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INTELLIGENT MEANS IN THE SYSTEM OF MANAGING A MANUFACTURING AGENT

The subject of the study is intellectual means in the system of managing an intelligent manufacturing agent; **the goal** is to ensure the quality of managing a flexible integrated robotic system by developing the intellectual decision support system. The following **problems** are solved in the work: current tendencies of developing and implementing the intelligent systems for production management are considered; the demands for developing simulation models of decision support systems for solving flexible integrated production systems are formulated; the logical model of a decision support system for an intelligent manufacturing agent is developed, this model describes the decision-making process in the form of the functioning strategy formation on the basis of the knowledge of the current state of the integrated system, the system of knowledge describing probable actions of the robotic equipment, the objectives of the production system, and adapts the strategy if the working space of the integrated system or its individual goals change; the system of knowledge of a flexible integrated system is presented as a set of standard description of probable actions for robotic equipment; the distributed workspace of integrated systems is considered and described; separate objects are identified using the means of computer vision. The research is based on the following **theoretical and practical** foundations: the theory of sets is used to represent general simulation models of the decision support system; the theory of predicates is used to create a logical model of decision-making; knowledge-oriented methods and the tools of Prolog programming language use used to represent the knowledge system of a flexible integrated system, the MatLab system is used to analyse the workspace of a flexible integrated system. **The following results** are obtained – mathematical and informational software of the system for managing an intelligent production robotic agent is developed. The possibilities of the proposed model application in the system of managing an intelligent robot are shown and the ways for improving such systems are suggested.

The keywords: logical model, intellectual agent, mobile robot, the theory of predicates.

Introduction

The automation of modern production is based on a large-scale introduction of flexible integrated systems (FIS) of various types. Their features are the capability to adapt quickly to changes in the technology of manufacturing products at the levels of technical re-conditioning of individual units, equipment and tools, the possibility of reprogramming in accordance with new technological challenges. Also, the key feature of FIS is their close interaction and structural implementation in existing production systems, which provides the possibility of their gradual upgrading in a modular way, facilitates the operation of technological systems and their maintenance. This way of designing, developing and implementing technical systems is typical for modern car manufacturing, aircraft construction and shipbuilding, mechanical engineering, the production of electronic and other devices.

Flexible integrated manufacturing systems (FIMS) are considered as a way of organizing production, which provides complete management of the production process and involves the integration of machine tools and other process equipment into a single system using a local computer network to combine the threads of processing or assembling streams, applying cutting tools and other equipment and corresponding information flows [1].

The use of industrial robots (IR) in flexible integrated systems enables increasing the efficiency of production and reducing the cost of a unit of production. For instance, [2] shows the examples of cost reduction by 3 times. On the other hand, using robots does not always suggest high results. The experience of administrative implementation of robots in the USSR [3] indicated the unreliability of IR, their limited application, the significant amount of costs for buying and introducing, a small number of personnel that was discharged from employment due to the use of IR, a rather low level of quality and the lack of component parts, the lack of necessary microcontroller control systems. Probably, such experience, at the same time, showed the lack of preparedness of specialists for the widespread introduction of industrial robotics.

The analysis of the construction of flexible integrated production systems shows that the artificial intelligence (AI) of a robot is mainly implemented by using a computer system that controls the movements of robot manipulators or their transport system (chassis). The artificial intelligence of robots is based on a highly developed sensor system consisting of different kinds of vision systems, a number of touch-sensitive sensors, range finders, gyroscopes, compasses, light sensors, colour and sound sensors and other ones. In addition to recognizing scenes and tactile feelings, speech recognition and natural language processing play an important role in the intellectualization of FIMS [3, 4].

The analysis of the trends in the development of flexible integrated production systems indicates the growing complexity of the organization of modern production, both in a separate workplace and in the conditions of a work section, shop or factory. Under such conditions, the role of automated control systems using AI tools is growing and is capable of receiving information about the state of production systems in a timely and appropriate manner with the help of sensory systems, of analyzing it, and making decisions to ensure the operation of the enterprise. On the other hand, the role of making production decisions at each specific workplace increases, which becomes a function of the servicing equipment: industrial robots, robocars, other technological and support systems.

Thus, the topical problem is the development and implementation of intellectual tools of decision support at different levels of production management and individual

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units of flexible integrated production systems.

The analysis of literary sources and problem statement

The areas of using artificial intelligence systems are constantly expanding. Today we are talking not only about the use of classical automated technologies but also about flexible intelligent manufacturing systems (IMS) which include parts of machine intelligence. The expansion of IMS should replace human manual labour. The IMS includes systems that can support decision making, knowledge acquisition, training and adaptation to changes in the work environment and can interact with real equipment [5].

An intelligent manufacturing system is a system with the built-in property of adaptation to unpredictable changes, in particular, changes in the necessary assortment of goods, market requirements, technological changes, social requirements. However, the intelligence of such systems is often understood as software management but not as the implementation of modern technologies of machine-based artificial intelligence. Intellectual production systems contain subsystems like FMS: technological, transport, manipulative ones.

Subsystems should be equipped with the means that provide them with a certain level of intelligence. They should be considered as the highest phase of FMS.

The functional capabilities of IMS should include [5]:

- intellectual design;
- intellectual support of technological operations;
- intellectual management;
- intellectual planning;
- intellectual support of processes.

The objectives of implementing IMS are:

- reduction of production costs;
- Reduction of time spent on manufacturing;
- easy integration of new processes, subsystems and technologies, their updating, maintenance of operational interaction;
- reduction of manufacturing defects, environmental impact;
- rapid reconfiguration, adaptation to expected and unexpected events.

IMS operation requires that they should be created as an open architecture with a modular structure that enables using different methods of knowledge representation and their integration into manufacturing systems, decision-making processes and knowledge acquisition.

IMS should integrate the following methods and technologies for processing knowledge and decision-making processes:

- artificial neural networks that are an AI tool capable to simulate complex functions, to imitate learning processes that occur in the human brain;
- fuzzy logic – a set of technologies and methods for formalizing natural language, linguistic and quantitative data processing;
- genetic algorithms and methods of evolutionary modelling which include learning algorithms based on theoretical achievements of evolutionary theory enriched with artificial intelligence technologies.

When the tools, in which knowledge is represented symbolically, are combined with the expert system, sophisticated complex software solutions for decision-making tasks at each stage of production operation can be created.

The structural organization of *IMS* is grounded on the basic rule of object-oriented methods, in which the processes of information and processes modelling coincide. It is also assumed that the development process is based on the conceptual description of an object. The approach should take into account the methodology of the development and implementation of computer-integrated enterprises CISMOSA (Open System Architecture for CIM), developed in the context of the projects of the European Union.

An intelligent control system can be considered as a distributed system in the following way:

$$IMS = \langle M, R(M), F(M), F(IMS) \rangle,$$

where $M=\langle Mi \rangle$ is a set of formal or logical-linguistic models that represent certain intellectual functions;

$R(M)$ is the function of selecting the necessary models (a set of models) for a particular situation;

$F(M)=\{F(M)i\}$ is a set of model modification functions;

$F(IMS)$ is the function of modifying ICS and its basic elements are M, $R(M)$, $F(M)$. The conceptual structure of the ICS is presented in fig. 1.

Thus, the current trends in the development of manufacturing systems are the use of technical means with bio-like and human-like properties (intelligence, experience, knowledge) and can be used in ICS. ICS should be built as open structures that unite existing information systems with subsystems, use artificial intelligence methods to create the integrated environment for solving problems of intelligent manufacturing systems (IMS). At the same time, increasing the adaptive and intelligent means of technological and maintenance equipment should be focused on, in particular, industrial and transport robots, which generates a need to improve the mathematical, organizational, algorithmic and software solutions for robotic systems.

The goal and objectives of the research

It was mentioned above that the task of robotics in terms of the nature and result of the performed tasks is mostly a multi-stage one. For example, in the case of planning strategies for solving tasks of robotic assembly, the result is a sequence of individual technological transitions or operations, and the end result is the assembled product or its part.

When considering the process of designing a robotic technology, each separate strategy planning act is important at each stage of a technological operation. Solving the problems of planning the movements of mobile platforms is similar - the result of movement is a set of operations connected with movement in a certain direction, stops, changes in directions, individual

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movements of a manipulator (if it is installed on a platform). However, if during the movement there is a need for additional actions that are related, for example, with preventing a collision with an obstacle which suddenly appears, the planning task should not focus on the entire multi-stage structure but on the planning of each individual decision regarding work actions.

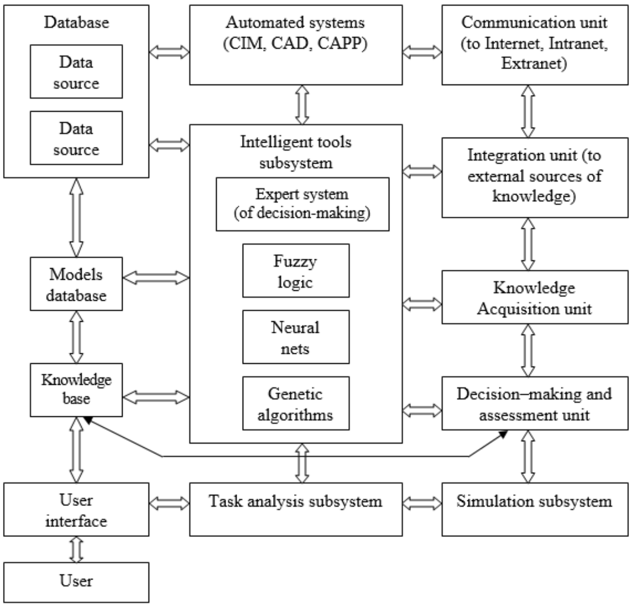

Fig. 1. The conceptual structure of the intelligent manufacturing system [5, 6]

Most of the individual strategic planning tasks are adaptive, that is, they should change when the environment changes either predictably or unpredictably. Although adaptive systems in technical planning systems are not studied thoroughly, works in the area of psychology and human decision making pay significant attention to the mentioned systems [7, 8].

The ability of a person (or another organism or technical system) to adapt to a slow, moderate or rapid change in the impact of external factors and at the same time stay capable to perform set tasks is called adaptation. Adaptation is certainly possible only under conditions when the organism (or technical system) can react to the outside world, that is, they have sensory organs (sensors) that enable monitoring any changes in the environment or in the state of objects according to which a certain task is performed (a decision is made). In addition, the mechanism of the organism response to external impacts is needed, including internal changes and an external reaction in the form of specific actions of a human or a robot, which consist in eliminating external impacts (for example, detouring around stones or removing them from the way of movement) or in adapting to them (choosing actions that correspond to the conditions of chassis operation).

Such reasoning, however, does not fully answer to how a robotic system (including a mobile one), which has certain means of perceiving the environment in the form of sensors, an intellectual component like a component of planning travels; executive mechanisms in the form of manipulators, will be able to react to changes in the external world and rebuild its actions correctly regarding the complexity of pre-set tasks and the need to support its functional ability.

The methods of adaptive are understudied in the theory of automatic control. Among classical sources, [9] should be noted, which understand the control system, which automatically determines the necessary control law by analyzing the behaviour of an object, as an adaptive one. At the same time, adaptive systems are divided into two classes: systems capable of self-organization, and systems capable of self-configuring.

During operating, a control algorithm is formed in systems capable of self-organization. This algorithm enables optimizing the system from the point of view of the control objective. Such tasks arise in conditions of changing the structure and parameters of a control object, depending on the mode of operation if a priori information is insufficient to determine the current mode. In this case, the free structure of a controller [9] and rather complex problems are referred to.

The tasks of synthesizing for continuous dynamic objects are described in [9]. Let the control object is influenced by measured disturbances (initial effects) $Y=Y(t)$, immeasured effects $N=N(t)$ and control effects $U=U(t)$. The output variables of the object $X=X(t)$ should be monitored. The object behaviour depends on a set of unknown parameters that create the sum total ξ. A set Ξ of probable values ξ is given; it determines the class of admissible objects and perturbations. The goal of control, that determines the behaviour of the control object, is set. The result should be the synthesized control algorithm that will use the values that are measured or calculated on the basis of measurements, which do not depend on $\xi \in \Xi$ and will ensure achieving a set goal of control for each $\xi \in \Xi$ [10-11].

In the terms of FIMS, adaptivity means capabilities to maintain the operability of the manufacturing system in the terms of changes in the conditions of its operation due to external factors (other FIMS, heat, power and ventilation systems, etc.) and internal factors (the operation of individual machining centres and numerically controlled machine tools, the actions of personnel, heat systems and so on).

In such circumstances, the FIMS should adapt to the available conditions and change the schedule (plan) for the entire system or its individual nodes, ensuring the adaptation of the strategies of its operation.

The task of adapting the strategies of functioning is formulated under certain conditions of real mechanical assembly, in particular, the housing assembly parts of fuel systems of aviation equipment of PO “FED”, radio electronic equipment of NDVO “Kommunar”.

The technological process of machining and assembly should be carried out in one or several shops that contain machining centres, CNC machines, industrial and transport robots, storage and transportation systems that connect the technological equipment with an automated warehouse.

The shortcomings of the manufacturing process organization in the mentioned machine-assembly departments particularly include:

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- the fixed nature of the transport system and its low level of automation with limited use of transport robots
- manual loading methods for CNC machines;
- lack of automated means to eliminate abnormal or non-standard manufacturing situations.

To overcome these shortcomings, it is suggested

- to introduce a mobile transport-assembly robot into the equipment of the flexible integrated system of shops (fig. 2.)
- to develop mathematical, and algorithmic software for the specified robot.

A mobile transport-assembly robot should meet the following requirements:

- the robot freely moves within the shop outside the working spaces of individual units of technological equipment;
- the robot ensures the delivery of blank parts and other materials to the working area of machining centres and CNC machines;
- the robot provides the delivery of the necessary equipment or tools for regular or urgent calls;
- the robot provides cleaning operations;
- the robot monitors technological equipment and other equipment of shops;
- the robot monitors the operation of the technological equipment.

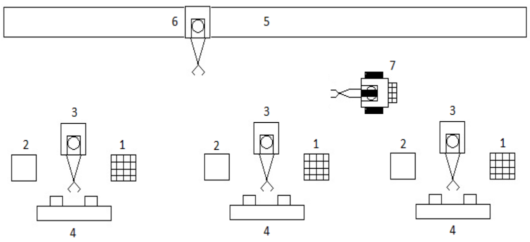

Fig. 2. The structure of the flexible automated area

(1, 2 – input and output storage devices, 3 – industrial robot, 4 – CNC machine, 5 – transport system, 6 – transport robot, 7 – intelligent transport and cleaning robot)

To ensure its functionality, a transport-cleaning robot should meet specific design requirements, in particular, it should be fitted out with:

- a mobile platform chassis;
- a manipulator (or several manipulators)
- a cargo compartment for transportation of blanks, parts, tools and equipment;
- a telecommunications system;
- a control system based on the onboard computer;
- the sensor system of the chassis and manipulator.

The transport-cleaning robot should be selected on the basis of available models of transport robots and manipulators.

A separate element of the system for controlling a mobile transport-assembly robot is the decision support system (DSS). Due to the dynamic nature of the working space, the DSS should ensure moving the transport-assembly robot to individual workplaces, should plan the necessary operations for loading and unloading the technological equipment, tools and accessories, plan individual assembly operations. The dynamic nature of the working space of transport and assembly robot, which is determined by manufacturing, requires adapting the operational strategies that should ensure the stability of flexible integrated manufacturing systems.

Basing on the conducted analysis, it can be concluded that the topical problem of modern flexible integrated manufacturing systems still is to ensure manufacturing functions at all levels of the enterprise organization: at the levels of centralized or local management, at the level of planning manufacturing functions, at the level of direct execution of production processes. A significant shortcoming of automated control systems of flexible integrated robotic manufacturing is the fact that changes in the working environment of technological equipment are not taken into consideration as well as the means for further adaptation of the subsystems of controlling industrial and transport robots at the level of decision support systems that should monitor the states of flexible integrated systems, ensure the development, operation and adaptation of the strategies of manufacturing functions [12].

An intelligent control system that takes into account changes in the working environment and the conditions of a flexible integrated manufacturing system should develop a plan for the operation of technological equipment and industrial and transport robots servicing it, monitor the conditions for its implementation in the process of decision making and, if necessary, adapt (modify) strategies of implementing manufacturing functions by robots and other technological equipment. The introduction of the systems of the adaptation of operational strategies should significantly improve the characteristics of the robotic control systems and, therefore, is a topical scientific direction.

The goal of the research is to solve a topical scientific and applied problem of developing theoretical foundations of intellectual support for decision-making in automated control systems for flexible robotic integrated systems for manufacturing radio electronic equipment, mathematical and information software for planning manufacturing tasks for FIMS operation, which takes into account changes in the states of the manufacturing system and workspace, quickly re-build plans for solving complex practical problems in the process of their implementation and will increase the efficiency of the process of control the flexible integrated system for manufacturing radio electronic equipment

The objectives of the study are:

- the panalysis of the current state of development of automated control systems for flexible integrated robotic systems in general and intelligent decision support systems for autonomous robots;
- the research and development of the concept of the operation of adaptive flexible integrated robotic systems;
- the development of models of intellectual support for decision-making in automated control systems based on the method of adaptation of strategies for the operation of flexible integrated systems;
- the development of knowledge representation models and the method of creating intelligent decision support systems in automated control systems for flexible integrated robotic manufacturing;

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- the development of information software for intelligent decision support in automated control systems of flexible integrated robotic systems for manufacturing radio electronic equipment.

The concept of adapting the operation strategies

To solve the task of creating intelligent systems of decision support of flexible integrated robotic systems (FIRS), the following concept of adapting the strategies of operation is suggested [14]:

a) there is a subject (subjects) of planning strategies in the form of a mobile or manipulative robot (robots) equipped with an automated control system (ACS);

b) there are FIRS objects about which a decision is made and is implemented;

c) there is a working space, including subjects and objects of planning strategies, as well as foreign objects that can influence the process of planning strategies, the nature of the FIRS space is defined and can be either deterministic or stochastic;

d) a subject of strategy planning (robot ACS) has the following properties:

- technical characteristics (capability to implement the decision);
- the development of operational strategies in accordance with the current state of the workplace;
- the implementation of the strategy for moving in space or manipulating objects in accordance with the developed strategy;
- the adaptation of the strategy in case of a change in the manufacturing task or in the working environment;
- the adaptation of implementation of decisions in accordance with the strategy

e) the intelligent decision support system of the control system of an actuator, respectively, consists of the following parts:

- the unit accumulating information about the environment (in the simplest case, it is a database, in a more complex one - it is connected with the sensor system of the actuator);
- a unit of operator schemes that contains standardized descriptions of the solution of individual subtasks (in other words, the knowledge database of the robot ACS);
- a unit of strategy searching which puts forward a hypothesis (in general) on the operational strategy basing on the information about the goal of an individual step of planning the strategy or on the basis of a global goal ;
- a unit of planning the policy that, along with the sensor system, should actually observe (monitor) changes in the system workspace and thus change (modify or adapt) the plan of decision implementation [15];
- a unit for formulating the aim of the system;
- a unit for verifying the results of the robot ACS;
- a unit for creating and executing movements (manipulations).

The mentioned components of ACS are shown in fig. 3.

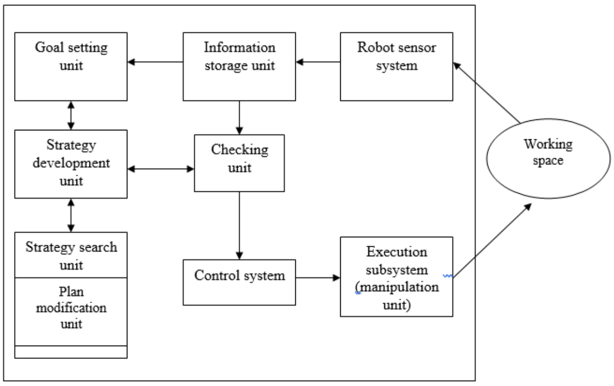

Fig. 3. Structural diagram of the automated control system of FIRS

The developed structure perceives information about the state of the working environment and modifies the process of planning strategies in accordance with changes in the environment, that is, it has features of an adaptive system.

The following description of the data of the automated control system (ACS) of a robot can be specified. ACS in terms of planning strategies is characterized by the following sets:

The robotic system (RS) that is a part of FIS whose state is characterized by a set of elements $x_i \in X, i = 0...n-1$ as a vector of states $X = \{X^0, X^1, \dots, X^{n-1}\}$ that at the moments of time $t_0, \dots, t_{n-1}$ take values $X_0 = \{x_0^0, x_0^1, \dots, x_0^{n-1}\}$, $X_1 = \{x_1^0, x_1^1, \dots, x_1^{n-1}\}, \dots,$ $X_{n-1} = \{x_{n-1}^0, x_{n-1}^1, \dots, x_{n-1}^{n-1}\}$.

A RS operates in a working space (WS) $s_i \in S, i = 0...m-1$.

The WS is two- or three-dimensional and depends on time. A set of the WS characteristics is determined as a vector of states $S = \{S^0, S^1, \dots, S^{n-1}\}$ and at the moments of rime $t_0, \dots, t_{n-1}$ takes values $S_0 = \{s_0^0, s_0^1, \dots, s_0^{n-1}\}$, $S_0 = \{s_0^0, s_0^1, \dots, s_0^{n-1}\}, \dots, S_{n-1} = \{s_{n-1}^0, s_{n-1}^1, \dots, s_{n-1}^{n-1}\}$;

The RS can plan decisions $d_k \in D, k = 0...l-1$ on the transformation of their states and states of WS. A number of decisions made by the strategy planning system (SPS) of the automated control system (ACS) form a vector $\vec{D} = \{d_0, d_1, \dots, d_{m-1}\}$, where m is a number of decisions made within the time period $t_0, \dots, t_{n-1}$;

Decisions are implemented by RS actions: $a_i \in A, i = 0...l-1$.

A number of actions $A = \{a^0, a^1, \dots, a^{n-1}\}$ is implemented by a robotic system as the implementation of made decisions $\vec{D}_i$ within movements or manipulations $a_{mv} \subset A$, $a_{mp} \subset A$.

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The goal of RS operation is the state $y \in X$ which is achieved by the sequential transformation of states: $x_0 \to x_1 \to ... \to x_{n-1} = y$.

Thus, while achieving the goal, the following transformation takes place:

$$x_1 = f_1(x_0, y, s_0, d_0, a_0) + \varepsilon_0, \ \|x_1 - x_0\| \le \varepsilon_0,$$

$$x_k = f_k(x_{k-1}, y, s_{k-1}, d_{k-1}, a_{k-1}) + \varepsilon_k, \ \|x_k - x_{k-1}\| \le \varepsilon_k,$$

$$y = f_n(x_{n-1}, y, s_{n-1}, d_{n-1}, a_{n-1}) + \varepsilon_n, \ \|y - x_{n-1}\| \le \varepsilon_n,$$

f is a transition function, ε is a transition faluire.

Transitions are characterized by the cost $c_i \in A, i = 1...n$ and duration $t_i \in T$, $i = 1...n$. The goal is to find such sequence of transitions $f_1, \dots, f_n$ which will ensure the transition of the system from the initial state x_0 to the target one *y*.

The conditions of searching are: $\sum_{i=1}^{n} t_i \to \min$, $\sum_{i=1}^{n} c_i \to \min$, $\sum_{i=1}^{n} \varepsilon_i \to \min$.

The mentioned sets represent particular elements of ACS.

In particular, the robotic system (X set), from the point of view of solving ACS tasks, can be described in the following elements:

- a manipulator (the description of the movements of individual manipulator joints);
- a control system (a set of signals sent or received by the manipulator);
- a sensor system (sensors providing the transmission of signals about the state of the working space (WS) to the robot control system (CS));
- a vision system (provides observing (monitoring) of WS and signalling in the robot CS);
- a communication system (transmitting and receiving signals from the robot CS, other robots);
- a robot chassis (receiving information from CS, transmitting data to CS, implementing movements).

A set of decisions *D* can be described within:

- the decision to move a manipulator (manipulators) at the level of individual operations (take an object, move, put, change objects in places, etc.), including reaching a target point;
- the decision on the direction of movement of the chassis of a mobile robot (right, left, forward, back, etc.), changes in speed and acceleration;
- the requests of sensors and the systems of technical vision;
- the expected result (the decision made)
- prerequisites for making decisions.

A set of objects of the external environment *S* can be described as:

- the objects of space (coordinates of objects, the direction and speed of movement, the class of the object ownership, technical condition, the possibility of using it while implementing the decision);
- the state of the environment (the terrain feature, tracks and their condition, obstacles and their changes, meteorological conditions, light, etc.).

A set of goals *Y* of the robot ACS can be described as:

- the location of the robot at the point of space (or near the necessary object);
- operations (manipulations) at the point of space (or near the necessary object);
- data on the state of space obtained using a sensory system or a computer vision system.

A robot can be tasked:

to be _at_ point (x, y, z);
to conduct an operation (take_object(class(nut))).

An example of the arrangement of the FIRS working space is shown in fig. 4-a.

Another example of the working space is a task of a manipulation robot that operates within an assembly FIRS.

A flexible integrated assembly system (FIAS) is presented as a part of assembly machines (soldering tools), transport-assembly robots, storage devices that form a set $eq_i \in Eq, i = 0...n-1$. The goal of the FIAS is to ensure assembling the devices (units) of radio electronic equipment, in particular on printed circuit boards *M* [13].

And $M = < B, Ch, T, R, C, L, ... >$, where *B* is a printed circuit board, *Ch* is microprocessor devices, *T* is semiconductor devices, *R* is resistors, *C* – capacitors, *L* – inductors.

The configuration of the device is determined by its design project M^G which determines the target arrangement of the elements on the printed circuit board. In fact, the unit (board) is a rectangular matrix, which is filled with the elements of the set *M* (is shown in fig. 4-b).

Initially, M_0 is a null matrix. THE FIAS generates decisions $d_k \in D, k = 0,...,l-1$ that are implemented by the action (technological transitions): $a_k \in A, k = 0,...,l-1$. The decision $\vec{D}$ on the order of implementing assembly operation is the sequence of operations which involves establishing the individual elements of sets *Ch*, *T*, *R*, *C*, *L* ... in *B*, for example

$$\vec{D} = \{Ch_0, Ch_1, T_0, T_1, R_0, Ch_3, C_0, L_0, ...\}.$$

While achieving the target state M^G, there are transformations $M_i = f_i(Eq, D_i, M_{i-1})$:

$$M_0 \to M_1 \to M_2 \to ... \to M^G.$$

Filling in *M* is determined by the order of assembly operations. This order is defined by the project M^G, technological rules Tr, technological equipment capabilities E. Thus, there is $\vec{D} = g(M^G, Tr, E)$. The goal is to find such sequence of transitions $f_1, \dots, f_n$ which

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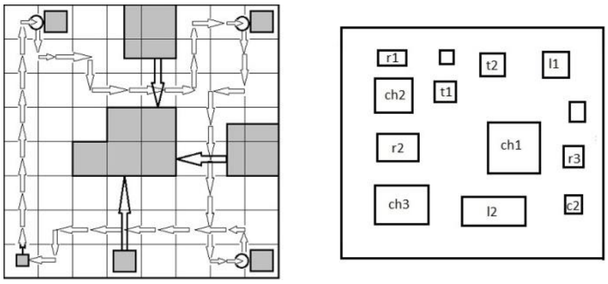
will ensure the transition of the system from the initial state M_0 in the target one M^G.



a) b)

Fig. 4. The examples of organization of the FIS working space
(a) – the tasks of a transportation robot,
(b) – the tasks of a manipulation robot

The process of planning strategies is a process of constantly comparing the goals of the system with its current position, current capabilities and so on. The process of planning a strategy in accordance with the discreteness of operations should be discrete and correspond to the achievement of the goal and implement certain technological operations.

Generally, the process of planning strategies is the reflection of:

$$F: D \times X \to Y, \qquad (2.1)$$

that is the process of planning strategies means the application of a set of the operations of a decision $D = \{D_0, D_1, \dots, D_n\}$ to the sets $X_0, \dots, X_{n-1}$ at every step, which is formally regarded as the Cartesian product of set $X \times D \to Y$, where Y is a set, characterizing the state of ACS at the time of achieving the decision.

The process of the transition of a robotic system from its initial state in a target one is the sequence of the system state transformations and looks like:

$$\begin{bmatrix} x_0^0 \\ x_0^1 \\ \dots \\ x_0^{n0} \end{bmatrix} \Rightarrow \begin{bmatrix} x_1^0 \\ x_1^1 \\ \dots \\ x_1^{n1} \end{bmatrix} \Rightarrow \begin{bmatrix} x_2^0 \\ x_2^1 \\ \dots \\ x_2^{n2} \end{bmatrix} \Rightarrow \dots \Rightarrow \begin{bmatrix} x_n^0 \\ x_n^1 \\ \dots \\ x_n^{nn} \end{bmatrix} \equiv \begin{bmatrix} y^0 \\ y^1 \\ \dots \\ y^n \end{bmatrix}. \qquad (2.2)$$

This corresponds to the real situation when in the process of generating and executing solutions, the evolution of the states of the robotic system

However, this sequence of changes can characterize not only the decision-making process but also the dynamics of changes in the states of the system over time. When planning strategies, the state of the system changes in an active mode, that is, at each step of strategy planning, the characteristics of the system should change. Considering the sequence of actions for planning strategies, the function (vector) of decision-making should be determined as $\vec{D} = \{D_0, D_1, ..., D_{n-1}\}$.

Therefore, the application of the decision D_i at each step of ACS operation results in the transformation of $X_i^j \to X_{i+1}^j$ column of robotic system states.

$$\begin{bmatrix} x_0^0 \\ x_0^1 \\ \dots \\ x_0^{n0} \end{bmatrix} * D_0 \Rightarrow \begin{bmatrix} x_1^0 \\ x_1^1 \\ \dots \\ x_1^{n1} \end{bmatrix} * D_1 \Rightarrow \begin{bmatrix} x_2^0 \\ x_2^1 \\ \dots \\ x_2^{n2} \end{bmatrix} * D_2 \Rightarrow \dots \begin{bmatrix} x_{n-1}^0 \\ x_{n-1}^1 \\ \dots \\ x_{n-1}^{n-1} \end{bmatrix} * D_{n-1} \Rightarrow \begin{bmatrix} x_n^0 \\ x_n^1 \\ \dots \\ x_n^{nn} \end{bmatrix} \equiv \begin{bmatrix} y^0 \\ y^1 \\ \dots \\ y^n \end{bmatrix}. \qquad (2.3)$$

It should be also noted, that in the case of adaptive planning strategies, the third party should be taken into in consideration, for example, as an object of as objects of the external world or a competitor party that affects (negatively or positively) on the process of planning a strategy. On the one hand, the system should feel the effect of the external environment and then, in order to take into account its existence and effect on the process of planning a strategy, an additional factor S should be introduced. This factor characterizes the state of the external environment (which includes a certain set of objects $S_i = \{s_i^0, s_i^1, \dots, s_i^m\}$, where the index i means that the external environment is discrete):

$$\begin{bmatrix} x_0^0 \\ x_0^1 \\ \dots \\ x_0^{n0} \end{bmatrix} * \begin{bmatrix} s_0^0 \\ s_0^1 \\ \dots \\ s_0^{m0} \end{bmatrix} * D_0 \Rightarrow \begin{bmatrix} x_1^0 \\ x_1^1 \\ \dots \\ x_1^{n1} \end{bmatrix} * \begin{bmatrix} s_1^0 \\ s_1^1 \\ \dots \\ s_1^{m1} \end{bmatrix} * D_1 \Rightarrow \dots \begin{bmatrix} x_{n-1}^0 \\ x_{n-1}^1 \\ \dots \\ x_{n-1}^{n-1} \end{bmatrix} * \begin{bmatrix} s_{n-1}^0 \\ s_{n-1}^1 \\ \dots \\ s_{n-1}^{m-1} \end{bmatrix} * D_{n-1} \Rightarrow \begin{bmatrix} x_n^0 \\ x_n^1 \\ \dots \\ x_n^{nn} \end{bmatrix} \equiv \begin{bmatrix} y^0 \\ y^1 \\ \dots \\ y^n \end{bmatrix} \qquad (2.4)$$

Another approach is introducing the functional dependence of individual acts of planning strategies on the state of the environment:

$$F: D(S) \times X \to Y, \qquad (2.5)$$

and consequently:

$$\begin{bmatrix} x_0^0 \\ x_0^1 \\ \dots \\ x_0^{n0} \end{bmatrix} * D_0\left(\begin{bmatrix} s_0^0 \\ s_0^1 \\ \dots \\ s_0^{m0} \end{bmatrix}\right) \Rightarrow \begin{bmatrix} x_1^0 \\ x_1^1 \\ \dots \\ x_1^{n1} \end{bmatrix} * D_1\left(\begin{bmatrix} s_1^0 \\ s_1^1 \\ \dots \\ s_1^{m1} \end{bmatrix}\right) \Rightarrow \dots \begin{bmatrix} x_{n-1}^0 \\ x_{n-1}^1 \\ \dots \\ x_{n-1}^{n-1} \end{bmatrix} * D_{n-1}\left(\begin{bmatrix} s_{n-1}^0 \\ s_{n-1}^1 \\ \dots \\ s_{n-1}^{m-1} \end{bmatrix}\right) \Rightarrow \begin{bmatrix} x_n^0 \\ x_n^1 \\ \dots \\ x_n^{nn} \end{bmatrix} \equiv \begin{bmatrix} y^0 \\ y^1 \\ \dots \\ y^n \end{bmatrix} \qquad (2.6)$$

Therefore, D_i as an act of planning strategies depends on the state of the objects of the external environment.

Externally, the two approaches are slightly different, but their interpretation may seem different. In the first case, the strategy planning system interacts directly with the environment and this interaction leads to changes in the states of the robotic system, so the act of planning a strategy concerns the state of the system that has been affected by the environment. In the second case, the act of planning depends on the state of the environment and should take into account its influence while determining the procedures (strategies) of decisions and a decision maker changes the state of the robotic system as it depends on the environment.

Thus, the goal of the ACS in the phase of planning strategies for implementing the task is to determine the ordered set (vector) $\vec{D} \subset D$ as , a set of acts of decision making that will ensure the implementation of the ACS transition by the robot from the initial X_0 to the target Y according to the reflection $F: D \times X \to Y$.

The need for planning the adaptive strategy arises under significant changes in the conditions of the implementation of decisions. In the static environment of the robot, the task Y, as a state of the robotic system,is

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achieved by using a set of possible actions $\vec{D}=\{D_0, D_1, ..., D_{n-1}\}$, which transfers the system from the initial state X_0 to the target $X_{n-1}=Y$. A set of selected actions $\vec{D}$ is regarded as a decision plan.

Under the conditions of static working space, the initial decision plan $\vec{D}_0=\{D_0^0, D_1^0, D_2^0 ..., D_{n-1}^0\}$ should be developed and separate acts of a decision (strategy) are directly interrelated, and the use of the local act of decision making D_i in the current state X_i will transfer the system in the state X_{i+1}, which, in fact, is the target for the act of decision D_i. In its turn, the state X_{i+1} is initial for a new state D_{i+1}, which will transfer the system from the state X_{i+1} in X_{i+2} and so on.

Under the conditions of the dynamic state, DSS, by its acts of decision D_i can transfer the system in the state X_{i+1}, which might be insufficient for implementing the act D_{i+1} and might need additional acts of decision D'_{i+1}, D'_{i+1}, etc. Therefore, the changes in the environment will lead to the uncertainty of available means for their solving.

The variants differ by the sequence of their implementation. If the interaction of the robotic system and the environment occurs before the act of decision-making, the expression (2.1) is true, if the interaction occurs during the act, the dependence of the decision-making function on the impact of external factors should be taken into account, and, consequently, (2.2) should be considered. Although, both variants undoubtedly have should be the same result.

When developing automated control systems for mobile and manipulation robots, an important stage is selecting models for planning strategies, taking into account the specific conditions of the working space, the capabilities of the robot model, the characteristics of its sensor system and other indicators. The character of the selected models determines the essence of the methods of planning strategies.

Planning a strategy takes place in real-time mode and beyond it. As a rule, the initial decision is made under the conditions of setting the task and taking into account the initial state of all the objects involved in the process. At the same time, operator procedures of ACS, which satisfy the initial and current decision-making conditions to the greatest extent, are searched for. The developed will correspond to the model of decision-making that was selected at the initial stage.

The suggested plan is carried out at the implementation stage. It is carried out in real time and can be limited by the duration of actions of other objects and by internal factors (for example, a limited charge of mobile robot batteries). The deviation of the operating conditions of the robot from the planned ones, external factors that significantly affect the implementation of decisions will require adapting the approved plan at the level of restructuring the individual parts of the plan (with respect to solving individual subtasks) or restructuring the entire plan for solving the task. Thus, the method of adaptive strategy planning should take into account changes in the working space and adapt planning strategies in accordance with them.

The logical model of making decisions on the strategy of the operation of robots under the conditions of FIRS

Selecting a logical model as the basis for building a model for planning strategies is not random. The planned actions of a robot should look consistent, verified and, therefore, logical in the ordinary sense. Another feature of the decision is its trueness in accordance with the current condition of the working space, that is, the decision made in the space S is true at time t and may be untrue at time t + 1 but the solution will always have a true value.

While considering the logical model, a number of symbols that are similar to the set-theoretic model of the previous subdivision will be used.

Let sets X, D, S of RS states, its decisions, WS states are given.

Then, $x_i \in X, d_i \in D, s_i \in S$ are the atomic expressions of the model of RS and WS actions.

Among the separate elements of sets X, D, S, operations $\neg, \wedge, \vee, \rightarrow, \leftrightarrow$ are introduced.

Therefore, the formulas that are correctly constructed are:

$$\neg x, x \wedge y, x \vee y, x \rightarrow y, x \leftrightarrow y .$$

To describe the theory of sets, X, D, S functions and predicates are introduced.

The transformation function of RS conditions is as follows: $x_i = f(x_0, ..., x_{i-1})$,

The transformation function of WS conditions is as follows: $s_i = f(s_0, ..., s_{i-1})$.

Predicates that connect the elements of sets X, D, S are also introduced

$$pt(x_i),\ pt(s_i),\ pt(d_i),\ pt(x_i, s_i),\ pt(x_i, d_i),$$

$$pt(d_i, s_i),\ pt(x_i, d_i, s_i)$$

and ensure describing the properties of RS and WS, their mutual influence and dependence.

The following predicates are determined:

$pr(x_i, s_i) \subset pt$ is a set of descriptions of RS in WS,

$ps(x_i, s_i) \subset pt$ is a set of descriptions of WS in view of with RS,

$pa(x_i, s_i) \subset pt$ is a set of actions of RS in WS,

$pg(pr, ps) \subset pt$ is a set of goals of RS in WS.

The goal of RS is set as a new or (or available) state of RS or WS:

$$pg(pr, ps) \leftarrow (pr(x_i, s_i) \vee ps(x_i, s_i)) .$$

The database of RS is determined as a set of descriptions $pr()$, $pt()$:

$$pr(x_i),\ pr(x_i, s_i),\ ps(s_i),\ ps(x_i, s_i) .$$

The database of RS is determined as a set of descriptions $pa(x_i, s_i)$ of possible actions of RS in WS.

The description $pa(x_i, s_i)$ is a strategy of goal solving

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$pg(pr(x_i,s_i), ps(x_i,s_i))$, is there is such conjunction of sets for RS actions $pa(x_i,s_i)$, which ensures $pg(pr(x_i,s_i), ps(x_i,s_i))$:

$$pg(pr(x_i,s_i), ps(x_i,s_i)) \leftarrow pa^0(x_i,s_i) \wedge pa^1(x_i,s_i) \wedge ... \wedge pa^{n-1}(x_i,s_i),$$

or

$$pg(pr(x_i,s_i), ps(x_i,s_i)) \leftarrow \wedge_{i=0}^{n-1} pa^i(x_i,s_i),$$

and:

$$\exists f, f \in F : x_i = f_i(x_{i-1},s_{i-1}), \exists \psi, \psi \in \Psi : x_i = \psi_i(x_{i-1},s_{i-1}).$$

Therefore, $pa(x_i,s_i) = T\left\| f_i + \psi_i \right\|$.

The process of decision-making is a successive set of *m* alternatives to the solution of the objectives of the system:

$$pg^0(pr, ps) \leftarrow pg_0^0(pr_0, ps_0, pa_0) \wedge pg_1^0(pr_1, ps_1, pa_1) \wedge ...$$
$$\wedge pg_{n-1}^0(pr_{n-1}, ps_{n-1}, pa_{n-1}) = \wedge_{i=0}^{n-1} pg_i^0(pr_i, ps_i, pa_i)$$

……………………………………………………………

$$pg^m(pr, ps) \leftarrow pg_0^m(pr_0, ps_0, pa_0) \wedge pg_1^m(pr_1, ps_1, pa_1) \wedge ...$$
$$\wedge pg_{n-1}^m(pr_{n-1}, ps_{n-1}, pa_{n-1}) = \wedge_{i=0}^{n-1} pg_i^m(pr_i, ps_i, pa_i).$$

Thus, the general goal is described as:

$$pg^{total}(pr, ps) \leftarrow \vee_{j=0}^{m-1} \wedge_{i=0}^{n-1} pg_i^m(pr_i, ps_i, pa_i).$$

Under the conditions of RS goal setting, the initial plan is worked out; this plan involves the following transformations of the system states:

$$pr(x_1,s_1) \leftarrow pa_0^0(pr(x_0,s_0) \vee ps(x_0,s_0)),$$
$$pr(x_2,s_2) \leftarrow pa_1^0(pr(x_1,s_1) \vee ps(x_1,s_1)),$$

…………………………………………………..

$$pr(x_n = Y, s_n) \leftarrow pa_{n-1}^0(pr(x_{n-1},s_{n-1}) \vee ps(x_{n-1},s_{n-1})).$$

Under the conditions of the dynamic state of RS, separate $pg(pr(x_i,s_i), ps(x_i,s_i))$ cannot be achieved:

$$pr(x_i,s_i) \neq pa_i^0(pr(x_{i-1},s_{i-1}) \vee ps(x_{i-1},s_{i-1})).$$

Under such conditions, the system should be modified:

$$pr(x_i,s_i) \leftarrow pa_i^*(pr(x_{i-1},s_{i-1}) \vee ps(x_{i-1},s_{i-1})),$$

$$pr(x_{i+1},s_{i+1}) \leftarrow pa_{i+1}^*(pr(x_i,s_i) \vee ps(x_i,s_i)),$$

which results in modifying the decision strategy:

$$pg^{m*}(pr, ps) \leftarrow pg_0^{m*}(pr_0, ps_0, pa_0) \wedge$$
$$pg_1^{m*}(pr_1, ps_1, pa_1) \wedge ...$$
$$\wedge pg_{n-1}^{m*}(pr_{n-1}, ps_{n-1}, pa_{n-1})$$
$$= \wedge_{i=0}^{n-1} pg_i^{m*}(pr_i, ps_i, pa_i).$$

In particular, $X = \left\{X^0, X^1, \dots, X^{n-1}\right\}$ is determined as a set of states of a robotic system.

Let automated control system, while implementing the approved decision, ensure transforming the initial state $state(x_0^0, x_1^0, x_2^0, \dots, x_{n-1}^0)$ into a particular target state $state(x_0^m, x_1^m, x_2^m, \dots, x_{n-1}^m)$.

If the system (a robot and the environment around it) at the initial moment of time makes up a set of arguments $x_0^0, ..., x_n^0$ and is characterized by the state $state(x_0^0, x_1^0, x_2^0, \dots, x_{n-1}^0)$, while considering the discrete process of planning strategies that comprises separate actions *action₀,…, actionₖ*, it can be mentioned that the transition from one discrete state to another is a certain relationship among objects:

$$state(x_0^1, x_1^1, ..., x_n^1) \leftarrow action_0(state(x_0^0, x_1^0, ..., x_n^0)), \quad (2.34)$$

where *state* is the relation (predicate) which characterizes the state of the system in general, *action(state)* means the action of changing one state to another.

All the actions for transforming the system from one state to another (by implementing a list of decisions) are a set of predicates

$$state(X^1) \leftarrow action_0(state(X^0)),$$

$$state(X^2) \leftarrow action_1(state(X^1)), \quad (2.35)$$

……………………………..

$$state(X^{n-1} = Y) \leftarrow action_{n-2}(state(X^{n-2})).$$

Thus, the goal of planning strategies is to find a corresponding number of $action_i$, which would meet the conditions $state_i$ of the system.

Selecting $action_i$ for transforming $state(X^i)$ in $state(X^{i+1})$ is carried out by the compatibility of arguments *action* and the corresponding state X^{i+1}, which in practice will mean the possibility of realizing the state (local goal) of X^{i+1} by performing ACS actions *action*:

$$X^{p+1} \leftarrow action(X^p), \quad (2.36)$$

where X^{P+1} is a possible result of *action* under the conditions of X^P state and the following conditions should be met:

a) $X^i \sim X^P$ is the compatibility of initial data of *action* with the current initial data;

b) $X^{i+1} \sim X^{P+1}$ is the compatibility of *action* with the local goal X^{i+1}.

Thus, the definition can be introduced:

Definition 2.9. The predicate scheme is adaptive if the constituent parts of the antecedent (the right side of the predicate expression) and the result of the scheme (the consequent) change depending on the changes in the state of the ACS and the workspace (WS):

$$state(Y) \leftarrow action(S_0), action(S_1), \dots, action(S_{n-1}), \quad (2.37)$$

where *Y* is the goal of the system;

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$S_0, S_1, \ldots S_{n-1}$ are successive states of ACS.

However, under the conditions of the dynamic state of WS (a robot environment) and the state of the robot might change (changes are not obligatory but probable) and the situation can occur when, at the particular state $state(X^{i-1})$ the action $action_{i-1}(state(X^{i-1}))$ does not result in transforming the system in the state $state(X^i)$, тобто:

$$state(X^i) \neq action_{i-1}(state(X^{i-1})) . \quad (2.38)$$

At first glance, in these conditions, a predicate *action* that would meet the condition of the expression should be found. However, in fact, a number of possible real actions is limited (in contrast to a number of states), so the conclusion will consist in finding such the discrete sequence $\overrightarrow{action}$ (a vector of predicates) that will meet the objectives of the system.

Therefore, if there is a set of objects *X* and the initial state is X^0, to achieve the target state *Y*, the sequence of actions that is reflected by the predicates *action* should be planned, while the state of the system – by the predicate *state*:

$$state(X^0),$$
$$state(X^1) \leftarrow action_0(state(X^0)),$$
$$state(X^2) \leftarrow action_1(state(X^1)), \quad (2.39)$$
$$\ldots\ldots\ldots\ldots\ldots$$
$$state(Y) \leftarrow action_{n-1}(state(X^{n-1})).$$

If at a certain level *i*, the state X^i cannot be achieved, that is $state(X^i) \neq action_{i-1}(state(X^{i-1}))$, the adaptive system of planning strategies should generate a new sequence of the predicates of actions $\overrightarrow{action}$, which will meet the changes in the WS:

$$state(X^{i1}) \leftarrow action^1_{n-1}(state(X^{i-1})),$$
$$state(X^{i2}) \leftarrow action^2_{n-1}(state(X^{i-1})), \quad (2.40)$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$state(Y) \leftarrow action^{m-1}_{n-1}(state(X^{n-1})).$$

The similar situation occurs when SPS has information about changes in the system goal. This means that the target state *state(Y)* changes for a certain *state*(Y^i). In this case, two situations are possible:

а) information about the goal change comes at the moment when the system is in the state *i* – *state*(x^i) and the plan $\overrightarrow{action}$ can be generated for the transition from the state x^i in the state y^i;

б) information about the goal change comes at the moment when the system is in the state $state(x^i)$ but the plan $\overrightarrow{action}$ can be generated only from the state $state(x^{i-k})$, where $k \leq i$, that is for generating the system should return to the previous states up to the state $state(x^0)$.

This will also cause the necessity to generate a new sequence of predicates-actions.

According to the definition 2.7, the decision plan will include sets $\{action_0, action_1, \ldots, action_n\}$ and the complete plan will include all the plans that were developed while making a decision. The adaptive plan of the decision will be expressed as:

$$plan^{adaptive}(Y) \leftarrow action_0(state(X^0), action_1(state(X^1), \ldots, action_{n-1}(state(X^{n-1})))) .$$

Such a plan is the final decision of the ASPS.

It should be noted that the developed plan will be changed until the final subgoal of the planned sequence has been completed. That is, the capability of the plan to be adapted is its essential characteristic.

Let us also consider the time of assessing the actions are planned by the SPS in the sequence of predicates.

The predicate is known to have the true value, in the classical sense – the mapping of n arguments to the true value. Although taking into consideration the fuzzy logic, the concept of a fuzzy predicate can be introduced [15]. The classical predicate has only *true* and *false* values. From this point of view, the transition of the DSS from one *state* (X_{i-1}) to the *state* (X_i) state will also have a true or false value, that is, the system either turns into a new state or not. Probably, even in the terms of the idealized approach, the state of the whole system is difficult to predict, and especially unambiguously assess the state of the system in binary values "true" and "false". Individual characteristics of the system can rather be considered as true and false. According to the predicate theory, the robot world can be described as a set of relations among the objects within such a world, for example, *is_a* means that an object belongs to the type of objects, *is_at* means that one object is located near another one, *stands* means that the object is in a certain state, and so on.

Developing information on the robot working space with computer vision technique

The implementation of intelligent robots requires that the control process should be carried out with the help of an autonomous control system or, under certain conditions, by a human operator.

There are several types of organization of information input into the robot control system, which can be classified as follows:

- the input of information from the onboard decision-making system;
- the introduction of control commands from the human operator;
- the input of information using voice commands
- the input of information using a visual control system.

The onboard decision-making system controls the robot with the help of decision-search algorithms, which are built in the device itself. The basis for the operation of the decision-making system is information obtained from the sensory system. Sensor devices of the robot and computer control make up a map of the terrain.

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Controlling the robot includes its positioning on this map. The operation of the sensory system has limited capabilities, in particular, when changing the environment, it is not always possible to re-arrange immediately the working space of the map where the orientation and control are carried out.

Another example of the organization of information input is command-based control the operator provides using the control device. The control algorithm is limited by a list of commands and an increase in the time to enter.

In the third case, the remote control of robots is carried out with the help of voice commands and analyzers. Each of these commands is set by an individual user. Such a system also requires a lot of time to input and a human operator, besides, the drawback is the lack of clarity and individuality while giving commands.

The main task of the multi-zone system is to monitor the object in different working areas with the help of several cameras, object recognition, the determination of the motion trajectory. The OpenCV computer vision library was used to solve the problem [9]. A number of cameras can vary but when connecting a large number of cameras, there is a problem associated with a heavy load when transferring a significant amount of video information. This problem is solved by reducing the size (quality) of the image or reducing the frame rate. The observation zones of the chambers are shown in fig. 5, a.

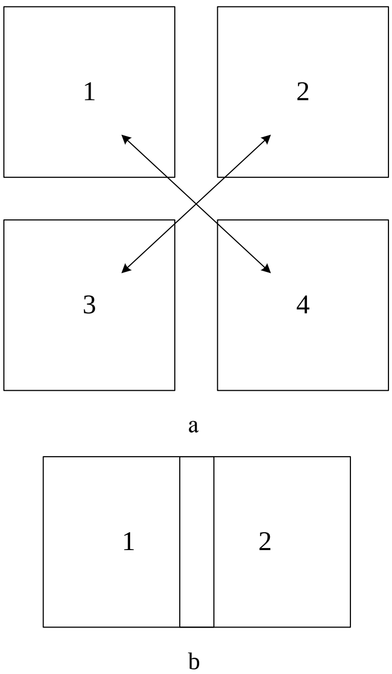

Fig. 5. The areas of cameras: a – an example of working space; b – the intersection of working areas

All the camera observation areas will intersect one another, as shown in fig. 5, etc. This simplifies determining the trajectory of the object motion. If the object is off the visual field of the cameras, then it is necessary to wait until the object appears. To do this, the cameras one by one prompt for movement. This is done with some delay in order to reduce the load on the system. If the object is in the camera visual field, the active camera is selected in the direction of the object's movement. But in this case, the common coordinate system for several cameras is necessary. If the object is on a flat surface and the cameras are perpendicular to this surface, the image dimensions can be used to determine the coordinates. In this case, the initial coordinate system is the coordinate system of the first camera where the motion was detected. If the object is detected by two cameras simultaneously, the coordinates of the object on the second camera are the coordinates of the object on the first camera. Then, the displacement of the coordinate system is calculated.

Movements can be identified in various ways. The most correct is selecting the moving contour and recording the trajectory of motion. The trajectory of motion is necessary for determining the direction of the object movement. Using the camera, in the visual field of which the object will appear, the direction of motion can be determined but only if the position of the cameras are known.

Let the mechanisms of connection of distributed areas of the working space be considered. Let the workspace of an intelligent robotic object be equipped with a set of video cameras (computer vision systems), where the working spaces of all cameras intersect in some areas (fig. 6).

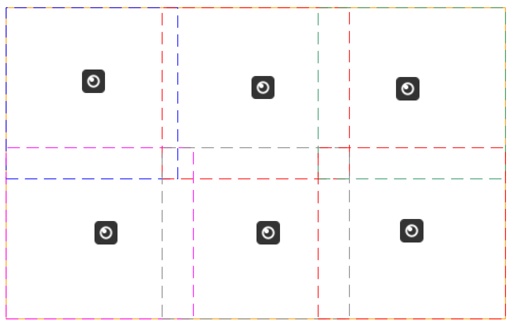

Fig. 6. Working space with cameras placed inside.

where  is a web-camera which acts as a computer vision system; different colours indicate the visual angles of each camera.

All schematic symbols presented on the fig. should be commented on in the way to clarify the sense it contains.

Fig. 6 shows the working space where a mobile robot operates; this robot is a part of the flexible integrated system, in particular, a global system of computer vision. If there are several cameras in the working space, the image of each of them may differ in several parameters, such as:

- the matrix resolution;
- the matrix type;
- brightness and contrast;
- sensitivity;
- viewing angle;
- frame rate, etc.

It follows that the image or streaming video received from the cameras can have different parameters, which makes it difficult to stitch it into one image for further work.

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As the stitching algorithm, the SIFT (Scale Invariant Feature Transform) algorithm is suggested. The algorithm consists in finding the singular points on the image and their descriptors. As points of singularity, those points that are most likely to be found on another image are considered. Descriptors are unique parameters of singular points.

To find such points, it is necessary to calculate the Gaussians (the application of Gaussian blur to the image) and their differences.

The descriptor for the SIFT method is a vector that is calculated on Gaussian nearest in scale to the key point, which is on the gradient in a window with selected key points. Before calculating the descriptor, this window is rotated to the angle of the direction of the key point, which ensures the invariance as for the rotation.

On the basis of the obtained singular points, there is an opportunity for stitching the images, that is, for obtaining a panoramic image.

The algorithm for obtaining a panoramic image consists of the following steps:

- loading images;
- registering the pairs of images;
- initializing the panorama;
- creating a panorama.

To create a panorama, successive pairs of images should be registered using the following 3 steps:

- identifying and comparing the characteristics of the last and penultimate image
- assessing geometric transformations;
- calculating the transformations necessary to create a panoramic image.

Fig. 7 shows original images and fig. 8 shows the result of their stitching (panoramic imaging) made by SIFT method.

Fig. 7. Original images

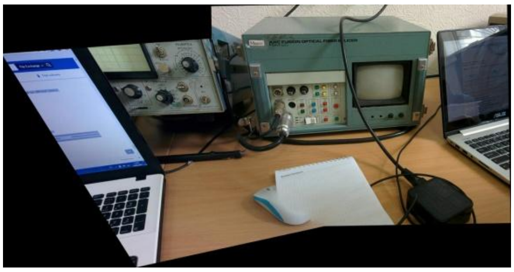

Fig. 8. Panoraming the images

Initializing a panorama means to create an empty panorama where images will be stitched together.

When the transformation with the input images is completed, the mixing function is performed in order to overlap the images. As a result of these actions, a panoramic image is obtained.

The selection of features and their comparison can be used to find necessary objects. To do this, the SURF (Speed Up Robust Features) method can be used.

The main advantage of this method is the speed of the key point detector. This is achieved using the integrated images and calculating the weighted determinant of the Hess matrix. Two-dimensional Haar wavelets are used to construct the descriptor. The main advantage of SURF is the speed of the key point detector. In addition, SURF is invariant to the scale and rotation of the image, small changes in lighting.

Let the algorithm of the software for searching for objects (in this case, the robot-hexapod) implemented in the MatLab environment be considered.

First, those images with which are going to be worked with are loaded (fig. 9 – 10).

After that, the resulting images turn into gradations of grey colour.

Fig. 9. The target object

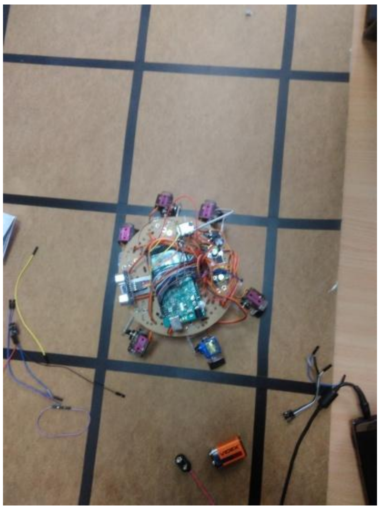

Fig. 10. The object working space

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Then, all the key points on the image should be found and displayed. To do this, the algorithm SURF is used. The MatLab environment of the Image Processing package provides the function detectSURFFeatures for finding singular points and selectStrongest for displaying the strongest of them (fig. 11).

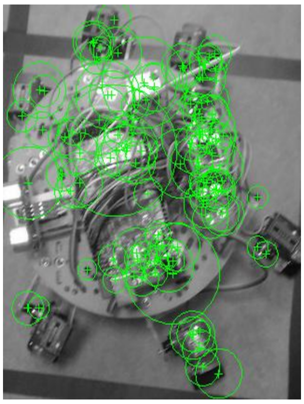

Fig. 11. The image of the strongest points

The main characteristics in the singular points on the two images are determined and extracted (the function extractFeatures).

Similarities are found according to their features on the images (matchFeatures).

After this, settled matching points are shown.

Peaks - the values of the experimental values that differ enormously - can appear on the images. They are eliminated by estimateGeometricTransform function.

Also, a polygon should be created, this polygon will limit the object that should be highlighted and shown. To do this, the transformPointsForward function is used.

The result of programme operation is shown in fig. 12.

Thus, the developed software implements SURF algorithm for determining the positions of individual objects of the working space of FIMS. And the working space includes one or several working areas that are united with the help of the software based on SIFT method.

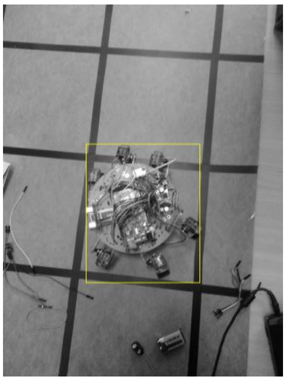

Fig. 12. The result of object selection by SURF method for finding the key points

Conclusions

According to the results of the studies carried out in the proposed article, the following is achieved:

Intellectual production systems, in particular, the control systems of itelligent type, were analyzed.

The features of operation of flexible integrated robotic systems are considered, to support them, mobile robotic transport-assembly platforms using decision support systems should be used.

The concept of adapting the functioning strategies as a basis for building an intelligent management system is suggested.

The logical model of decision support system is suggested, it is capable of solving transport and manipulation problems.

The software is developed that uses computer vision tools to unite the distributed parts of a workspace and to monitor its objects by recognizing and identifying mobile robots, process facilities and the most significant participants in the technological processes under the conditions of modern FIMS.

Experimental studies were carried out to recognize and identify mobile robots in a complex workspace with the help of the developed software.

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ІНТЕЛЕКТУАЛЬНІ ЗАСОБИ В СИСТЕМІ КЕРУВАННЯ ВИРОБНИЧИМ АГЕНТОМ

Предметом дослідження є інтелектуальні засоби в системі керування інтелектуального виробничого агента, **метою** – забезпечення якості управління гнучкою інтегрованою роботизованою системою шляхом створення інтелектуальної системи підтримки прийняття рішень. В роботі розв'язано наступні **завдання**: розглянуто сучасні тенденції розвитку та реалізації інтелектуальних систем керування виробничого призначення, сформульовано вимоги до формування імітаційних моделей систем підтримки прийняття рішень для розв'язання завдань гнучкого інтегрованого виробництва; розроблено логічну модель системи підтримки прийняття рішень інтелектуального виробничого агента, яка на основі подання даних про поточний стан інтегрованої системи, системи знань із описом можливих дій роботизованого обладнання, цілей виробничої системи описує процесс прийняття рішень у вигляді формування стратегії функціонування, здійснює адаптацію стратегій у разі змін робочого простору інтегрованої системи або окремих її цілей; сформовано подання системи знань гнучкої інтегрованої системи у вигляді стандартизованного опису можливих дій роботизованого обладнання; розглянуто формування опису розподіленого робочого простору інтегрованих систем та ідентифікації окремих об'єктів за допомогою засобів комп'ютерного зору. В основу дослідження покладено наступні **теоретичні та практичні засади**: теорія множин – для формування спільного подання імітаційних моделей системи підтримки прийняття рішень; теорія предикатів – для формування логічної моделі прийняття рішень; знання-орієнтовані методи та засоби мови програмування Prolog – для подання системи знань гнучкої інтегрованої системи, система MatLab – для аналізу робочого простору гнучкої інтегрованої системи. В **результаті** розроблено математичне, інформаційне та програмне забезпечення системи керування

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інтелектуального виробничого роботизованого агента. Показано можливості застосування запропонованої моделі в системі керування інтелектуальним роботом та вказано на можливості удосконалення подібних систем.

Ключові слова: логічна модель, інтелектуальний агент, мобільний робот, теорія предикатів, комп'ютерний зір

ИНТЕЛЛЕКТУЛЬНЫЕ СРЕДСТВА В СИСТЕМЕ УПРАВЛЕНИЯ ПРОИЗВОДСТВЕННЫМ АГЕНТОМ

Предметом исследования являются интеллектуальные средства в системе управления интеллектуального производственного агента, **целью** – обеспечение качества управления гибкой интегрированной роботизированной системой путем создания интеллектуальной системы поддержки принятия решений. В работе решены следующие задачи: рассмотрены современные тенденции развития и реализации интеллектуальных систем управления производственного назначения, сформулированы требования к формированию имитационных моделей систем поддержки принятия решений для решения задач гибкого интегрированного производства; разработана логическая модель системы поддержки принятия решений интеллектуального производственного агента, которая на основе представления знаний о текущем состоянии интегрированной системы, системы знаний с описанием возможных действий роботизированного оборудования, целей производственной системы описывает процесс принятия решений в виде формирования стратегии функционирования, осуществляет адаптацию стратегии в случае изменений рабочего пространства интегрированной системы или отдельных ее целей; сформировано представление системы знаний гибкой интегрированной системы в виде стандартизированного описания возможных действий роботизованного оборудования; рассмотрено формирование описания распределенного рабочего пространства интегрированных систем и идентификации отдельных обьектов при помощи средств компьютерного зрения. В основу исследования положены следующие **теоретические и практические основы**: теория множеств – для формирования общего представления имитационных моделей системы поддержки принятия решений; теория предикатов – для формирования логической модели принятия решений; знание-ориентированные методы и средства языка программирования Prolog – для представления системы знаний гибкой интегрированной системы, система MatLab – для анализа рабочего пространства гибкой интегрированной системы. В **результате** разработанным является математическое, информационное и программное обеспечение системы управления интеллектуального производственного роботизированного агента. Показаны возможности применения предложенной модели в системе управления интеллектуальным роботом и указано на возможности усовершенствования подобных систем.

Ключевые слова: логическая модель, интеллектуальный агент, мобильный робот, теория предикатов.