Development of an Automated System for Monitoring and Diagnostics a Guided Robotic Vehicle

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Abstract This research considers the development of an automated system for monitoring and diagnostics of a controlled robotic vehicle. This system is based on an algorithmic approach performed by creating models in the form of fuzzy behavior charts. A key feature is the ability to represent a continuous change in time as a set of modes. While decomposing the diagnostics object (a robotic vehicle), there were created models of its main nodes in the form of fuzzy behavior charts of the second rank. For the diagnostics of the selected nodes, there were considered all possible faults, which also was compared with those ones that can be traced using the created models. Based on the tables of possible malfunctions of the electric motor, the battery, and the infrared proximity sensor, there was obtained a list of malfunctions and abnormal situations that can be organized in the knowledge base structure. Analysis of fault tables allowed developing the structure of an automated system for monitoring and diagnostics of abnormal and emergency situations. The obtained results (models and algorithms) were used to create a software product.

Keywords Mobile robots · Diagnostics of abnormal situations · Fuzzy behavior charts · Knowledge base

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1 Introduction

The autonomous robotic vehicle is a device that performs various operations associated with spatial movements with loads and is capable of effective behavior in a changing environment [1–7]. Considering a robotic vehicle as a diagnostics object, we can say that it is a complex system consisting of a large number of heterogeneous components and subsystems [8–12].

The state diagnostics of autonomous robots is necessary as it is complex technical objects, and such an approach is one of the main methods of increasing the efficiency of their use. The diagnosis objective of the robot state is to identify and alert abnormal situations and malfunctions in the operation of the main elements and subsystems. Among these problems, functional diagnostics tasks are of great importance when monitoring and malfunctions diagnosing are carried out in real-time directly during the robot operation [13–15].

It is possible to significantly improve the diagnosing quality for such objects as robots and various vehicles by creating embedded (onboard) diagnostic devices.

Essentially, any diagnosis is a classification: the definition of the object state from source data (signals from location sensors, control, video surveillance, etc.) can be considered as a task of classifying depending on the output information transformation, where the classes are the different states of the same object.

Another possible method for diagnosing the sensors of the mobile vehicle is based on the analysis of mismatch signals arising between physical and virtual sensors (models of sensor operation).

The most promising direction is the creation of methods based on artificial intelligence techniques, in particular, diagnostics methods based on artificial neural networks and fuzzy logic. Thus, in [16] is described the usage of neural network diagnostics of the robot state according to the integral parameter. At the same time, it is necessary to note the shortcomings of neural networks application: the lack of methods for determining the network structure, the number of neurons in the hidden layer and the parameters of the activation function, the complexity of network training. A method for diagnosing sensors of mobile vehicles using fuzzy logic methods is presented in [17].

Given the above, it is proposed to create a diagnostic system that will simplify a human's task of tracking the object state. To create such systems, it is advisable to use the algorithmic approaches, in particular, based on the construction of the models in the form of fuzzy behavior charts. A feature of this approach is the ability to represent a continuous in time change of a variable as a set of modes [18, 19].

2 The Selection of Nodes

The development of a system for monitoring and diagnosing abnormal and emergency situations based on fuzzy behavior charts for a controlled vehicle implies the sequential implementation of the following stages [20–22]:

1. Representation of the control and diagnostics object in the form of nodes (decomposition).
2. Determination of disturbing factors for each node.
3. Construction of membership functions for each disturbing factor.
4. Composing a rule that is based on fuzzy behavior charts of nodes (FBCN).
5. Composing the failures base on each node.
6. Determination of abnormal situation or malfunction of a specific node, taking into account the state of the FBCN and the decision-making control formation.

The robotic vehicle is a combination of the control object (robotic trolley) and an onboard control device. When decomposing a diagnostic object, let us single out: brushless DC motors built into the wheels, energy elements—batteries, and internal structure control devices—a controller with electronic interfaces to peripherals, for which monitoring and diagnostics are carried out by testing.

The node is a part of an automated vehicle. This part corresponds to a specific output variable and includes all disturbing factors affecting it [23, 24].

There are the following nodes with their output variables highlighted:

1. The wheel.
2. The rechargeable battery.
3. The inductive sensor.
4. The infrared proximity sensor.

For built-in brushless DC motors (Fig. 1), the input variables are a motor voltage (U), rotor current (A) and the speed of rotation (T). The output variable is the moment on the shaft—μ (N m).

For the battery (Fig. 2), the following variables were chosen as input: temperature (t), rotation speed (T), battery voltage (U). The output variable is the battery capacity—C (Ah).

For an analog inductive sensor (Fig. 3), the input variables are a supply voltage (U_{sp}), temperature (t), current (I), and the output variable is a distance—L (mm).

For the infrared proximity sensor (Fig. 4), the following input variables are taken:

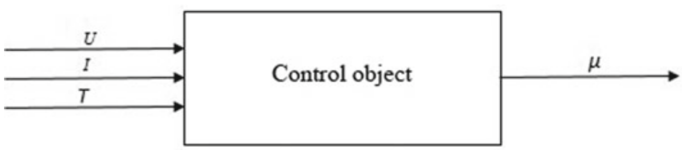

Fig. 1 The node “Wheel”

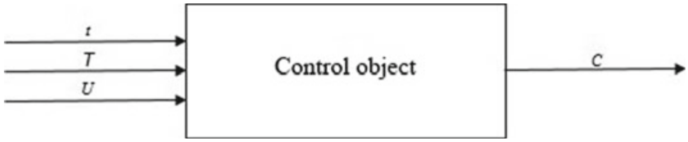

Fig. 2 The node “Rechargeable battery”

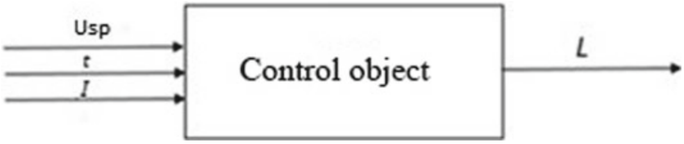

Fig. 3 The node “Inductive sensor”

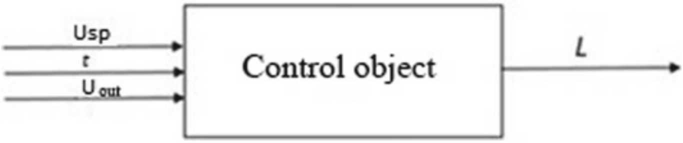

Fig. 4 The node “Infrared proximity sensor”

supply voltage (U_{sp}), temperature (t), output voltage (U_{out}). The output variable is a distance—L (mm).

3 Identification of Possible Faults for Each Node

There were created models in the form of fuzzy charts of the second rank for the selected nodes. In order to diagnose the malfunction of the presented nodes, it is necessary to consider all possible malfunctions, and also to compare them with those that can be traced using the created models in the form of the fuzzy behavior chart. The flexibility of this method lies in the fact that with the additional nodes and disturbing factors, a wider range of faults and abnormal situations can be diagnosed.

All faults for each node were considered and possible faults for diagnostics were selected.

Table 1 shows a fragment of motor malfunctions for the node “Wheel”.

Here are shown some standard situations and service actions when a malfunction happens, and the control system can form the suggestion to make the system able to work with some reduction of its quality by using the knowledge base. For example, if the motor could not rotate only if the power for it is on, that wheel could be powered off and let it operate in the freewheel mode with direction correction by the rest of wheels. Another example is when the motor couldn’t reach the set speed and heats.

Table 1 Drive malfunctions

Fault type	Cause of fault	Troubleshooting
When turning on the power, the rotor (anchor) is still fixed	There is no voltage at the input terminals of the motor or it is too low	Check the power supply line, repair the damage and ensure that the rated voltage is applied
When the power is on, the rotor is still fixed and intense heating	Bearing is destroyed; touching the rotor on the stator; the jammed shaft of the working mechanism	Disconnect the motor shaft from the shaft of the mechanism and turn on the engine again; if the motor shaft remains stationary, remove the motor
Motor stop	Voltage disconnected, motor protection was tripped	Find and eliminate the gap in the supply circuit, find out the cause of the protection operation (motor overload, the voltage in the network has changed significantly), eliminate it and turn on the motor
The motor does not reach the required speed, it is significantly overheated	Motor overloaded Bearing is out of service	Eliminate overload Replace bearing
The motor is overheating	Motor is overloaded The mains voltage is out of limits The outside temperature is higher than normal Motor ventilation is interrupted (air channels to the fan are blocked, engine surface is dirty)	Eliminate the overload Find out and eliminate the cause of the voltage deviation from the nominal Eliminate the cause and decrease the temperature to the acceptable value. Clean the air supply ventilating channels to the fan and clean the rotor surface
The motor is accompanied by a strong buzz, smoke appears	Turns of some stator winding coils have a shortcut	Send the motor to repair
The strong vibration of the motor	The fan wheel of the motor or another element mounted on the motor shaft is unbalanced	Eliminate unbalance of the fan or other element installed on the motor shaft
The bearing overheats, the noise is heard in it	Bearing and grease are dirty Bearing worn The alignment of the shaft of the engine and the working machine is broken	Remove the grease from the bearing, rinse it and lay down a new grease, replace the bearing, align the shafts

The suggestion could be to decrease the rotation speed to the not critical heating level or if it is not able then to power off and let it work in the freewheel mode.

3.1 Obtaining Knowledge Base and Identification of Abnormal and Emergency Situations with the Help of FBCN

When a table of all possible malfunctions is created for all major modes: the electric motor, the battery, and the infrared proximity sensor, it is created a list of malfunctions and abnormal situations that can be diagnosed using the suggested approach.

Each malfunction is associated with a state in a fuzzy behavior chart of a node and using indices, it indicates the terms to which the disturbing factors of a particular node in a certain state belong.

For the node "Wheel" (Fig. 5):

1. Motor stop—Status 1.
2. Slipping of one or several wheels—Condition 7.
3. The motor does not start—Status 2.
4. The motor does not reach the required speed—State 3.
5. The motor consumes high current during start-up—State 13.
6. The rotation frequency is higher than the nominal—State 6, 7.
7. The rotation frequency is less than the nominal—State 5, 9.

For the "Battery" node (Fig. 6):

1. Electrolyte freezing—Condition 1.
2. The internal circuit of the battery is open—State 2.
3. Fast discharging of the battery—Status 7.

For the "Infrared proximity sensor" node (Fig. 7):

1. The sensor is off—Status 1.
2. The termination of operation during normal operation of the power source—Status 9.
3. The inaccuracy of data—Status 7.

In this fuzzy behavior chart of the second rank, each position corresponds to a specific state that represents a specific fault and has a set of three values; this set is an index of the term belonging to one of *n*—disturbing influences.

Similar fuzzy behavior charts are constructed for the remaining nodes.

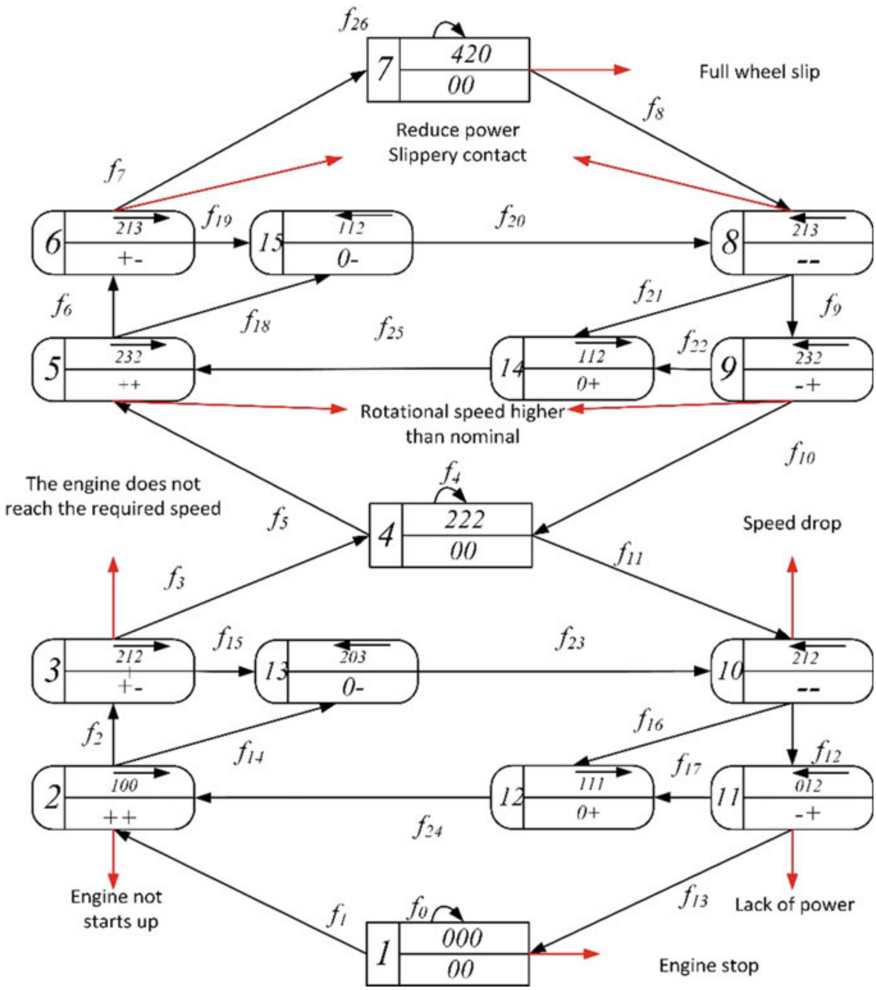

Fig. 5 FBCN mapped to the base of failures for the node "Wheel"

3.2 *The Development of the Diagnostic System Structure for Abnormal and Emergency Situations*

Analyzing the fault table, the structure of the system for diagnosing abnormal and emergency situations in the form can be shown in Fig. 8.

Wireless communication block. Responsible for transferring data from a robotic vehicle to the system of diagnostics and emergency situations, using LoRa modules.

Input block. Responsible for the processing of input data, that is, the PC records the received data into the array (the dimension corresponds to the number of disturbing factors) for further transfer to the main program.

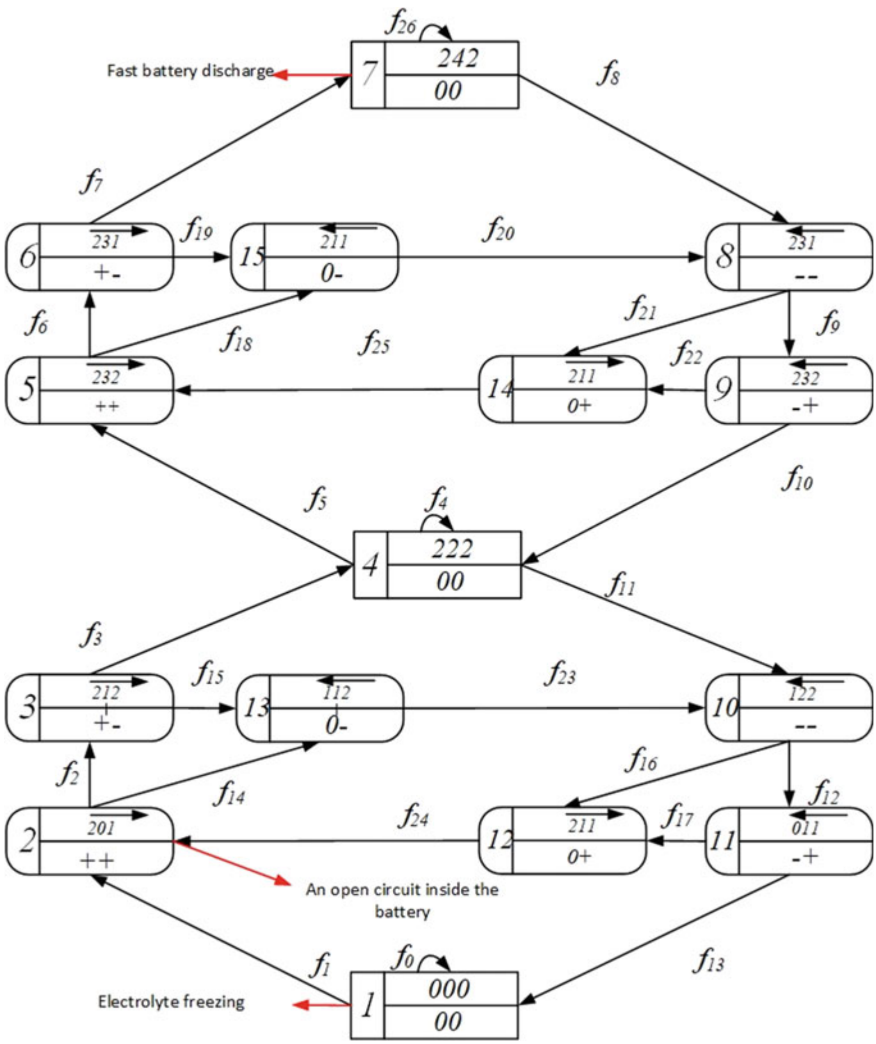

Fig. 6 FBCN mapped to the base of failures for the node "Battery"

Block of construction the membership functions. After entering the boundaries of the membership functions via the interface, they will be transferred to the "*trimf*" and "*trapmf*" methods together with the disturbing factor. These methods determine the numerical value of belonging to a particular term with given boundaries. These methods will be called in the next block.

Block for determining the degree of truth for each term. This block takes one of the disturbing factors as input, then passes it to membership functions, together with the boundaries for each of them, and returns the index of the term for which the degree of accepted membership value is greater than the rest.

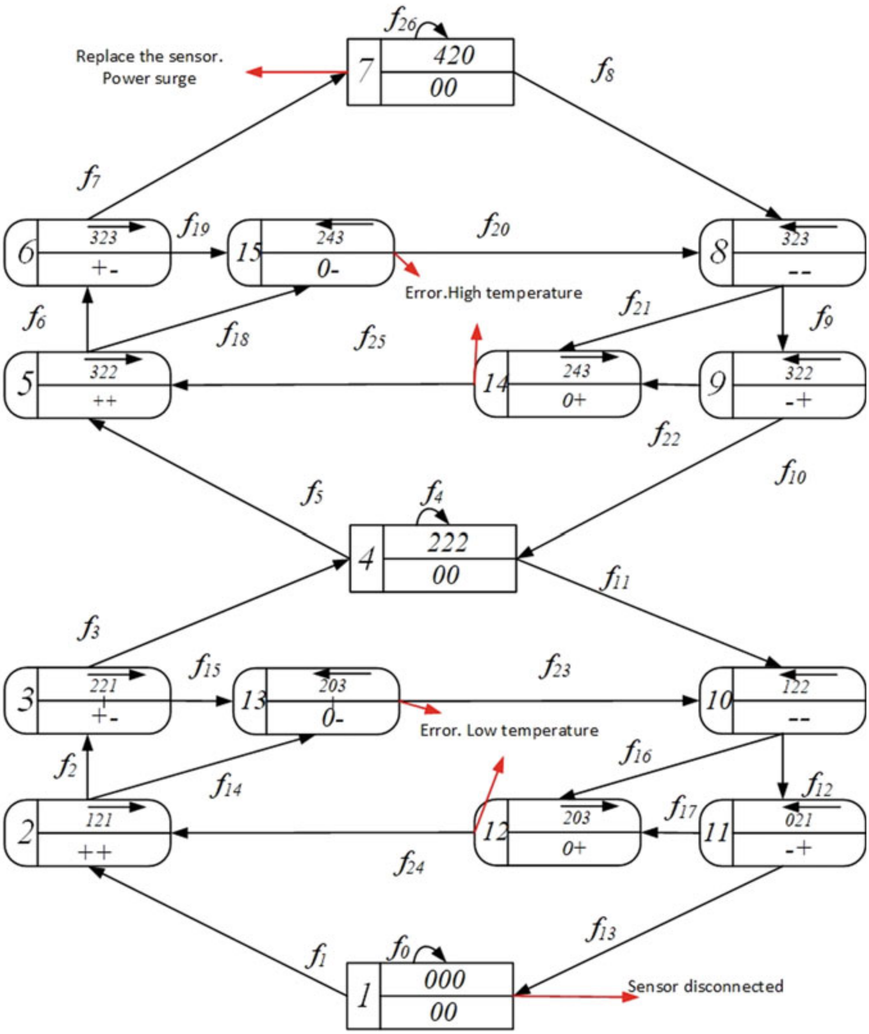

Fig. 7 FBCN mapped to the base of failures for the node "Infrared proximity sensor"

State definition block on FBCN. The block includes an array of Boolean states and rules for transition from one state to another. After determining the index for each disturbing factor, the combination of indexes that are used in the transition rules determines the state on the FBCN.

Knowledge base. It contains a list of faults and abnormal situations.

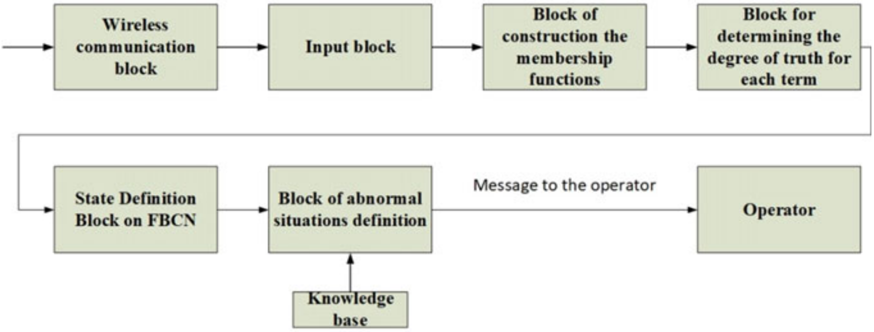

Fig. 8 Structure of the system for diagnosing abnormal and emergency situations

Block of abnormal situations definition. It compares the position on the FBCN with the knowledge base.

The block diagram of the diagnostic system is presented in Fig. 9 and its scheme of functioning in Fig. 10.

3.3 Software Implementation of the Developed Models and Algorithms

The Python was chosen as the programming language for creating a software product based as the fittest for artificial intelligence objectives. The Python supports several programming paradigms, including structural, object-oriented, functional, imperative, and aspect-oriented. The main architectural features are dynamic typing, automatic memory management, full introspection, an exception handling mechanism, support for multi-thread computing and convenient high-level data structures. The Python code is organized into functions and classes that can be combined into modules (which in its turn can be combined into packages).

Development and description of the software interface. The software interface consists of several windows. Figure 11 represents the main window in which could

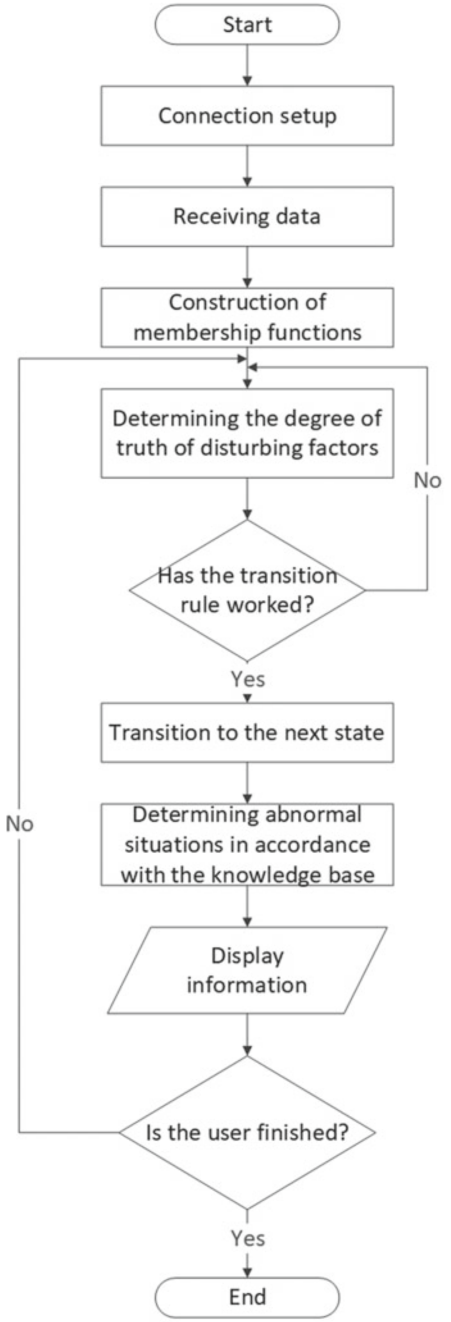

Fig. 9 Block diagram of functioning the automated system of monitoring and diagnosing abnormal and emergency situations

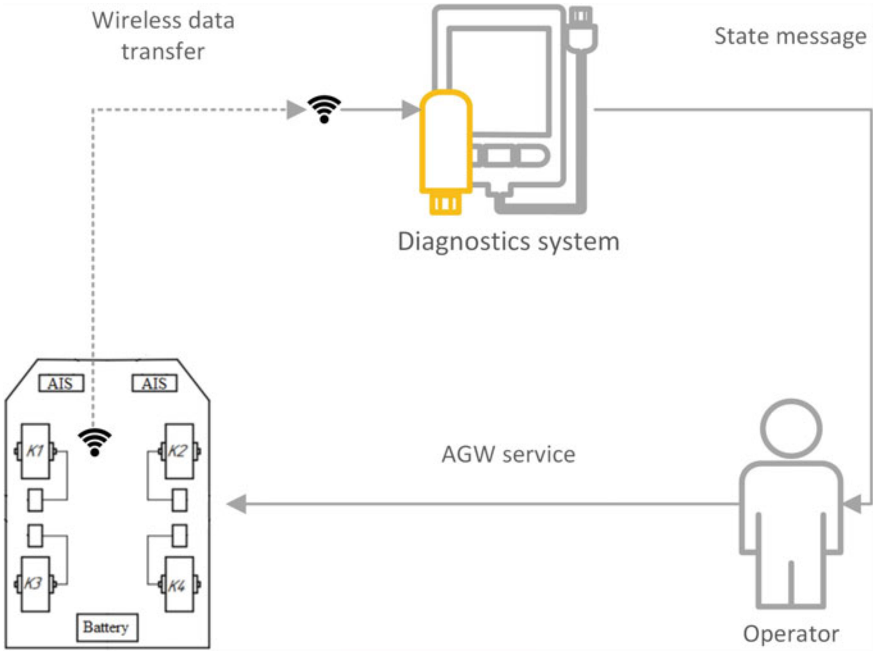

Fig. 10 Functioning scheme of system emergency situations diagnostics

be entered the parameters of membership functions for each disturbing factor and the output of the malfunction of a particular node, as well as possible emergency situations. In the second window (Fig. 12), the membership functions are constructed taking into account the data entered in the main window.

Figure 11 shows that the operator has a table for entering values, each element of which is responsible for a particular node (wheel, infrared sensor, battery) and its input disturbance factor (temperature, voltage, torque, etc.). Each input field is responsible for a specific term.

After transferring data to the main program, you can view the status of each node, as well as see information about possible abnormal or emergency situation by pressing the button “status”.

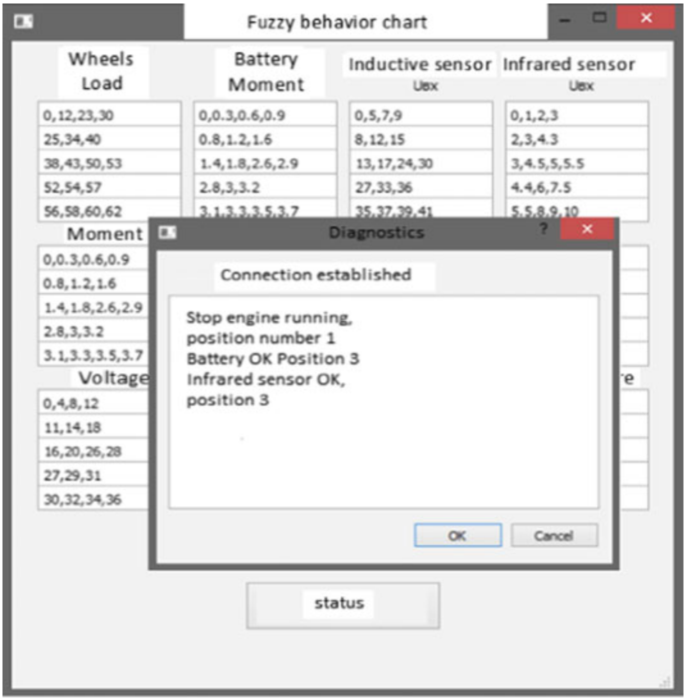

Fig. 11 Main software window

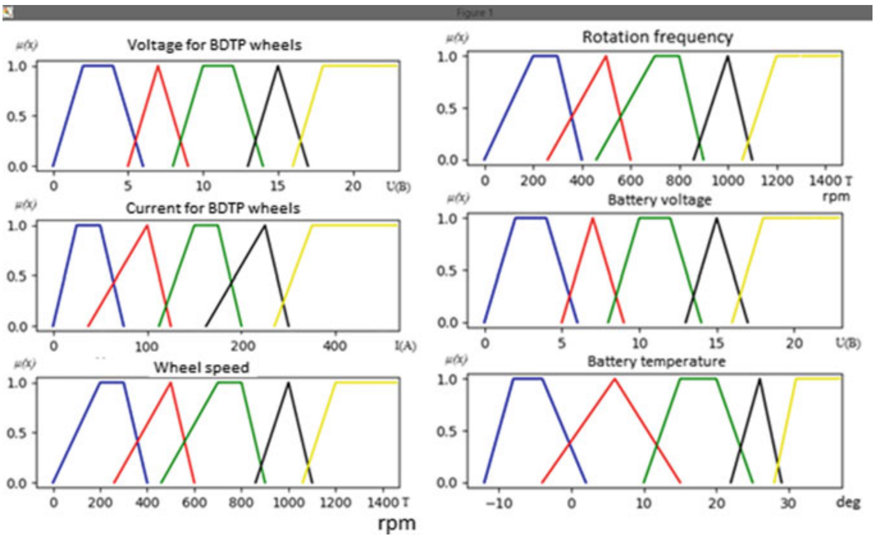

Fig. 12 Membership functions for each disturbing factor

4 Conclusion

There was developed the structure of an automated system for monitoring and diagnostics of a guided robotic vehicle, taking into account previously created models of nodes in the form of fuzzy behavior charts of the second rank. The research data allows to identify the area of possible malfunctions for each node and to obtain the corresponding knowledge base, which allows identifying abnormal and emergency situations using fuzzy behavior charts. There was created an algorithm for the functioning of the control system for diagnosing emergency situations. The proposed software was created on the basis of the achieved results. Its interface was also tested on the real robotic trolley. The overall malfunctions number is about two hundred and the third quarter of it could be resolved to make the system working without critical stops. The average quality decreasing level is about 15–18% from the faultless operation mode.

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