International Journal for Quality Research 9(3) 495–512
ISSN 1800-6450

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Article info:
Received 17.05.2015
Accepted 23.07.2015

UDC – 54.061

MODEL OF FORMATION OF THE FEEDBACK CHANNEL WITHIN ERGATIC SYSTEMS FOR MONITORING OF QUALITY OF PROCESSES OF FORMATION OF PERSONNEL COMPETENCES

Abstract: *The authors of this work develop a management model of quality of process of competences development and support of decision of low-formalized tasks of management of learning quality process. On the basis of research of features of creation of a complex of feedback realization within the "operator – environment – machine" system the model is developed which provides the stage-by-stage evolutionary development of this complex when modeling various external and internal influences, and can be integrated into modern management systems. Systems of images recognition, a status functions method, testing systems, video recording, and photogrammetric methods are used. Taking into account some assumptions, the proposed approach can be widely applied in difficult training complexes, anthropomorphous training systems, in distant education, and for complex assessment of difficult social and economic objects condition.*

Keywords: *monitoring of quality processes of education, ergatic system, decision support system, evolutionary learning, status functions, professional competences*

1. Introduction

Implementation of modern systems of quality management is impossible without informatization of training processes which are the cornerstone of programs of management of organization development. Now corporate integrated information – analytic system (IIAS) belonging to a class of information processing systems (IPS, or OLTP systems) are actively developed and start being implemented. At the present stage of development of information technologies there are information management systems which are ready to be integrated into developed IPS. However specific problems of management for which there is no ready software are peculiar to the sphere of education. First of all, these are training process management tasks.

Now there is a common understanding of the development of the content of qualifications in terms of competence levels and learning outcomes, as a mechanism for promoting the purposes and principles of quality management system.

Studying methods of management of competences development reveals complexity and high cost of such assessment

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(Metaver, n.d.). Implementation of similar systems pursues the aim to achieve a certain administrative and economic effect in the future. However management of competence-based approach formation progresses in the conditions of uncertainty over a future of competences of participants as well as requirements of environment to the content of these competences. The problem of the assessment becomes more complicated not only because of need to assess a performance of competences, but also because of competence overlapping. Therefore the task to reduce risk of inefficient management of competences development rests on a problem to reduce the uncertainty.

Competences are interpreted as the uniform (agreed) language for description of academic and professional types and levels of the higher education. Sometimes it is said that competence language is the most adequate for the description of education outcomes. The education outcomes expressed by the competences language is a way to extend academic and professional recognition and mobility, and to increase comparability and compatibility of certificates and qualifications. In Russian conditions the realization of competence-based approach can act as an additional factor of keeping the uniform educational, vocational and cultural space (Center for research of specialist training quality problems, n.d.).

As a competence can be estimated only when it manifests in action, a competences assessment means rather complex and resource-intensive procedure which supposes a person (or persons) who will constantly observe the manifestation of competences. If a teacher will carry out this assessment, then the time of assessment can be commensurable with training time and this fact seems to be an inefficient expenditure of personnel resources. Development of competence assessment expert system within which all participants of educational process can indicate the competences manifested in traditional precedents of training process is expedient. Before drawing up directly a program realizing the expert system electronically, it is necessary to develop methods of mathematical modeling of competences development, their assessment, and decision-making on the basis of it. The system for monitoring of competence development processes should be based on an evolutionary automated control system. Today the most of typical technogenic objects are ergatic systems which are understood as complex control systems which component is an operator (a human) of the automated complex (machine). The automated systems for supervisory control in the production sphere, a transport operated by a person (a car, a train, an airliner, and etc.), distance learning systems, telerobotic systems, and etc. belong to this class of systems (Novozhilov, 2012). In these systems the controller operates a machine indirectly, but via information model which is "an image" of the machine. Through this image, as in a mirror, the controller assesses a condition of the operated system at each next timepoint and makes a decision on intervention in the machine operation in order to restore it to a required state. Thus the controller is the main source of contingencies and emergencies within the ergatic control systems (ECS), provoking up to 70% of total quantity of incidents (Petukhov, 2012). Quality of the decisions made by the controller depends on influence of negative factors associated with sensory, emotional, and intellectual overloads (Petrin, 2010). Methods to reduce accidents rate can be aimed at development of numerous approaches to assessment of professional suitability of the machine controller providing the required accuracy and reliability of assessment results (Petukhov, 2013). Now the most known are approaches to the professional suitability assessment on a basis of job description (Vlasov, 2003). Another way to reduce the accident rate is directed on improvement of processes of management of technical condition of complex technical systems with application of management information systems (Pavlov, 2009a). Besides, the "human – environment – machine" system (HEM) can be analyzed as a closed system within which components are exposed to casual influences which can lead to spasmodic changes which are termed accidents (Arnold, 2000; Hacken, 2005). Complexity of interrelations between all components of the real HEM system is very high and creating a mathematical model for more complex object requires comprehensive mathematical methods (Wentzel, 1972; Khichin, 1963).

Until recently, possibility to adapt the ECS was realized through flexibility of operator behavior. Now the most urgent is the question of implementation of intellectual technologies of the decision support system (DSS) and realization of models and algorithms of the ECS adaptation depending on the current psychophysiological state of the person and indicators of efficiency of his/her activity. Modern ECS are designed for the "ideal" or an average controller; they don't consider his/her professional skills and level of fatigue.

The present paper deals with issue of development and implementation of methods based on identifying characteristics of social phenomena similar to wave functions in quantum mechanics.

The problem to create an information model which corresponds to the operator's capability to percept and process full volume of encoded information and to manage a machine efficiently demands to apply new mathematical methods of modeling of HEM interaction. We will assess of components in order to find the best ways of to improve the effectiveness of quality management interaction of the HEM system.

2. Human and his/her reaction

Specificity of problems of interaction between a human and a machine are connected with increasing volume of information and speed of information streams that inevitably lead to increasing number of errors. Time and quality of actions which are carried out by a controller are also influenced by fatigue. Within the automated systems the total number of errors increases eventually and can be estimated at from 20 to 53%.

We will be basing on human physiology and we will describe a procedure of an administrative decision adoption by an operator. Ergonomics data led to formation of the modern model of ergatic system (Figure 1). The description of procedure of decision-making by the operator is based on general knowledge and motivation. The primary stage is based on information perceived by receptors. The next is the afferent synthesis (Figure 1 (A)). On the basis of the afferent synthesis the operator makes a decision which removes uncertainty in choosing of one of numerous possible options of behavior (Figure 1 (B)). If there is a decision, there is an afferent synthesis on the basis of which the program of specific actions (Figure 1 (C)) is made. Concurrently with the action program the acceptor of action result is formed which serves for prediction of parameters of result of the future action. It is a situational afferentation, due to which a possibility and an expediency of the action directed to result with the predicted parameter are defined. However, formatting of the program and the action result acceptor doesn't mean the start of action execution. For the start a triggering stimulus is required.

The description of procedure of decision-making by an operator of a complex HEM system is based not only on algorithms of a machine operation, but also on features of human physiology. Thousands of various researches are devoted to studying the total response time and its components (Boiko, 1964; Lupandin and Surnina, 1988). Thus both the dependence on a number of external factors and individual distinctions, and the instrumental use of the response time for the analysis of mechanisms of cognitive processes are studied. The known model of the controller actions sequence by Y. Liu and C. Wu (Liu, 2006) distinguishes sensory, cognitive, and motor level in this sequence.

At the same time, to use all analyzers simultaneously in the case of the situational afferentation is rather complex problem. Besides, the speed of human neurons impulses transmission can fluctuate. So, for example, in extreme situations the perception of pain, taste, and temperature is inhibited. But the visual perception becomes important. The field of vision extends; sensitivity of optic nerves increases. Such situation can lead to an overload of the visual analyzer, to inhibition of perception and even, to a temporary loss of sight (for example, in the case of overloads and so forth).

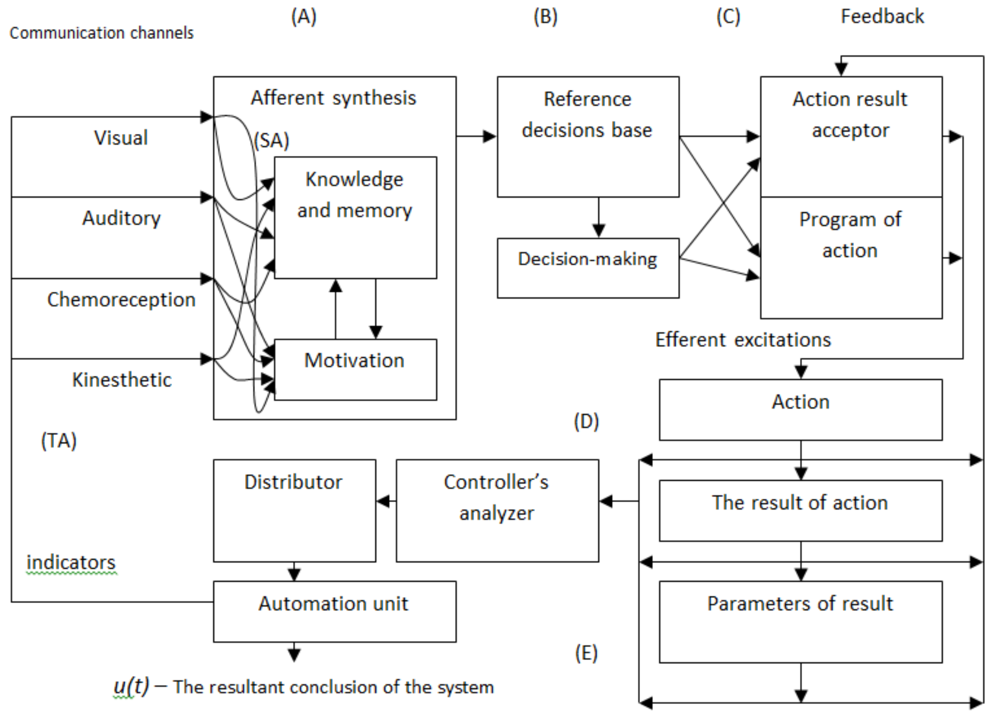

Figure 1. Model of the "human-machine" ergatic system. (A) – stage of the afferent synthesis; (TA) – triggering afferentation; (SA) – starting afferentation; (B) – decision-making; (C) – formation of resistant action acceptor and its afferent program; (D-E) – achieving action results and formation of afferent feedback for comparison of the results with the preset (initial).

An operator, for example a pilot, intends to perform an action (plane landing) on the basis of the dominating stimulus. This decision mobilizes the process of extraction of information on ways how to achieve the purpose and create a specific program of actions (which is developed on the basis of skills obtained in the course of training and is perfected practically and by using simulators). In the case of a favorable situational afferentation (a landing authorization by the flying control officer and favorable prognosis of the action result by the pilot) the start of the behavioral act is initiated by triggering stimulus. The triggering stimulus initiates the action and the pilot lands a plane. In the case of situational afferentation, a possibility and an expediency of the action directed to the result with predicted parameters are defined.

On April 12, 2015 fans have waited for beginning of a concert of the "Thirty Seconds to Mars" rock band in Saratov. But on the basis of the situational afferentation the pilot couldn't land the plane because of strong fog. The triggering stimulus to perform the planned action wasn't initiated. The pilot can lose control over a machine or over himself because of physiological (depressurization) or psychological (change of the dominating stimulus) reasons.

In the given examples it is possible to find the following groups of reasons: insufficiency of visual information; inadequate instruments readings, and difficulty to track them simultaneously by the pilot; psychological reasons.

Limitation of a human ability to process information can conditionally be divided into 2 levels – sensory and cognitive-activity. At the sensory level the information is processed by 5 systems – visual, auditory, somatosensory, olfactory and gustatory. The volume of information perceived with eyes is 90% of total amount of the received information. The other 4 systems perceive only 10% of total volume of information. One of the main reasons for these problems is information congestion of visual perception channels. The possible solution of this problem can be found by identification of ways to reduce volume of information perceived with eyes by means of creation of various forms of indication displaying results of automatic processing of secondary information, and use of other sense organs. Development of specialized models and methods will enable to create algorithms, to find out connections between sequences of control actions of the operator and technical characteristics of ECS in order to reduce number of errors.

At the second level the person's mind creates a model of the real situation. The accuracy of this process is influenced by both external and internal (personal) factors. Insufficiency of information on surrounding conditions can be referred to external factors (an example with a plane landing), and etc. Peculiarities of intelligence, education, life experience, age, fatigue and etc. we will refer to internal factors.

In order to increase a safety level of ECS operating, it is necessary to formalize conception of ECS by the person. The carried-out analysis allows declaring that at the second level of information processing except the cognitive and motor stages of operator actions it is necessary to divide the additional motivation stage. Then within ECS, stages of interaction of an operator with a machine must be characterized as follows:

- Somatosensory stage is caused by reaction time. The rigid lower bound caused by human physiological abilities is characteristic (not less than 100 ms (Boiko, 1964)).
- Cognitive stage. The upper bound changes in the wide range and usually is connected with distinctions of attention and a functional state of the specific person (Lupandin and Surnina, 1988).
- Motor stage. Similar to cognitive.
- Motivation stage. Time isn't limited.

The last, motivation stage, is very difficult for analysis of interaction within HEM system. Active research of ways to formalize information volume in ECS conducted by many authors (for example (Gorbachev, 2011; Pavlov, 2009b)) doesn't put the appropriate emphasis to processes of motivation of the operator because of high complexity of these processes and lack of assessment models and measuring scales. For creation of interaction model of HEM it is necessary to embed in it a subsystem enabling to analyze a state and actions of the operator.

3. Ergatic system model with operator analyzer

To the general scheme of the ergatic system (Figure 1) it is necessary to add a system of operator actions analyzer (Figure 2). The operator analyzer is a complex of systems and devices, which:

- controls a psychophysical state of the operator under various working conditions by means of indicators (encephalograph, impulse measurement, and etc.)
- indicates training level of the operator at the moment of time by means of micro tests (the operator shouldn't know that he/she is being tested).
- compares an operator with "the ideal operator" standard model and generates corrective voltage for input into the information control – display unit in order to reduce the amount of the operator errors
- signals to the operator possible violations in his actions
- includes system of automatic control in case of the operator work failure (for example, concussion, a faint, etc.)

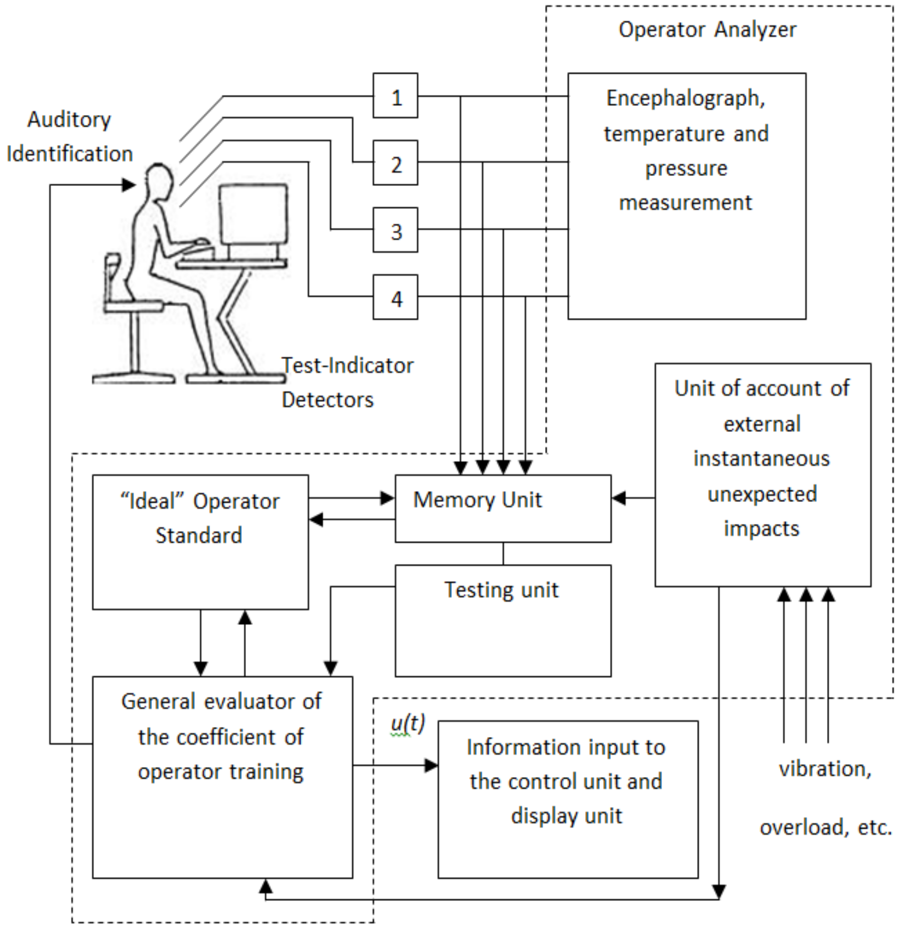

Figure 2. Operator analyzer subsystem in model of "human-environment-machine" ergatic system

The subsystem of the operator actions analysis allows accumulating information about system state and actions of the operator. Accumulation of these data allows processing them statistically and to create a model of the "ideal" operator. On the basis of comparison of actions of the "ideal" and real operators the function of general assessment of operator u (t) is formed. In case of failure threat the subsystem alerts.

The proposed system scheme has a “recommendation” operating mode and practically doesn't interfere in the operator work. It considers features of each operator and reconstructs a control system individually for each operator (for example, arrange indication of systems according to anthropology of the operator, etc.)

4. Problem of feedback projecting

4.1. Necessity for introducing complex functions of scores

Let a model of the "ideal" operator be created during the work with ECS. The operator executes some functions in the set sequence, i.e. he/she fulfills algorithms of operator activity. Let's assume that reliability of hardware and software of the ECS is much higher, than reliability of operators. Administrative tasks solution time within HEM depends on physical and psychological features of the operator and should be considered as a random variable. Its ascertaining is institutional. Let's assume that any random variable attributed to a state of the operator is made up of that it is Z and comparisons with the "ideal" operator Z’.

Then in order to implement a measurement system of the operator state it is necessary to introduce an ordered pair of valid random variables S = {S1, S2} that belong to various sets of evaluation of "events" observed which are corresponding to measurement of the operator state. S1 is the operator evaluation random variable which is measured in practice, S2 – is the assessment of perception of the event S1 in comparison with the "ideal" operator. There are at least two numbers forming the ordered pair or the vector containing versatile evaluations. Results of measurement can be interpreted on the basis of the classical concept of probability; and these results are processed by means of statistical methods. Then it is possible to calculate a correlation between the versatile evaluations.

Applying of linguistic evaluation allows considering specifics of the assessed object. In this case there is no “classical” probability; methods of the set theory are applied and membership functions which form fuzzy sets are attributed to evaluations. It is rather difficult to consider correlations of evaluations.

The third way to interpret measurement results is also based on the nonclassical concept of probability which allows choosing rules for processing of results so that these results can be verified by experiment. Thus the vector can be considered in general.

Let’s assume that a function ψ which is described by probability distribution P (ψ) is attributed to the operator state. Let us measure 2 probable states of operators 1 and 2 which are defined by the attributed functions $\psi 1$ and $\psi 2$. If these states interact, then distribution of probabilities of Complex Socio-Economic System shall be described as follows:

$$P = |\psi_1 + \psi_2|^2$$

It corresponds to the nonclassical definition of probability in quantum mechanics (Klishko, 1994). Such mathematical representation conforms well to many interconnected processes within ECS. For example, the made action is not independent of the previous one, except an hierarchy of decision sequence and the made actions which are interiorly interconnected with each other.

The applied evaluation methods introduce errors into the measured states. This fact inevitably affects the management principles. Introduction of complex functions of evaluations will enable to overcome this discrepancy.

4.2. Canonical decomposition of stochastic functions

We will set the objective to make a model for describing the operator actions based on random complex variables. Signals which are generated both in a natural language and in the digital form can be presented in the form of a linear combination of uncorrelated random variables having the expected value which is equal to zero. There is a problem to represent the scalar stochastic function F(r) as follows:

$$F(r) = m_F(r) + \sum_v V_v f_v(r)$$

where V_v is uncorrelated scalar stochastic functions the expected value of which is equal to zero, and f_v is some determinate functions. The separate summands of the V_v f_v form are elementary stochastic functions. Let the random variables V_v be termed initial decomposition weight coefficients, and the functions f_v be termed coordinate functions. Initial decomposition of stochastic function generally represents an infinite series. In special cases the initial decomposition can be the final sum (Sinitsin, 2011).

We will define the unknown coordinate functions f_v (r). For this purpose according to (1) it is necessary to present the stationary centered stochastic function F0 (r) = to F(r) − mF(r) in the form of the sum:

$$F_0(r) = \sum_v V_v \, f_v(r)$$

where f_v (r) is the unknown coordinate functions. We will multiply (3) by the complex conjugate random value V_μ^* and we will compute the expected value:

$$M[F_0(r)V_\mu^*] = \sum_v M[V_v V_\mu^*] \, f_v(x,y) = D_\mu f_\mu(r)$$

therefore:

$$f_\mu(r) = \frac{1}{D_\mu} M[F_0(r)V_\mu^*]$$

Initial decomposition of stochastic functions is very suitable for performance of various analysis operations over stochastic functions. It can be explained by that in canonical decomposition of stochastic function its correlation with argument *r* is expressed by means of coordinate functions that provides opportunity to lead performance of various linear operations over stochastic functions (for example, differentiation, integration, the solution of the linear differential equations, etc.) to usual operations of the mathematical analysis over nonrandom coordinate functions.

Let V_v be any uncorrelated random variables the expected value of which is equal to zero. The unknown coordinate functions f_v are root-mean-square optimal coordinate functions (Sinitsin, 2011).

4.3. Status functions introduction

We will provide interpretation of the stochastic functions theory. We will introduce some functions which are constantly attributed to a status of evaluation of the operator state. Basing on the institutional nature of evaluation let these functions be termed the status functions (SF) (Searle, 2007). We will present the algorithm and we will use them as the coordinate functions f_v.

We will specify sets of competences being measured. We score them according to the scheme that is consisting of 5 levels: cognitive, practical, reproductive, productive, and exploratory. On the unit interval [-0.5; 0.5] the bell-shaped membership functions are chosen so that at peaks they are equal to unit, they are symmetrized against r=0 and the value is less than 10^{-7} on borders of the interval. It defines a width of the Gaussian curves and the position of maximum values. If to consider a score as an expected value of membership function, than scores will be in an interval [-0.28; 0.28]. Correspondence between scores and linguistic terms look this way: -0,28 – cognitive, -0,093 – practical, 0 – reproductive, 0,093 – productive, 0,28 – exploratory (Figure 3). Such membership functions are typical for the Fuzzy Sets Theory. Thus the average score is calculated as an expected value *r* via membership function.

At the defuzzification stage the linguistic statements (for example, "training is provided effectively", or "the subject has the set competences within limits of normal range and is positive to continue training", and etc.) shall be derived from wave functions on the basis of certain procedures. These conclusions allow making administrative decisions. Depending on chosen defuzzification procedures a certain presentation of membership functions will be suitable. If to be restricted to a traditional presentation in the Fuzzy Sets Theory at the defuzzification stage we will receive an average score as a key parameter for decision-making. If we aim to get more detailed information on the subject and process of training, it is expedient to use other defuzzification procedures which are partially described below.

For transition to complex membership functions we will carry out procedure of orthogonalization of a basic set according the Gram-Schmidt algorithm. Further design of expert system supposes recognition of its state at the stage of output of results of the carried-out analysis (a defuzzification stage) that’s why such presentation will allow simplifying this procedure.

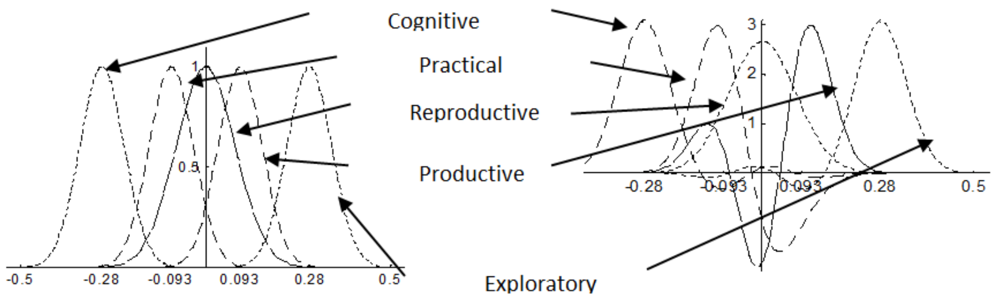

Figure 3. Membership functions of knowledge, skills and abilities of a part of the competence a) centralized before normalization; b) after orthogonalization and normalization

For presentation of a personal characteristic of a participant we will introduce three levels of assessment k =-1,-0.333,0.333,1. For the lowest level k =-1 we have proposed an evaluation: passive – sluggish, inactive, indifferent to surroundings. Usually people with the low self-esteem are passive, and this behavior is obviously losing. The next level when k =-0.333 is the declarative level. It contains general provisions and statements without substantiations and specification. This assessment level corresponds to the "not to be, but to seem" behavior style, when a person proves himself/herself in order to declare possibilities, but not in order to achieve cognitive purposes, in order to project an image, but not for self-improvement. The majority of those who consciously approaches a process of creation and management of the own reputation chooses this way. They make a start from what they want to be in the opinion of people around. The assessment level k=0.333 – the disciplined level. It characterizes a behavioral type as accurate, correct, organized, and obedient. The highest level of the evaluation system (k=1) – active – means that a person vigorously proves himself/herself, finds knowledge and strength, is interested in many questions. The term “activity” is widely used in various spheres of science both as independent and as the additional one in various combinations. Activity is considered as a characteristic of a person, personal education which is manifested in internal willingness to purposeful interaction with environment which is based on needs and interests of a person which is characterized by passion for action, commitment and persistence, enterprise and initiative.

Usually assessment system is based on membership functions and that demands a difficult normalization ratio because of basic functions nonorthogonality. Then in mathematical model of possible scores set it is difficult to realize statements set completeness provision. When using sign-variable orthonormal basic functions the normalization ratio is:

$$1 = \sum_j |c_j|^2$$

where j = 1..., 15 (5×3) in this case, and c_j is a range of probability to find a system in a state j.

In practice it is impossible to assess competences or knowledge by means of direct measurement. The assessment arises from indirect experience and is represented as a result of interaction between a probationer and an examiner during direct contact (as in oral examination), or when using measuring tools (tests), or by other ways. Thus we will define compliance probability of evaluated level characteristics with the recorded results:

$$|\psi|^2 = \psi^* \psi$$

where through ψ^* a value which is complex conjugate ψ is designated. Thus, we must believe that during assessment of education results we determine a value which is similar to probability density. The probability theory prescribes to consider a probability of a certain event as equal to 1. Therefore the carried-out normalization procedure resulting in orthonormal functions system seems to be an appropriate and logical action in terms of integration.

The orthonormalized basis allows using the principle of superposition. The biggest part of knowledge and competences gained overlaps, therefore presentation of a probationer state in the form of sum of states in which he/she can be, makes practical sense in respect of analogies of quantum mechanical wave functions and possible states of the probationer.

The complex part of the got wave function isn't measured during real experiments; but contributes to result like a fluctuation phase. Let us take measurement of competences at some fixed time point t=0.

We will make a status function of "pure states" as a product of coordinate membership function and $e^{i2\pi kr}$:

$$\psi_{lk}(r) = f_l(r) e^{i2\pi kr}$$

The number of basic state is equal to 5×3=15. It is easy to check that in this state the expected value of an impulse is equal to:

$$\int_{-\infty}^{\infty} dr f_l(r) e^{i2\pi k_l r} \left[-i \frac{\partial}{2\pi \partial r}\right] \left[f_l(r) e^{i2\pi k_l r}\right] = k_l$$

It should be noted that the mean value of the co-ordinate (score) doesn't relate to k ("the impulse"). With such choice of values of k and basic functions, their orthogonality is preserved at least approximately. If there is a superposition of basic states, the membership function of an output variable will be correlating to "impulses". Complex sign-variable membership functions of competences are made by now. Now we should discuss making superposition of these functions in order to build a membership function of an output variable. According to the Fuzzy Sets Theory principles the resultant status function is formed as a superposition of membership functions of experts scores with weight coefficients.

These functions which are used as membership functions by analogy with the Fuzzy Sets Theory methods, are similar to quantum-mechanical wave functions in meaning and form. However it is incorrect to term the built functions membership functions or wave functions. Such function describes an equivalent of the external social status and internal personal willingness to accept this status or to change it. That's why we introduce for them a new term – the status functions (SF).

4.4. Status functions introduction

We will calculate weight coefficients for each competence from the entered set. It is possible to use various methods of weight coefficients evaluation. In the simplest case they are defined by a teacher. Along with expert methods of evaluation the statistical methods exist, for example, one of methods to calculate weight coefficients of competences is based on that the weight reflects the relative frequency with which each competence distinguishes best and average students. In this case it is necessary to calculate correlation coefficient for each competence with the total amount of scores received by students for the test. Two column matrix should be made for this purpose. The one of them contains scores of all students for the same competence; another contains a total amount of the test scores.

For calculation of correlation coefficient the following technique is used (Avanesov, 1998). At first add the squares of deviances of students' scores from the arithmetic mean of scores for the interesting criterion K_j:

$$SS_j = \sum_{i=1}^{n} K_{ij}^2 - \frac{\left(\sum_{i=1}^{n} K_{ij}\right)^2}{n}$$

where K_{ij} –scores of the *i* student for the *j'th* competence, n – number of the tested students.

Then add the squares of deviances of total test scores of students from arithmetic mean of scores for the whole test:

$$SS_y = \sum_{i=1}^{n} Y_i^2 - \frac{(\sum_{i=1}^{n} Y_i)^2}{n}$$

where Y_i – total test scores of the *i* student, n – number of the tested students.

At the following stage we will calculate the mean value adjusted sum of paired products of scores for the *j'th* competence and total test scores of each student:

$$SP_{jy} = \sum_{i=1}^{n} K_{ij}\, Y_i - \frac{\left(\sum_{i=1}^{n} K_{ij}\right)(\sum_{i=1}^{n} Y_i)}{n}$$

The first part of the formula (12) represents the sum of products of each student scores for the *j'th* competence and the final test score. The second part of the formula (12) represents a weighted sum of each student scores for the *j'th* competence.

The last step is to calculate the correlation coefficient of the *j'th* competence with the final amount of scores:

$$r_{jy} = \frac{SP_{jy}}{\sqrt{SS_j \cdot SS_y}}$$

The higher the value r_{jy} the greater is a potential contribution of the *j'th* competence in the final test score. Competence weight is defined as ratio of correlation coefficient to the sum of all coefficients.

4.5. Calculation of mixed states of HEM

Usually a score is just a set of real numbers with this or that level of randomness of congruence with a state. Respectively, the score is a random variable. The operator analyzer rates his/her actions. In the case of regular performance of sequence of the same actions the score turns out identical or close. Change of actions conducts to spread in scores. If action sequences strongly differ from each other the spread in scores turns out essential. Statistical processing of measuring allows creating the "ideal" operator model. Usually all these results are used for assessment of operator at the given moment. The measured state doesn't provide information about the past. Prediction of score at the next moments can be based on comparison with the "ideal" operator on the basis of developed rules. SFs enable to develop a system in which aprioristic scores and prediction of the operator actions can be got. SFs are formed on the basis of the ordered pair of scores of the "ideal" and real operator S = {S1, S2} are formed. These functions can be attributed to possible idealized elementary states of system, we will call them pure states functions.

Let the state of the HEM with the number *j* be workable and correspond with successful implementation of the *k*'th k=1,n required operation. Let *r* be a basic variable of HEM action assessments. Then ψ_k and φ_k are scalar complex-valued deterministic random function of possibilities of distribution of operator and system actions grades, which are pure states of the system. They form sets of coordinate functions of possible states of the operator and the machine. We need to determine all the numbers that define pure states. Existing in reality, the state is a mixed state and is formed from a set of basic random functions:

$$\Psi = \sum_{i=1}^{n} \nu_i \psi_i \text{ , } \Phi = \sum_{j=1}^{n} \mu_j \varphi_j$$

In this case Φ determines a machine response to the operator's actions Ψ. These functions are attributed to states of HEM. Formation of Φ and Ψ occurs according to the algorithm of forming of complex-valued SF (Veshneva, 2012). Sets of the operator actions sequence represents a vector:

$$|\Psi\rangle = (\Psi_1,\ \Psi_2,\ \Psi_3 \ldots\ \Psi_k)$$

The response function of a machine can be built on the basis of the action of HEM operator. Let it be presented as follows:

$$|\Phi> = \widehat{\Theta}|\Psi>$$

All possible states of the system are formed by a state matrix:

$$|\Phi >< \Psi| = \begin{bmatrix} S_{11} & \cdots & S_{1k} \\ \vdots & \ddots & \vdots \\ S_{k1} & \cdots & S_{kk} \end{bmatrix}$$

Thus, when creating within the analyzer of operator actions a model of his/her actions on the basis of SF, we get the analogue of the system state vector. These states can be determined as a result of a sequence of measurements of HEM interaction process. Thus application of status functions for the analyzer operator actions shall enable development of methods (Dubois, & Prade, 1990) and algorithms of HEM reliability improvement (Boran-Keshishian, 2012).

4.6. Results of experiment and the discussion

We will compare different evaluation models. During a training semester of the linguistic students in the discipline "Basis of mathematical information processing" regular assessment of process of common cultural and specialized competences formation on the basis of the SF method was conducted.

Attributed SF formation algorithm

1) Define sets of input and output competences and their weight coefficients.
2) Introduce a system of orthonormal sign-variable basis function for linguistic terms of expert evaluation, which are similar to the

Fuzzy Sets Theory membership functions. Assess measured part of the competence (elementary SF ranges) in linguistic terms.
3) In order to represent a motivation characteristic of participant, introduce three evaluation levels (passive, declarative, and active) determining value of SF phase which are determining value of each competence of each student examined. To carry out the evaluation.
4) Introduce weight coefficients. It is possible to apply different methods of weight coefficient evaluation. In general cases they are determined by a teacher.
5) Build resultant functions for the built elementary SF which are corresponding with evaluation of each competence of each student.
6) Compute the moment integral for resultant status functions and make a conclusion.

The course program consists of 8 topics. Let us follow a process of formation of common cultural competence which involves the ability to use scientific and mathematical knowledge in order to navigate in the information space of nowadays. Let us mark the topics which are involved in the formation. For each topic we will introduce a complex system of evaluation. We will conduct evaluation twice on the base of the SF method.

The first SF (close to the traditional evaluation system) consists of tasks solution during practical class for the SF module and evaluation of student activity by a teacher during the class (the second part of the ordered pair of scores which is used at the imaginary part of exponential factor of the coordinate SF). The expert scores SF is formed on the base of these scores.

The second SF which is got via intelligent information system (IIS), involves testing by a computer program (the first part of the ordered pair of scores provides the coordinate SF module) and assessment of cognitive activity via video recording and computing cognitive activity by a pattern recognition system (the first part of the ordered pair of scores provides exponent multiplier).

Within the IIS noninvasive methods of students feedback is applied (remote psychodiagnostic) by means of multispectral analysis and a neural network expert system. An analyzer takes into account peculiarities of facial expression and head position, dynamics of eyes, lips and hands movements, and also degree of intensity (saturation) of body (face) color of each student. Measurement results are statistically processed by means of discriminant analysis on the base of new algorithms of the geometric optical analysis with applying the SF method. The approved technology is associated with synchronized transition from a collective educational environment to the individual, which is directed to realization of personal needs which is formed by the students as a result of interaction with the external (collective) educational environment. Due to inclusion of a feedback channel (the noninvasive diagnostic) in the IIS there is constant monitoring and psychophysical state (through regulation of input information data unit) of as each individual student so a group (training group) as a whole, allowing for more flexibility to level various features of the software script. The IIS includes: basic unit which contains a video system; structured (infrared) illumination system; hardware and software unit consisting of a personal computer and the appropriate software; network data interface; physiological parameters analyzer.

The example is presented in the Figure 4.

Figure 4. Different periods of the class

Assessment of cognitive activity is divided into 4 levels – the passive, the declarative, the disciplined, and the active. Each student receives a personal system ID. An activity histogram is displayed which corresponds to 46 min. 17 sec. of the class. Red color correlates with the passive assessment level, yellow color correlates with the declarative assessment level, light blue color correlates with the disciplined assessment level, and green color correlates with the active assessment level according to the proposed classification. Figure 5 presents the example of forms of the SFs.

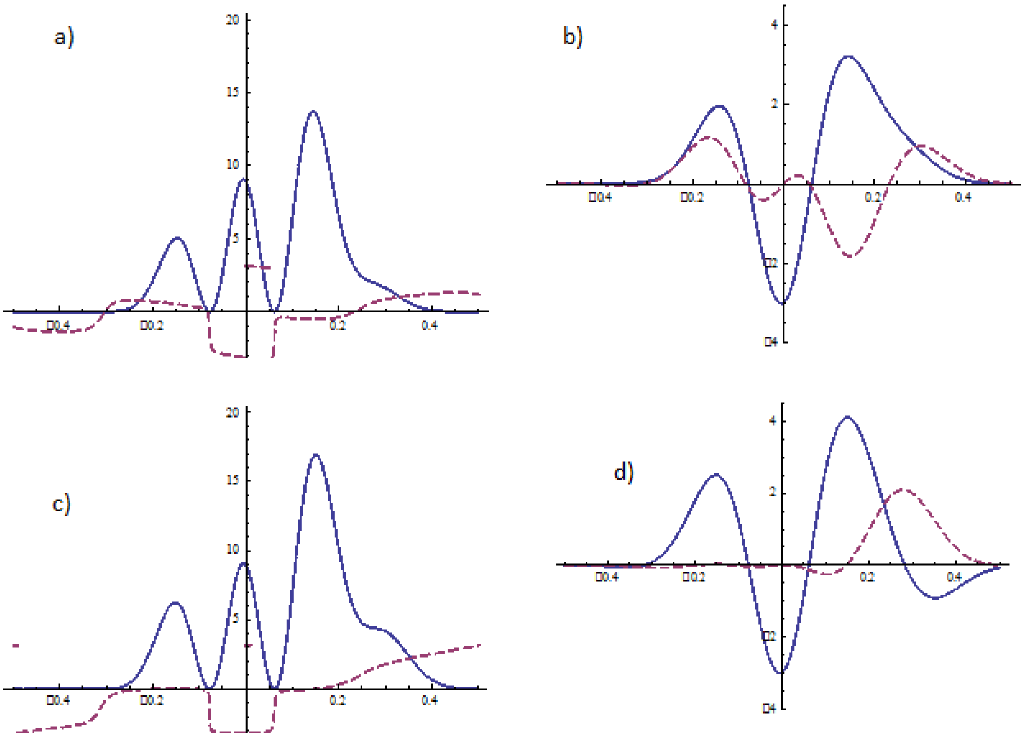

Figure 5. Above is the random function built on the basis of scores of experts a) the square of the modulus and argument of a random function, b) the real and imaginary part of the random function. Below is the random function built on the basis of scores of the system c) the square of the modulus and argument of a random function, d) the real and imaginary part of the random function

Perception evaluations are differs for a student with ID 05. The recognition system refers this participant to the declarative type of activity. Expert without any hesitation refers the student to the active type of participation in cognitive activity. The video record shows us that the mentioned student responds quickly to the attention of a teacher and immediately turns his/her attention to things irrelevant to training as soon as he/she is out of teacher's eyeshot. Total values of calculated integral characteristics resulting from analysis of SF of competence formation process scores are presented in the Table 1.

Table 1. Values of moments integral of the SF for the participant with the ID 05.

	Expert score	System score
Expected value	0.345677	0.1919
Variance	0.113587	0.0625417
Skewness	0.0215133	0.00892209
Kurtosis	0.00726563	0.00296191

Thus, the introduction of automated assessment of the process of formation of competences allows achieving a good match by the existing system of assessment for the majority of participants in the learning process. On the basis of proposed physical and psychophysical methods and new mathematical and information models the system for monitoring of quality of process of professional competence formation of students.

5. Conclusions

The paper presents features of creation of a complex of feedback implementation within the “operator – environment – machine” system. The proposed complex creation model provides stage-by-stage evolutionary development of this complex when modeling various external and internal influences and enables to create new samples within HEM or to be integrated into modern control systems.

The used technology is based on photogrammetric methods and is characterized by high speed and accuracy of measurements, simplicity of use, and high automation degree. It can be used without core transformations in the conditions of high level of noise in audience, independence from network data, and real-time change of structure of measurement objects.

Development of control units which are based on the principles of attributing status function model to a condition of a system enables to use for management purposes the information in the form approached to quantum mechanics models which is difficult to formalize when implementing traditional regulation principles. The built models are insensitive to casual perturbation in the certain range and are functioning simultaneously with classical regulators, like regulators on the basis of the fuzzy sets theory.

If to consider the complex-valued SF attributed to a system condition as stochastic functions, in this case fuzzy probabilities of its state are result of the analysis of HEM reliability. These probabilities are result of combination of functions of state of operator and machine models. All possible values form a matrix of HEM states. For this purpose the complex-valued SF attributed to a condition of model have to be considered as stochastic functions of pure states. The linear combination of products SF and random variables forms a vector of system state. Impact on a vector of consistently measured states of the operator transform a model of operator’s actions to a vector of states of the machine according to some rules. The matrix of probabilities of HEM states can be calculated from vectors of the operator and the machine states. The set of all possible states is full. On the basis of the set the way to compute nonclassical probability of no-failure operation of HEM is created. The probability of failure can be calculated similarly.

The paper presents a method of design and development of a model of a system for control of process of competence formation which enables to make factual administrative decisions according to the principles of modern quality management systems.

Taking into account some assumptions, the described approach can be widely used for complex training complexes, anthropomorphous training systems, for remote education. The main scope of the developed educational IIS: creation of perspective information and education complexes (system of distance learning, educational simulators, VR and AR systems, and so forth); interactive monitoring of educational and learning process; psychophysiological monitoring of states of students (real time control, registration and processing of information); noninvasive medical express diagnostics of students; and other general education and specific projects

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