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Control algorithms of the operating mobile robot

Abstract: The article presents the control algorithms for discrete operation carried out by the work transfer robot and the communication system in a flexible automatic transportation system. Algorithms for transmission and reception of the information between the master complex of the control station and the slave controller of the mobile robot are considered.

Keywords: mobile robot, discrete operations, control algorithms, communication system, automatic system.

Algorytmy kontrolne obsługi robota mobilnego
Streszczenie: Artykuł prezentuje algorytmy kontroli dla operacji dyskretnych prowadzonych przez robota przemysłowego oraz dla systemu komunikacji w elastycznym systemie transportu automatycznego.

Słowa kluczowe: robot przemysłowy, operacje, algorytmy kontroli, system komunikacyjny, system automatyczny.

1. Introduction

The analysis of shipping and warehouse processes of the enterprises that use the method of shipping goods in packages and in distribution containers makes it possible to create an automatic transportation system based on mobile work transfer robots and come to unmanned (semimanned) manufacturing technology. The robotic application of stock movement with the use of distribution containers and large-sized packages solves an important social task – it eliminates heavy, monotonous, unskilled human labor of little prestige in the field of shipping and warehousing services of technological workshops at the various enterprises; and the main and the most important idea is that it allows to come to unmanned technology, create workshops and production fully-automatic-controlled facilities. The software and hardware of the system-wide and special software of the flexible automatic transportation system (FATS) have features in relation to the specifics of work transfer robots as typical mechatronic devices. It should be borne in mind that the environment of an industrial transportation vehicle, into which onboard microprocessor tools are embedded, is more rigid than the environment in which elements and devices usually operate. The low-current microelectronics of information-processing equipment is affected by electrical noise, voltage fluctuations of an autonomous onboard power source, radiated electromagnetic alternating fields caused by the operation of power onboard electrical equipment — electromechanical actuators and crosspoint elements that make up the high-current part of the work transfer robot. In addition, it is necessary to take into account the mechanical vibrations of moving work transfer robots (WTR) and the realistic conditions for their operation in industry.Vision.

In modern robotics great attention is paid to the information sphere and to the executive bodies, which are based on computing facilities and electric operation. However, autonomous power supply, rational electrical energy consumption and generally the optimal ratio between information, mass and energy on board are of great importance for an autonomously moving WTR. It is necessary to link the projected mechanisms, control systems and information-software, coordination of high-current and low-current parts of the WTR and the development of methods and means of increasing the reliability of operation, operational safety and survivability of the FATS. The basic methods of achieving these tasks are the modularization and decentralization of WTR and FATS software and hardware. Microelectronics, embedded in the mechanisms of WTR and FATS modules, make it relatively easy use automatic control in real time of all devices of the transportation system from the CENTRAL computer in a production environment. The selection of computer facilities, which are necessary for this class of MECHATRONIC technology, is subject to the solution of three main tasks, namely:

1) providing the interfacing of the electromechanical partof equipment with computer facilities (microcomputers);
2) ensuring the control of motion and manipulation (of the cargo receiver, the seizure of distribution containers during reception or release from it during delivery, guidance system and maneuvering of the work transfer robot in accordance with the addresses of a specific transportation task (TT);
3) providing communication with the human operator for the on-line programming and reprogramming of the transportation task (TT).

For such mechatronic devices as work transfer robots, the third task is supplemented by solving the task of keeping track of the operation of work transfer robots (WTR) or control over the execution of a transportation task (TT), which is carried out by means of bidirectional communication of the WTR with a dispatching point (DP) of transportation service or link of the person with moving and (or) fixed mechatronic devices suballocated over the maintenance facility (MF). When developing the WTR as a system, two main aspects should be taken into account, namely: the target orientation or specialization of the robot and the universalization of the means of technical implementation of the robot. Overviev.

In other words, the design of the automated guided vehicle system is subject to two opposite features: specialization and universalization. Specialization is determined by the sphere of application and a target goal, which are achieved through the designed WTR. If upon reaching the first aspect – specialization, the second aspect is not achieved – universalization, then an automated device will be designed.

From the practical point of view, a good-quality automated device will be created because the implementation of a specific target orientation is carried out, as a rule, with the optimization of its structure – elements and connections. However, to use the automated device in other cases is either impossible or very difficult, since the second aspect, oriented towards universalization, is not affected. Universalization and, consequently, the transition of the automated device to a new quality – the robotic device (system) is provided by software and hardware, because the calculating machine (the computer) is considered to be the most universal device among the machines created by the human. The universality of the computer is due to carefully designed microprocessor commands and software systems representing combinations of these commands (computer software).

The robotic system, supplemented by the necessary software, can carry out numerical calculations, as well as logical conversions (operations), process alphabetic, symbolic and graphic information, identify the state of the external environment, ("trace" the route of march and the marker, the transshipping station and the pallet for the cargo, "recognize" the station's readiness to accept-deliver the cargo, "feel" the mass of the cargo unit and its correctness), analyze and make decisions ("keep in mind" the application for transportation services and the transportation task (TT), a set of emergency situations and reactions to them), manage specific mechanisms. Thus, the capabilities of the computer's hardware (microprocessor) give a certain set of commands, the capabilities of the software part provide with a certain combination of commands (program) and the logic system. And, as a result, we have a specific implementation of the target designation. Built-in microelectronics and on-board computer of the work transfer robot are characterized by a variety of functions that can be attributed either to recognition or to action.

Recognition and actions are connected by intellectual connections (cause-consequence) in the mechatronic system. For the standard functioning of individual work transfer robots and the entire transportation system, the recognition and action processes are carried out within the framework of artificially created (fictitious) parallel processes on a real-time basis by logical combining sets of functions and using special programs, consisting of two parts. Programme.

One part deals with the software, the sequence of certain actions of the work transfer robot and modules of the transportation system, such as the library of standard subprograms, which is constantly increased and updated. The other part deals with the action program in the maintenance facility (MF) or in an environment, where the work transfer robot manipulates or interacts with objects in the process of transportation service. The first part is programmed as procedures related to sensing through a combination of sensory devices and to the action of specific operative devices. In addition to the controlling operators, syntactic structures are used, that carry out alignment of sensing and action in this part of the program. The second part of the software (with reference to WTR) contains the interpretation of the transport task, i.e. description of the maintenance facility (MF) and the required states and orientation of the WTR in the MF elements, necessary information concerning the objects interacting with the WTR, about the WTR itself (its working and emergency conditions) and common bonds.

When using high-level programming languages, programs are processed by the translation software to translate it into assembler language, and the object program of the mode that carries out the specified sequence of functions is formed for the control program of parallel processes. The management of parallel processes and the implementation of the required feedback are coordinated and synchronized by the computer's operating system. The task of the WTR tracking over a given trajectory and generating a controlling action when using a computer requires a large amount of computation. In real conditions and taking into account the dynamics of industrial WTR while tracking a given trajectory, it is advisable to use an analog controller rather than a digital controller to achieve the required stability of the system and the quality of tracking. During discrete representation of signals (data), the narrowing of the automatic controlling system (tracking) takes place, at the same time, with a decrease in the data sampling interval (in order to reduce information loss in the digital system), forced oscillations arise in the closed loop control system with a period approximately two times greater than the period of discrete data representation. If case of increasing the gain in the feedback circuit of the automatic controlling system in order to improve the quality of control, then the digital controller may lose its ability to respond to changing parameters of the work transfer robot.

Therefore, it is advisable to attach the function of the WTR to monitor a given trajectory to the analog controller. It is advisable to use the WTR onboard computer for carrying out discrete (final) operations in an automatic transportation system. The onboard computer deals with the tasks of the logical combination of the existing set of functions and the coordination of all the actions of the WTR in accordance with the target goal set for it.

These tasks include: bidirectional communication for the exchange of information between the work transfer robot and the dispatching point of the transportation system, transportation service, diagnostics of the WTR and modules of the automatic transportation system for postimplementation maintenance. The actions, connected with the processes in these tasks, are completely determined by the programs recorded in the read-only memory (ROM) of the computer. According to the physical nature of the tasks being solved and simplicity of the organization of the programmed process for achieving the goal, namely transportation service, stack-oriented computers can be considered the most appropriate architecture for the microprocessors used.

They have temporary areas — stacks — and the corresponding functions for processing: sending data to the stack and retrieving them from it by using the stack organization principle – "last in – first out". The stack oriented microprocessor selects, memorizes or processes the command and automatically changes the address of the next command per unit; therefore the boundaries of the local variables area of the executable procedure and the address of the stack memory boundary are specified in the memory area. Such microcomputer architecture (controller) mostly satisfies the physical principles of addressing the target goal with flexible programming of the transportation process technology using work transfer robots, where there is no unambiguous (unchanging) feedback between the information elements of the route-track module (RTM) of the maintenance facility of the transportation system and the functions performed. As a result, each information element of RTM becomes a multifunctional one. It makes possible modify the structure of the RTM in a wide range, without affecting the structure and feedback of the onboard system of automatic addressing of the WTR, in other words, to create software transportation services, not bounding to the specific capabilities of the rolling stock of the transportation module. If the individual units of the transportation module do not contain a number of functions defined by a set of programs, then the current transportation task for such work transfer robots simply does not contain an appeal to the subprograms of these functions. For example, the WTR number 4 cannot move in transverse directions.

The current transportation task for this device does not contain a call to the "Transverse" subroutine, and working microstructions are not extracted from the standard subroutines library, namely: "Stop / Move across to the right (forward)","Stop / Move across to the left (reversal)", "Reset of lateral movement (forward),"Reset of transverse movement / Reversing". As a result, controlling commands (signals) are not formed, and the corresponding input / output ports of microcomputer information are not involved. With flexible programming, the set of possible functions of the transportation process can be expanded and supplemented with new ones, as the WTRs are created with broader and more diverse functional capabilities or the need of compliance with any specific conditions of transportation service for a specific manufacturing unit, especially in the subband of acceptance – delivery of cargo units to automatic technological equipment.

The flexible programming can be of the first or second type for the WTR. The flexible programming of the first type implies the formation, modification, input and control of the input correctness of the transportation task into the onboard memory by the operator-dispatcher from the onboard programming control panel; in other words, it does not include the information exchange system (IES) as an organizational and technical means of implementing these and other functions from the computer of the dispatching point or the computer of higher rank. The organization of remote automatic tracking over the operation of work transfer robots and monitoring the execution of the transportation task, as well as providing communication at the dispatching point with moving and / or stationary-based work transfer robots distributed throughout the maintenance facility, characterize flexible programming of the second type, i.e. the presence of IES between the distributed onboard "memory" and the dispatching point "memory" of higher rank. The basis of the controlling transportation service process is the TT, which specifies the sequence of elementary functions (operations) to the work transfer robot in time and space. The series of steps of the WTR connected with the course of the transportation service process is determined by the program stored in the memory of the WTR onboard computer. However, the generated transportation service process exists in memory by itself, as the programmed process is in an inactive state.

Changing of the process into the active state is carried out by the controlling program, which forms the requirement for the execution of the process, i.e. performs initialization or excitation of the programmed process. An excited process can assume one of the following states: "readiness for execution", "execution" and "waiting". When the robot control program transfers some processes to the state of "readiness for execution", it simultaneously sets them into a queue of "readiness for execution" according to the principle of organization of the stack, i.e. the queue is considered as the main component of the stack model, filled with the names of the processes in the "waiting" state. The kernel of the robot control program contains the basic functions for controlling: state transitions, sequence of processes, and others. The kernel operation is organized by interrupts:

1) according to time intervals:
2) system interrupts:
3) external signals.

An external interrupt is caused by software and is generated by the robot control program commands. An external interrupt is generated by an interrupt of input / output signal. In particular, the interrupt signal "Emergency state of WTR" interrupts the current stage of the transportation service process, which goes to the end of the waiting queue, and transfers the transport service program to an emergency analysis subroutine (this external interrupt signal is the highest priority level among other signals of external interrupt such as "Marker" and "Communication". The information concerning the status of the current stage of the transportation service process is stored during the interruption process. The final stage of processing of the external interrupt signal with the identifiers "Marker" and "Communication" is terminated with the automatic resumption of the state of the interrupted transportation service process and the removal of the ban on interrupting the current external signal from these identifiers. At next sampling times these signals can be received again. The information exchange system (IES), a communication system, in an automatic transportation system implement their main purpose through a variety of functions defined by the exchange protocol 2 .4 levels, including the transportation level, the network lever and the control level of the data link channel (L1).

Therefore, there is the dispatching point with a central processor in the transportation system, distributed in the space of the WTRs with microcomputers (microcontrollers) and various technological equipment integrated into a single system using the data link channel. The basic programs in the computer structure of the dispatching point (DP) are the programs for generating transportation service requests and a list of TT (user programs) and related controlling programs with presentation and communication session. The combination of these three elements form a process (Fig. 1). The algorithms defining the interaction of TT programs according to requests of transportation service (user information), presentation and session are set by protocol of the 7th, the 6th and the 5th levels (Fig. 1).

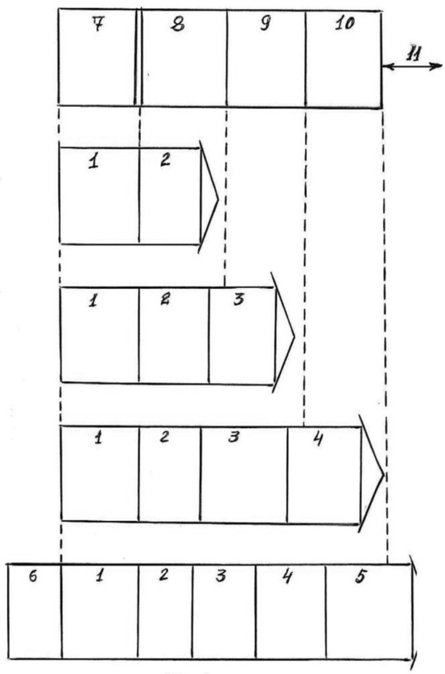

Fig 1

Figure 1 demonstrates messages processed by protocols of 2 … 4th levels, and the structure of messages. The main task of the DP computer is to provide the interaction of remote processes, in particular, performed by the WTR, which are carried out by the exchange of arrays of information between processes. An array of information has an arbitrary length, so it is divided into blocks of a certain size and provide service information – the process tittle. The responsibility for the correct and timely transmission of message blocks in the distributed microprocessor system of the transportation module is borne by the protocols of the transportation, network levels of the data link channel. Each of these levels (Fig. 1) encases the block with additional service information, breaking the block into fragments, the fragment is divided into information packets, the packet is divided into frames. As a result, frames with a large number of command boxes are sent to the data link channel. An important role in providing timely and accurate messaging is played by the control protocol of data link channel, which defines a significant number of managed exchange functions, namely: a) control of procedures for initialization and deinitialization of the data link channel; b) packaging of transmitted information into frames prior transmission and its unpacking after transmission over a physical data link channel; c) generation and reading of control frames; d) providing the transparency of the data link channel: e) transmission and reception of acknowledgments of reception of frames: e) encoding and decoding the contents of the frame in order to detect transmission errors: g) retransmission of those frames that have been lost or in which an error has been detected: h) flow control of frames to both sides of the physical data link channel.

2. Instrumentation

The implementation of the computational facilities of the WTR and the entire automatic transportation system (ATS) is successfully solved by means of microprocessor technology, including microprocessor controllers — finished products, designed in the form of a microprocessor module, a memory module and an interface. For example, a 16-bit microcontroller MCS-296 of INTEL (80C296SA) has a built-in register random access memory (RAM) equal to 512 b. The amount of built-in RAM programs – 2 KB. The number of input-output lines is 64, the number of external interrupt requests is 4, and the most important thing is that it has a built-in port of logical input-output of the information that makes it possible organize the data link channel in the PBX (L2). The possibility of expanding the memory and the number of input-output lines is provided, to which the signals of the sensors characterizing the state of the WTR and the transportation system are transferred. The presence of embedded reprogrammable memory in the single-chip microcontrollers with erasing information by ultraviolet radiation allows the programmer to independently set the functions solved by the controller by recording its own program

into read-only memory (ROM). The command system makes it possible carry out logical and arithmetic operations, set and reset information on individual input-output lines, etc. A processor, completed on a single chip, contains traditional elements, such as:
1) Command decoder:
2) Arithmetic and logical unit (ALU);
3) Flags of signs;
4) Accumulator;
5) Commands counter;
6) Stack pointer.

Such kind of structure and a set of micro-commands (more than 100) makes it possible implement complex control algorithms. In Figure 1 the protocols of the 1st level describe the physical, electrical, and procedural characteristics of establishing, maintaining, and disconnecting a physical interface at a point between the terminal device of receiving and transmitting information and data circuit terminating equipment of the data link channel. Control of the data link channel between two microprocessors is regulated by protocols of the 2nd level of two types: byte-oriented and bit-oriented. The protocols of the 3rd level regulate transmission control in the network and include functions that provide priority service of messages, choice of message transfer route, inter-node exchange, local control of information flows, and access to the WTR microcontrollers, to the core network of the transportation system, and various service functions. The 4th – level protocol determines the message delivery between a pair of computer ports during the exchange of information between them. This protocol carries out addressing of the message (search for the required work transfer robot) and its connection to the exchange channel formed with it, control of errors, loss of messages at the acceptance, detection of their distortions and recovery of the message for retransmission.

Wired communication channels (WCC) for the WTR are not suitable. It is necessary to use inductive WCC with an air gap between the information loop (IL) of the exchange, laid down along the motion route of the WTR and transmitter /receiver unit of the WTR. This air gap is not protected from industrial electromagnetic signals and interference; it does not allow the use of standardized or industry-proven communication protocols of 2 ... 4th levels. These protocols are designed for automated process control systems of technological process, and oriented to wired communication channels, which are least affected by external interference. Therefore, the protocols do not contain procedures for checking the correctness of acceptance of each transmitted byte or character of the message, detection of specific corrupted bytes, recovery of information only distorted bytes and others. The control of the correctness of the transmitted and received information in these protocols is carried out by the end result – a checking sum that characterizes the reliability of the transmitted message or the message block as a whole: true or false.

3. Result

Evaluation of the accuracy of the transmitted and received information on the final result leads to undefined "hang-ups" or loops of the exchange program between computers in the transportation system, because the inductive communication channel is open to accidental external interference from the manufacturing department and the WTR itself. Therefore, the information exchange system (IES) of an automatic transportation system, the information exchange protocol provides for byte-serial transfer of information from the master computer (DP) or the attached one (WTR microcontroller) with confirmation of the reception. In case of confirmation the results the master computer (DP) transfers the next byte.

Therefore, the protocols of 2 … 4^{th} levels with byte transfer of information provide measures to combat interference by self-restoring a message at a certain level of errors in the exchange process and to combat the reflection of the transmitted signal in the transmission channel, the so-called "echo" of the sent signal. To combat this phenomenon, the protocol provides the following actions:

1) the master computer (DP) sends the current byte to the attached microcontroller (WTR) and switches its transmitter-receiver from the "delivery" mode to the "acceptance" mode;
2) having received this byte, the attached controller (WTR) inverts it, sends it to the RAM for temporary storage, switches its transmitter-receiver from the "acceptance" mode to the "delivery" mode and sends the inverted byte to the master computer (DP);
3) the master computer (DP) receives the inverted byte or the response of the attached controller, inverts it again, compares it with the sent byte and switches its transmitter-receiver from the "acceptance" mode to the "delivery" mode;
4) if there are no distortions during acceptance by the attached controller (WTR), then the master computer (DP) transmits the following information byte and all manipulations with this byte are repeated;
5) if there are errors during acceptance (distorted bits) of this byte on the side of the attached controller (WTR), then the master computer (DP) retransmits the current byte (the number of retransmissions is set by the protocol);
6) depending on the results of retransmissions, either the reliability of the byte received by the attached controller (WTR) is set, or the number of this distorted byte is stored in a specific memory area;
7) at the end of the communication session, a list of errors is issued for analysis and further action. To combat interference in the inductive communication channel, IES and PBX are endowed with the property of self-restoring, the essence of which is as follows.

The fixed number of retransmissions of each byte, for example, 10 is established in the exchange protocol. If all 10 byte transfers have been used (with confirmation of acceptance) and in all 10 repetitions, the IES has detected acceptance errors, the system issues the error code information “No connection” or “The communication channel is faulty”. If the system carried out 6 byte retransmissions and found that bytes had been received with an error in 5 repeats, and received without errors in the 6th repeat, then the IES software goes off: the system stops carrying out the remaining 4 transmissions of this byte, takes the timeout (waiting time is set by the protocol) and starts the transfer process from the beginning. This makes it possible eliminate the effect of random interference in the transmission channel in a given communication session.

The microcontrollers of the INTEL MCS – 296 series, in their structure, have a built-in asynchronous transmitter-receiver, which allows organizing an information network to control an automatic transportation system. This system contains various technological equipment, such as cargo handling stations for acceptance and delivering cargo trucks, temporary cargo storage stations, acceptance stations and cargo delivery stations assigned to processing equipment, an automatic warehouse for storing semi-finished and finished products, etc. All these elements are assigned an information number.

With asynchronous transmission, each byte sent to the communication line has a start signal at the beginning; it has one bit of information or one bit of a binary number. Then the signal is a sign of the transmitted byte, which indicates whether the byte belongs either to the data or to the control commands. This is another bit in byte format. Then the data is 8 bits. Sending data ends with a parity or control of parity or odd parity of the signal. The stop signal completes the sending of one byte information; it takes 2 bits (L3). Thus, it is required to send a single byte of 13 bits, which can be increased, if different signs to search for errors are added.

4. Algorithms

The computer word of microcontrollers is usually equal to 8 or 16 bits. In this case, it is advisable to transfer the bytes with 4-bit information packets or as two nibbles, and store them in general purpose registers of the microprocessor combined in pairs, for example, VS or DE. Such an organization of information packets facilitates the identification of an incorrectly received byte, the search for the distorted byte in the message block and the correction of a specific byte, but not the entire message. Diagrams of algorithms for transmitting and receiving information from the computer of the dispatching point or microcontroller of the work transfer robot (single symbol or nibble) are presented in Fig. 2, Fig. 3, Fig. 4.

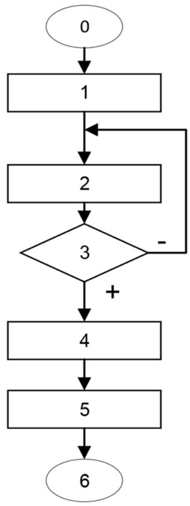

Fig. 2. Nibble Transmission Algorithm . .

Figure 2. Nibble Transmission Algorithm, where block 0 – the beginning of the algorithm, block 1 – send the transmitted symbol from the accumulator to the register “C”, block 2 – polling the control port (P1). block 3 – is the transmitter ready? “Yes – no”, block 4 – writing to the data port of the transmitted symbol, block 5 – recovering of registers “BC”, block 6 – returning to the main exchange program.

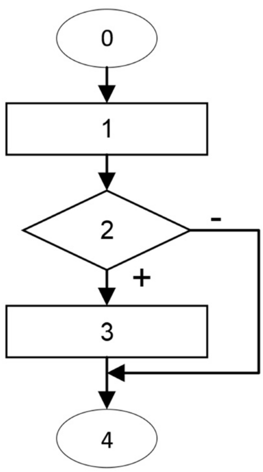

Fig. 3. Algorithm for the reception of a nibble

Figure 3. Algorithm for the reception of a nibble, where block 0 – the beginning of the algorithm, block 1 – reading the status word from the control port and writing to the register “C”, block 2 – is the receiver ready? “yes-no”, block 3 – reading the received symbol, block 4 – returning to the main exchange program.

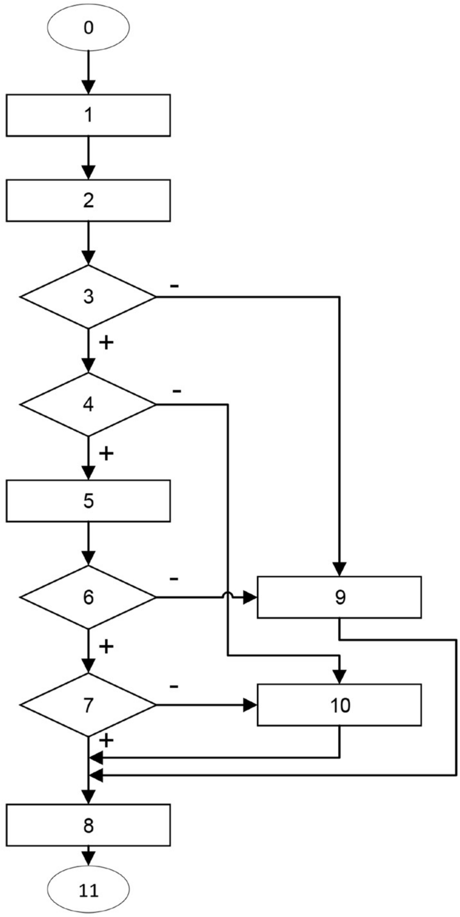

Fig. 4. Algorithm for restoring a byte of information when receiving two nibbles

Figure 4. Algorithm for restoring a byte of information when receiving two nibbles, where block 0 – the beginning of the algorithm, block 1 – the reset of reception errors, block 2 – the subroutine “reception of a nibble” – reception of the 1st symbol, block 3 – is it a reception ? “Yes-no”, block 4 – is it a parity check? – “yes-no”, block 5 – subroutine “reception of a nibble” – reception of the 2nd symbol, block 6 — is it a reception? “yes – no”, block 7 – is it a parity check? “yes – no”, block 8 – resetting the error code, block 9 – setting the error code (no answer), 10 – setting the error code, 11 – returning to the main exchange program.

5. Conclusion

The efficiency of algorithms was verified in the working environment. Developed algorithms tested under production conditions can be used to control a group of mobile robots operation in a unified automatic transport system in organization of unmanned production.

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