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Self-organized intelligent quantum controller: quantum deep learning and quantum genetic algorithm – QSCOptKB™ toolkit

V.V. Korenkov[a,b], **A.G. Reshetnikov**[a], **S.V. Ulyanov**[a,*], **P.V. Zrelov**[a,b], **D.P. Zrelova**[a]

[a] *Joint Institute for Nuclear Research, Meshceryakov Laboratory of Information Technologies, 6 Joliot-Curie St., Dubna, Moscow Region, Russia, 141980*
[b] *Plekhanov Russian University of Economics, Stremyanny lane 36, Moscow, 117997, Russia*
E-mail: ulyanovsv46_46@mail.ru

Strategy of intelligent cognitive control systems of ill-defined control objects based on quantum and soft computing presented. Quantum self-organization knowledge base synergetic effect extracted from intelligent fuzzy controller's imperfect knowledge bases described. That technology improved of robustness of intelligent cognitive control systems in hazard control situations described with different types of robot cooperation. Examples demonstrated the introduction of quantum fuzzy inference gate design as prepared programmable algorithmic solution for board embedded control systems. The physical interpretation of the process of controlling self-organization at the quantum level is discussed on the basis of quantum information-thermodynamic models of exchange and extraction of quantum (hidden) valuable information from/between classical particle trajectories in the "swarm of interacting particles" model. The main physical and information-thermodynamic aspects of the model of quantum intelligent control of classical control objects are discussed and described. An approach is considered for constructing reference control models based on new laws of quantum deep machine learning applying neural networks in mega-science project NICA.

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1. Introduction

New information-thermodynamics law of intelligent self-organized control and intelligent cognitive robotics was introduced as the background for the guaranteed achievement of control goal in unpredicted control situations [1]. Quantum self-organization algorithm of imperfect knowledge bases (KB) of hybrid fuzzy controllers developed for the design in on-line of robust KB from non-robust individual KB [2]. This new synergetic effect is impossible in classical information domain and can be created by a new type of quantum search algorithm as quantum fuzzy inference (that is the particular case of quantum self-organization algorithm.) This report is concerned with the problem of discovering a new family of quantum search and decision-making algorithms (QA's) based on quantum genetic algorithm and quantum neural networks [2,3]. Quantum software engineering created with the platform of quantum deep machine learning applied toolkit of quantum genetic algorithm and quantum neural networks. The presented method and relative hardware implement matrix operations performed in second and third step of a QA (the so-called interference and entanglement operators) and type of quantum correlation for gain coefficient schedule of conventional PID controllers defined with the application of quantum genetic algorithm to the superposition of possible solution space. This approach differs from other methods of quantum optimization. These operators make it possible to achieve a substantially increasing in computational speed-up with respect to the corresponding software realization of a traditional and a new quantum search algorithm (QSA). A high-level structure of a generic entanglement block that uses logic gates as analogy elements is described [4,5]. This model has the advantage that proving lower bounds is tractable which allows one to demonstrate provable speed-up over classical algorithms or to show that a given QA is the best possible [2,4-6]. Next, we will describe the method of designing main quantum operators and related topics concerning the intelligent control in robotic of an ill-defined process. Main attention is concentrated on search-of-minima entropy uncertainty intelligent operations. The approach under consideration is based on a new QSA with a built-in quantum genetic algorithm; it is a new QSA that allows you to set the most probable solutions in a superposition of possible desired solutions. This approach makes it possible to speed up the search for the optimal gains of traditional controllers. As a result, it is possible to control complex semi-structured control objects under conditions of uncertainty with a traditional regulator. Quantum supremacy of intelligent robotic control with quantum fuzzy inference (QFI) is demonstrated on Benchmarks.

Remark. The described approach to design of self-organized quantum controllers based on quantum algorithm of QFI is original and do not have analogies [5].

2. Problem's formulation

The learning and adaptation problems of fuzzy controllers (FC's) design are the important topic in advanced control theory. Many existing solutions are using different models of artificial neural networks based on the back-propagation (BP) algorithm, Kohonen multilayer structure and so on [7]. Unfortunately, methods based on BP-algorithms and iterative stochastic algorithms do not guarantee the required control robustness level and accuracy in complex unpredicted control

PoS(DLCP2022)012

situations. Such schemes are successfully working if the control task performed in absence of underdetermined stochastic noises in world environments, in sensors, in control loop, etc.

Therefore, one of the central problems of developing intelligent control system (ICS) was in the finding a constructive solution of design KB tasks and intelligent robust cognitive control in a given problem-oriented application. On the other hand, one of the key tasks of modern robotics is the development of technologies of cognitive mechanical interaction, which allow you solving intelligent control functions due to the redistribution of knowledge and control on the software level. The solution of this task based on Soft Computing Optimizer (SCO) is developed in [7-9]. QFI-model implements the self-organization of imperfect knowledge bases in the structure of intelligent control system. [5,10-12]. QFI apply the laws of quantum computing technologies [2] and applies next operations: superposition, quantum correlations (entanglement or quantum oracle), and interference [5,11,12].

3. Method of solution and its physical background

Proposed QFI system consists of a few FCs, each of which provides solution in one set conditions of control system. QFI system revises the results of fuzzy inference of each independent FC and proposes in on-line the generalized control signal output. The output QFI signal combines best features of each independent FCs. Extracted quantum hidden information amount from classical control states considered as additional powerful recourse of thermodynamic entropy control force and quantum intelligent force control realized on useful work of cognitive controller. New approach for robust cognitive controller design applied based on quantum information thermodynamic law [1]. The changes of entropy and the quantum mutual information lay new limit for the marginal part of work which exceeds the conventional second law of thermodynamics. Surprisingly, if two measurements are preformed, it finds a new inequality due to the entropic uncertainty relation with the assistance of quantum memory, which provides a lower bound for the work gained from the heat engine. This result describes an opposite fact of the thermodynamics by considering entanglement in quantum information science [2].

Quantum soft computing optimizer toolkit of KB – design processes based on QFI – model is described in [5,7]. Benchmarks of robust KB design from imperfect FC-KB as the new quantum synergetic information effects of extracted quantum information demonstrated. Moreover, the new force control law from quantum thermodynamic described: with extracted hidden quantum information from classical control signal states (on micro-level) possible to design in on-line new control force that can produce on macro-level more value work amount than the work losses on the extraction of this amount of hidden quantum information [2]. It is a new control law of physics-cybernetics open hybrid systems including port-Hamiltonian controlled dynamic objects [2] and as method design of robust cognitive controller applied.

Main goal. The main purpose of QFI is to produce a self-organization capability of the conventional PID – controller for many unpredicted control situations. QFI produces robust optimal control signal for the actual control situation using a redundant amount of information in KB's of individual FCs [12]. In this work the main ideas of quantum computation and quantum information theory [4,5] applied in developed QFI methods are introduced. Robustness of new types of self-organized intelligent control systems is demonstrated.

PoS(DLCP2022)012

4. Robust QFI-based intelligent control system

Figure 1 shows the structure of a robust QFI-based ICS. Soft computing optimizer toolkit (SCOptKB™, the box "SCO" in Fig. 1) is a design KBs of FCs (see boxes "FC1" and "FC2" in Fig. 1) on learning situations that can be non-robust (imperfect) in other control situations. The input of the quantum fuzzy inference (see box "QFI" in Fig. 1) with quantum genetic algorithm (QGA) extract a hidden quantum information from imperfect KB responses of two fuzzy controllers (FC1 and FC2) on unpredicted control errors realized quantum fuzzy controller in on line without changing production rules numbers of KBs in FC1 and FC2 [5,9,11]. Based on the principle of superposition, a templating mechanism is implemented, as well as micro- and macro-level information exchange between active agents. Based on the choice of the type of quantum correlation with the use of a source of communication and information at the micro level, the process of self-assembling takes place, determining the level of stability of the KB fuzzy inference. Determining the most significant parts of the flow of information for control is engaged in the coordination of quantum oracle, making calculations of the intelligent quantum state. Based on the principle of interference, the result is extracted, which makes it possible to design a robust KBs in online [11].

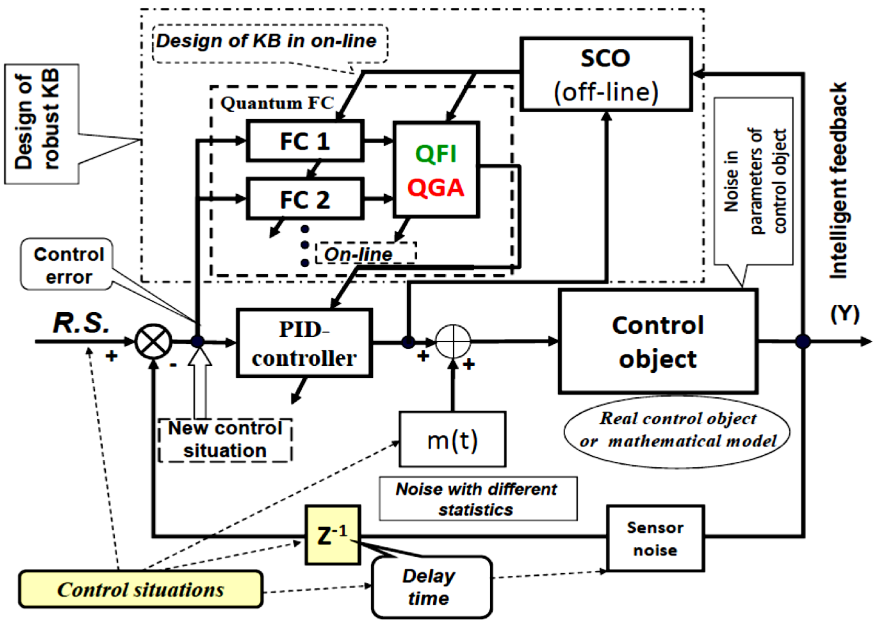

Figure 1: Structure of a robust QFI-based self-organized ICS

FC – fuzzy controller, QFI – quantum fuzzy inference, QGA – quantum genetic algorithm.

In Fig. 1 two feedback are introduced: conventional global negative feedback of conventional automatic control system and intelligent global feedback for the knowledge extraction from control object behavior and KB design of FCs.

In quantum computing, the design of a universal quantum simulator is possible with classical models [2,5], thus it is possible to represent the calculation model of the QA in the five stages:

1. preparation of a classical or quantum initial state $|\psi_{in}\rangle$;
2. preparing the superposition state: applying Hadamard transforms for the initial state;

3. applying an entangled operator (quantum oracle) to a superposition state;
4. applying of the interference operator;
5. applying of the measurement operator to the result of quantum computations $|\psi_{fin}\rangle$.

Accordingly, for the global optimization of the structures of basic ICS using quantum computing, quantum deep machine learning algorithms and quantum genetic search, it is possible to use the quantum gate approach [10,12]. When implementing the quantum knowledge algorithm for QFI, the result of a fuzzy processed independently for each FC, extracts useful information hidden in individual KB. The online control signal is implemented in all knowledge sets of a FC, and the QFI output signal is a set of PID controller coefficients schedule effort design. Thus, the principle of self-organization is realized.

5. Structure of self-organized ICS system based on QFI

The role of specific quantum hidden information effects for smart control design described in [2]. The amount of hidden quantum information [9-12] extracted from control classical states considered as the additional information-thermodynamic control force source. In systems inspired by nature, robustness is determined by the natural process of self-organization [1,2]. The process of quantum self-organization of KBs, in which the robustness property is achieved, is shown in Fig. 1. Natural evolution consists of the following stages: 1) creating a template; 2) self-assembling; 3) self-organization.

As is known from the theory of quantum computing, each QA contains such unitary quantum operators as interference, superposition, entanglement (quantum oracle) and measurement classical operator (irreversible and used for measurement of quantum computations). The QFI-model is based on the corresponding quantum operators and accumulates the principles of self-organization. The QA in the model of QFI is a physical prototype of production rules, implements a virtual robust KB for a fuzzy PID controller in a program way (for the current unpredicted control situation), and it is a problem-independent toolkit.

6. Information - thermodynamic trade-off between control quality measures

Assume that the control object is described in general form by the equation $q_i = \varphi(q,t,S(t),u)$ where the generalized coordinate q_i describes the movement of the control object, *u* is the control force and $S(t) = S_{CO}(t) - S_C(t)$ is the generalized entropy of the system, as the difference between the production of control object entropy $S_{CO}(t)$ and the entropy production $S_C(t)$ of the controller.

Consider the following equation [1,5,8]:

$$\underbrace{\frac{dV}{dt}}_{\text{stability}} = \underbrace{\sum_{i=1}^{n} q_i \varphi(q,t,S(t),u)}_{\text{controllability}} + \underbrace{(S_{CO} - S_C)(S_{CO} - S_C)}_{\text{robustness}} \tag{1}$$

Equation (1) relates in analytical form such qualitative concepts of control theory as stability V (Lyapunov function), controllability and robustness based on the concept of entropy of phenomenological thermodynamics [1,9,12].

This approach allows you to find the necessary trade-off distribution between the levels of stability, controllability and robustness, which allows you to achieve the goal of control in unforeseen situations with a minimum consumption of useful resource by using as a fitness function in the genetic algorithm the minimum production of generalized entropy, which is included in the right part of (1).

For Fig. 2 the equation of distribution of control qualities of dynamic system connects in the analytical form on the basis of concept of entropy of phenomenological thermodynamics such qualitative concepts of the theory of control as stability, controllability and robustness [8,9].

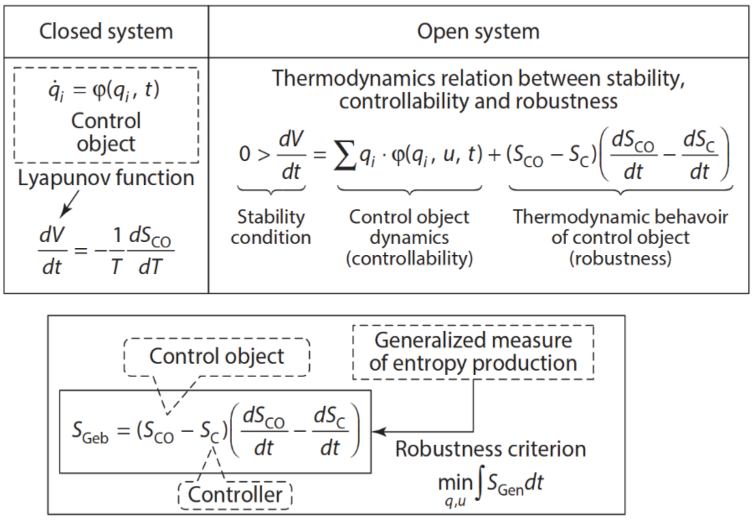

Figure 2: Thermodynamic criterion of distribution of quality of robust control

As a result, the necessary distribution between the levels of stability, controllability and robustness, as a fitness function in the genetic algorithm, the criteria for the minimum production of generalized entropy applied, which allows you to achieve the goal of control in unforeseen situations with a minimum consumption of useful resources. The thermodynamic definition of S and information entropy H are related by the von Neumann relation as [2]: $S = kH = -k\sum_i p_i \ln p_i$, where $k = 1.38\times10^{-23}$ is the Boltzmann constant. For Fig. 2 the following notations are introduced: V is a Lyapunov function; S_{CO}, S_C are entropy production amount in the of control object (CO) and the controller, respectively; and

$$V = \frac{1}{2}\sum_{i=1}^{n} q_i^2 + \frac{1}{2}S^2; \;\; S = S_{CO} - S_C .$$

Remark: *Extractable work in quantum thermodynamics*. In quantum thermodynamics the entropy production of a system can be expressed as the product of a thermodynamic force and a thermodynamic flow. The maximal amount work extractable from the system is bound by the nonequilibrium free energy change. Irreversible processes can in general be thought of as 'thermodynamic forces' driving 'thermodynamic flows' [2]. The thermodynamic flows are a consequence of the thermodynamic forces. Entropy and correlation reversely related. Work can be extracted from the correlation between the system and the memory [2]. Dissipative information characterizes the waste of such correlation work (see in details Appendices 1-3 in [2]). Thus, positive quantum dissipative information characterizes a potential work waste and the information related to the environments is considered as lost. The conditional mutual information can be regarded as part of the entropy production. The conditional free energy is equal to the maximal extractable work from the system given the information of the memory. In other words, more work can be extracted from the correlation between the system and the memory if the correlation is accessible (see, in details [2] and corresponding references).

The generalized minimal work formulation of thermodynamics for non-equilibrium distributions gives an important relation between two major concepts in physics, energy and information: in non-equilibrium quantum thermodynamics the internal energy can also be decoded (negative irreversible work) to be used by the system to perform more work than what is expected [1,2].

7. Benchmark's simulation of smart control with QFI

In Fig. 3 shows the results of an experiment of control in unexpected situations for an object "cart-*double* pole" and a 7 degrees of freedom *redundant* manipulator.

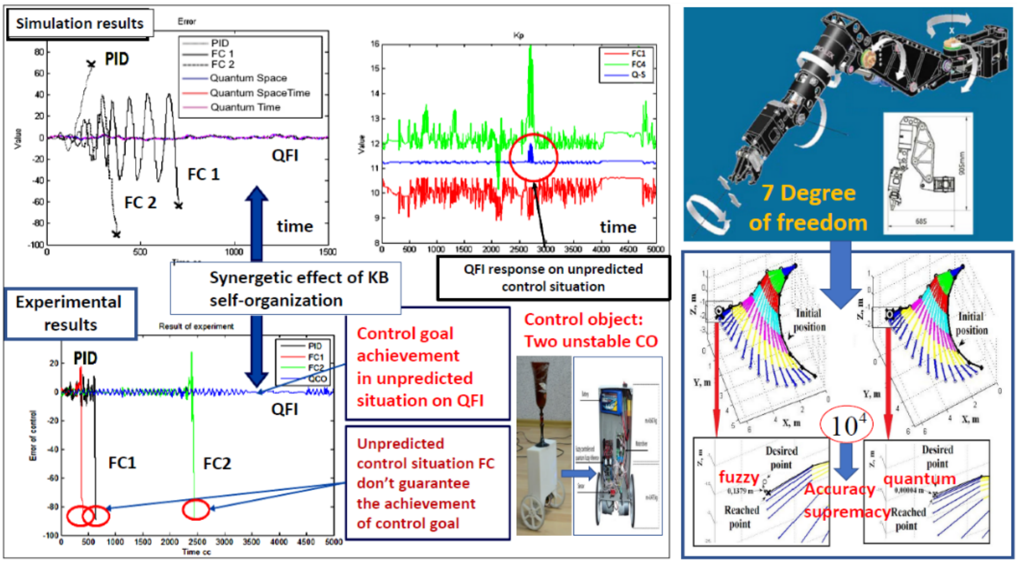

Figure 3: The experiment of control in unexpected situations for an object "cart-double pole" and a 7 degrees of freedom redundant manipulator

The experiment compares the different controllers: PID controller, two fuzzy controllers (FC1, FC2) and three QFI controllers based on different types of correlations: Quantum-Time (Q-T), Quantum-Space (Q-S), Quantum-Space Time (Q-ST). In the simulation and experiment, the structure of a robust ICS based on QFI and QAG (quantum algorithmic gate) (see Fig. 1) was used. Based on the training signal taken directly from the control object, using the QCOptKB™

software toolkit, a KB of FC was designed. An abnormal situation was simulated by a threefold delay in the feedback sensor signal. The experimental results show that the accuracy of a quantum controller is more than 10,000 (see Fig. 3, right side) times higher than that of a controller based on soft computing. Under conditions of uncertainty, the controller based on soft computing dramatically increases the control error, thereby failing to achieve the control goal (see Table 1).

Comparison of controllers shows the presence of a synergistic effect of self-organization in the design of robust KBs based on imperfect KBs of FCs. The control coefficients of the PID controller are based on the feedback of imperfect KB (see the "QFI block" in Fig. 1), forming a control action in online. This is achieved by extracting an additional information resource using QFI in the form of quantum information hidden in the classical states of the control action as a new control error of the output signal of an imperfect KB [1,2].

Table 1: Comparison of the different regulators

Time, sec	Cart motion, cm					
	PID	FC1	FC2	QFI (Q-S)	QFI (Q-ST)	QFI (Q-T)
1	-1	-1	-1	1	-1	-1
2	5	3	5	5	3	4
3	-35	-4	-26	-4	-2	-3
4	60	5	36	6	4	5
5	-	-5	-60	-5	-4	-7
6	-	10	-	5	8	6
7	-	-14	-	-4	-6	-9
8	-	23	-	4	5	7
9	-	-32	-	-6	-8	-3
10	-	50	-	9	6	4
11	-	-	-	-9	-4	-7

Remark. In [10], a reduced quantum genetic algorithm (RQGA) was proposed, which is an implementation of a genetic algorithm on a quantum computer. The search procedure for the desired solution is performed in one operation. Structurally, the algorithm consists of the following steps:

1. initialization of the superposition of all possible chromosomes.
2. assessment of the fitness function by operator *F*.
3. applying Grover's algorithm.
4. using a quantum oracle.
5. using Grover's diffusion operator.
6. evaluation of the solution.

As can be seen from Fig. 4, after 1000 generations about 70% of spatio-temporal correlations have the best probability. After 5000 generations, the probability remains unchanged.

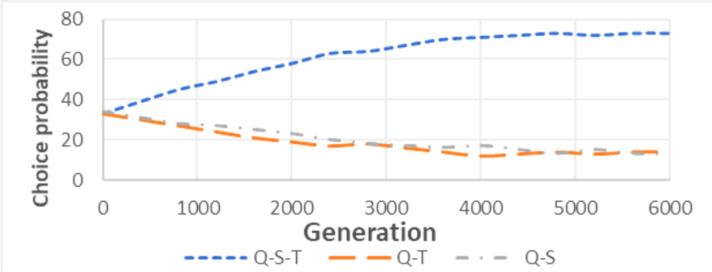

Figure 4: The result of the QGA

However, after 200 generations the probability of spatio-temporal correlations decreases to 60% (see Fig. 5). The described method is differed from others results described in [13-16].

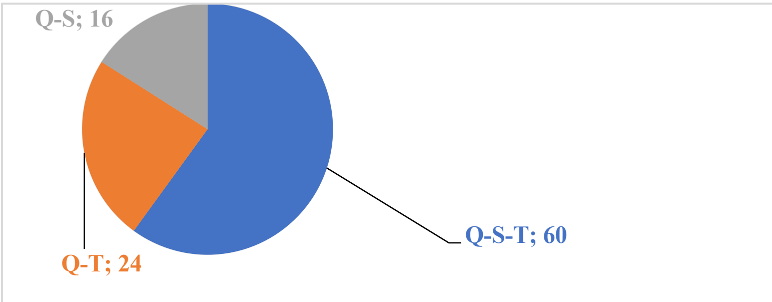

Figure 5: The probability of spatio-temporal correlations after 200 generations

Remark. The choice of correlation type is determined by the properties of the considered control objects [11,12]. Thus, in [11] multiple results of simulation of complex nonlinear control objects have shown that the spatial correlation is efficient for design of robust ICSs for globally dynamically unstable control objects; temporal correlation is reasonable for locally unstable nonlinear control objects; for nonlinear control objects with dynamic instabilities of different structure (as regards generalized coordinates) mixed spatio-temporal quantum correlation can be applied. The application of the chosen form of correlation in combination with different types (external or internal) of correlation between components of control signals extend the resource and increase the potential of quantum correlations. This approach is considered below for a particular example.

The relation between the complete, classical, and quantum correlation types (as the measure of quantum state uncertainty) is determined as follows [12]:

$$\text{Complete uncertainty} = \text{Classical part} + \text{Quantum part} \tag{2}$$

Relation (2) is satisfied for closed quantum states in the case of measurement without message exchange between these parts. In the open-loop system, additional message exchange between active agents (situated on classical and quantum levels) and self-organization levels is possible [9]. This means that *mutual* (mixed) correlation between *real* and *virtual* states of normalized control signals is present. Classical correlation in this case is a particular case of complete quantum correlation. In this case, according to [5,11], messages are sent via quantum channels providing organization of transmission of signal superposition with different forms of correlation between agents.

According to [5,11,12], such quantum channels of information transmission are a special class of quantum correlated (between input and output) communication channels, in which it is sufficient to have finite memory of quantum Maxwell demon and it is possible to realize new quantum strategies of message transmission with simple communication protocol. Coding of messages in such communication channels with finite memory and specific features of mixed communication channels provide efficient transmission of information flows via quantum mechanisms of data extraction (decoding).

Therefore, complete correlation consists of the following parts: classical (between real values of the normalized control signal); quantum (between virtual values of normalized control signal); and mixed (between real and virtual values of normalized control signal). The first two types of correlations are studied in the correlation theory of random (classical and quantum) processes. In this case, the intensity of quantum correlation is higher than that of classical correlation (Bell's inequality).

The third type is new in the theory of quantum random processes and reflects the effect of *interference* of classical and quantum correlations. This type of complete correlation contains hidden classical correlation in quantum sates of formed superposition of quantum bits and serves as the information resource for extraction of additional (unobserved) valuable quantum information [2].

Thus, physically classical correlation is responsible for self-organization of the structure on the macrolevel; quantum and mixed correlations are responsible for the microlevel and information transmission from micro- to macro-levels, respectively. Information exchange and coordinated control between gains of designed robust fuzzy PID controller is performed using internal and external correlation types.

Let us consider the effect of extraction of hidden and increment of additional quantum information from the point of view of quantum information theory and its software formation in the structure of quantum algorithm of knowledge base self-organization.

The application of the chosen form of correlation in combination with different types (external or internal) of correlation between components of control signals extend the resource and increase the potential of quantum correlations.

8. Intelligent robust liquid nitrogen flow control system in the collector of a cryogenic plant for control of superconducting magnets

By controlling the nitrogen supply valve, it is necessary to regulate the pressure and flow rate of nitrogen in the collector. The control loop status is monitored by a pressure sensor and a nitrogen level sensor. In this state of superconductivity (SC), the magnet winding must be maintained at the equilibrium point of the permissible range of changes in current, temperature and magnetic field.

The SC magnetic element of the accelerator complex itself during the tests has the following features: heat gain due to eddy currents leading to heating of the core, heat gain from the walls and uneven cooling in the connecting nodes. These features of an individual magnetic element also impose the complexity of managing a group of similar elements.

The principle of intelligent control implies compensation for the uncertain and imperfect parameters of a magnetic element existing in a real object through the use of soft and quantum computing technologies and taking into account the peculiarities of individual KBs.

In [17] shows the input data - indicators of the state of the system and output - parameters of the actuators controlled by an intelligent control system for the conditions of the state of nitrogen in the stand collection. The efficiency of pumping, cooling the magnetic element and maintaining the SC regime depends, among other things, on the pressure in the cooling system, and therefore on the nitrogen pressure in the collector and its level. In this case, it is necessary to take into account the increase and decrease in the nitrogen consumption in the process of heating and cooling the magnetic element, taking into account the inaccuracy of the actuator (valve).

Figure 6 shows the control loop of the first level, implemented in the form of a proportional-integral-differential (PID) controller with adjustable control parameters (K_P, K_I, K_D).

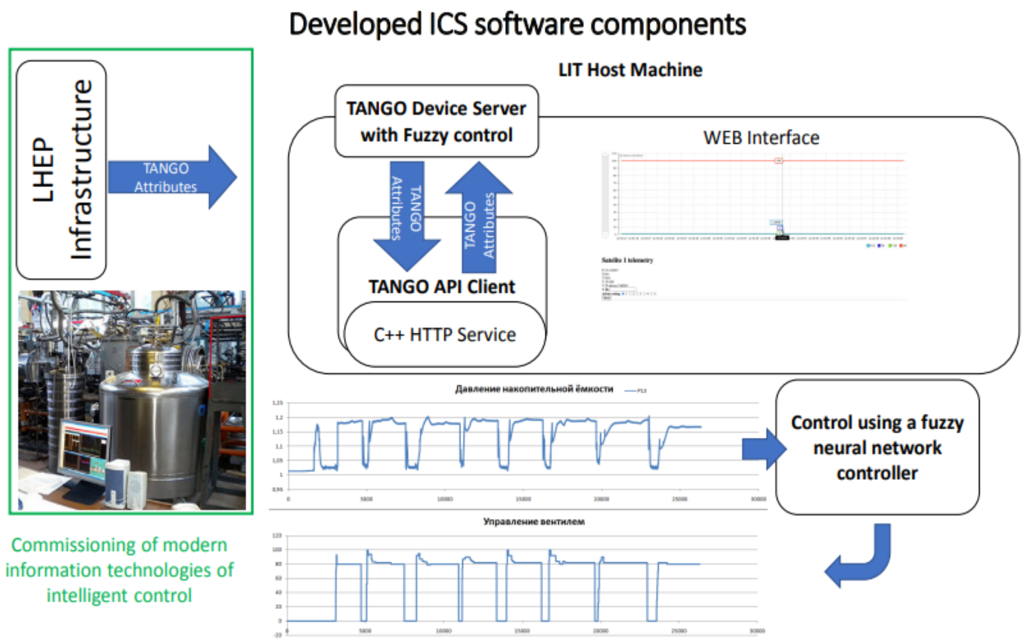

Figure 6: Developed and implemented software and hardware components of the control system

The choice of optimal control parameters depends both on the listed features in the implementation of a separate magnetic element, and when controlling a group of magnetic elements.

Let us consider an example of designing an ICS for pressure control in a storage tank with nitrogen of a test bench of a magnet factory. At the first design stage, the indicators and parameters set by the operator in the control system were recorded (Fig. 6). Further, the most effective trajectories of valve control (operator actions) were selected from the point of view of maintaining the required pressure level and nitrogen flow rate. Based on these data, using soft computing software tools, a FC was designed (Fig. 7).

Example. A very important control task in this mode is to maintain the required pressure when filling nitrogen. The fact is that during the test, the cooling must be continuous, and the refueling process itself implies a decrease in pressure for the supply of nitrogen, while the pressure in the nitrogen source through the communicating vessels affects the pressure in the collector. The complexity of this mode lies in the need to maintain a given pressure (for continuous cooling) and at the same time refuel the storage tank. Sharing plays an important role *V*19 (pressure control) and *V*20 (volume control) valves. Typically, the operator opens *V*19 to release pressure, primes the system with nitrogen, and then proceeds to equalize the pressure. For this technological stage, it is possible to use the automatic mode, and to control both *V*19 and *V*20 (nitrogen supply) at the same time. For the automatic control mode *V*19, the PID, FC, QFI controllers were considered.

Let's consider the results of the conducted studies in the nitrogen cooling mode. Figure 8 shows the time dependence for the pressure level (in bars) during nitrogen cooling for a period of about 40 minutes.

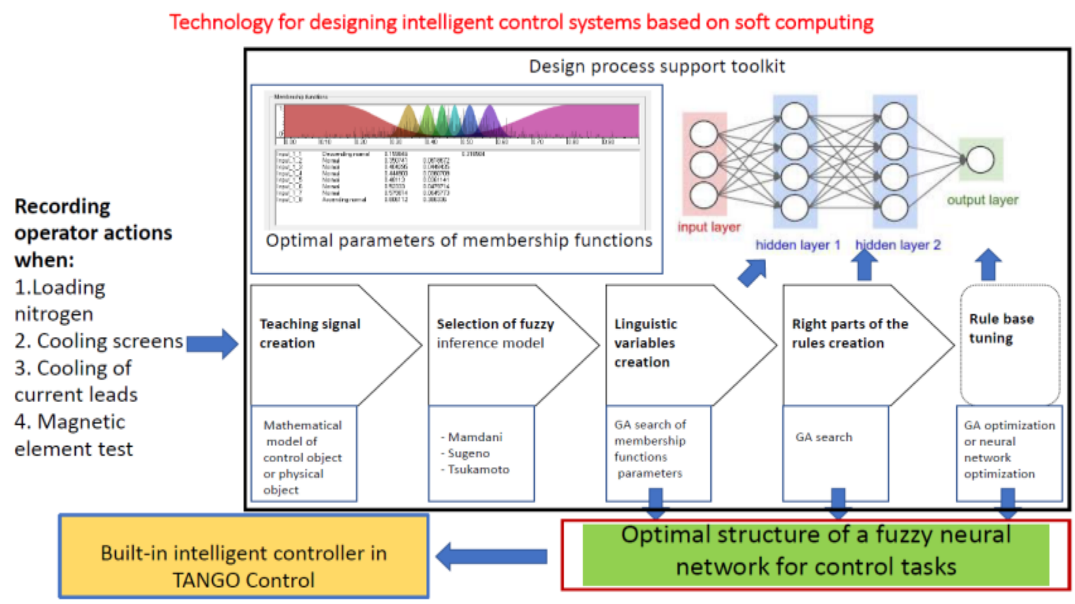

Figure 7: ICS design technology and interaction with Tango-Control

Designations: Control Objective – the target pressure value (1.17 bar), Control Operator – the pressure value when controlled by the operator, PID Control – automated control of the standard means of the regulator, FC Control – automated control using a fuzzy controller, QFI Control – automated control mode using a quantum FC.

It is clearly seen that all regulators cope with the task of stabilizing the pressure in the collection in 40 minutes. However, the analysis of the results shows that the classic PID controller has a low speed and a high level of overshoot (1.29 bar), which is critical and can be considered as close to an emergency (1.30 bar). At the same time, the FC and the quantum controller (QFI control in Fig. 8) on the QFI- model demonstrate high performance (relaxation time 210 and 215 seconds, respectively) with a low level of overshoot (1.24 and 1.21 bar, respectively). The operator coped well enough with the task of setting the required pressure (overshoot 1.21 bar and speed 280 sec), but could not set the required pressure value (steady-state mode 1.18 bar) (Table 2).

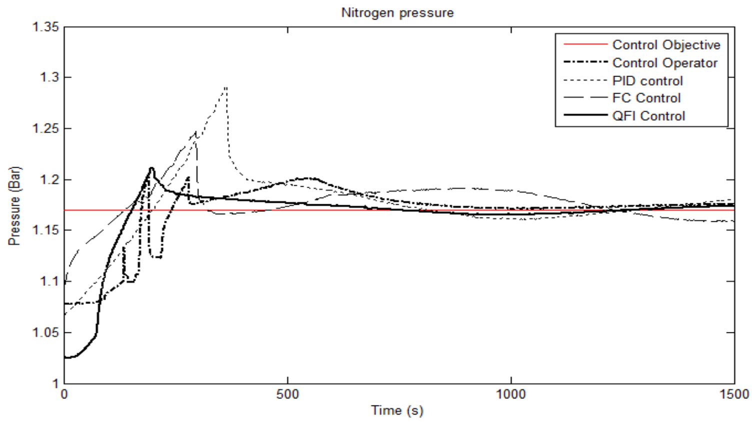

Figure 8: Pressure in the nitrogen collector with nitrogen cooling

Table 2: Comparison of the quality criteria of the transition process in nitrogen cooling mode

Control type	Overshoot	Performance	Control complexity
Operator	0.013	0.5	0.2
PID	0.021	0.78	0.5
FC	0.017	0.65	0.91
QFI	0.012	0.3	0.52

Figure 9 shows the consumption of the useful resource (nitrogen) of the installation. It is clearly seen that automatic control due to continuous monitoring demonstrates a more efficient use of a useful resource and allows you to reduce consumption by 50%, in particular, the PID controller - by 50%, the fuzzy controller FC– by 54%, the quantum fuzzy controller QFI – by 53%. Moreover, from the point of view of the consumption of a useful resource, QFI and FC reduce nitrogen consumption by more than 50% (Fig. 10), i.e. they reduce the number of nitrogen refills by 2 times.

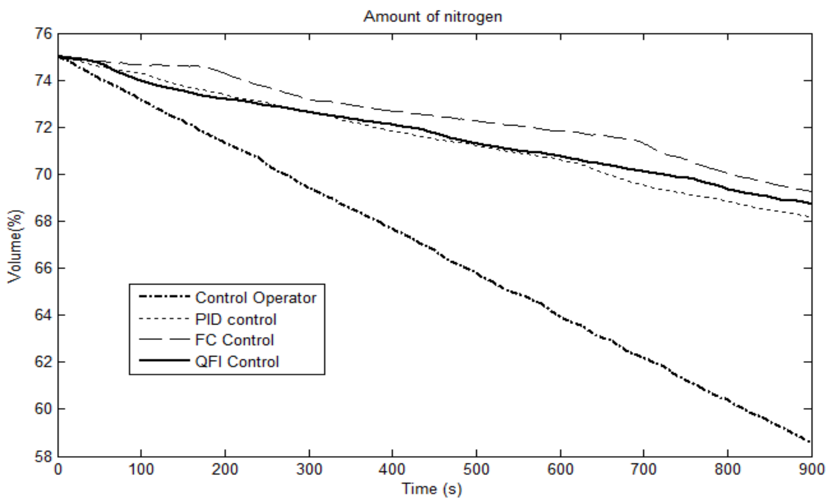

Figure 9: Nitrogen consumption in the storage tank

A very important control task in this mode is to maintain the required pressure level when refueling nitrogen. The fact is that the cooling must be continuous, and the refueling process itself implies a decrease in pressure for nitrogen intake, while the pressure in the nitrogen source through the communicating vessels affects the pressure in the collector. The complexity of this mode lies in the need to maintain a set pressure (for continuous cooling) and simultaneously refuel the storage tank.

In this case, the joint use of valves *V*19 and *V*20 plays an important role. Usually, the operator opens the *V*19 valve to relieve pressure, refills the system with nitrogen, and then proceeds to equalize the pressure. An automatic mode can be applied to this technological stage, and for simultaneous synchronous control of both the *V*19 valve and the *V*20 nitrogen supply valve. For the automatic control mode *V*19, the regulators PID, FC, QFI were considered.

Figure 10 shows results of quantum supremacy in intelligent pressure control for nitrogen charging.

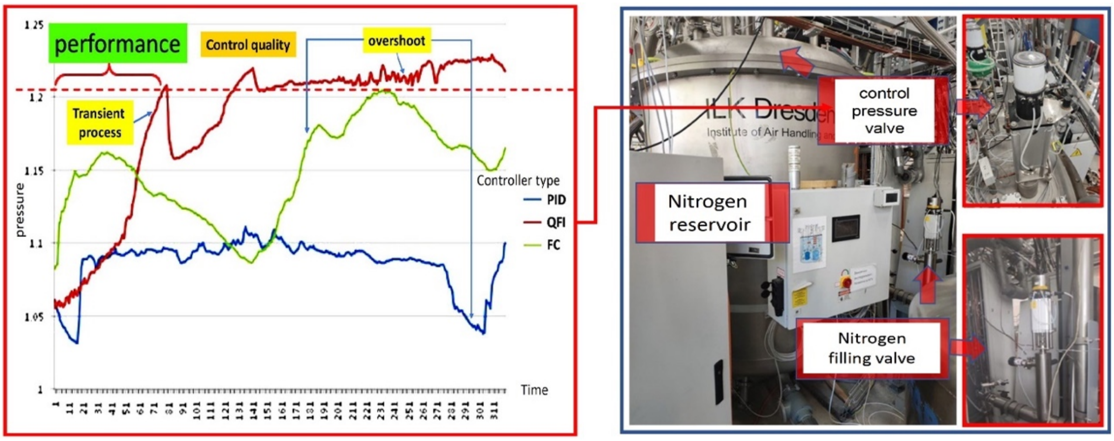

Figure 10: Pressure P13 when filling with nitrogen in the mode of cooling current leads and screens

The preliminary results show that the heating of the magnet joint during refueling suits the test regulations. Automatic control allows you to maintain the required pressure level during refueling, which allows you to reduce the warming of the magnet and maintain the temperature in the specified ranges.

This circumstance shows the possibility of using intelligent control when cooling superconducted magnets in conditions of optimization according to the criterion of contradictory indicators of control qualities.

In other words, intelligent control based on QFI has a low level of overshoot, allows you to reduce the consumption of useful life (nitrogen), increase the service life of the valve and increase the performance of the entire system with guaranteed achievement of the temperatures required by the testing regulations.

In general, at this stage, the work of the regulator was assessed as correct. The conducted studies show that the use of quantum and soft computing in the problem of controlling the pressure and flow of nitrogen increases the reliability of the system, reducing the amount of nitrogen flow.

The studies carried out have shown that when regulating in the control mode of a FC, the nitrogen flow rate decreases. Thus, with the considered example of the process of designing an ICS of inverted pendulum (see, Fig. 3), the possibility of creating an intelligent robust control system with an increased level of robustness due to the application of quantum computing technologies and various information resources in the process of extraction and formation of KB demonstrated.

9. Conclusions

- This work presents a new circuit for the implementation of the quantum gate design method. The presented approach allows us for fast classical efficient simulation of search QAs is developed.
- The realization of quantum simulator of QFI on the supercomputer with classical architecture demonstrate the possibility to apply general methods of quantum computing for successful search of intractable classical problem solution [18].
- On specific examples, the effectiveness of the application of the QAG approach in intelligent control systems with quantum self-organization of imperfect knowledge bases is shown, thereby demonstrating quantum superiority over classical computations.
- Results of controller's behavior comparison confirm the existence of synergetic self-organization effect in the design process of robust KB on the base of imperfect (non-robust) KB of fuzzy controllers: from two imperfect KB with quantum approach robust KB can be created robust KB of quantum intelligent controller using only quantum correlation. In classical intelligent control based on soft computing toolkit this effect is impossible to achieve.

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