Multilevel Intelligent Control of Mechatronical Technological Systems

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1. Introduction

Up-to-day mechatronical systems intended for production are provided with new properties to meet the following quality requirements: fast action, accuracy, reliability and others. The new properties should fit the varying technological conditions, adapt to the set goals, consider the mechatronical objects state, that is perform non-formalized or difficult to formalize tasks. In these cases they should implement decision making and control functions close to the human brain ones. These functions are realized with the help of modern information technologies (Makarov and Lokhin, 2000; Burns, 1997; Millan and Yeung, 2003).

Many mechatronical systems of technological application are aimed at quality production to the required demands unity. As a rule the control is effected on completion of the process. So in metal-cutting machine tools working under the unmanned machining the product quality is evaluated by its parameter control after either completing the whole operation or some stage of it. As to the working parts movement control it is evaluated only in case of errors of disagreement during machining. The instability in performing working parts control can be explained by stochastic character of machining, varying external factors, improper initial and real positions of the working parts and tools, parts state and the tool cutting edge (Millan K., Yeung 2003; Tugengold A.K. 2001). It is therefore necessary to evaluate the process as a whole and chiefly the degree of product quality parameters to obtain the right choice of alternative control options. Due to the varying set of conditions the latter is difficult to obtain and is a complicated task though it is quite possible by using intelligent control systems.

2. Intelligent Control System of Technological Equipment

By using mechatronical systems a new approach to software under intelligent control can be realized. Initially at the first stage of receiving information the intelligent control synthesizes a great variety of behavior alternatives and possible modifications of controlled process parameters compared with the set program. Then at the next process stage in several steps the control system limits to min the variability of different alternatives. The final stage is implemented as a rule with the parameters of machining corresponding to the last stage of a set program, that is target ones. It allows to reach the synergetic effect it technological process realization and provide the appropriate quality result.

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The intelligent control system the structure of which is given in Fig.1 is based on decision making in machining a part in accordance with current environment. The sequence it system operations are as follows:

- evaluation of the control object state , technical process, its result;
- correction of criteria and limitations;
- simulation and replaning movement program;
- correction of working parts movement control.

This sequence is effected by the control system with multilevel hierarchical structure which has a set of levels typical for mechatronical systems with intelligent control: tactical – 1, coordinative – II and organizing – III.
Level I have traditional schematic working parts movement object control to implement technical process.
Its distinguishing feature is to execute operating corrective control within transition regimes based on real state drives and machining. The goal is to decrease the error of the tool path trajectory, consequently increase the part accuracy by using neural networks.

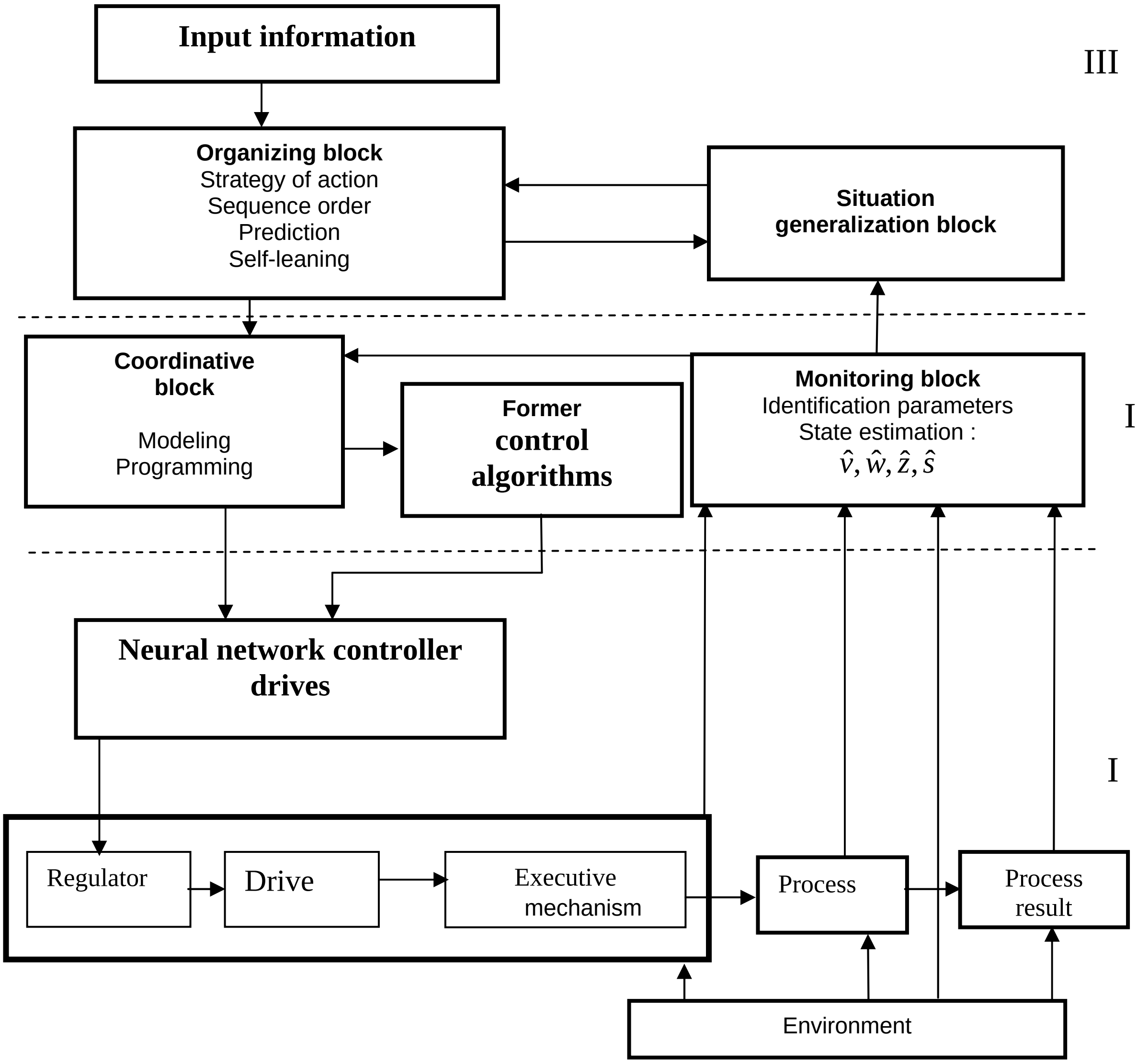


Figure 1. Structure of intelligent control system

Trajectory error minimization, occurring due to the dynamic process within the working parts speed change is included in to the intellectual control function at the tactical level. The preventing control is used for this reason, while the preventing signal is transmitted to the drive. The signal meaning depends upon the large number of the factors. (Many factors influence upon the signal meaning.) The main of them are the tool real position dynamic error, cutting force change, cutting edge variations, drive state.

The availability of priory information from intelligent control about current and future movement area parameters allows realizing a preventing control. To determine the control value position error information, difference of drives speeds from planned ones, cutting force evaluation is used. Forming a compensating control is performed by static three ply neural network with direct transmission signal. As efficiency criterion of correcting control for transient regimes the minimum criterion for space limited by ideal and real trajectories is taken. Fig. 2 shows tool movement trajectory without correction (Fig. 2a) and with correction (Fig. 2b). Max trajectory error is defined as the normal from ideal speed changes point to real movement trajectory and amounts as Δ_t=0.047 mm without correction and Δ_t=0.014 mm with correcting control. Thus application of neural network preventing correction allows to trajectory error in transient process by 60-80%.

Level II includes monitoring blocks, a coordinator and a former with corresponding. Monitoring block tasks are to provide information about space vector parameters necessary for decision making. The block identifies parameters under control of environment state, object control, technological process and its result, diagnose these states and evaluate them. The evaluation obtained by block expert system tells about state qualitative changes.

On the basis of these data the expert system of coordinator formulates decision-making about necessity of changing in working pasts movements in program and forming algorithms of their realization. At this level situation evaluation of qualitative system state necessary to achieve coordination control is implemented. Coordinative block executes situation simulation based on qualitative models describing object control functioning with regard to monitoring results.

It plans the sequence of working parts movement adequate to the current situation. Impact controllers at tactical level are formed based on accepted sequence and algorithms of control. The equipment control is implemented in accordance with chosen decisions and algorithms. To reduce errors in form and size of parts caused by dynamic errors in electromechanical drives a neural network controller for drive feeds is applied.

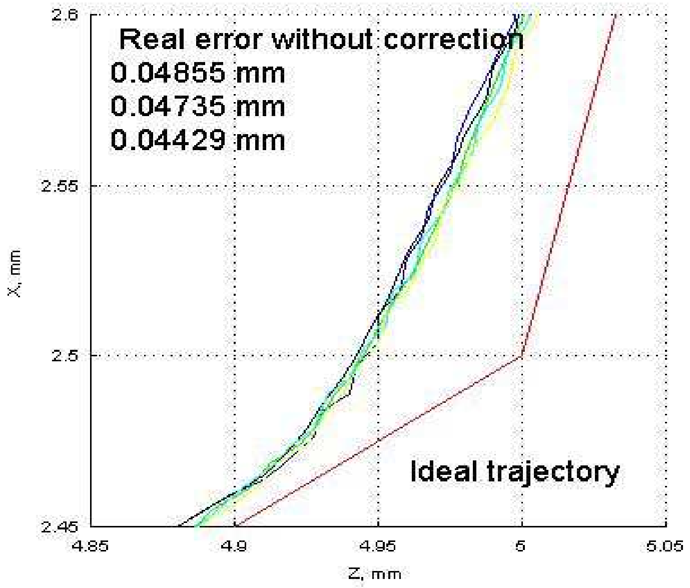
Level III (expert system of organizational block) executes action strategy choice of mechatronical object: rearranging the stages of action (compared with initial program) to achieve the main goal; current goals functions; corresponding to forming criteria bases and limitations.

New action strategy takes as its basis expert generalization of synthesized macro models of the current situation in technological process. The possibility of achieving each stages goals and target result is obtained by procedures of predicted evaluations.

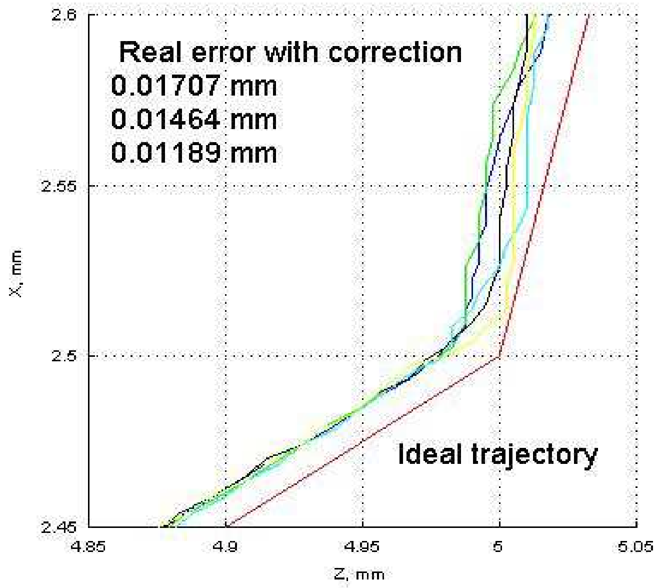
Besides, level III includes the checks of achieved goals, learning methods with accumulation of knowledge about the character of processes (technological and within the object itself) and control models necessary to perform these purposes.

Generalization block implements information analysis, provided by monitoring block generalization procedure uses the image of numerical values of internal and external parameters and their balanced relation as quality notions as well as their group analysis. The goal is a consideration of a current set of parameters that might be suitable for any former situation or combination of states in order to establish any differences if they are any them make appropriate decisions in an organizing block. As an example of such decisions they may be such as decision about limited accuracy of machining next part; necessity of changing the passes number during machining the finest surfaces, etc.

At should be noted that the functions performed at Levels II, III cannot be formalized analytically since it is necessary to use not numerical but qualitative evaluations and notions. For processing, accumulation and utilization know ledge dynamic expert systems are applied working in real time scale and capable to improve mechatronical object behavior due to the in-built algorithms of learning and self-learning.



a)



b)

Figure 2. Dynamic trajectory error of servo drives. (a - without neuro networks control unit; b – with neuro networks control)

At tactical level I state vector of working parts of mechatronical object $\mathbf{x=x(t)}$, $\mathbf{t_H<t<t_K}$, where $\mathbf{t_H}$ is start time of the process or its stage, $\mathbf{t_K}$ is finish time of the process or its stage, becomes dependent not only on impact control vector **u**, but on dynamically varying properties of the elements taking part in the process and also on specific dynamic phenomena accompanying the process. Thus when cutting materials by machine tool mechatronical system the essential influence factors are instability of machined materials characteristics, tools, non-uniformity of machining allowances for parts; auto vibrations and others. And in mechatronical rolling systems in metallurgy there are changes in friction coefficient between rolls and rolling material, in stresses of deformed materials and others.

Mechatronical object parameters, the process, the process result and environment are difficult to measure; if impossible for some parameters. Often one can judge about them only by indirect route. For this reason monitoring block evaluates the whole system state according to parameters vectors to be measured: v – mechatronical object considers, **w** – process, **z** – process result, **s** – environment. This evaluation of technological system state is conducted by block expert system based on knowledge considering the professional operator's experience. Expert system solutions are not well defined state models **v**, **w**, **s**, **z** respectively and impact extents of different factors on process results.

Coordinative block based on data obtained from monitoring block (Level II) evaluates disagreement between real and planned object behavior, process and attained result. Controlling action model to perform executive mechanisms of planned behavior controlled coordinates, with the obtained state evaluation results can be presented by non-linear differential equations of the type.

$$u = A(q,p) + b(q,\dot{q},...,q^{(r-1)},p),$$

where u - is m measuring control vector;
q is executive mechanisms controlled coordinates vector ;
$q^{(r)}$ is the later time derivative;
p is the n parameter measuring vector, evaluated as

$$p =< \hat{v},\hat{w},\hat{z},\hat{s} > .$$

Fuzzy logics formalisms unstable unities form this equation mechanism. The 2nd and 3rd level of machine mechatronical as system the decision making process includes the following stages:

1. detail surface mixed by machine accuracy differentiation information sufficiency
2. evaluation according to the corresponding initial half-finished surface;
3. decision-making on insufficient information obtaining method during the machining;
4. Data and measurement result evaluations new stages of the controlling program for expediency evaluation decision procedures record;
5. determining factors evaluation to prevent possible prevailing influence upon the insufficient surface machining;
6. variants' strategic planning based upon the prognosis;
7. machining variants tactic planning;
8. controlling action model forming program stages correction;
9. passes results evaluation ; decision – making on the further surface machining;
10. decision on the final surface machining validity; results and possible ways to reduce the machining time.

Stated the 5 - 6 stages planning corresponding to the different level generalization. For instance, at the 5th stage decision – making search is effected generally, forming, new pass sequence to obtain the final surface without all the technological parameters indication , while at the 6th stage only the next pass with the error compensation variant workout is formed , that is the selected tactic task is solved in details.

3. Controlling Expert System Environment

At the designing of the environment fitting an all-level system control hierarchy of expert system, the following requirement execution was envisaged:

- structure formation unified method of the data and knowledge bases at a certain subject field;
- high – speed decision making, providing the expert system real-time work
- knowledge replenishment realization and self-education during the functioning period .

Besides at the expert system at the subject field under consideration has to work with the input information, having substantial uncertainty. That is why knowledge image models and decision making methods, based upon the unstable unities and unstable logics, are used.

Original expert system (Expert 2.0) environment contains neural network elements, where each separate "node" is an independent neural network responsible for the local task solving. The node being an element of the general neural net, receives signals (data, decisions) from the preceding nodes, effects their data analysis and depending upon the result activates the definite signals at its output.

Description space is formed to differentiate the situations (processes, events). At this very space the situations may have different parameters but belong to the same classes, occupying the definite area at the sign space. The situation can be referred to a definite class according to the input information set at the definite moment of time. Input signal analysis functions according to which neural node makes its decision, combine verification and summing up.

Neural nodes realization program allows the expert system to change the neural net structure and weight indices depending upon the accumulated experience – either confirmation or rejection the taken decision appropriation while the weight indices are consequently update. This corresponds to the program principle ability to self – educate. The initial educating set (input data – result) can be taken from theoretical reasons and expert qualified personal practical.

Conception base for the expert system program – module architecture design and conclusion (making) methods is a flexible structure of a program configured neural net.

Expert system environment is based upon the object – oriented programming principles and includes the following components:

- Project Manager executing all the system constituent components controlling functions;
- expertise manager, controlling expert system environment work during the expertise , as wall having expertise recording function;
- knowledge base structure editor aimed at structure creating and modification. Using subordinate objects (elements editor, connection editor, junction adjuster) it effects setting of the elements, forming the knowledge base structure .

- element editor for the forming structure setting
- node adjuster effecting educating function for logical conclusion making ;
- elements- any objects, effecting structured functions;
- knowledge – base node – elements producing any logical conclusion;
- elements responsible for the system adequate information supply.

Self – learning process proceeds as following. Expert system environment chooses one of the examples obtained during the execution process and being "Input data –result" set sends real data do the node receiver and lets the node make any conclusion. Then the obtained conclusion is compared to the example result and should they did not coincide, the "weight indices" correction of the given node is effected. Thus the base example skipping is effected up to the time the node starts making right decision for each example. At this stage the self – learning process is completed.

She system possibility to self – educate using the examples, knowledge base real time correction refer to the given method advantages. That is provided due to the fact, that each expertise effected, adds one more example to the accumulated example base, which are used for the system self – learning, précising the function of the situation area division. The education method based upon the input example has the following advantage, as it does not require expert rule replenishment to make the conclusion, as this work is effected by the environment independently.

Designed expert system environment is realized in a form of a program, written in object – oriented language Delphi 5.0. OLE technology usage simplifies the change implementation process into the software and allows the system to develop gradually without total overwork, if any initial requirements substantial changes occur.

4. Action Results Prognosis

Machining resulting accuracy is characterized by the set of the output parameters $y_1, ..., y_n$. Vector parameters $\mathbf{y} = \{y_1, ..., y_n\}$ changes occurs under the influence of the planned action sequence with the object and under the influence of the many factors, those record complexity and stochastic makes consider the parameter changes as any random function $\mathbf{y}(g,t)$, $t \in T$, $g \in Q$.

There Q – that is random events multitude;

T – pass multitude (or time or any determined changed parameter).

At the probability space Q(F,P), where F is a Q, P sub multitude algebra, P is a probable measure, the random function:

$$y(t) = \{y_j(t)\}_{j=0}^{n},$$

may be considered as general model of the parameter change process. The peculiarities of the parameter change process are explicit inflexibility and stochastic.

The action result prognosis task under the inflexibility of the random process is closely connected with the random function extrapolation, that is classically revealed the following way. There are giving, $\mathbf{z_w(t)}$, $\mathbf{t \in T}$, and "non – observed" random process $\mathbf{z(t)}$, which is statistically connected with $\mathbf{z_w(t)}$. At the $\mathbf{t \in T_p}$, moment, where $\mathbf{t = \{t_0, ..., t_k\}}$ and $\mathbf{T_p \in T}$, the "observed" process $\mathbf{z_w(t)}$ is known. It is necessary to assess the "non-observed" random function $\mathbf{W(t)}$ for the future time moment $\mathbf{t=t_{k+1}}$, $\mathbf{t_{k+1} \in T \,|\, T_p}$, using the known $\mathbf{z_w(t)}$ realization. At the control – diagnostic interval the prognostic process may be observed under the measurement error **e(t)** condition. The probable assessment of the planned action at the next stop can be taken as one of the variants. The random process model under the half uncertainty condition and at expert process evaluation can be presented as following

$$Y_i(t) = a_{i,j}\cdot\{f_i(t)\}, \quad i=0, \ldots, n \tag{1}$$

where $a_{i,j}$ - random value; $\{f_i(t)\}_{j=0}^{m}$ - determined pass function.

The model treats the random process division on the determined base, characterizing the trend. Degree, exponential and other function may be used as a basis (as cutting, e. g.).

The prognosis parameter is influenced essentially by the random character process as cutting, for instance the fluctuating influence of which cam be treated as convertible changes. Taking into consideration all the stabilizing factors the random process of the parameter changes may be approximated by the equation

$$y(t) = Y(t) + F(t), \tag{2}$$

where Y(t) – unstable; random process of the parameter changes;

F(t) is a stable, random fluctuation process, initiated by inner and external action.

Since the random process parameter value z(t) measured differs from genuine y(t) value for some random value e(t) – that is the measurement error, then

$$z(t) = y(t) + e(t),\ t\in T_p \in T.$$

The true measurement evaluation, with the occasional error, may be obtained by well-known math statistics procedure, presuming e(t)'s independence, uniformity normal conditions. The measurement process is presumed to be discreet and continuous. The math classical statistical methods form the problem solving algorithm basis – that is, the least squares, maximal to life, optimal filters, etc.

From the point of realizations simplicity the optimal filtration method usage is of great interest. The task peculiarity lets to be limited by the linear optimal filters aimed at unstable sequences extrapolation.

The multi - purpose use Kalman - Bucy filter is easily realized on a computer due to the recurrent representation form. The results obtained are optimal in the approximate square meaning being competent effective and a unbiassed estimator. The random process under consideration may be described by the difference equations of the type

$$x_t = F(t,\ t-1)\cdot x_{t-1}, \tag{3}$$

where F(t, t – 1) is trans missing matrix, characterizing $\mathbf{x}_t$ structure, while the observation should meet the

$$z_t = P_t \cdot x_t + e_t, \tag{4}$$

relation requirement where P_t - is the limitation matrix of x_t observation; e_t - is the observation error.

To solve the y(t) prognosis problem solving one should bring the (1) model in conformity with (3) expression. The transformations are effected on the state space expanding basis, that is new coordinates introduction into the technical task state. Matrix F(t, t – 1), P_t and vector x_t structure, occurs as a result of y(t) model transformation.

The well – known relations, determining Kalman - Bucy filter and transformed to the state of form the 3 4th equation solving:

$$X_{t+1|t} = X_{t|t-1} + W_t(z_t - P_t \cdot X_{t|t-1}), \tag{5}$$

$$W_t = K_{t|t-1} \cdot P^T(P_t \cdot K_{t|t-1} \cdot P^T{}_t + R_t), \tag{6}$$

$$K_{t+1|t} = K_{t|t-1} - W_t \cdot P_t \cdot K_{t|t-1}.$$

Where: Xt+1/t is a prognosis observation evaluation X (relative mat expectation X) for the time moment t+1;

Xt/t-1 is the moment t X prognosis evaluation;
Kt/t-1 is a Xt/t-1 vector component covariant matrix;
Kt+1/t is Xt+1/t vector component covariant matrix;
Wt is a corresponding filter transmission matrix;
Wt is a y(t) observation result at the t moment;
R is a e(t) measurement error covariant matrix.

As a result of the 5 6 correlation prognosis calculation the

$$M[X(t_k + 1) \,|\, t_k] \; \text{и} \; D[X(t_k + 1) \,|\, t_k],$$

meaning is obtained as experience math expectation evaluation and X dispersion.

5. Conclusion

The structure under consideration as a whole meets the following intellectual controlling systems requirements:

- Intellectual functions plenitude due to the realized procedures of the artificial intellect strategic, coordinating and executive level methods.
- Methods actions directions, connected with given task completion and the decision – making search.
- Cardinal perceived information stream expanding (due to the very object and environment evaluation) and variety alternatives of behaviors.
- Planning and controlling at the decision – mating system hierarchy.
- Reciprocal subordination of the regulation task, action planning and behavior strategy choice as a form of parallelly acting reverse connection. System state image synthesis intellectuality due to the expert evaluation; image level ranging, situation generalization and prognosis.
- Evaluation of the factors, having no data obtained by the direct measurement; experience basis presumption formation.
- Controlling system function preserving at the half or total intellectual loss, with any process realization quality detriment.

Thus, intellectual controlling realization at the upper decision making level (methods and order to obtained the set detail parameters), combined with the drive neural network controlling lets gradually increase detail production accuracy and quality.
The system adequate transformation under the changing technological conditions is supplied by this structure. The intellectual system for complex mechatronical objects controlling under the uncertain conditions constructing principles were taken as a basis at the design level, including expert system technologies, fuzzy logic, neural network structures.

Since the monitoring block as a part of a subsystem of intelligent control is considered to be important for research it is suggested that the authors do further research and publishing in this field.

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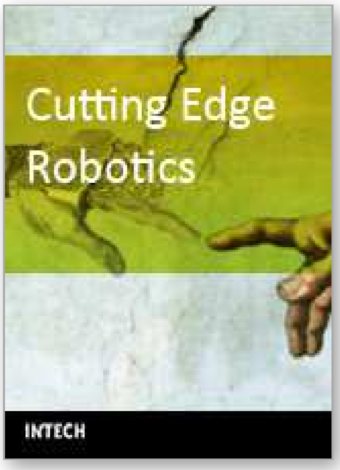

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This book is the result of inspirations and contributions from many researchers worldwide. It presents a collection of wide range research results of robotics scientific community. Various aspects of current research in robotics area are explored and discussed. The book begins with researches in robot modelling & design, in which different approaches in kinematical, dynamical and other design issues of mobile robots are discussed. Second chapter deals with various sensor systems, but the major part of the chapter is devoted to robotic vision systems. Chapter III is devoted to robot navigation and presents different navigation architectures. The chapter IV is devoted to research on adaptive and learning systems in mobile robots area. The chapter V speaks about different application areas of multi-robot systems. Other emerging field is discussed in chapter VI - the human- robot interaction. Chapter VII gives a great tutorial on legged robot systems and one research overview on design of a humanoid robot.The different examples of service robots are showed in chapter VIII. Chapter IX is oriented to industrial robots, i.e. robot manipulators. Different mechatronic systems oriented on robotics are explored in the last chapter of the book.

How to reference

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