# Adaptive Decision-making for Robotic tasks

Oleksandr Tsymbal
*Department of Computer-Integrated Technologies, Automation and Mechatronics*
*Kharkiv National University of Radio Electronics*
Kharkiv, Ukraine
mcdulcimer@ukr.net

Artem Bronnikov
*Department of Computer-Integrated Technologies, Automation and Mechatronics*
*Kharkiv National University of Radio Electronics*
Kharkiv, Ukraine
artem.bronnikov@nure.ua

Andriy Yerokhin
*Department of Software Engineering*
*Kharkiv National University of Radio Electronics*
Kharkiv, Ukraine
andriy.yerokhin@nure.ua

***Abstract***— **There is proposed the analysis of decision-making problem in its application for flexible integrated robotic systems. The intelligent systems in form of problem-solving components are considered as key component of automated control systems. There is observed the proposed concept of adaptive decision-maling for flexible robotic systems, based on a set of models and methods of adaptive decision-making, data science methods.**

***Keywords — adaptivity; decision-making; mobile robot; flexible integrated system; data science***

## I. Introduction

Application of industrial robots in flexible integrated manufacturing systems (FIMS) allows to increase the production efficiency and to decrease the cost for unit of production. For example, [1] shows the examples of cost decrease in three times. From other hand, the high results of robot's application are not overall. The experience of administrative introduction of robots in former USSR [2] shown the unreliability of industrial robots, application limits, essential cost for purchase and introduction, few number of personal, freed by application of robots, low quality level and lack of parts, lack of required microcontroller control systems. Probably, such experience simultaneously has shown also the unreadyness of specialists for broad introduction of industrial robotics.

Inside the integrated automated manufacturing industrial robots solve a number of important tasks, among which are:

– transition of details and instrument inside the manufacturing cell with round equipment location about robot;
– welding and sealant applying at conveyer lines;
– loading and unloading of billets, details and instruments at machines and transport units (robocars);
– stationing and centering of details and devices for assembling;
– trimming, washing, coating and other operations;
– on-line (operative) and off-line (autonomous) checkout;
– instrument's setup at gripper of robot;
– Hazardous production.

The analyzes of FIMS shows, that the robot's AI is mainly implemented by computer system, which controls the robot manipulator's movements or his mobile platform. The AI of robots is based on highly developed sensor system, which includes the technical vision systems of different types, sensors of tactile type, meters of distance, gyroscopes, compasses, sensors of color etc. In addition, apart from the recognition of scenes and tactile sensoring speech recognition and natural speak processing have important role for FIMS intellectualization [3, 4].

The integrated automated manufacturing must include the in-built artificial intelligence tools, which supply the optimization of whole FIMS taking in account the overall cost of operations and resources. In this condition the manufacturing ACS have to supply the solving for the next problems: [5]:

– optimal application of instruments and equipment;
– minimization for details displacement and for billet storage level;
– minimization for machines and robots downtime;
– maximization for rate and output volume of production;
– minimization for production costs by materials and tools flows checkout;
– Computation of safe transition paths for systems of robots and interacting robocars with supplement.

The industrial robots need such AI-tools, which give possibility for self-education on base of collected data's on machines timeouts and declining of their characteristics, for response to emergency situations (tool breakage, outside objects appearance in workspace) and for required adaptation on manufacturing system functioning. Robot's, able for self-education and estimation of surrounding workspace can become the assistants of human in manufacturing sphere, which doesn't replaces him, but enriches by functions and simplifies the works with instruments, materials and informational flows.

The tendencies analyzes for FIMS development shows the rising complexity of modern manufacturing as for stand-alone work cell as for workshop or factory. For such conditions the role of automated control systems, which applies the AI-methods and are able with sensor systems to get information on state of manufacturing systems, to analyze it and to make decision on functioning of factory. From other hand, the part of manufacturing decisions at every workplace, which becomes the function of supplement equipment: robocars, industrial robots, and other technological and supplement systems?

Therefore, the problem of development and introduction of tools for intellectual decision-making support at different levels of manufacturing control and for particular units of FIMS is still actual.

## II. Adaptive Decision-making Systems and Robotics

The consideration of robotized technology design process shows the importance of every planning strategies act at every stage of technological operation execution. The similar case is for movement planning of mobile platforms: the transition result is the sequence of operations to move to some direction, to stop, to change direction, to move manipulator's joints (if platform has it). But, if movement needs additional actions like to prevent collisions with

978-1-7281-1814-7/19/31.00 © 2019 *IEEE*

random obstacle, the planning task is accented not on whole multi-stage structure, but on planning of every partial decision for action of robot.

The most of particular tasks of strategies planning have to be of adaptive manner because of execution for conditions of predictable or unpredictable workspace. While the adaptive systems still have no first positions in technical planning systems, they have publications on psychology and human decision-making [2].

To solve the tasks of intellectual system decision-making support for flexible integrated robotized system (FIRS) there is proposed the following concept on adaptation of functional strategies:

a) there are the subject (subjects) of strategies planning – the mobile or manipulation robot (robots), equipped by automated control system (ACS;

b) there are the objects of FIRS, for which the decision is made and decision's implementation is executed;

c) there is the workspace, which includes the subjects and object of strategies planning, also other objects, having effect to strategies planning process, the nature of FIRS workspace is given and can be determinate or stochastic;

d) the properties of strategies planning subject (ACS of robot) are:

– technical characteristics (ability for decision execution);

– functioning strategies development according to current state of workspace;

– strategies execution by way of movements in space or manipulation with objects as to developed strategy;

– strategy adaptation for cases of manufacturing task changes or changes in workspace;

– solution execution adaptation according to strategy;

e) the intellectual system of decision-making support of executing subject's control system, correspodently consists of the following parts:

– workspace information storage unit (for simplest case – database, for more complex cases is connected to sensor system of executive subject);

– the unit of opetative schemes with standardized description of particular problem solutions (in other word, the knowledge base of robot's ACS);

– strategies search unit, which on base of information of the particular strategies planning stage or on base of global target proposes the hypothesis (in general case) for functional strategy;

– strategies planning unit, which on base of sensor system interaction must monitor the workspace changes and, therefore, change (in other terms modify or adapt) the solution implementation plan;

– target formulation unit;

– ACS results verification unit;

– movements and manipulation formation unit.

The mentioned components of ACS are shown in Figure 1. The proposed structure gets robot's workspace information and modifies the planning strategy as to workspace changes, so it has feature of adaptive system.

Let's set the next description of data for robot's automated control system (ACS). ACS from strategies planning viewpoint is depicted by sets::

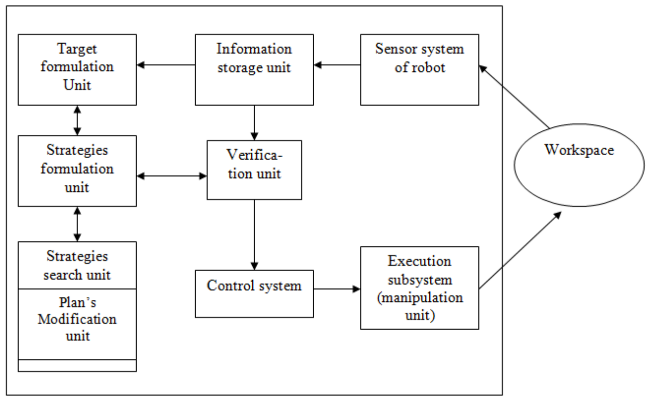


Figure 1 - Structural scheme of FIRS automated control system

Robotic technical system (as part of FIS), with states of set $x_i \in X, i = 0...n-1$, is a vector of states $X = \{X^0, X^1, \dots, X^{n-1}\}$, that at time moments $t_0, \dots, t_{n-1}$ has values $X_0 = \{x_0^0, x_0^1, \dots, x_0^{n-1}\}$, $X_1 = \{x_1^0, x_1^1, \dots, x_1^{n-1}\}$, ..., $X_{n-1} = \{x_{n-1}^0, x_{n-1}^1, \dots, x_{n-1}^{n-1}\}$.

RTS exists in a workspace (WS) $s_i \in S, i = 0...m-1$.

WS is 2-dimensional or 3-dimensional and depends of time. The set of specifications of WS is given as vector of states $S = \{S^0, S^1, \dots, S^{n-1}\}$ and at time moments has $t_0, \dots, t_{n-1}$ values $S_0 = \{s_0^0, s_0^1, \dots, s_0^{n-1}\}$, $S_1 = \{s_1^0, s_1^1, \dots, s_1^{n-1}\}$,..., $S_{n-1} = \{s_{n-1}^0, s_{n-1}^1, \dots, s_{n-1}^{n-1}\}$;

RTS is able to generate decisions $d_k \in D, k = 0..l-1$ on transformation of its states and states of WS. The set of decisions, generated by strategies planning system (SPS) defines vector $\vec{D} = \{d_0, d_1, \dots, d_{m-1}\}$, with $m$ – the number of decisions for times $t_0, \dots, t_{n-1}$;

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

The set of actions $A = \{a^0, a^1, \dots, a^{n-1}\}$ is executed by RTS as implementation of found decitions $\vec{D}_i$ with subsets of movements or manipulations $a_{mv} \subset A$, $a_{mp} \subset A$.

The purpose of RTS functioning is a state $y \in X$, which is reached by sequential states transitions: $x_0 \to x_1 \to \dots \to x_{n-1} = y$.

Therefore at process of target achievement there are tranformations:

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

……………………………….

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

……………………………….

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

$f$ - transition function, $\varepsilon$ - transition error.

Transitions are described by cost $c_i \in A, i = 1...n$ and duration $t_i \in T, i = 1...n$. The aim is to find such sequence of transitions $f_1,...,f_n$, which will supply the system transition from initial state $x_0$ to purpose $y$. Conditions of search 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 present the real elements of ACS.

In particular, RTS (set *X*) from ACS problem-solving point of view is proposed to describe consisting with the next elements:

– manipulator (with description of movements for particular joints of manipulator, movements execution);
– control system (with signal set, sent/received by manipulator or chassis);
– sensor system (with sensors to supply the transmission of signals on WS states to the control system of robot);
– technical (computer) vision system (with monitoring of WS and transmission of signals to robot's ACS);
– communication system (to transmit/send the signals from robot's control system, from other robots);
– robot's chassis (to transmit/send information to/from, movements execution).

The description of decision set *D* is proposed as containing:

– decision on manipulator (manipulators) movement for particular operations level (take object, move, put, replace objects), including the achievement of goal point;
– decision to direct the mobile robot's chassis movement (rightward, leftward, direct, back etc.), to change speed and acceleration;
– requests to sensors and technical vision system;
– expected result (accepted decision);
– pre-conditions of decision-making.

The description of external workspace objects set *S*:

– objects of WS (object's coordinated, direction and velocity, class of object, technical state, ability to use for decision execution);
– state of WS (topographis, availiable paths and their conditions, obstacles and their changes, fallouts, lighting etc.).

The description of goals set *Y* of robot's ACS:

– to position robot to WS point (or near the needed object of WS);

– to make operation (manipulation) at WS point (or near the needed object of WS);

– to get date on WS (with sensor system or CVS).

The examples of robot's goals (task) setting are:

*being_at_point(x, y, z);*

*make_operation(take_object(class(nut))).*

The example of WS arrangement for FIRS is shown at Figure 2.

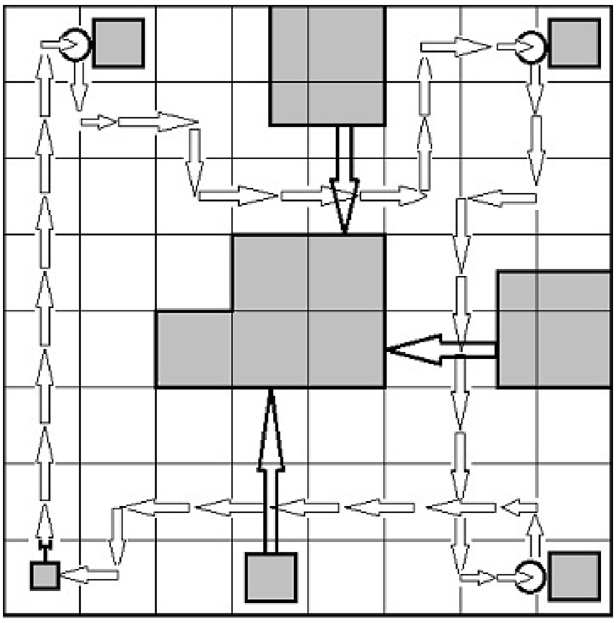

Figure 2 - Example of workspace organization for transport robot task

## III. Adaptation of Decision-Making Strategies

The development of ACS for mobile and manipulation robots has important stage of strategies planning models selection, which may take in account the real conditions of WS, the robot's model possililities, sensor system options and other parameters. The nature of selected models determines the core of strategies planning methods.

The strategies planning can be implemented for realtime mode as well as off realtime mode. As a rule, the initial decision is accepted for the task setting and takes in account the initial states for all the objects of process. At this point there is provided the search of operative ACS procedures, which maximally satisfies to initial and current conditions of decision-making. The developed plan corresponds to decision-making model selected at initial stage.

The stage of decision execution means the implementation of proposed plan. It is carried out in realtime mode and can be limited by duration if other object's activity and by internal issues (f.e. by limited charge of mobile robot battery). The deviation of robot's expoitation conditions from the plan, the arising of external factors with essential affect to decision implementation will set the problem of accepted plan adaptation at level of plan's particular parts reconstruction (in particular subgoals decisions) or at level of whole plan rebuilding. Therefore, the method of adaptive strategies planning must take in account the workspace changes and adapt the strategies planning according to them.

The method of adaptive strategies planning is a description of techniques and operations, applied by intellectual control systems of robots to solve the complex problems of practical robotics. Let's propose the fundumentals of this method.

1) Method considers RTS as a set of objects and subsystems $X=\{X_0, X_1, ..., X_{n-1}\}$.

2) Method assumes to get information of robot's WS states with sensor system, which forms the WS objects set *S*.

3) The goal of system must be formulated as the needed state Y.

4) The goal of system is considered as set of discret elements – subgoals of ACS, reached by decision set $Y=\{G_0, G_1,...,G_{n-1}\}$.

5) To achieve the formulated goal ACS must define the action's set – the decision plan $D=\{D_0, D_1,...,D_{n-1}\}$, which allows to reach sequently all the subgoals, defining the global goal.

6) The determination of global goal and of particular ACS goals must take in account the states of ACS and of its WS: $G_i=f\{X_i, S_i, D_i\}$.

7) If the effect of internal ACS state and of WS doesn't permit the execution of particular action on implementation of subgoals to reach the global system goal $D_i*X_i*S_i\neq G_i$, the decision plan must be changed (adapted) in such way $D_i'*X_i*S_i \neq G_i$, to supply the transition from current state of ACS to the purpose (global goal).

8) The quality of the plan to reach the ACS goal must be evaluated according to current and next states of ACS and of robot's workspace: $||D_{imp} - D_i|| < Q(X_i, S_i, G_i)$.

The next steps can be in detalized consideration of described elements intercation and, simultaneously, of the whole strategies planning process.

Classical approach to ACS strategies planning considers certainty of all events on the binary level. So, the event exists or not. Necessity to consider the risks connected with actions implementation and robot state causes another approaches using for strategies planning process modeling in particular based on probability theory and theory of fuzzy sets. Fuzzy sets using for strategies planning most is fuzzy evaluation (fuzzification) of classic decision making theories.

As usual several classes are switched among strategies planning tasks [6]. According to one criteria strategies planning task are classified by one or several subjects providing strategies planning availability. Such tasks belong to individual or several persons (collective) strategies planning. According to others criteria those task are switched that require simple utility function optimization, optimization with some limitations, with several goals. Moreover, strategies planning may be performed in one step or iteratively as a sequence of steps (stages).

To the existing models fuzziness is introduced in different ways, moreover strategies planning task is characterized by next components existence:

– set *A* of possible actions;

– set of goals $G_i\,(i \in N_n)$, each of which is written as a fuzzy set determined on *A*;

– limitations set $C_j\,(j \in N_m)$, by the similar record conditions.

Let $G_i'$ and $C_j'$ are fuzzy sets, determined on sets $X_i$ and $Y_j$, likewise, where $i \in N_n$ and $j \in N_m$. Let's say that these fuzzy sets represent goals and limitations, expressed by strategies planning system. Then for each $i \in N_n$ and $j \in N_m$ let's describe actions values on the set *A* in terms of sets *X* and *Y*:

$g_i: A \to X_i, \quad c_j: A \to Y_j$, and display goals $G_i$ and $C_j$ by compositions $g_i$ from $G_i'$ and $c_i$ from $C_i'$, i.e.: $G_i(a)=G_i'(g_i(a)), C_j(a)=C_j'(c_j(a))$.

Fuzzy decision *D* is considered on set *A* and must correspond to specified goals $G_i$ and conditions $C_j$ at the same time, i.e.:

$$D(a)=\min[\inf_{i\in N_n} G_i(a), \inf_{j\in N_m} C_j(a)], \text{ for all } a \in A.$$

Proposed fuzzy model allows strategies planning system to describe goals and conditions in terms that have to display strategy planning situation more accurate. The fuzzy goals membership function in this model are for the same goals as the utility function and target function in the classical strategies planning model that regulate the output values according to preferences. Unlike the classical planning strategies theory within the limitations of symmetry between the goals and conditions in the fuzzy model allows to treat them in the same way.

## IV. CONCLUSION

The described adaptation of flexible manifacturing Decision-Making procedures have a number of possible extentions. The extention of problem workspace mostly leads to growth of operator's schemes and their complexity. If one goal can be reached by several ways, every of possible operator's schemes must be evaluated. For every scheme of conflict set, providing the same goals, there will be a special coefficient and the whole set will present a fuzzy set or can be soled by methods of probalility theory. The FIS and robot's functioning in real time mode will need the improvement of procedures for adequate operator's schemes search, including the backward procedures with restorations of previous states of workspace, what must be supported by introduction of extended sensor system as one of key part of FIS. The expansion of problem field will expand also the number of operations, executed by FIS's elements, and the order of operations execution (technological process) will define the strategy of following activity, while the experience of production system will supply the application of most effective strategies using data science methods.

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