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DEVELOPMENT OF AN INTELLIGENT ROBOT CONTROL SUBSYSTEM

Abstract. The subsystem should provide the following functionalities: planning of trajectories of movement of an intelligent robot in an a priori uncertain dynamic environment of operation: representation of opposing objects of the environment and functional and executive nodes of a mobile robot using a fuzzy configuration space; formation of a movement trajectory with a fixed level of confidence; updating the environment map when exploring new areas of the operating environment; real-time operation of the scheduler; modularity and scalability of the subsystem. To successfully navigate in space, the robot control system must be able to build a route, control movement parameters, correctly interpret information about the world around it received from sensors, and constantly track its own coordinates. The paper investigates the development of control subsystems for an intelligent robot. To achieve this goal, the initial data were analyzed, the general principle of building a simulation model of the robot was described, and a structural diagram of the control system of an intelligent robot was developed.

Keywords: intelligent robot, sensor, navigation system, interface.

Introduction

The subsystem under development is designed to plan the targeted actions of an intelligent mobile robot in an a priori uncertain environment [1]. It is difficult to develop such a subsystem based only on a rigid algorithm for working out a given trajectory of movement of the robot's executive subsystems (RS). The absence of feedback on the operations performed indicates a low flexibility of the system as a whole, which significantly reduces the possibility of using the RP in real conditions of automated production. The direct operation of such a system faces the following problems

- the need to create a flexible distributed structure of flexible production modules;
- solving the problem of time coordination of several robots performing a single task;
- the need to change the control program when moving to new unstructured production areas, where it is difficult to enter the trajectory of the robot's technological operation.

The main disadvantage is the strict requirement for the accuracy of the reference trajectory, the violation of which during operation leads to a disruption of the entire technological process (TP), and this situation is difficult to automatically correct, requiring intelligent action planning [2–5]. The subsystem should provide the following functionalities:

a) planning of trajectories of movement of an intelligent robot in an a priori uncertain dynamic environment of operation:

1) representation of opposing objects of the environment and functional and executive nodes of a mobile robot using a fuzzy configuration space;

2) formation of a movement trajectory with a fixed level of confidence;

3) updating the environment map when exploring new areas of the operating environment;

b) real-time operation of the scheduler;

c) modularity and scalability of the subsystem.

When filling the knowledge base, the operator is responsible for selecting the general characteristics (name, code, etc.) of known objects. Object traversal parameters are recorded as additional object parameters. Changes to the trajectory in the object knowledge base are made only by the subsystem itself; the operator cannot change these characteristics manually.

The subsystem should provide for updating decision-making methods due to the object-oriented structure of the information and modeling complex, i.e., recomposition without changing the basic relationships between modeling objects.

1 General principle of building a robot simulation model

In accordance with the traditional model of modeling organization, when information flows are exchanged between the researcher-designer and the simulation model, feedback on the results of the simulation is provided by a chain external to the simulation modeling system - a person with the involvement of auxiliary tools and software methods. At the same time, the researcher-designer performs the function of information transformation, which consists in interpreting the results and making decisions on managing experiments and generalizing information to the knowledge base of an intelligent robot. Automation of experiment management involves the creation of a closed software-implemented control loop of the simulation model within the framework of external software [6–9]. The structure of the model is shown in Fig. 1.

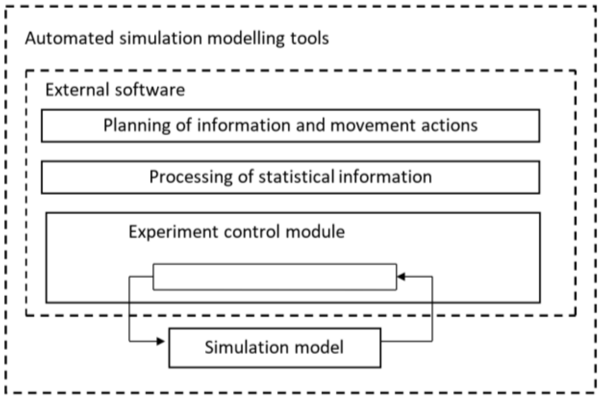

Fig. 1. Structure of the information and control model

Targeted series of experiments, in accordance with the set goal of the robot's functioning and taking into account the constraints of the configuration parameters, are organized by modules that are specifically included in the external software. In general, these modules must set the initial data sets, initiate model runs as a whole, process the results, and make decisions about the further development of experiments in accordance with the implemented modeling control algorithm.

Such an algorithm, directing the experiments, searches for such a combination of parameters in the field of permissible values of parameters that would ensure the optimum of a given quality indicator, i.e., essentially solves the optimization task:

$$f(\bar{x}) \xrightarrow[\bar{x} \in X]{} \max , \qquad (1)$$

where f – the objective function represented by the algorithmic simulation model; $\bar{x} = (x_1, x_2, ..., x_n)$ – vector of parameters of the modeling object; X – a set of valid values of input parameters.

Thus, a set of algorithmic and software tools that provides the process of automated modeling forms a simulation automation modeling system (SAMS). Since the user does not enter each set of initial data for the next run of the simulation model and only specifies the goal or criterion and the range of parameter variation, while the search for valid solutions to simulation problems is performed automatically by the SAMS, the definition of an intelligent simulation system can be applied to the latter. For example, the functions of the SAMS in the control loop of a flexible production system generally consist in analyzing alternative options for robot behavior after making a particular possible decision on dispatching and operational planning of information and motion actions, etc.

The effectiveness of these functions is due to the replacement of the rigid control logic of an intelligent robot, which involves the use of specified and fixed heuristics in certain situations, with a flexible and dynamic mechanism that ensures decision-making not only on the basis of a similar analysis of the current state of the robot, but also taking into account the prospects for its development. The problem of automating the management of experiments, synthesizing knowledge and building a knowledge base can be represented by the logical structure of the step-by-step solution of individual tasks of an intelligent robot, as shown in Fig. 2. At the first stage of automating the control of experiments, two tasks are solved:

- structural and algorithmic construction of the control module itself is performed;
- forming the substantive basis and formal requirements for the organization of information exchange with the simulation model.

The task of structural and algorithmic construction of the experiment control module and synthesis of the knowledge system is solved in the following sequence: the composition and structure of the module are determined (the conditions of interaction of its components and position in the overall structure of the SAMS are developed).

When performing a series of simulation model runs, a targeted variation of parameter values occurs, which can affect the value of the objective function not only through direct influence on the functioning of the modeling object, but also indirectly through other elements of the object (robot) that are connected. As a result, cost and other indicators change. In addition, restrictions can be imposed on the values of some parameters, in particular, some of them can be fixed, i.e. set declaratively. This can be reflected in the formation of initial data sets and initialization of the initial states of the knowledge system modeling process.

Considering a simulation model as a means of purposeful transformation of information in accordance with a certain system of prescriptions, it makes sense to talk about a simulation modeling algorithm. Then the formal interpretation of the requirements under consideration can be written as follows:

$$S \in Q; \quad S \in C, \qquad (2)$$

where S – input word of the simulation modeling algorithm; Q – a set of valid sets of robot parameter values; C – the scope of the simulation modeling algorithm definition.

The input word S specifies a set of initial data of a particular data set, i.e. $S = (i, \xi_j, ..., \xi_z)$, where each value ξ_j corresponds to a certain value of a certain parameter of the modeling object. The domain is determined by the software implementation of the simulation algorithm, and it can be formed by the set D_{in} of input alphabet sets. All values ξ_i that have a permitted realization of the modeling object U. Thus, expressions (1) respectively define the conditions for matching S with the simulation model and algorithm. The task is to develop an apparatus for formal analysis of the consistency of changes in semantically interrelated parameters to ensure that the variation does not violate condition (1) and does not lead to changes in fixed parameters. At the second stage, the automation of experiment management and the construction of a knowledge system is carried out, and the following stages are solved:

- development of principles, interaction of the logical inference system and numerical optimization procedures;
- selection (development) of an apparatus for implementing logical inference from combined algorithms for managing experiments;
- development of effective inference algorithms based on the proposed apparatus, taking into account the specifics of interaction with numerical optimization procedures.

This stage solves the problem of developing optimization procedures used in planning extreme

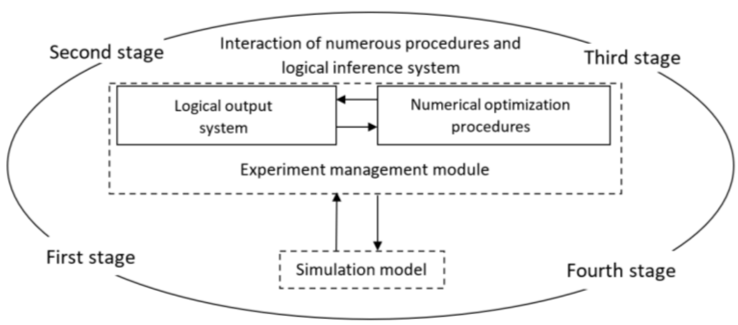

Fig. 2. Automated modeling of an intelligent object

actions. At the same time, the issue of developing algorithmic support can be considered for specific aspects of object modeling, namely

- automation of experiments management under conditions of linguistic uncertainty of parameters, for example, "degree of similarity/difference..." has no natural numerical measurement;
- organization of extreme experiments in the problems of one-parameter optimization with a significantly uneven location of points in the middle of the interval, for example, a unimodal response function, and fixing the corresponding states in the model of the knowledge system;
- reduction of search time with a significant duration of the simulation model run, which is important for multi-iterative search algorithms, full search of options, etc.

2 Block diagram of the robot control system

The main task of an intelligent control system (ICS) is to physically implement various movements of an intelligent robot, with an adequate response to uncontrolled environmental changes and unpredictable drift of the robot's parameters. To fulfill the main task of the ICS during operation, it is necessary to solve many additional tasks that interact with each other. The analysis of these tasks and the specifics of controlling an intelligent robot led to the construction of a control system in the form of a three-level hierarchical structure, shown in Figure 3.

At the first level, the ICS makes a decision on the possibility or impossibility of movement, determines the composition of electromechanical devices (EMDs) used for movement, and builds a general plan of movement (maneuver). At the second level, EMD control programs are formed, their control models are determined, the current situation is recognized, and self-learning is performed during operation. At the third level, controlling influences are formed to perform movements in an optimal way: for a minimum time, with a given accuracy, quality of transients, etc. with the necessary adjustment (adaptation) of EMD control models.

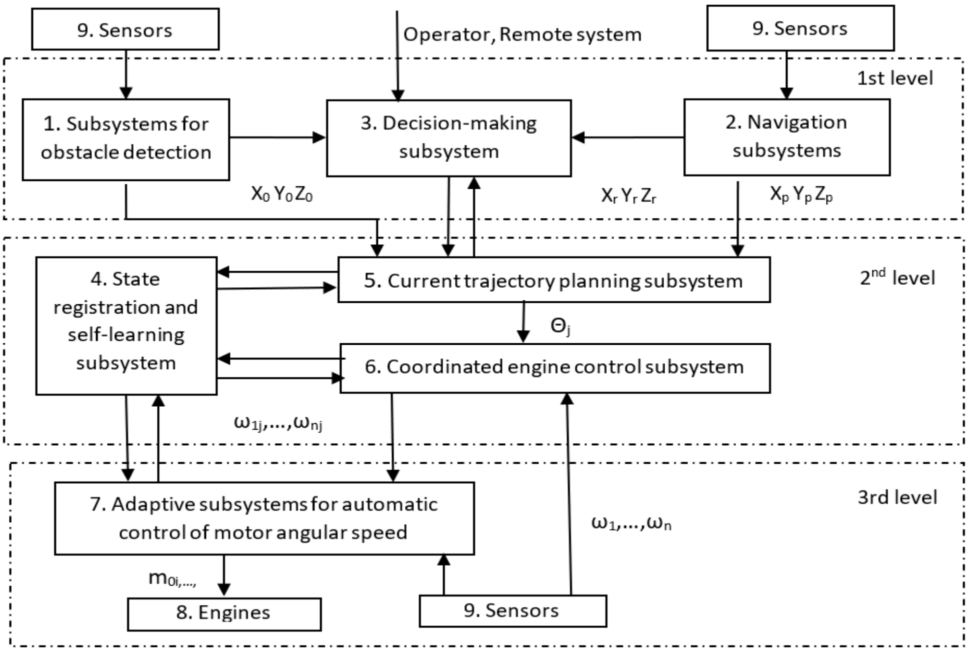

Fig. 3. Structure of an intelligent control system for an intelligent robot

The structure is focused on the realization of IR movements in real time, in which the interaction between levels occurs according to a limited number of movement parameters: linear speed V; position coordinates X, Y; heading angle Z (angle between the main axis of the IR and one of the coordinate axes); angular velocities of wheels and motors ω . In the proposed system for controlling the movements of the IR, the current goal of the movement or movements is received from the upper-level control system (external computer) in the form of parameters X_r, Y_r, Z_r , or parameters defined regarding the obstacle X_o, Y_o, Z_o.

The movements are controlled as follows. Block 3 receives a request to perform the movement of the IP (movement of the IR in the workspace, location of the working body of the attachment, or performing these actions simultaneously). Based on the data of blocks 1 and 2 on the current location of the intelligent robot and obstacles to movement in the workspace, as well as information from the second and third levels of control, block 3 determines whether the specified movement can be performed or not. In case of a positive decision, the coordinates of the points of the trajectory ending at the target point X_r , Y_r , Z_r are calculated. These coordinates are transmitted to the second level block 5.

In block 5, according to the incoming coordinates and knowledge about the properties of the current working space of the intelligent robot and the location of fixed obstacles in it, as well as knowledge about how this goal was achieved in the past, the desired linear speed V_g and the desired steering angle ω_g of the steering device (if any) for the next point of the trajectory are determined. For this purpose, the information coming from the navigation system X_p, Y_p, Z_p or the subsystem for determining the position of the robot relative to the obstacle X_o, Y_o, Z_o, as well as the knowledge accumulated in block 4 by experts during the design of the system and during the period of operation of the robot is used. In the absence of navigation subsystems and an obstacle positioning subsystem, the current trajectory planning subsystem uses its own path calculator to determine the coordinates of its position based on data from wheel rotation sensors, motors, or special travel distance sensors.

If V_g and θ_g are calculated, then in block 4, based on information from the upper-level systems and the internal state of the robot, the current situation is recognized and adaptive EMD control models adequate to the current situation are selected. These models are sent to block 6. In block 6, the angular velocities of the motors ω_{1g}, ..., ω_{ng}, participating in the movement, are calculated. The sequence ω_{1g}, ..., ω_{ng} in time represents the control program for the corresponding motor (motors) and is stored in block 4. Thus, block 4 accumulates the movement programs that the system uses in the absence or malfunction of the navigation subsystems. In addition, these programs include programs for maneuvers (turns and movements) in a limited space that are not described by smooth continuous trajectories.

The calculated angular velocities are sent to block 7 of the third level. The task of the block is to generate control influences m_{0i}, ..., m_{vi} on all the motors involved in the movement. Block 7 implements the functions of parametric adaptive automatic control systems that monitor the angular velocity of wheels or motors. If the disturbances go beyond the permissible limits, the current trajectory planning system at the second level or the decision-making subsystem at the first level is accessed to make a decision on further control.

During operation in block 7, the parameters of automatic control systems are identified using real data from block 9.

These parameters are processed and accumulated in block 4. They are then used to determine the initial conditions of the adaptive control subsystems when performing subsequent movements in similar conditions.

In addition, all data are stored for subsequent processing to determine control errors and develop methods for their accounting. In the simplest case, when moving repeatedly along the same trajectory, this subsystem determines the average values for the desired parameters of each trajectory point.

Conclusions

To successfully navigate in space, the robot control system must be able to build a route, control movement parameters, correctly interpret information about the world around it received from sensors, and constantly track its own coordinates. To achieve these goals, we have developed an architecture and a generalized algorithm for controlling a mobile robot and a block diagram of the robot control system.

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Розробка підсистеми управління інтелектуальним роботом

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Анотація: Підсистема має забезпечувати такі функціональні можливості: планування траєкторій пересування інтелектуального робота в апріорно невизначеному динамічному середовищі функціонування: репрезентація протидіючих об'єктів середовища та функціонально-виконавчих вузлів мобільного робота з використанням нечіткого конфігураційного простору; формування траєкторії пересування з фіксованим рівнем довіри; оновлення карти середовища при дослідженні нових ділянок середовища функціонування; режим роботи планувальника в реальному часі; модульність і нарощуваність підсистеми. Для успішної навігації в просторі система управління робота повинна вміти будувати маршрут, керувати параметрами руху, правильно інтерпретувати відомості про навколишній світ, одержувані від датчиків, і постійно відстежувати власні координати. В роботі проведені дослідження з розробки підсистем управління інтелектуальним роботом. Для досягнення мети проведено аналіз вихідних даних, описано загальний принцип побудови імітаційної моделі робота і розроблено структурну схему системи управління інтелектуальним роботом.

Ключові слова: інтелектуальний робот, датчик, система навігації, інтерфейс.