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SIMULATION MODELLING OF THE DECISION-MAKING ACTIVITY OF THE AUTOMATED CONTROL SYSTEMS OPERATORS USING NONLINEAR ELEMENTS

Introduction

The development of modern automated control systems, the complication of systems and technology of hardware components, the extensive usage of computer technology in the organization and management of production process lead to an increased human's role in management and restructuring of his activity [Timo07, Pavl07].

Thus, on the one hand, the following is still typical for automated control systems operators:

– *efficient type of thinking*, acquiring extended number of specific characteristics (indicators), which describe the particular *conditions* for the implementation of the thought process;
– *methods* that are involved in the process of thinking and interpretation of operator's *choice* (the *decision*), the main of which are the following: the close, actually transforming into unity, connection between perception and comprehension of the rapidly changing information and conditions of the situation; *decision* often merges with the process of its *implementation*;
– *decision-making process* is increasingly fraught with a *stressful* situation, characterized by *unstructured*, *incomplete* and at the same time *congestive* contradictory initial information coming;
– *decision-making process* is increasingly associated with rules of strictly *limited time*.

On the other hand, primary modes of work of the automated control systems operators are still the following [Stre01]:

- *normal conditions* (the operator only monitors the technological process, without interfering in it);
- *emergency conditions* (operator works in semiautomatic or mechanized mode, much depends on the accuracy of its sensorimotor actions and ability to assess the situation);
- *boundary conditions* – technological process still goes on within the prescribed limits, but is already close to its borders (problem statement – keep the process within required parameters of the technology);
- *"free" conditions* – the operator constructs new mode of working (task – the empowerment of operating system, saving of the material part, energy and own forces).

Balance and order in the above-mentioned provisions can make a modern decision-making theory, which divides the situations that require decisions into two categories: **programmed** and **unprogrammed**:

1. **Programmed** situations – are associated with the solving of routine, repetitive and well-structured problems, based on pre-established rules, regulations, as well as on operator's experience and technical knowledge.
2. **Non-programmed** situations – are associated with the occurrence of uncertainty. They are characterized by semi-structured and unstructured problems. Solutions, which have been received in the non-programmed situations, contain the risk. These solutions require specific personal and professional qualities and creativity.

In this case the automated control systems operator, depending on interpretation of the current situation, can prefer one of the following models of decision-making: rational; bounded rationality; intuitive [Kahn94, StWe99].

Rational decision-making model defines the solution as a result of an ordered thought process and based on the notion of discretionarity. Discretionary actions of a person are those [Kahn94] based on deliberation, which includes comparison of the available alternatives to these actions explicitly. In this case the selection's criteria of the preferred embodiment are usually set in advance, and the solution (the chosen alternative) is the most competitive (optimal) for specific circumstances.

The *bounded rationality decision-making model* was proposed by Herbert Simon. Instead of discretionary it is presupposed to use the *heuristics,* which could be described as follows: a set of prescriptions connected with desired (forbidden) patterns of behavior, that emerged as a result of personal professional experience and practical skills of problems solving, and which have the similar initial conditions and prerequisites, and which are used in situations, when the rational decision-making model cannot be used as a „soft" option of rationality in a situation of individual choice.

Thus, bounded rationality is an information behavioral prerequisite for modeling for *individual* solutions. However, if the time selected for a decision-making is not enough to perform the comparison or none of the template situations are suitable to describe the real situation, it is possible to use the *intuitive* decision-making model.

Intuitive decision-making model is based on the usage of "internal intuition", common sense, associative and logical thinking, professional and emotional experience, impressions. The decision-making is equally (or differently) influenced by the knowledge, experience, motivational structure, purpose, life principles and values of the decision, and by the limited timeframe decision.

The taxonomy of the specific *operational thinking*, depending on the decision-making models [Beac78, Chri09] and the main conditions of automated control systems operators, is formulated and presented by the author in Table 1.

Table 1

Indicators of Operational Thinking
Depending on Decision-Making Models

Indicators	**Conditions of Operator's Activity**		
	Normal Conditions	**Boundary Conditions**	**Emergency Conditions**
		"Free" Conditions	
	Decision-Making Models		
	Absolutely Rational	**Bounded Rationality**	**Intuitive**
1	2	3	4
Capacities			
Completeness of information	Complete	Incomplete	Arguable
Structuring of the problem	Structured	Semi-Structural	Nonstructural
Speed	Deliberate	Rapid	Instant
Goal	Clear	Fuzzy	Competing
Indeterminacy	Certainty	Risk	Uncertainty
Techniques			
Problem Processing	Problem Solving	Problem Resolution	Problem Finding
Accuracy	High	Sufficient	Low
Tools	Value	Heuristic	Judgment
Options Difference	Weighted	Acceptable	Indistinguishable
Situational Awareness	Details	Patterns, Clusters	Big Picture

Table 1 cont.

1	2	3	4
Accountability	Statistics, Analytical Tools	Pre-Formulated Rules	Perception, Mental simulations, Feelings
Experience	Not necessarily	Embedded in Direct Habit	Embedded in Direct Experience
Emotional Level	Emotion Free	Legitimate Role for Emotions	Emotionally Associative
Effort	Requires Cognitive Effort	Requires Developed a Range of Successful Adaptive Strategies	Appears Effortless
Choice			
Metrics	Numerative	Good enough	Failure or Success
Time Horizon	Present	The Near Future	Future
Level of Detail	Detailed	Grouped	Aggregate
Decisions Formulation	Prescriptive	Suggested	Descriptive
Nature	Objective	Subjective	"Gut Feeling" Based
Conscious Level	Conscious	Traditional	Unconscious
Creativity	Creativity Free	Creativity Free	Creative
Decisions	Optimal	Satisfied	More Relevant

1. Problem Statement

High demands to the operator's efficiency and reliability as elements of a closed loop of the automated control systems bring to the fore the problem of investigation of *human intellectual activity* with the purpose of enabling clarification of the main behavioral characteristics of an operator in the decision-making process and making recommendations on the classification and identification of operators based on degree of their compliance to certain required procedures/methods of decision-making.

It is obvious that the most objective results of evaluation of the human intellectual processes can be obtained on the basis of experimental studies of their activity directly at the workplace. However, such research is almost impossible due to high economic expenditures.

Development of analytical models of *operator's intellectual activity* is often difficult due to the lack of adequate methods for formalized description (strict algorithm) of this processes and the inability to take into account all the factors influencing the process.

Authors [Pavl05, Zhab07, Pupk74, Youn79, Korm01, Rizu12, Rizu2013a, Rizu13] carried out a general analysis of human behavior as an element of information and technical systems with the use of Automatic Control Theory:

The main tool for the study of operator's behavior as a closed-loop subsystem is its description by means of the transfer function, described in the research results of the following scientists: L. Russell, 1960; J. Elkind, 1964; Anastin, 1960; D. Makruera, E. Krendel, 1959; M. Silvestrov, 1984 [Korm11]. The most widely used are the following quasilinear models: J. Henderson model $W(s)=\frac{k(1+T_1 s)}{(T^2 s^2+2\xi Ts)s}e^{-\tau s}$, D. Makruera and E. Krendel model $W(s)=\frac{k(1+T_3 s)}{(1+T_1 s)(1+T_2 s)}e^{-\tau s}$, and also the extended and transformed model of the automated control systems' operator, based on the previous models.

However, from the author's point of view, unresolved problems in parts of these models are as follows:

1. During the development of these models authors take the preconditions of good structuring and definition of human-machine systems as the basis and tend to ignore the leading role of a human in situations of *uncertainty,* as well as the elements of *subjectivity,* which are added to output and input of system.
2. The object of operator's activity analysis, which is taken into account during mathematical modeling, is the dynamics of operator's behavior as a closed-loop subsystem: the average time of free-error operation, failure frequency, mean time to repair, availability factor, the probability of timely fulfillment of tasks (in the stages of input perception and decision-making) as well as the inertia of its neuromuscular mechanism (in the stages of his activity). But the emphasis on the *specificity of the operator's intellectual activity* processes is in different situations *absent*, leading to the making and implementation of concrete solutions for transforming the input information signal.

In order to analyze the possibility of using the mentioned quasilinear models of operator's behavior for interpreting the features of his intellectual activity processes, a simulation model was developed by authors with the use of the MathCad. For these purposes it was suggested that: the simulation of Rational Decision-Making Model as a process of performing a certain number of stages of logical analysis of the problem by decomposing the original problem into simpler components and gradual approximation to the desired solution could be accomplished by using harmonic exponentially damped cosine signal $x(t)=A\cdot e^{-\gamma\cdot t}\cdot cos(\lambda\cdot t)$.

For these purposes the authors have suggested that: the simulation of *Rational Decision-Making Model* as a process of performing a certain number of stages of logical analysis of the problem by decomposing the original problem into simpler components and gradual approximation to the desired solution could be accomplished by using harmonic exponentially damped cosine signal.

1.1. Simulation of the J. Henderson Operator's Behavior Model

During simulation experiment the parameters of J. Henderson operator's behavior model (Figures 1, 2), from the point of view of the decision-making process operator, could be interpreted in author's edition as follows:

T_1 and T – the time-constants, which characterize the operator's activity of alternative solutions processing and the decision making/implementation correspondingly;

k – the level of problem domain awareness (gain);

ξ – the level of development of analytical thinking skills (the damping coefficient);

τ – the ability to perceive the rate of changing the input information for decision-making (delay).

$\lambda := 0.05 \quad T1 := 1 \quad T2 := 0.1 \quad T3 := 1 \quad \omega := 1 \quad \tau := 2 \quad k := 10$

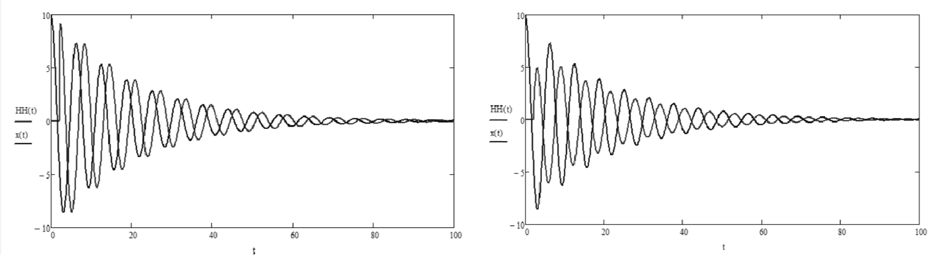
$$W2(s) := \frac{k\cdot(1+T3\cdot s)\cdot e^{-\tau\cdot s}}{(1+T1\cdot s)\cdot(1+T2\cdot s)} \qquad W1(s) := \frac{s+\lambda}{\omega^2+(s+\lambda)^2}$$

$HH(t)=W2(t)\cdot W1(s)\cdot$ invlaplace, $s \rightarrow 9.9497512\cdot\phi(t-2.0)\cdot e^{0.1-0.05t}\cdot\cos(t-2.0)-9.9497512\cdot\phi(t-2.0)\cdot e^{20-10.0\,t}+0.99999\cdot\phi(t-2.0)\cdot e^{0.1-0.05\,t}.\sin(t-2.0)$

$Amplitude := 10$

$x(t) := Amplitude\cdot e^{-\lambda\cdot t}\cdot\cos(\omega\cdot t)$

Fig. 1. Simulation model of J. Henderson

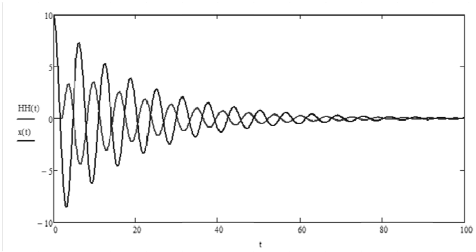


$T1 := 1 \quad T2 := 0.1 \quad T3 := 1$
$\omega := 1 \quad \tau := 2 \quad k := 10$

a)

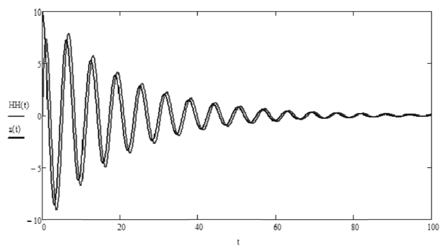
$T1 := 1 \quad T2 := 1 \quad T3 := 1 \quad \omega := 1$
$\tau := 2 \quad k := 10$

b)



$T1 := 1 \; T2 := 1 \quad T3 := 0.1$
$\omega := 1 \;\; \tau := 2 \;\; k := 10$

c)



$T1 := 1 \; T2 := 1 \quad T3 := 1.9 \quad \omega := 1$
$\tau := 0.1 \;\; k := 10$

d)

Fig. 2. Transient responses (a-d) of J. Henderson model for different values of input parameters

1.2. Simulation of the D. Makruera and E. Krendel Operator's Behavior Model

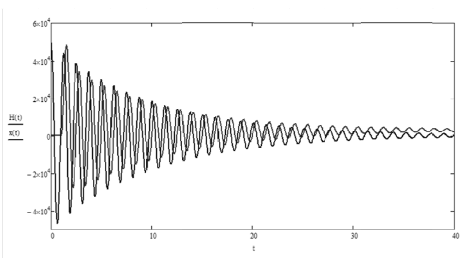
During the simulation experiment the parameters of D. Makruera and E. Krendel operator's behavior model's (Figures 3, 4), from the point of view of the decision-making process operator, could be interpreted in authors' edition as follows: T1, T3 and T2 – time-constants, which characterize the operator's activity of alternative solutions processing, logical processing/analysing of alternatives and the decision making/implementation correspondingly.

$\lambda 1 := 0.1 \;\; T1 := 40 \;\; Amplitude1 := 0.5 \cdot 10^5 \;\; \omega := 5 \;\; \tau := 1 \;\; k := 1 \;\; \xi := 0.01 \;\; T := 0.01$

$W3(s) := \frac{k \cdot (1 + T1 \cdot s) \cdot e^{-\tau \cdot s}}{\left(T^2 \cdot s^2 + 2 \cdot \xi T \cdot s\right) \cdot s} \qquad W4(s) := \frac{s + \lambda}{\omega^2 + (s + \lambda)^2} \qquad x(t) := Amplitude1 \cdot e^{-\lambda \cdot t} \cdot \cos(\omega \cdot t)$

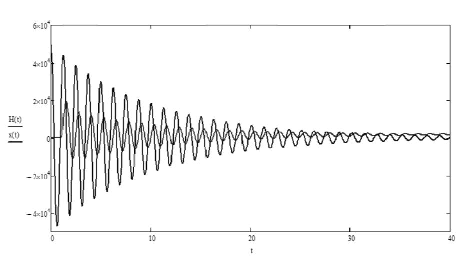
$H(t) = W3(t) \cdot W4(s) \cdot$ invlaplace, $s \rightarrow \phi(t-1.0) \cdot (9.9999 \cdot t + 13371.23513 \cdot e^{2.0-2.0 \cdot t} - 13966.13564 \cdot \cos(5.0 \cdot t - 5.0) \cdot e^{0.05-0.05 \cdot t} + 5205.8328 \cdot \sin(5.0 \cdot t - 5.0) \cdot e^{0.05-0.05 \cdot t} + 584.901513)$

Fig. 3. Simulation model of D. Makruera and E. Krendel



T1:=100 T=0.01

a)



T1:=40 T=0.01

b)

Fig. 4. Transient responses (a, b) of D. Makruera and E. Krendel model for different values of input parameters

In the view of the analysis of the subjective influence of the operator to input signals the main results are expressed in the phase and amplitude of the signal shift (delay). It may correspond to different degrees of decision-making success from the given (optimal) time as well as from the degree of processing (analyzing) of the possible alternatives.

The *advantage* of J. Henderson operator's behavior model with relation to control quality is the presence of an ideal integrator term. Due to this fact with minimal lag (instant response to an input signal) and with certain values of the time-constants it is possible to provide the fairly accurate reproduction of input cosine signal.

1.3. Simulation of the Operator's Making-Decision Activity as a PID Controller

Basic operator's behavior model as an element of a closed-loop system is the so-called *accompanying tracking*, in which he sees an input signal and a signal about the current condition of a managed object. The operator's purpose in this situation is to keep the difference between these signals close to zero.

The authors suggest the concept of interpretation of "automated control systems operator's intellectual activity within the decision-making as a process of correspondence (maintenance) to the adjusted (required) setpoint level of the set problem solving (optimal, sufficient solution") [Rizu13, p. 13-15].

In this view the authors propose the hypothesis that: basic processes of the operator's decision-making activity could be adequately simulated and identified by the transient processes of the proportional-integral-derivative (PID) controller.

Mathematical form of the PID-algorithm is:

$$u(t) = K_P \cdot \left(e(t) + \frac{1}{K_I} \cdot \int_o^t e(t)dt + K_d \frac{de(t)}{dt} \right) \qquad (1)$$

Authors propose the following interpretation of the PID-controller transfer function coefficients: K_p – the level of operator's personal characteristics, which are necessary for solving this type of problem (confidence, endurance, stamina, ability to control the situation, persistence); K_I – the problem domain awareness level; K_d – speed of logical operations performance.

Taking into account the main purpose of PID-controller – operator's activities for keeping the setpoint measured parameter – these analogies similarly allow us to identify the main stages of decision-making in accordance with the *given instructions and algorithms in the standard (programmed) conditions* with a clearly defined only one correct (optimal) solution. This concept corresponds to the interpretation of the *automated control systems operator's intellectual activity* as a PID-controller in the conditions of using the *rational decision-making model*.

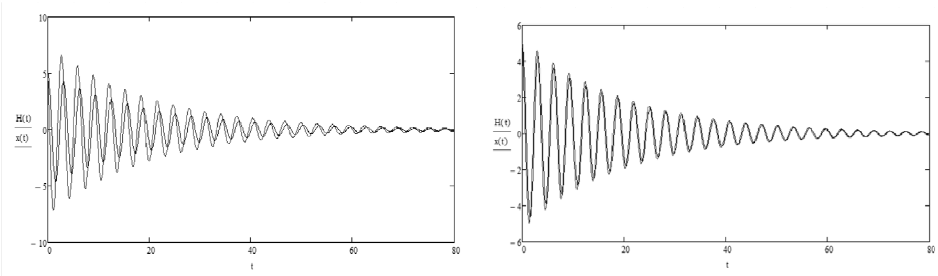
Results of the simulation of automated control systems operator's intellectual activity as a PID-controller transient characteristic using input harmonic exponentially damped cosine signal is shown in Figures 5, 6.

$$\lambda := 0.05 \quad Td := 1 \quad Ti := 8 \quad Kp := 5 \quad \omega := 2 \quad x(t) := Kp \cdot e^{-\lambda \cdot t} \cdot \cos(\omega \cdot t)$$

$$W5(s) := Kp + Td \cdot s + \frac{1}{(Ti \cdot s)} \qquad W6(s) := \frac{s + \lambda}{\omega^2 + (s + \lambda)^2} \qquad \Delta(t) := 0$$

$$H(t) = W5(t) \cdot W6(s) \cdot \text{invlaplace}, s \rightarrow \Delta(t) + 4.94843 \cdot e^{-0.05t} \cdot \cos(2.0 \cdot t) - 1.937539 \cdot e^{-0.5\,t} \cdot \sin(2.0 \cdot t) + 0.00156152$$

Fig. 5. Simulation model of operator's intellectual activity model as PID-controller



Td:=1 Ti:=3 Kp:=5
a)

Td:=1 Ti:=8 Kp:=5
b)

Fig. 6. Transient characteristics (a, b) of operator's intellectual activity model as PID-controller for different values of input parameters

The advantages of this model, conducting an analogy between decision-making processes of the operator and PID-controller transient's processes, compared with previous models (Figures 1-4), are the following:

- accounting the *additional possibility* of the presence not only of the delay effect, but also *pre-empt the decision-making process* with respect to the time of receipt of the initial information;
- presence of sophisticated capabilities of model management and more flexible and gradual reaction of the output signal on the changing of its parameters, which could be interpreted as an imitation of a higher degree of *subjective* (professional) approach to decision-making (having their own style of decision), but not simplistic attempts of automatic repetition of the given algorithm of decision-making with minimal delay; from the view of the transient characteristic form it is expressed in the asymptotic approximation of the signal to the given solution.

However, the unresolved part of the problem in this solution is the absence of interpretation and analysis of the *divergent* PID-controller transient process, which could be interpreted as a lack of ability to make a decision using well-known logic algorithms – as a result of a high degree of *uncertainty* of the problem and/or *lack of information*, *time constraints.*

According to the above-mentioned analysis results (Table 1), decision-making in non-programmed situations requires form the operator the nonstandard decision-making methods, based not only on logic, but on intuition, professional experience and "gut feeling".

Thus, the problem of identifying the decision-making process and studying the dynamic behavior of the automated control systems *operator* in the conditions of *uncertainty* and *risk* is a *topical* scientific problem, allowing, on the one hand, to assess the reliability and stability of the management system, on the other – to formalize a set of qualitative and quantitative requirements for professional operator skills.

Continuing the analogy between human intellectual activity and the Automatic Control Theory, the authors proposed the following required analysis and verification of the preconditions and hypothesis:

Precondition:

On the one hand, from the Automatic Control Theory it is well-known that the signal passing through the nonlinear elements, is "enriched" by additional harmonic components defined by the parameters of this elements.

On the other hand, operators, using their own experience and intuition (subjective vision, feeling of the current and future situation) for decision-making in non-programmed, precarious and often stressful situation, alter input information, "enrich" it by new subjectively formed components (decision) on the basis of their own knowledge, professional experience (skills) of the decisions adoption and implementation and the current state of psycho-physical activity.

Hypothesis:

Basic conditions, methods and results of the operative type of operator's thinking in non-programmed situations (boundary, emergency, "free") can be adequately simulated and identified by the transient processes of the nonlinear elements.

Thus, the **purpose of this paper** is to develop a simulation model to perform the identification and classification of automated control systems operators by the characteristics of nonlinear elements' behavior, using the criteria the different decision-making models, which operators apply in the conditions of uncertainty and risk.

2. Identification of the Operator's Decision-Making Activity Models Using Nonlinear Elements

The main result, obtained by authors during the simulation experiment, is the Nonlinear Element's Taxonomy in terms of the decision-making models used by the operator under conditions of uncertainty and risk (Table 2).

Table 2

The Taxonomy of the Nonlinear Elements
Depending on the Decision-Making Models

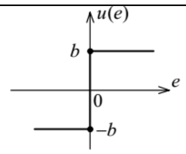
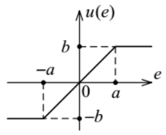
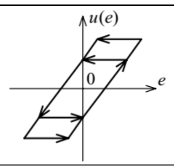
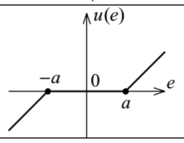
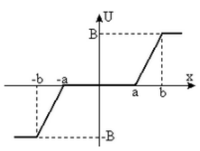
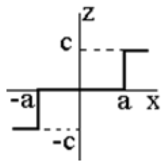
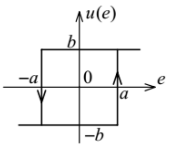
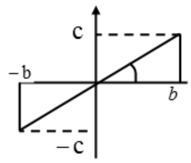
Nonlinear Element's Type and There Transient Characteristics		Decision-Making Models		
		Absolutely Rational	**Bounded Rationality**	**Intuitive**
		The Conditions of Operator's Activity		
		Normal Conditions	**Boundary Conditions**	**Emergency Conditions**
			"Free" Conditions	
1	2	3	4	5
Two-position relay		-	$x(t) > 0$, b $x(t) < 0, -b$	-
Saturation		$-a < x(t) < a$	$x(t) < -a$ $x(t) > a$	-
Backlash		$-a < x(t) < a$		$x(t) < \lvert a \rvert$
Deadband		-	$x(t) < -a$ $x(t) > a$	$-a < x(t) < a$
Deadband with saturation		$-b < x(t) < -a$ $a < x(t) < b$	$x(t) < -b$ $x(t) > b$	$-a < x(t) < a$

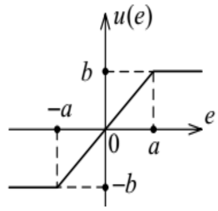
Table 2 cont.

1	2	3	4	5
Three-position relay without deadband		-	$x(t) < -a$ $x(t) > a$	$-a < x(t) < a$
Two-position relay with deadband		-	$x(t) > 0$, b $x(t) < 0, -b$	$x(t) < \lvert a \rvert$
Author's nonlinear element		$-b < x(t) < b$	-	$x(t) < -b$ $x(t) > b$

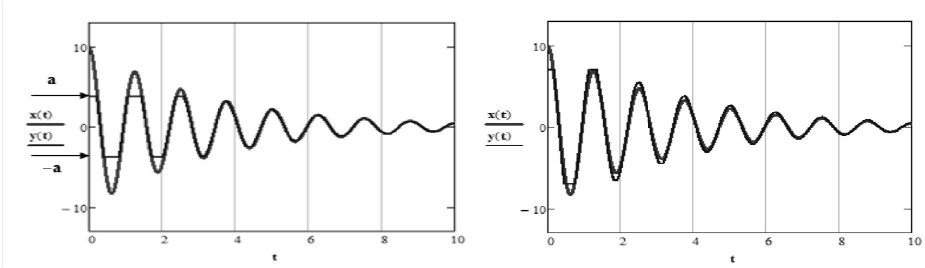
Authors' interpretation of the main characteristics of nonlinear elements, presented in Table 2, allows to perform qualitative identification of the specifics of the operator's decision-making activity under conditions of uncertainty and risk, as follows:

1. The simplest nonlinear elements perform **static** (instantaneous) nonlinearity. Their output variable $y(t)$ depends only on the input value $x(t)$, and this dependence is strictly unambiguous.

1.1. Nonlinear element "**Saturation**" − in terms of basic characteristics (its amplitude and phase) of a signal being input – accurately tracks the phase change, limiting the amplitude at the output beyond value $\lvert -a \rvert$ (Figure 7). This type of nonlinearity is proposed by the authors to interpret (at a certain ratio of the amplitude values of the parameters A and parameters value – b and c) as a following type of operator's decision-making activity:



- using the *bounded rationality* model with limited amplitude in situations, where conditions do not meet (greater than $x(t) < \lvert a \rvert$) the conditions of application of the rational decision-making model;
- transition to the *rational* decision-making model with decreasing (in terms of the operator) degree of non-programmed (uncertainty) tasks.

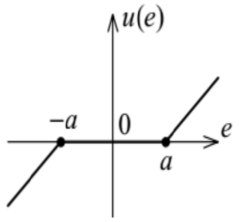


a) b)

Fig. 7. The forms of output signals of nonlinear element “Saturation” on the harmonic exponentially damped cosine signal

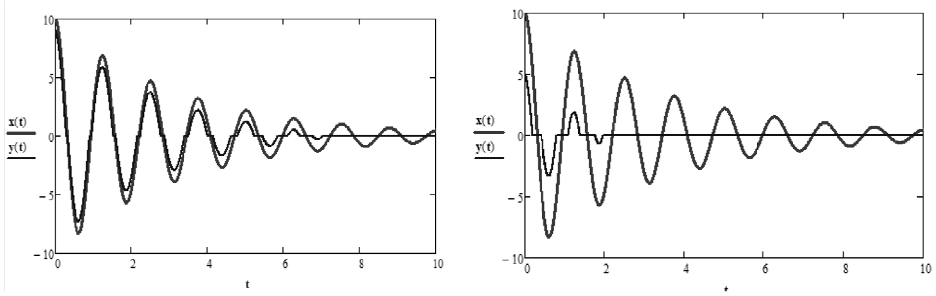
At a certain ratio of basic system’s parameters the obtained “sufficient” solution became close to the optimum (Figure 7a and 7b).

Thus, the author’s interpretation of the nonlinear element “**saturation**” is the following: on the stages and levels, which were identified by operator as non-compliance conditions of the task to the rational decision-making model, heuristics are used as a “framework” for limiting the depth of analysis of the problem. Decision-making process as a whole has a tendency and retains elements discretionary (rationality).



1.2. Nonlinear element “**deadband**” − is characterized by tracking the changes in the phase and amplitude of the input signal (at $|x(t)| > a$) taking into account the deadbanded *b*, and also has a reduction in amplitude when going beyond the value $|-a|$. Authors propose to interpret this type of nonlinearity (at a certain ratio of the amplitude values of the parameters *A* and parameters value – *b* and *c*) as a following type of operator's decision-making activity:

– using the *bounded rationality* model with delay (time for searching the rules/heuristics, defined by the level of operator’s confidence in decision-making results) and reduction in amplitude (simplification of decisions via replacing the *rational* decisions onto the *rules/heuristics*); the values of this parameters are determined by the size of the deadband (operator’s individual abilities/capabilities to make a decision in a particular level of mismatching the conditions of the task to the rational decision-making model);
– *intuitive* pre-term (do not meet the optimal time) making the most appropriate decision, which is also determined by the deadband size.



a) b)

Fig. 8. The forms of output signals of nonlinear element "Deadband" on the harmonic exponentially damped cosine signal

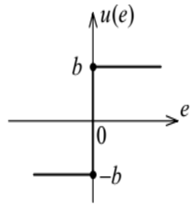
Increase of the deadband size leads to a substantial simplification of the decision-making process (the minimum number of heuristics available to the operator) (Figure 8a).

Maximum matching with desired (ideal) rational decision-making model (in conditions of a certain combination of the basic task's parameters and the type of operator) does not provide *optimal* solution, but "*good enough*" solution can be intuitively obtained in a forced limited time period (Figure 8b).

Thus, the authors' interpretation of the nonlinear element "**deadband**" is the following: in decision-making process the selection of the appropriate heuristics (restrictive rules, simplifications) is implemented by identifying the solutions of real (recognizable) situation – matching with a set of template situations, which are the result of accumulated tacit operator's knowledge.

In case if none of the template situations are suitable to describe the real situation, it is possible to create a new template and formulate a new or a modified rule for it.

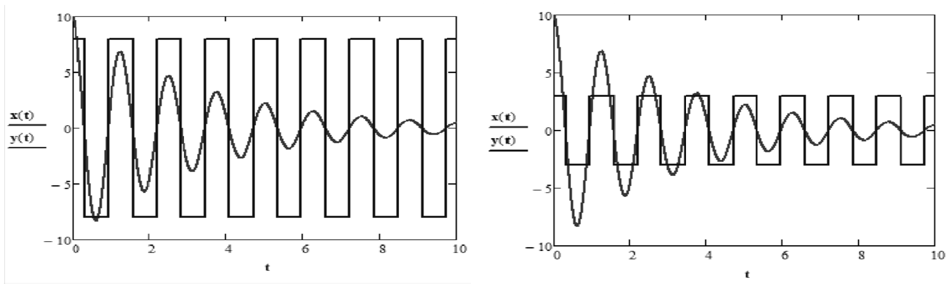
Decision-making process retains elements of the simplified discretionarity (rationality), which is typical for a decision-making within the limited time.



1.3. Nonlinear element "**two-position relay**" − is characterized by tracking the phase with the constant (limited) value of the output signal amplitude ($y(t) = |c|$), which does not depend on changes of the input value (Figure 9a and 9b). This type of nonlinearity is proposed to be interpreted as a type of operator's decision-making activity using the absolute bounded rationality mode, in which operator's decision is *invariant* with respect to different circumstances of time and place.

Thus, the authors' interpretation of the nonlinear element "**two-position relay**" is the following: the result of formed automatism of perception, thinking and behavior, which leads to the reproduction of one possible solution in the situations identified as template (typical).

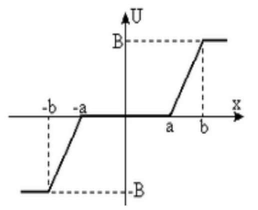
In the decision-making process the elements of discretionarity (rationality) are absent.



a) b)

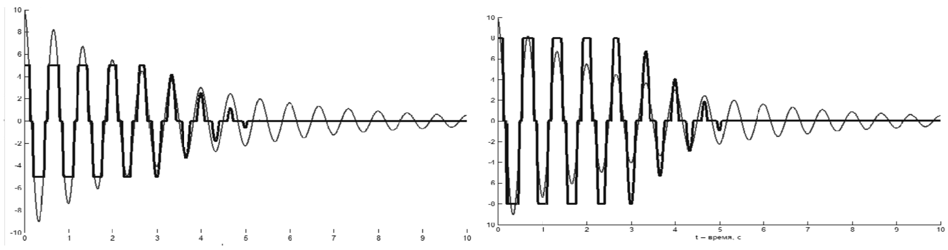
Fig. 9. The forms of output signals of nonlinear element "two-position relay" on the harmonic exponentially damped cosine signal

1.4. Nonlinear element "**deadband with saturation**" − it is a combination of several decision-making models: characterized by tracking phase of the input signal (*y(t)* = $|c|$), as well as a restriction in amplitude when going beyond the values $|-b|$ and its reduction – when going beyond the values from $-b|$ till $|-a|$.



This type of nonlinearity is proposed to be interpreted as follows: the model of bounded rationality with the consistent using of individual decision-making strategies, which are result of the impact of accumulated tacit knowledge, emotional memory and "behavioral bias", namely:

– using the *automatic* (irrational) decision-making model at the stage, which was identified by operator as an increased level of non-compliance to the rational decision-making model conditions;
– changing the strategy into using the *heuristics* at the next stages with a higher degree of compliance to the rational decision-making model conditions;
– the *intuitive pre-term* making of the most appropriate decision.

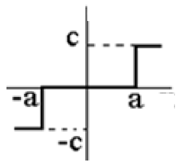


a) b)

Fig. 10. The forms of output signals of nonlinear element “deadband with saturation” on the harmonic exponentially damped cosine signal

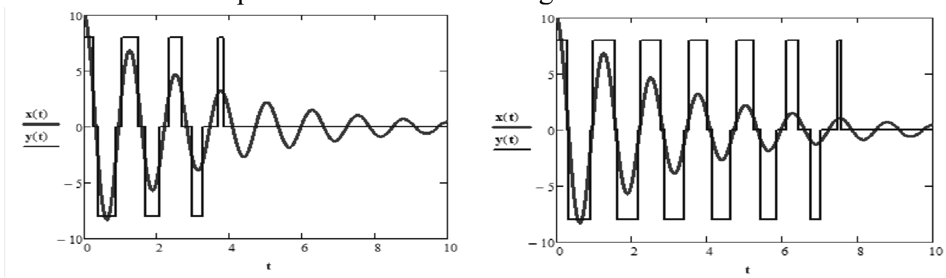
Decision-making process retains the elements of the simplified discretionary (rationality), acceptable in the decision within the limited time.

1.5. Nonlinear element “**three-position relay without deadband**” − it is proposed to be interpreted as a type of operator’s decision-making activity using a *bounded rationality model*, in which the solution, received by operator, is invariant with respect to different places and circumstances and taken with increasing time delay with subsequent pre-time decision-making of the first acceptable solution (Figure 11).



This type of nonlinearity is one of the possible variants of using the model of automatic decision-making activity in conjunction with the gradual intuitive decay of processing intensity and with pre-time decision-making.

In the decision-making process the elements of discretionarity (rationality) are absent. It is acceptable for decision-making in a limited time frame.

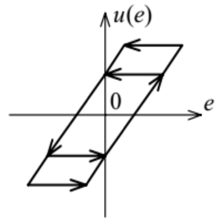


a) b)

Fig. 11. The forms of output signals of nonlinear element “three-position relay without deadband” on the harmonic exponentially damped cosine signal

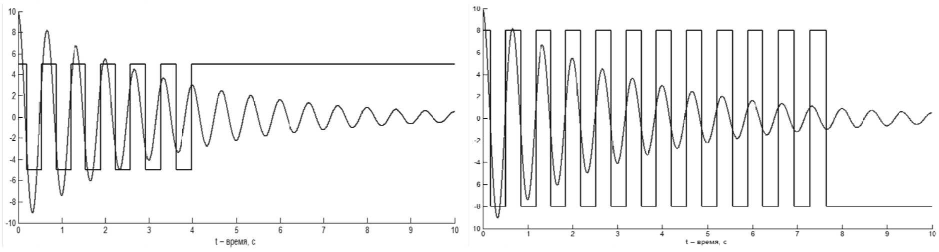
2. In **dynamic** nonlinearities the output value *y(t)* depends on the input value *x(t)*, and from its derivative.

2.1. Nonlinear element "**backlash**" − is characterized by a phase shift, which depends on the amplitude of the input signal and the value of $\pm a$ (Figure 12).



In the authors' interpretation the nonlinear element "**backlash**" is: one of the possible variants of the **automatic** decision-making activity in conjunction with subsequent intuitive making permanent (one correct) solutions for a long period of time.

In the decision-making process the elements of discretionarity (rationality) are absent. It is acceptable for urgent decision-making.



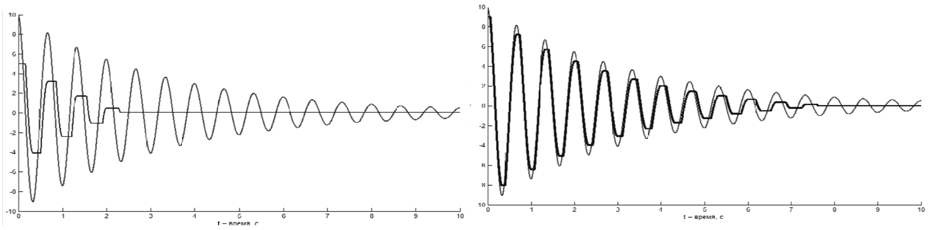
a) b)

Fig. 12. The forms of output signals of nonlinear element "backlash" on the harmonic exponentially damped cosine signal

2.2. Nonlinear element "**two-position relay with deadband**" − it is characterized by tracking the phase changes from a gradual phase shift, which depends on the amplitude of the input signal and the value of $\pm a$, reduces input signal amplitude with taking into account the value *b* (Figure 13).

This type of nonlinearity is proposed to be interpreted as a type of operator decision-making activity, as follows: applying the **bounded rationality** model under the time limit conditions, using **heuristics**, which limit the depth of the problem analysis, and pre-term decision-making of the most appropriate solutions.

Maximal compliance (particular combination of the basic problem's parameters and the operator's type) to the desirable (ideal) rational decision-making model with minimal precision allows to make the acceptable decision under time constraints and with the presence of discretionarity elements.



a) b)

Fig. 13. The forms of output signals of nonlinear element “two-position relay with deadband” on the harmonic exponentially damped cosine signal

2.3. **Author’s nonlinear element** [Tara08] − simulation model of this nonlinear element can be implemented:

- in MatLab, using two logical switch type >=, amplifier with coefficient *c/b*, blocks of constants for the parameters *b*,-*b* and multiplier blocks (Figure 14);

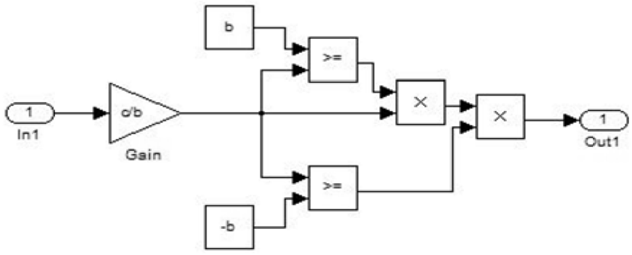


Fig. 14. Simulation model of author’s nonlinear element in MatLab

- in MathCad, with the help of the following code (Figure 15):

$NN := 15 \quad t_3 := 10 \qquad \mathbf{Amplitude} := 10 \qquad \mathbf{\Delta t} := 0.001 \quad \mathbf{t} := 0, \mathbf{\Delta t} .. t_3$

$$\boldsymbol{\xi} := \frac{1.5}{\sqrt{(\boldsymbol{\pi}\cdot NN)^2 + 2.25}} \qquad \boldsymbol{\xi} = 0.032$$

$$\boldsymbol{\lambda} := \frac{2\cdot\boldsymbol{\pi}\cdot NN}{t_3} \qquad \boldsymbol{\lambda} = 9.425$$

$$\boldsymbol{\Omega 1} := \frac{2\cdot\boldsymbol{\pi}\cdot NN}{t_3\cdot\sqrt{1-\boldsymbol{\xi}^2}} \qquad \boldsymbol{\Omega 1} = 9.43$$

$$\boldsymbol{\gamma} := \boldsymbol{\xi}\cdot\boldsymbol{\Omega 1} \qquad \boldsymbol{\gamma} = 0.3$$

$$\mathbf{a} := \mathbf{Amplitude}\cdot\mathbf{e}^{-\boldsymbol{\gamma}\,\mathbf{t}}$$

$$\mathbf{x(t)} := \mathbf{Amplitude}\cdot\mathbf{e}^{-\boldsymbol{\gamma}\,\mathbf{t}}\cdot\mathbf{cos}(\boldsymbol{\lambda}\cdot\mathbf{t})$$

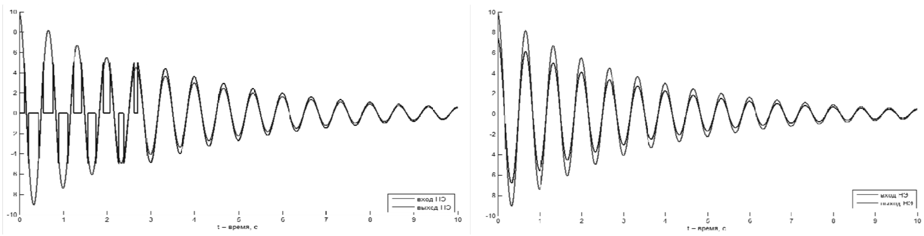
$$\mathbf{y(t)} := \mathbf{if}\left[\mathbf{x(t)} \le \mathbf{b}, \left(\frac{2c\cdot\mathbf{x(t)}}{\boldsymbol{\pi}\cdot\mathbf{b}}\right), \frac{2c\cdot\mathbf{x(t)}}{\boldsymbol{\pi}\cdot\mathbf{b}}\cdot\left[\mathbf{asin}\left(\frac{\mathbf{b}}{\mathbf{x(t)}}\right) - \frac{\mathbf{b}}{\mathbf{x(t)}}\cdot\sqrt{1-\left(\frac{\mathbf{b}}{\mathbf{x(t)}}\right)^2}\right]\right]$$

Fig.15. Simulation model of authors’ nonlinear element in MathCad

This type of nonlinear element is characterized by tracking the changes in the input signal phase up to full attenuation and reduction of the amplitude of the input signal with taking into account the value *b*.

The authors propose to interpret this nonlinear element as type of operator decision-making activity, which is characterized by a combination of several decision-making models (Figure 16):

- using the intuitive model with inversion/repetition (depending on operator's and nonlinear element's parameters) amplitude on the identified by operator stages and levels of non-compliance of the task's conditions to the rational decision-making model;
- with a gradual transition (at least simplifying and improving the compliance of the current problems degree to the ideal conditions) to the bounded rationality model, which is critically close to the rational model.



a) b)

Fig. 16. The forms of output signals of Authors' nonlinear element on the harmonic exponentially damped cosine signal

Maximal compliance (particular combination of the basic problem's parameters and the operator's type) to the desired (ideal) rational decision-making model with minimal precision allows to make the acceptable decision under time constraints and with presence of discretionarity elements.

Conclusions

The authors confirmed the hypothesis about possibility with sufficient accuracy to describe the specificity of the automated control systems operator's thinking (set of conditions, methods and results of decision-making) in nonprogrammed situations (boundary, emergency, "free") using nonlinear elements.

Simulation models and taxonomy of the nonlinear elements (operators) depending on the type of decision-making models were developed. The authors' original type of nonlinear element was proposed, which extends the possibility of the interpretation and formalization of qualitative and quantitative complex of requirements to the professional operator's skills.

References

[Beac78] Beach L.R. et al.: A Contingency Model for the Selection of Decision Strategies. „Academy of Management Review" 1978, No. 3, pp. 439-449.

[Chri09] Christopher L.: Intuitive and Rational Approaches to Decision Making in Education. Doctoral Dissertation, University of Hull by, BEd, MA, 2009.

[Khan94] Kahneman D.: New Challenges to the Rationality Assumption. „Journal of Institutional and Theoretical Economics" 1994, No. 150, pp. 18-36.

[Korm11] Kormyshev V.M.: Definition of Competence in Information Systems. 2011, p. 147.

[Pavl07] Pavlenko M.A. et al.: The Method of Analysis of the Automated Control Systems of Air Traffic Operator. „Information Processing Systems" 2007, No. 1 (59), pp. 78-81.

[Pavl05] Pavlovskaia O.O.: Methods for Determining the Parameters of a Linear Mathematical Model of the Operator. „Computer Technology, Management, Electronics" 2005, Iss. 5, No. 7 (79), pp. 41-44.

[Pupk74] Pupkoff K.: The Optimization of Connection between Human and Techniques in Man-Machine Systems. Preprints of JFAC-JFORS Symposium 1974, pp. 419-426.

[Rizu13] Rizun N.O.: Computer Modelling of Cognitive Processes. Proc. of the Federated Conference on Computer Science and Information Systems (FedCSIS), Krakow 2013, Poland, 8-11 September, pp. 747-750.

[Rizu12] Rizun N.O.: The Questions of the Testee Identification as PID-Controller in the Automated System of Professional Certification. „Vimiryuvalna obchislyuvalna tehnika tehnologichnih in process" 2012, No. 3 (41), pp. 133-141.

[Rizu13a] Rizun N.O. et al.: The Model of Identification of Testee's Cognitive Processes as Transient Characteristics of the Adaptive PID-Controller. International Scientific Conference SAIT 2013, pp. 176-178.

[StWe99] Stanovich K.E., West R.F.: Discrepancies between Normative and Descriptive Models of Decision Making and the Understanding/Acceptance Principle. „Cognitive Psychology" 1999, No. 38, pp. 349-385.

[Stre01] Strelkov Yu.K.: Engineering and Professional Psychology. Akademiya, 2001, p. 360.

[Timo07] Timochko A.I.: Modeling of the Decision Maker Activities in the Management Systems Networks. „Radiotekhnika" 2007, No. 151, pp. 85-91.

[Tara08] Taranenko Yu.K.: Formation of the Optimal Characteristics for Oscillating Systems Vibro-frequently Data Densitometers. „Math. Electronics Universities" 2008, Iss. 51, Vol. 7, pp. 47-58.

[Youn79] Young J.F.: Robotics. „Mechanical Engineering" 1979, p. 300.

[Zhab07] Zhabreev V.S. et al.: Models and Evaluation of Human Factors in the Large Systems: A Tutorial. Chelyab int putej Soobshcheniya, Chelyabinsk 2007, p. 219.

MODELOWANIE SYMULACJI DZIAŁANIA PODEJMOWANIA DECYZJI OPERATORÓW SYSTEMÓW AUTOMATYCZNEJ KONTROLI Z UŻYCIEM NIELINIOWYCH ELEMENTÓW

Streszczenie

W artykule została zaproponowana nowa koncepcja modelowania działań podejmowania decyzji przez operatorów z użyciem analogii do teorii kontroli automatycznej. Autorzy potwierdzili hipotezę dotyczącą możliwości opisu specyfiki myślenia operatorów systemów kontroli automatycznej (zbiór warunków, metody i wyniki podejmowania decyzji) w nieprogramowych sytuacjach (ograniczenia, zagrożenia, swoboda działania) z dostateczną dokładnością z użyciem nieliniowych elementów.

Zostało udowodnione, że główną cechą wyróżniającą Model Heurystyczny/Intuicyjny w porównaniu do modelu Racjonalnego Podejmowania Decyzji jest obecność tak zwanego zjawiska „wzbogacenia" („enrichment") informacji wejściowej o ludzkie preferencje, hobbies, tendencje, oczekiwania, aksjomaty, osądy, uprzedzenia i ich uzasadnienie.

W artykule rozwinięto modele symulacji i taksonomię nieliniowych elementów (operatorów) zależnych od rodzaju modelu podejmowania decyzji. Został zaproponowany autorski, oryginalny rodzaj nieliniowego elementu, który rozszerza możliwości interpretacji i formalizacji jakościowych i ilościowych wymagań dla wzbogacenia umiejętności decydenta.