach, which covers: navigation methods, methods of preliminary data processing; modern methods and algorithms of intellectual management and fuzzy logic; modern element base; methods of intellectual processing and evaluation of data from sensors in the conditions of interference and incompleteness of information; methods and means of automated design of hardware and software. The structure of intelligent motion control system is developed for wheeled mobile robotic platform. Set of the rules for fuzzy logic control system are developed. The results of modelling the movement of a wheeled robotic platform with different values of readings from sensors in the environment based on the developed rules are presented. It is proposed to perform software development of control system for mobile robotic platform in remote mode. Up-to-date information from sensors is transmitted via the Wi-Fi network. This information is processed by the control system under development, which transmits control signals via the same Wi-Fi network to the wheeled robot. Developed software, taking into account cross-platform nature of the development tools used, can be easily loaded into the control microcomputer of mobile robotic platform for regular use.

Keywords

Wheeled robotic platform, fuzzy logic control system, intelligent wireless sensors, set of the fuzzy rules

1. Introduction

An important problem when creating mobile robotic platforms (MRP) is to provide remote and autonomous movement management. To solve such a problem, it is necessary to develop an intelligent motion control system (IMCS) with high technical and operational parameters. The MRP should be able to build a route and control the parameters of movement (set the speed of movement and angles of rotation). The solution of such a problem requires the widespread use of a modern element base (microcontrollers, SoC, FPGA, etc.), the development of new methods, algorithms and hardware structures focused on effective implementation of algorithms for processing and recognition using fuzzy logic control. One of the ways to achieve high technical and operational characteristics of IMCS is the use of fuzzy logic control tools for evaluating data from sensors in conditions of incomplete information.

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2. Related works

The development of methods and means of managing mobile robotic systems with the use of computational intelligence is highlighted in the works of scientists, namely: Adina Aniculaesei and others – development of a control system for an intelligent mobile robotic system with self-learning [1]; S. Wang and others – research and development of methods of orientation in the surrounding environment of mobile robotic systems [2]; Medina-Santiago A. and others – methods and tools for a control system using artificial intelligence to bypass obstacles with mobile robotic systems [3]; Chen C.L.P., Yu D. and Liu L. – research in the field of management of many mobile robotic platforms [4] and others.

However, the use of special-purpose MRP requires a high level of system autonomy, which is proposed to be implemented with a comprehensive approach through the use of computational intelligence methods. Works [1-4] give partial solutions for the implementation of an intelligent MRP control system. In the case of mobile robot, it`s communication system must have high level of stability and data protection. In [5] proposed neuro-like cryptographic component for mobile smart system.

Conventional sensors have limitations in terms of detection distance, spatial resolution, and processing complexity. However, a promising approach is to equipped an autonomous mobile robot with Light Detection and Ranging (LiDAR) sensor to avoid obstacle [6]. In [7] omnidirectional mobile platforms that can independently and simultaneously perform translational and rotational motions are presented. In order to develop an autonomous omnidirectional mobile manipulator presented a platform based on four Mecanum wheels with higher carrying capacity and mobility than a standard four-wheel platform.

The paper [8] is concerned with the autonomous navigation of mobile robot from the current position to the desired position only using the current visual observation, without the environment map built beforehand. Under the framework of deep reinforcement learning, the Deep Q Network (DQN) is used to achieve the mapping from the original image to the optimal action of the mobile robot.

In [9], an autonomous navigation system for indoor mobile robots is introduced mainly based on open source provided by the robot operating system. The presented system is capable of autonomously navigating an unstructured indoor environment avoiding collision with static or dynamic objects. Paper [10] shows a development of a mobile robot platform with Mecanum wheels for autonomous navigation, including its mechanical design, system design and robot construction. In addition, the robot using NVIDIA Jetson TX2 installed with ROS as a high-level control to accomplish navigation tasks.

Another challenge is to build control system for robotic platform. Paper [11] describes the application of fuzzy logic methods in controlling the speed of a hexapod mobile robot by utilizing Takagi-Sugeno-Kang type of its inference system. Paper [12] describes the design and implementation of a wheeled mobile robot using fuzzy logic principles with Mamdani's fuzzy inference system so that the robot has the obstacles avoidance capability.

A promising approach is to combine neural networks and fuzzy logic methods as described in [13, 14] to achieve positive results. In order to solve the problem of poor path control effect of traditional robots, the intelligent fuzzy control algorithm for mobile path of mobile robots was studied in [15]. In this case the intelligent control of the mobile path of the robot is carried out by combining the fuzzy algorithm, and the path deviation and deviation correction parameters are calculated to complete the intelligent control of the mobile path of the robot. In paper [16] the semi-automatic navigation robot adopts artificial intelligence Fuzzy logic as an output processor that will be generated by the robot. Fuzzy logic on this robot is used to control the speed of the motor based on the distance of the obstacle that is read by the sensor and the input provided by the remote control. Paper [17] presents a method of a fuzzy controller to control the robot to avoid all fixed and mobile obstacles using fuzzy logic. Robot can be controlled by a human-machine interface or by a keyboard and communication between the human-machine interface and Robot is done by using wireless communication. Fuzzy logic controller, described in [18], used and optimised by two soft computer techniques: genetic algorithm, and Particle Swarm Optimization (PSO). These methods are used to adjust the inputs and outputs of fuzzy logic controller in order to improve the mobile robot navigation and three of methods have been presented.

3. Methods and materials

The creation of MRP with high technical and operational characteristics require the development of new methods, algorithms and hardware structures focused on effective implementation of algorithms for processing and recognition, modelling of the environment, planning of actions, laying of rational routes of movement and management of motion. When managing the movement of MRP, it is proposed to use a fuzzy logic control.

3.1. Requirements and principles for constructing IMCS

The main requirements for constructing IMCS is to ensure:

- Reduction of dimensions, energy consumption and cost of IMCS;
- Real-time movement management;
- Optimization of the route by the criteria of time and distance;
- Preserving the performance of the IMCS in the conditions of external factors;
- High reliability of equipment and software;
- The possibility of adaptation to the requirements of the customer;
- Versatility, compatibility and integration with existing MRP;
- The ability to independently perform tasks in conditions of uncertainty of the external situation;
- Use of IMCS and night in the conditions of radio electronic and information counteraction.

Creating such IMCS requires the widespread use of modern components (sensors, platforms, microcontrollers, SoCs, FPGAs, etc.), development of new methods, algorithms and means for processing in real time.

Real time mode imposes restrictions on the time of processing and forming the T_{cc} control commands that should not exceed the time of accumulation of T_{dl} data, ie:

$$T_{cc} \leq T_{dl}. \tag{1}$$

The time of accumulation of an array of data depends both on its volume N, the bit of data N and the frequency of F_d their receipt, and on the bit of n_k and the number of channels k that they receive. This time is determined by the formula:

$$T_{dl} = \frac{N_n}{F_d k n_k}. \tag{2}$$

To ensure the processing and formation of real-time management commands performance of Pc computer tools must be:

$$P_c \geq \frac{\beta R F_d k n_k}{N_n}, \tag{3}$$

where R is the complexity of algorithms for processing and formation of management teams; β is the coefficient of taking into account the features of computer implementation.

To provide the necessary performance of computer tools for processing data flows and the formation of real-time control commands we need to use specialized hardware, scalding and parallel data processing. When developing an IMCS, it is necessary to ensure a real time mode first of all and when minimize hardware costs. To evaluate the IMSC resources, it is proposed to use the Efficiency Criterion that binds the time of processing data to hardware costs and gives evaluation of performance system elements. Quantitatively the magnitude of the efficiency of use of equipment in IMCS is determined:

$$E_{AC} = \frac{R_{AC}}{t_A W_H}, \tag{4}$$

where R_{AC} is the complexity of algorithms for processing data flows and management commands; t_A – time of execution of algorithms; W_H – hardware costs for IMCS. High efficiency of use of equipment in the development of IMCS is proposed to be achieved by the use of universal processor nuclei supplemented with specialized hardware that implement complex computing algorithms.

Initial information for the development of MRP is:

- Algorithms for processing data flows;
- Methods and algorithms of fuzzy control of MRP movement;

- Database of rules for fuzzy control of MRP movement;
- Fuzzification algorithms, defuzzification and management decisions;
- The magnitude of the input array of N;
- Intensity of input flows;
- Requirements for external IMCS interfaces;
- Bit width of input data and the required accuracy of calculations;
- Technical and operational requirements and restrictions.

In the general task of developing IMCS can be formulated as follows:

- Choose algorithms for processing, fuzzification, defuzzification, management decisions and present them in the form of a specified stream graph;
- Determine the procedure for implementing the algorithms for the functioning of the IMCS;
- Develop the structures of the IMCS components with the maximum efficiency of use of equipment that take into account all restrictions and ensure the control of the MRP movement in real time;
- Determine the main characteristics of the components of the IMCS and develop them;
- Choose the ways of exchange, identify the necessary links, and develop a system of exchange data between IMCS's components.

The development of the IMCS is proposed to be carried out on the basis of an integrated approach that covers:

- Navigation methods, methods of preliminary processing of data;
- Modern methods and algorithms of intellectual management, fuzzy logic;
- Modern element base;
- Methods of intellectual processing and evaluation of data from the sensors in the conditions of interference and incompleteness of information;
- Methods and means of automated design of hardware and software.

The implementation of the IMCS is proposed to be performed on the basis of a problem-oriented approach, which involves the combination of universal and specialized tools that hardly implement the most complex computing algorithms.

The development of IMCS is proposed to be carried out on the following principles:

- The hierarchy of construction by dividing it at the level of management;
- Systematicity in which such connections are formed between the components that ensure the interaction and integrity of the system;
- Variable composition of equipment, which provides for the presence of processor core and variable hardware modules, through which the nucleus adapts to the requirements of specific use;
- Modularity, which involves the development of IMCS components in the form of functionally completed modules that have a standard interface;
- Openness of software and maximum use of standard drivers and software;
- Specialization and adaptation of hardware and software to the structure of algorithms of processing and formation of management commands.

3.2. Development of the IMCS structure

The implementation of the IMCS for the MRP is based on the analysis and interpretation of information from the surrounding environment, as well as on the constant tracking of their own coordinates. In IMCS will use both passive and active navigation. Passive navigation uses information about their own coordinates and other characteristics of the movement of MRP, which comes from external sources, and with active navigation, their own coordinates are determined exclusively with the help of devices placed on MRP.

IMCS must provide the following types of control:

- Remote controlling;
- Intellectual hybrid;
- Intellectual autonomous.

The remote controlling of the MRP is intended for receiving, analyzing remote control commands from the operator and forming control signals for the motion system. The peculiarity of remote control of the MRP is:

- The need to maintain a permanent communication channel;
- Limiting the radius of control of the MRP movement (only within the radius of the communication channel);
- Impossibility of self -making;
- Delays in management of management commands;
- Making erroneous actions in the fatigue of the operator.

The intellectual autonomous control of the movement of the MRP involves modelling the environment with varying degrees of detail, localization of the place of position of MRP, control of movement, detection and avoidance of obstacles. The peculiarity of such management is its use outside the communication channel.

It is advisable to use intellectual hybrid management to effectively manage the movement of the MRP, which combines the benefits of both remote and intellectual autonomous management. The disadvantage of this traffic management is that it only works within the radius of the communication channel.

The structure of IMCS is shown in Figure 1.

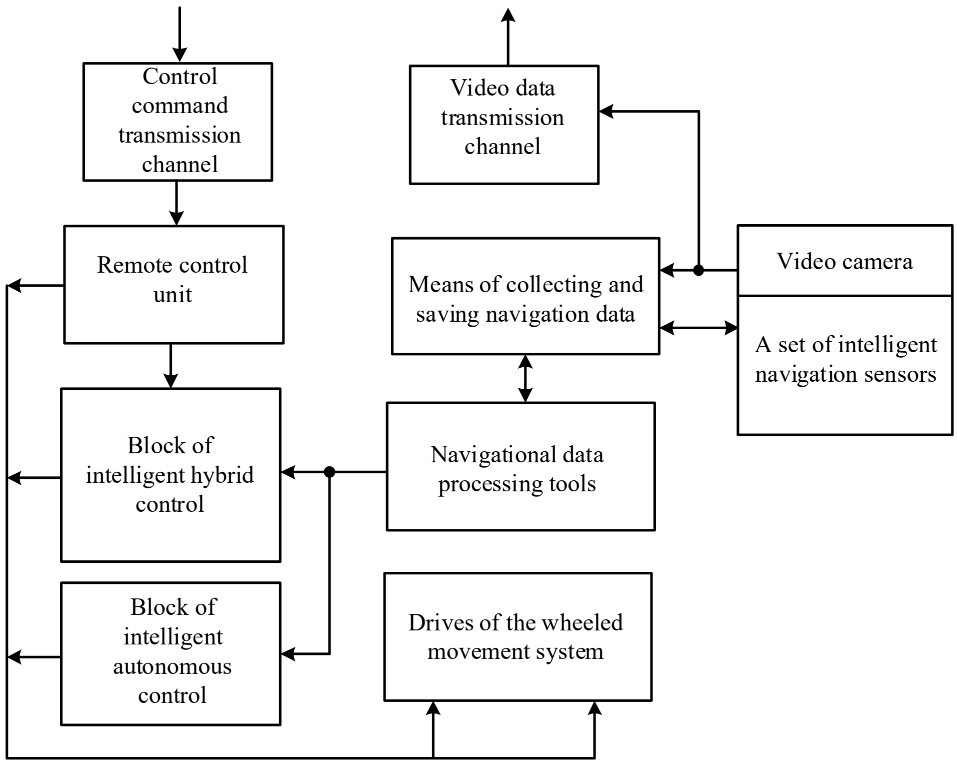

Figure 1: The structure of IMCS

The main components of the IMCS are: intellectual autonomous and intellectual hybrid control blocks, means of collecting, saving and processing of navigation data, video camera, set of intellectual navigation sensors, channels of video transmission and control command transmission, remote control unit.

One of the important functions of IMCS is the construction of the model of the environment in which the platform moves. This model of the environment should adequately reflect the current state and position of the platform, there may be obstacles to movement and dangerous areas of the path. When creating a model of the environment, the variety devices are used with variety technologies – ultrasonic, optical, etc., 2D and 3D lidars. Electronic accelerometers, compasses, and GPS-based positioning systems are used for spatial orientation and attachment of the MRP on the terrain.

Electronic accelerometers, compasses and positioning systems based on GPS technology are used for spatial orientation and anchoring of MRP on the terrain. MRP at indoor location rely almost entirely on the data of lidars, accelerometers and compasses. Data processing from sensors and building a model of the external environment is implemented by a SOC-based microcomputer module.

It is proposed to use fuzzy methods and remote intelligent sensors based on the technology of laser echolocation to control the movement of a wheeled MRP. Existing laser sensors provide operation both at low and at high levels of external illumination. Such sensors ensure high accuracy of measuring the distance to black objects at a distance of up to 30 meters and to bright objects at a distance of up to 65 meters.

The control command transmission channel in MRP is built with advanced industrial modules: a control microcontroller designed to match the SPI interface of the transceiver with the serial interface of the control microcomputer. The controlling microcontroller ensures the coordination of data reception/transmission speed by buffering them.

IMCS can be controlled out by 8, 12, 16, 20, 24 and more bit commands. A 16-bit command has been developed to implement the management of the MRP. In the control command, the first eight digits (1-8) of the operation code (feet, motion forward, back, motion to the left, movement to the right), and the second eight digits (9-16) – the parameters of the operation (speed, degrees of rotation, distance and time movement).

3.3. Fuzzy logic algorithms and MRP control means

Fuzzy logic (FL) is used in situations where there is a high degree of uncertainty, complexity and nonlinearity. Fuzzy control means use FL to classify data and make management decisions that ensure the avoidance of navigation problems as continuous loops, back tracking, dead end traps and movement in narrow passages. The structure of the means of fussy control of the movement of the wheel MRP is given in Figure 2.

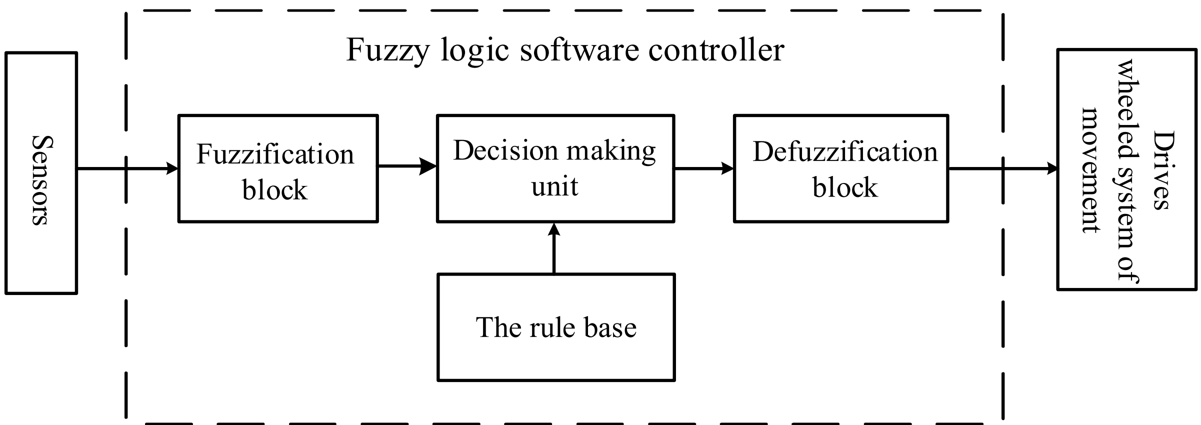

Figure 2: The structure of the means of fuzzy logic control of the movement of MRP

The main components of the means of fuzzy control of the movement of MRP are the sensors and software FL controller, which consists of fuzzification blocks, decision-making, defuzzification and the set of rules.

Changes in speed and trajectory of the MRP movement are made on the basis of information coming from onboard intellectual navigation sensors. Data from the onboard intellectual navigation sensors are admitted to the FL program controller, in which they are converted into control signals, through which the MRP movement is managed. The FL software controller operates with fuzzy quantities, which include fuzzy sets, fuzzy variables and linguistic variables.

A fuzzy set A in some space X is set by a set of pairs:

$$A = \{(x, \mu_A(x)); x \in X\}, \tag{5}$$

where $\mu_A(x)$ it is a function of belonging, which shows the degree of belonging $x$of each element to a fuzzy set *A*. The maximum value of the belonging function is 1, which means the complete belonging of the element to the fuzzy set.

The fuzzy variable is given a set $<\alpha, X, A>$, where $\alpha$is the name of a fuzzy variable; X – the area of its definition; A – fuzzy set that contains possible values that can take a fuzzy variable α.

The linguistic variable is set by a set of $<\beta, T, X, G, M>$, where β is the name of a linguistic variable; *T* – the set of values of the linguistic variable (term-set); *X* is the area of determination of fuzzy variables; *G* is a syntactic procedure that allows you to generate new terms (values) using elements of *T*-setting; *M* is a semantic procedure that allows for the new value of the linguistic variable, obtained by the procedure *G,* correspond a fuzzy set.

The main stages of the functioning of the FL software controller are: fuzzification, management decision-making and defuzzification. Let's look at each stage of the FL software controller in more detail.

At the fuzzification stage, the input data $x = (x_1, x_2, \dots, x_n)$ coming from intellectual navigation sensors are transformed from clear values into fuzzy ones. Such transformation is carried out by comparing the specific value of the input value and the value of the function $\mu_A(x)$ of the corresponding term of the input linguistic variable. The peculiarity of the fuzzification stage is the formation of the functions of belonging and determining the number of terms of linguistic variable.

An input linguistic variable – a "distance to the obstacle", which is formed on the basis of data from intellectual navigation sensors, can be used to control the motion of the MRP.

At the output of the fuzzification block, the values of the linguistic variable (term), for example, T = {"small", "average", "large"} may be generated.

The management decision-making stage is based on fuzzy rules. The peculiarities of the implementation of this stage are to ensure sufficient amounts and consistency of fuzzy rules, which should adequately reflect the purpose and cover all possible cases of managing the movement of MRP. For the FL software, the rules are written in the following form:

$$R_k(B): (X_1\ is\ A_{1k}\ and \dots and\ X_n\ is\ A_{nk})\ or \dots or\ (X_1\ is\ A_{1m}\ and \dots and\ X_n\ is\ A_{nm}), \quad (6)$$

where X_i – input variables, R_k – rule, A_{ik}, A_{im}, B_k – the term linguistic variables.

When constructing a fuzzy rules, it is first necessary to distinguish certain terms in each output linguistic variable and set their functions. The next step for each Term of the original linguistic variable is Rule using the conjunction (operation "and") and the disjunction (operation "or"). So, for the original linguistic variable "turn angle" values, that is, its terms can be: T = {"right", "forward", "left"}. For example, for the term "right" fuzzy rule will be written:

Rule 1 ("To the right"): ("distance to the obstacle of the first giver" is "great" and "distance to the obstacle of the second giving" is "big" and "distance to the obstacle of the third giver" is "small") or... or ("distance to the obstacle of the first giving "is" Medium "and ... and" Distance to the obstacle of the third giving "is" average ").

At the decision-making stage, a transformation of an input fuzzy set into an output fuzzy set using a fuzzy database of rules in accordance with the following expression is performed:

$$R_k = M_k \to N_k, \quad (7)$$

where $R_k$the rule, M_k, N_k is input and output fuzzy sets.

At the stage of defuzzification, the transformation of a fuzzy $N_k$output value that comes from the decision-making unit is made into a clear value, which is fed to the drive of the wheel system of MRP movement, in accordance with the following expression:

$$y_k = F(N_k), \quad (8)$$

where *F* is a defuzzification algorithm.

4. Experiment

Implementation of the structure of the intelligent control system of the wheeled MRP is carried out using separate functional blocks. For the construction of the specified blocks, ready-made modules were used. Today, the nomenclature of modules, for example, for building drives of the wheeled movement system of the MRP, is wide enough and provides adequate control of engines of relatively high power.

When developing a control system, software development of remote control blocks, intelligent hybrid control, and intelligent autonomous control is carried out in remote mode. For this, a laptop is used, on which the fuzzy control system is launched and debugged. In online mode, up-to-date information from sensors is transmitted to the laptop via the Wi-Fi network.

This information is processed by the control system under development, which transmits control signals via the same Wi-Fi network to the wheeled MRP. This approach allows you to quickly develop and debug the control system without the need to constantly download updated software to the mobile platform.

In the future, the developed and tested software tools, taking into account the cross-platform nature of the development tools used, can be easily loaded into the control microcomputer for regular use.

An interface using GPIO control signals is used to provide commands to the drives of the wheeled locomotion system. The control unit is implemented on the basis of an ESP-32 type microcontroller, the main task of which is to receive and execute commands regarding the direction of movement, determining the speed of movement and turning the wheel system of the MRP.

Detection of obstacles in the direction of movement is carried out using individual sensors that cover the field of vision in front of the platform and are designed to respond to such obstacles. Such a system is built on the basis of two non-contact distance sensors, which provide detection of obstacles at a distance of up to 1-2 meters.

The control command transmission channel for MRP testing is implemented using a Wi-Fi network. As a result of the use of MQTT server (broker), the possibility of remote data collection from all MRP sensors is provided, which provides the possibility of developing, building and debugging the model of the external environment and the software of remote control units, intelligent hybrid control and intelligent autonomous control in remote mode based on current information from sensors.

In the future, the developed and tested software tools are downloaded to the controlling microcomputer for regular use, taking into account the cross-platform nature of the used development tools.

For motion control, it is advisable to use ready-made industrial modules based on the ESP8266 and ESP32 families of microcontrollers. The main advantages of these families of microcontrollers are low cost, availability of software development tools (Espressif IoT Development Framework), PlatformIO, LUA, etc.), availability of expansion boards for receiving data from sensors and controlling various devices, etc.

Specialized modules are implemented on ESP32 microcontroller, which are the basis for building ready-made hardware solutions. Figure 3 shows the general view of the ESP32 C3-based obstacle detection module, made according to the IoT concept.

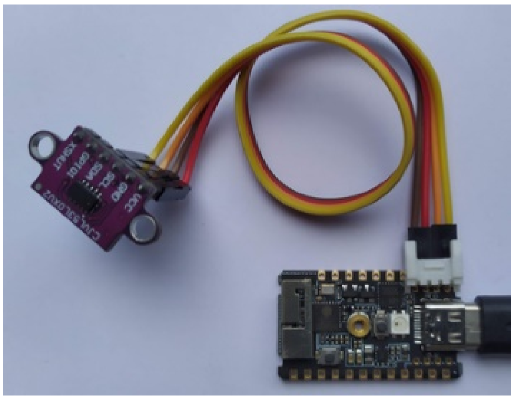

Figure 3: View of the VL53L0X remote-to-obstacle sensor module based on the M5Stamp board with an ESP32-C3 microcontroller

Figure 4 shows a graph of data from the VL53L0X distance sensor when it is placed at a distance of 100 mm from an obstacle and a histogram of the distribution of changes in these data (Figure 5).

The modules were tested using the thingspeak.com website. The site provides data storage of microcontroller systems and their display in the form of graphs, diagrams, histograms after analysis in the MatLab environment.

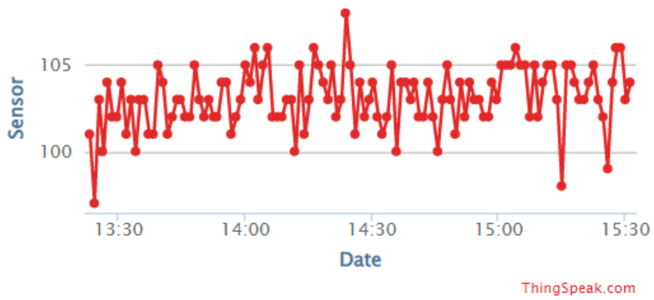

Figure 4: Received distance data from the VL53L0X sensor

The distance measurement using the VL53L0X distance sensor takes place according to the analysis of the distribution histogram with an accuracy acceptable for the operation of MRP. For the actual distance of 100 mm, the spread is no more than 3 mm, as it follows from the analysis of the histogram, there is an additive error of 2 mm, which can be eliminated by correcting the readings and calibrating the device.

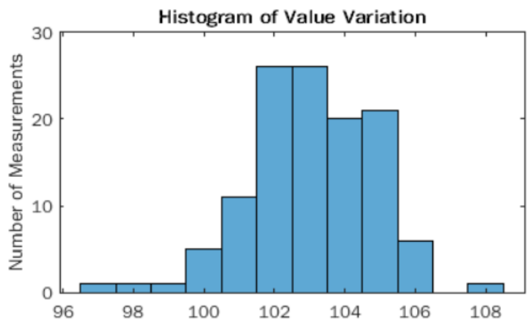

Figure 5: Histogram of the distribution of values from the VL53L0X distance sensor

The time of data transmission to the remote thingspeak.com server using the MQTT protocol was also checked. At the same time, the time from the moment of formation of the "publish" command to the receipt of data according to the subscription was estimated. The time distribution histogram is shown in Figure 6.

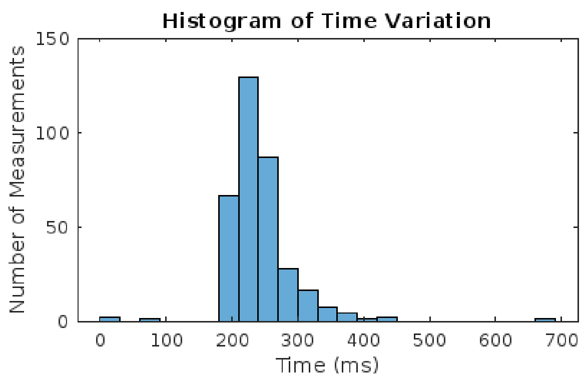

Figure 6: Histogram of the distribution of response time for the MQTT "publish" command for the remote server mqtt3.thingspeak.com

The readings of the built-in clock of the microcontroller were used to measure the values of the specified parameters. Next, a histogram of the parameter scatter was constructed using the Matlab site tools. The conducted analysis makes it possible to state that the indicated reaction time is 250 ms on average. The result is shown in Figure 7.

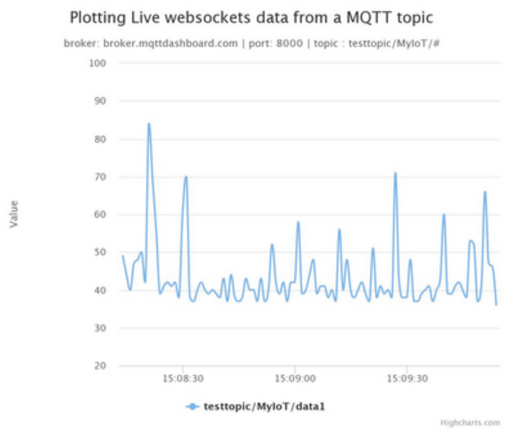

Figure 7: Response time for the "publish" command for the broker.mqtt-dashboard.com server

It should be noted that the specified values are obtained for the actual remote server mqtt3.thingspeak.com, physically located on another continent. For the broker.mqtt-dashboard.com test server, a similar parameter was about 45 ms.

Therefore, the indicated values of data transmission delay from sensors of about 50 ms should be considered acceptable for implementing the process of remote software debugging. This delay can be significantly reduced when using a local server and the UDP protocol.

Modelling of fuzzy logic control for IMCS was carried out using the JuzzyOnline environment. It is a browser-based toolkit for the design and execution of type-1, interval and general type-2 fuzzy logic systems. JuzzyOnline includes features for generating figures for all types of fuzzy sets [19].

Online version based on Juzzy – a java toolkit for the development of fuzzy logic systems [20].

The System View of fuzzy control system is shown on Figure 8.

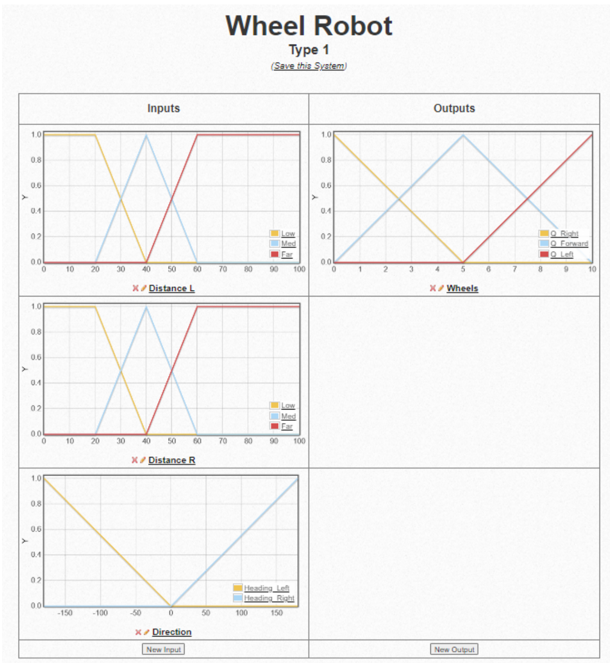

Figure 8: System View in JuzzyOnline environment

Type-1 fuzzy logic systems is used. In a type-1 fuzzy logic systems, the inference engine combines rules and gives a mapping from input type-1 fuzzy sets to output type-1 fuzzy sets. Multiple antecedents in rules are connected corresponding to intersection of sets. The membership grades in the input sets are combined with those in the output sets using the sup-star composition.

Multiple rules may be combined using the operation corresponding to union of sets or during defuzzification by weighted summation.

The simulation was performed for the case of MRP, which has two distance sensors located in front, to the right and to the left of the central axis of the MRP. They are used to detect obstacles in the direction of movement of the platform, which are located at a distance of up to 1 m. To set the general direction of movement, an electronic gyroscope sensor is used.

In this case, during simulation, data from the sensor is processed in such a way that the desired direction of movement corresponds to 0 degrees, accordingly, the deviations can be 180 degrees in both directions.

Part of the set of Mamdani rule antecedents and consequent, implemented in the JuzzyOnline environment, is shown in Figure 9.

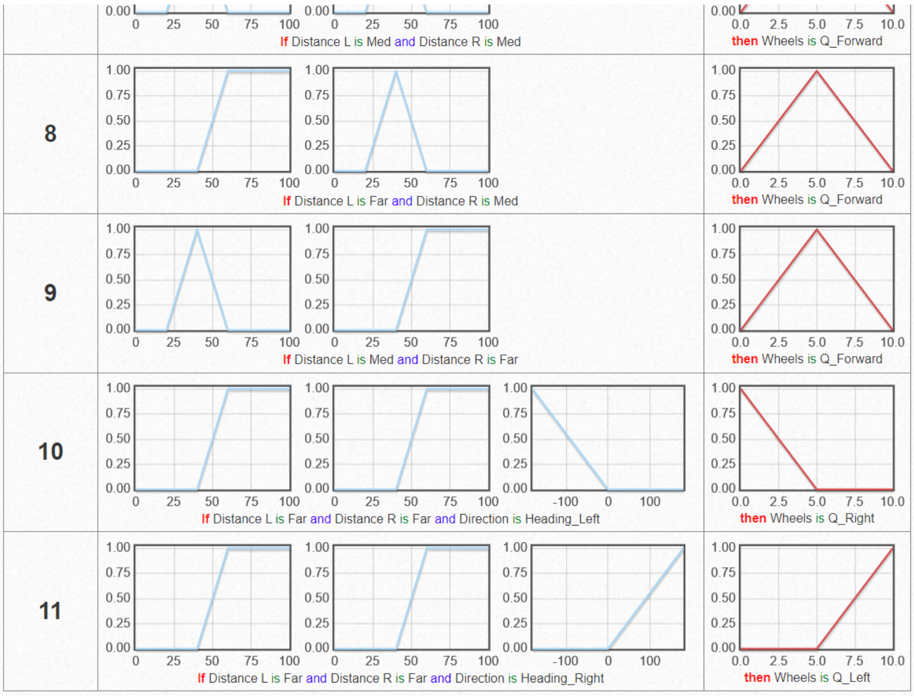

Figure 9: Mamdani rule antecedent and consequent

The input parameters are the distance to the obstacle received from remote sensors and the direction of movement. To describe the input parameters, the linguistic variables Distance L and Distance R are used, which correspond to the distance to the obstacle received from two distance sensors.

The linguistic variable Direction describes the parameter of the direction of movement in the range from -180 to 180 degrees.

Next, in the JuzzyOnline environment, for each input variable, it is necessary to set a set of values (terms) in the notation T={"Low", "Med", "High"}, denoting the small, medium and large distance to the obstacle, respectively. The notation T={"Heading_Left", "Heading_Right"} indicates the direction and magnitude of the MRTP deviation from the selected course. Next should be described

The membership functions of each term are given by pairs of numbers, the first of which indicates the value of the distance to the obstacle. The result of the processing is the turning angle of the MRP, which is described by the linguistic variable Wheels with three terms T={"Q_Right", "Q_Forward" and "Q_Left"}, which mean right turn, straight movement and left turn.

At the same time, the initial value of Wheels equal to 0 corresponds to the absence of movement, and 1 to movement at maximum speed. Input values in the range from 0 to 5.0 are interpreted as belonging to the control of the left MRP motor, and in the range from 5.0 to 10.0 – the right. Membership functions are given for each of the terms. The corresponding membership functions of the input linguistic variables and the output are shown.

Next, it was necessary to perform the formation of the rule base using the JuzzyOnline environment. The formation of the rule base is carried out for each term of the original linguistic variable using the input linguistic variables, their terms and corresponding operations.

The generated rule base is shown on Figure 10.

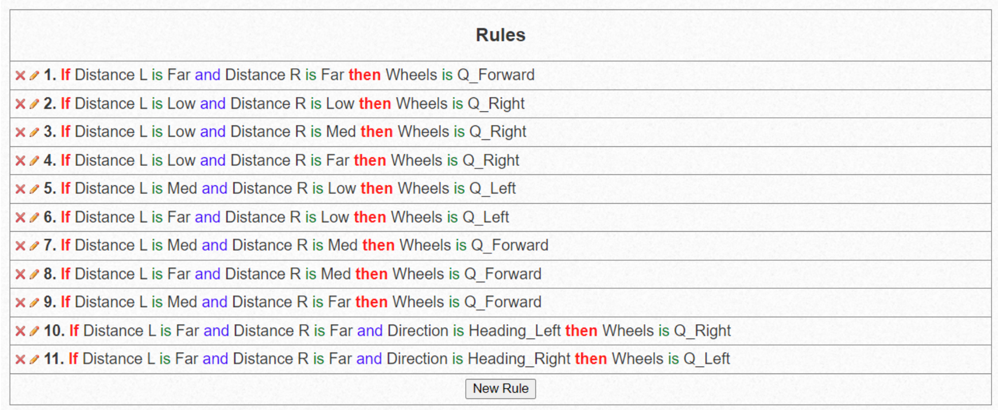

Figure 10: Set of rules in JuzzyOnline environment

The results of modelling the movement of a wheeled MRT with different values of readings from sensors in the environment based on the developed rules are shown in Figure 11.

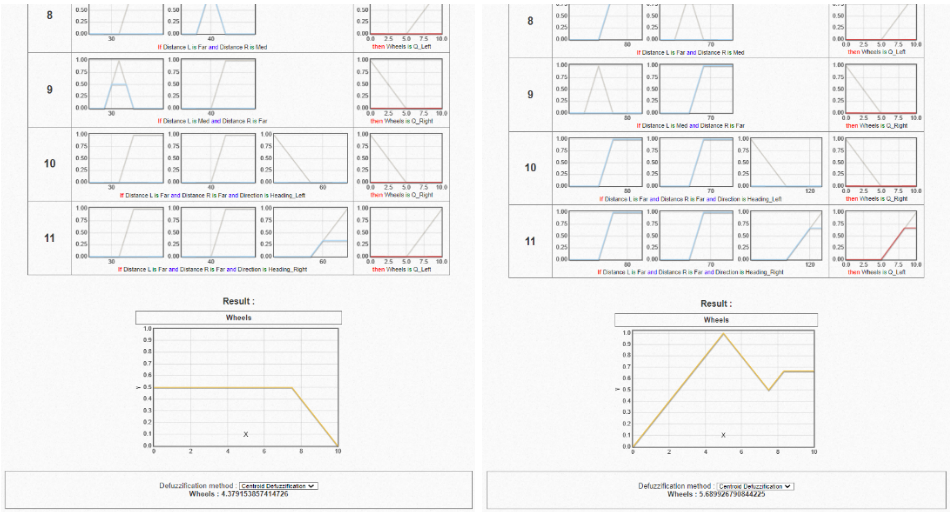

Figure 11: Fuzzy control system modelling results

Developed fuzzy control system modelling results in Surface View mode presented on Figure 12. Surface was built at values of readings for sensors named Distance R, Distance L and at 100 degree value from sensor named Direction.

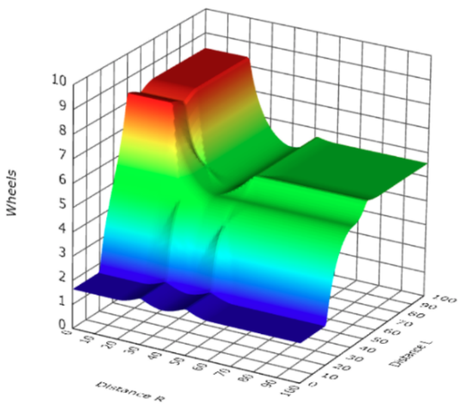

Figure 12: Fuzzy control system modelling results in Surface View mode for Distance R, Distance L parameters at Direction 100 degree

As can be seen, for the specified values, there is a change in the output value of the Wheel controller, which determines the different speed of rotation of a pair of MRP wheels and, accordingly, the change its movement as a reaction to the presence of obstacles or deviation from the chosen direction of movement.

5. Results and discussions

It is proposed, in case of mobile robotic platform, to develop a control system software in remote mode.

For these purposes wireless distance sensor and wireless robotic movement control unit developed.

Tested data transmission delay is about 50 ms and this value should be considered acceptable for implementing the process of remote software debugging.

In remote mode up-to-date information from sensors is transmitted to the control system to be developed via the Wi-Fi network.

This information is processed by the control system under development and transmits control signals via the same Wi-Fi network back to the wheeled MRP.

This approach allows us to quickly develop and debug the control system without the need to constantly download updated software to the mobile platform.

Developed software of IMCS, taking into account cross-platform nature of the development tools used, can be easily loaded into the control microcomputer for regular use.

Development of fuzzy logic control, especially in case of constructing rules, is complicated so future research in field of IMCS software can be based on neural or neuro-like network approach.

6. Conclusions

It is determined that the MRP motion must meet the following requirements: real-time management; optimization of the route by the criteria of time and distance; high technical and operational characteristics; high reliability of equipment and software; possibilities of adaptation to the requirements of the customer; multifunctionality, compatibility and integration with existing MRP; the ability to independently perform problems in conditions of uncertainty of the external situation; use day and night in the conditions of radio electronic and information counter.

It is proposed to develop a MRP on the basis of an integrated approach, which covers: navigation methods, methods of preliminary data processing; modern methods and algorithms of intellectual management and fuzzy logic; modern element base; methods of intellectual processing and evaluation of data from sensors in the conditions of interference and incompleteness of information; methods and means of automated design of hardware and software.

The following principles are selected for the development of IMCS for MRP: hierarchy; systematic; variable composition of equipment; modularity; openness of software and maximum use of standard drivers and software; specialization and adaptation of hardware and software to the structure of algorithms of processing and formation of management commands.

The structure of IMCS is developed for wheel MRP, the main components of which are: units for remote controlling, intellectual autonomous and intellectual hybrid navigation blocks, means of collection, storage and processing movement data from sensors, channels of transmission of video and control data.

Set of the rules for fuzzy logic control system based IMCS developed.

The results of modelling the movement of a wheeled MRT with different values of readings from sensors in the environment based on the developed rules are presented.

It is proposed to perform software development of IMCS for MRP in remote mode.

This approach allows to quickly develop and debug the control system software without the need to constantly reupload software to the mobile platform.

Tested data transmission delay about 50 ms of developed wireless distance sensor should be considered acceptable for implementing the process of remote software debugging.

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