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Intelligent Control Systems: Contemporary Problems in Theory and Implementation in Practice

A. V. Proletarsky[1], SHEN Kai[1,2*], K. A. Neusypin[1]

[1] Department of Computer Science and Control Systems, Bauman Moscow State Technical University, Moscow, 105005, Russia

[2] School of Mechanical Engineering, Nanjing University of Science & Technology, Nanjing, 210094, China

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Abstract. Problems of synthesizing modern control systems — Intelligent Control Systems were researched. The original concepts of synthesizing Intelligent Control Systems for dynamic objects were presented, which were developed based on the P.K. Anokhin Functional Systems Theory. Various approaches on synthesis of perspective control systems for flight vehicles by utilizing Intelligent Elements were developed as well. Consequently, practical applications of Intelligent Control Systems were thus illustrated by presenting examples of perspective Pseudo-intelligent Control and Measurement Systems of flight vehicles. In the paper, all the functional structures proposed of Intelligent Control Systems have great practical implementary values and can be applied for synthesis of various control systems for diverse dynamic objects.

Introduction

The development of control systems for perspective dynamic objects, e.g. flight vehicles, requires studying new technologies of their projections, creating new designing concepts, modernization of existing software designs, developing new hardware components, and implementation of new information technologies. Modern complex control systems of dynamic objects were researched, including consultative and advisory systems, Dynamic Expert Systems (DES) and various kinds of Intelligent Control Systems (ICS). At present, the most attention has been given to the research of the Intelligent Control Systems based on the P.K. Anokhin Functional Systems Theory [1].

On the basis of detail examinations of ICS operational principles and modern abilities of various realizations of dynamic objects control systems, a conceptual approach on synthesis of modern control systems for dynamic objects is developed. What's more, an approach on synthesis of Intelligent Control Systems using Intelligent Elements, such as Self-organization Algorithms, as acceptors of operation was also developed based upon the concept of Intelligent Systems (IS). In the ICS acceptor of operation, Self-organization Algorithms [2] can be employed for building prognostic models. Consequently, the realization of ICA synthesis in practice was thus illustrated by presenting examples of perspective Pseudo-intelligent Control and Measurement Systems of flight vehicles.

Modern Intelligent Control Systems

Rapid development of Cybernetics, Computer Engineering, Biotechnology and Artificial Intelligence (AI) has led to the appearance of new control and optimization methods for complex control systems. The junction of Modern Control Theory, Artificial Intelligence, Neurophysiology and Microelectronics has actively advanced the formation and development of new research areas, such as Intelligent Control Systems.

Since the 80-s, the interest on Artificial Intelligence has rapidly increased, and AI ideas and methods were then considered to be applied to control of various dynamic objects, such as flight as parts of Intelligent Control Systems are often called as Intelligent Elements of control systems. At present time, the most popular Intelligent Elements are as following: Neural Networks, Evolutionary Algorithms, Knowledge-based Systems.

Evolutionary Algorithms and Neural Networks possess a high parallelization feature, and consequently have a higher speed to process information, which is very important for control systems to act in a real time. These algorithms are widely used as separate parts of algorithmic softwares for building perspective multi-level, multi-criteria and multi-functional control systems with AI an ICS elements.

Nowadays, there is an opinion that the most adequate components of control systems for high intelligent functions are Intelligent Elements based on knowledge. Therefore, these Intelligent Elements are reasonably put into use as basic prototypes of modern AI systems. For examples, the information processing with the help of logical means allows to obtain some preferences with acceptable control solutions, and thus promote to find the most successful control outcomes. As the main mechanisms of intellectualization in such systems, the following reasoning mechanisms are usually employed: productive rule, "If condition is satisfied, then do something"; fuzzy rule, "much, little, …"; logical programming; deductive reasoning; automated theorem proving; automated hypothesis generation; analogical reasoning; object-oriented methods.

The classification of mechanisms for Knowledge-based Systems are presented above. Moreover, several mechanisms presented from similar classes usually are combined together to use. What's more, the Knowledge-based systems using object-logical languages, frame-based logics and logical programming are also considered as popular classes of Intelligent Systems nowadays. However, the most popular practical application in the area of Intelligent Systems are recognized as Dynamic Expert Systems which could be reasonably called as prototypes of modern Intelligent Control Systems [3].

Dynamic Expert Systems

Specifically, Dynamic Expert Systems are one of the classes of Knowledge-based Systems with large popularity and varied practical applications. Besides, Dynamic Expert Systems usually identify themselves as combinations of several subsystems, which 1) can availably estimate states of studied systems and external environment, 2) and also can compare expected parameters with realistic operations, 3) can accept solutions and select executive control in order to achieve the approving goals.

As illustrated above, Dynamic Expert Systems have following distinctive features: 1) adaptation to dynamic domain of problems, 2) ability to insert new elements and connections in the description of internal and external situations, 3) adjustment to rules and strategies of objects functioning during the process of accepting solutions and selecting control outcomes under conditions of half-full fuzzy and conflicting information. For the purpose of realizing those distinctive features, it is highly required that Dynamic Expert Systems must own enough stocks of knowledge and be able to effectively solve problems of interest.

Nevertheless, the most complex problem for synthesizing Dynamic Expert Systems is knowledge representation that will then be used for information processing etc. The knowledge employed in Dynamic Expert Systems can be divided into three groups:

- Conceptual knowledge represented in a special form of some rules whose combinations are considered as some knowledge about concrete subject domain, and consequently are called as models of subject domain;
- Factual knowledge, in a different way totality of information about qualitative and quantitative specifications of surrounding environment and concrete objects. Contemporary form of data accumulation are called Database as a rule. For organization without data and search for concrete information, it is very needed to apply conceptual knowledge as introduced before;
- Algorithmic knowledge, e.g. "skill", "technology" and so on. In general, algorithmic knowledge are employed in Dynamic Expert Systems by means of programmed product during computational process.

One of the basis block of Dynamic Expert Systems is the Database. With the Database, all the three groups of knowledge can be applied. What's more, the employment of Database can make the problem solving come true by applying abstract connections and combinations of those three groups of knowledge above. Therefore, Dynamic Expert Systems thus have the ability to make definite conclusions and obtain solutions of problems researched. In addition, methods of direct and feedback conclusion, methods of conclusion based on degree of reliability, Fuzzy Logic and Bayesian methods are also suggested to use in the mechanism of conclusion-making.

During the functioning process of Dynamic Expert Systems, there might exit conflict situations. Under those conflict situations, some problem solving rules must be employed for this moment. For instance, reference apparatus is one of the methods to settle conflict problems by using given priority in advance or on the basis of some algorithms, such as method of Stable-effective Compromises [4].

P.K. Anokhin Functional Intelligent Control Systems

The interpenetration between Modern Control Theory and Artificial Intelligence has led to the emergence of one new research direction—Intelligent Control (IC). Generally, Intelligent Control might be classified into Neural Control, Knowledge-based Control, Logic-based Control and so on.
In general, the common goals of Intelligent Control are listed as following:

- Applying accessible information and knowledge about objects of study and surrounding environment, for example, some priori criteria, expected trajectories, qualitative functional, objective sets etc. as much as possible;
- Control with creative approaches, e.g. employing prognosis of objects state and surrounding environment changes. Applying this control method, the robustness and effectiveness of control functions could be preserved under circumstances of substantial parameters change of studied objects and reconfiguration of external environment;
- Improving capacity and effectiveness of control as time goes on, e.g. with the help of training during the process of operation.

As introduced above, Intelligent Control Systems should have the ability to perceive the information of studied process, disturbance and functioning conditions, and thus to receive training and make conclusions. There do exit various types of Intelligent Control System architectures, yet only those architectures that can be employed in technological control systems for dynamic objects would be studied in this paper. In the area of Robot Technology, Intelligent Control Systems with two-layer structures are usually be designed by means of combinations of Intelligent Elements, for instance, by utilizing Neural Networks and Dynamic Expert Systems at the same time.

Neural Networks function in parallel with Dynamic Expert Systems that start working and replying for control at the beginning. As time goes on, Neural Networks receive training with the information from Dynamic Expert Systems and measurement information, and then product control for the system of interest with a higher quality. Dynamic Expert Systems ensure the robustness of system functioning, while Neural Networks provide fine adjustments under special conditions, such as leak of a priori information. Therefore, we can say that Dynamic Expert Systems provide the system with higher intelligence and lower precision of control, yet Neural Networks cultivate a higher precision of control with lower level of intellectuality.

At present, Intelligent Control Systems based upon fuzzy rules are implemented more commonly in the field of technological control process. In terms of Fuzzy Control, methods of representation and employment of expert knowledge of operators, technologists, developers and engineers are generally suggested to put into use. Moreover, the basic problem of building Intelligent Control Systems with Fuzzy Logic is the comparison between state expression of object controlling effect with true condition of rules functioning, and also the strategy detection or algorithm for rule usage. Compared with other traditional intelligent control methods, Intelligent Control with Fuzzy Logic have the following features: 1) more robust; 2) higher lever of automation for complicated process.

In practice, it is highly needed to apply method of Logical Conclusion in terms of the process of interest whose prior information is too little or even does not exist. Logical Conclusion can automatically put forward a hypothesis, complete investigation and demonstrate the required theorem. By utilizing Logical Conclusion, the basic problem of calculating system dynamicity, such as the data and knowledge changes, would be solved.

Currently, the global problem of the development of Intelligent Control is to increase the level of intellectuality in control systems. With the increasing complexity of researched systems which can be estimated by the information capacity, we must do our best to design and develop systems that are more intelligent. In [5], Vasilyev, Zherlov, et el. presented five principles for developing new Intelligent Control Systems: principle of information capacity; principle of ICS degree of openness for self-training and self-organization; principle of change prognostication; principle of accuracy increasing with decreasing intellectuality; principle of local degradation.

On the basis of those five principles above, four classes of systems are sorted by the increasing intellectuality: systems of identification control; systems of adaptive control (systems with self-regulation); systems of intelligent control without goal settings; systems of intelligent control with goal settings.

In Figure 1, one perspective Intelligent System was developed by utilizing P.K. Anokhin Functional Systems Theory based on those five principles above and with Dynamic Expert Systems in the center.

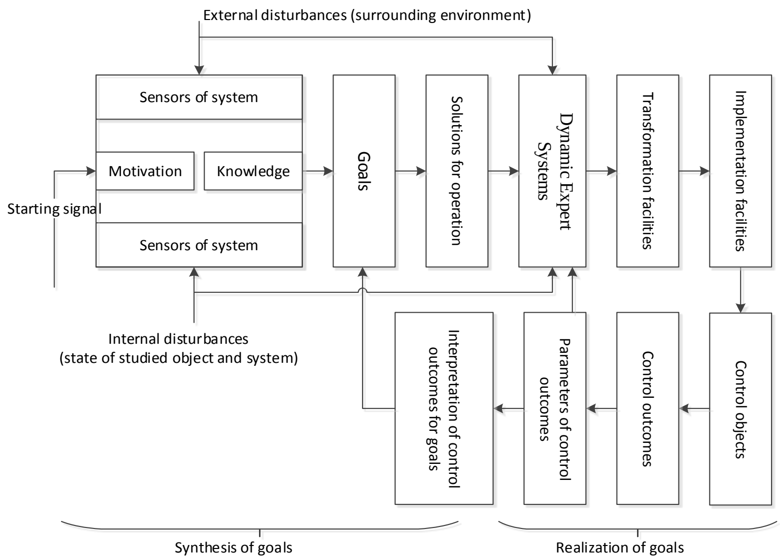

Fig. 1. One functional scheme of P.K. Anokhin Intelligent Systems

One of the perspective research direction of synthesizing Intelligent Systems is symbiosis of Dynamic Expert Systems, Self-organization Algorithms, acceptor of solutions, adaptive control and estimation theory in the frame of P.K. Anokhin Functional Structures. In terms of synthesis of Intelligent Systems, modern complex control systems can work smoothly just as functional systems with inherent fit effectiveness. Unlike other traditional Intelligent Systems, the P.K. Anokhin Intelligent Systems can reach the goals on the basis of auto-regulation principles, synthesis of goals, accepting solutions for operation, effective programming operation, acceptor of operation, feedback afferent action and prognosis of acceptor operation.

The basic advantages of applying P.K. Anokhin Functional Systems Theory to building Intelligent Control Systems are universal architectures and fine evolution mechanisms of functional systems. The block of synthesis of goals have the capacity to synthesize goals in consideration of external environment, inherent states, motivation and memory. In addition, acceptor of operation can be realized by utilizing Self-organization Algorithms which allow to building predicted models under a little prior information. Finally, the information about operation outcomes and predicted states would entry into Dynamic Expert Systems and the block of synthesis of goals. If the operation outcomes correspond with the predicted states, then we can know that the goals of

Intelligent Control Systems are reached. One functional scheme of such Intelligent Control Systems with P.K. Anokhin Functional Structures is illustrated in Figure 2.

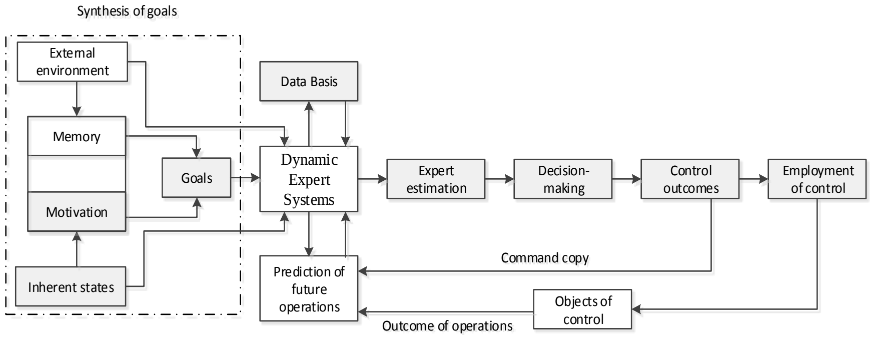

Fig. 2. One functional scheme of Intelligent Control Systems with P.K. Anokhin Functional Structures

As shown in Figure 2, such advanced Intelligent Control Systems with P.K. Anokhin Functional Structures are symbiosis of expert systems which can be established by applying Self-organization Algorithms, decision-making block, adaptive control units and synthesis of goals within the frame of P.K. Anokhin Functional Structures. In general, such P.K. Anokhin Functional Intelligent Control Systems are complicated functional systems, consisting of some simpler functional subsystems conversely. Based on decision-making block of Intelligent Control Systems, estimation and prediction of future acceptor operations would be made. Thus, it is possible to control the whole intelligent functional systems just as the control of classical common systems. Furthermore, during the functioning procedure of P.K. Anokhin Functional Intelligent Control Systems, not one integrated complex intelligent system but several simpler intelligent subsystems work together in order to save the system sources and reduce the difficulty of system integration. Consequently, we can make a conclusion that various Intelligent Control Systems for dynamic objects can be synthesized on the basis of P.K. Anokhin Functional Intelligent Systems.

Intelligent Control Systems for Flight Vehicles

By applying Intelligent Systems that possess complicated multi-level architectures, such as control systems of flight vehicles, it becomes more and more possible to realize the synergistic effect, i.e. increasing efficiency by utilizing mutual correlation and mutual intensification among various kinds of activities. During the modernization and development process of connections between functional systems, it is highly necessary to build and improve the mutualism of functional systems. Besides, symbiosis of subsystems should be mutual beneficial, and thus, optimization of such functional systems interactions is a complex problem. In general, to solve this complex problem multi-criteria optimization are suggested to put into use. Hence, the state parameters of each subsystem and the whole Intelligent Systems, as well as parameters that characterize the efficiency of connections between these subsystems would be optimized. Therefore, the maximization of positive interactions between all the subsystems of Intelligent Systems can be reached and the establishment of mutualism of all subsystems might thus be realized.

The functional systems structure of introduced Intelligent Control Systems for flight vehicles is illustrated in Figure 3.

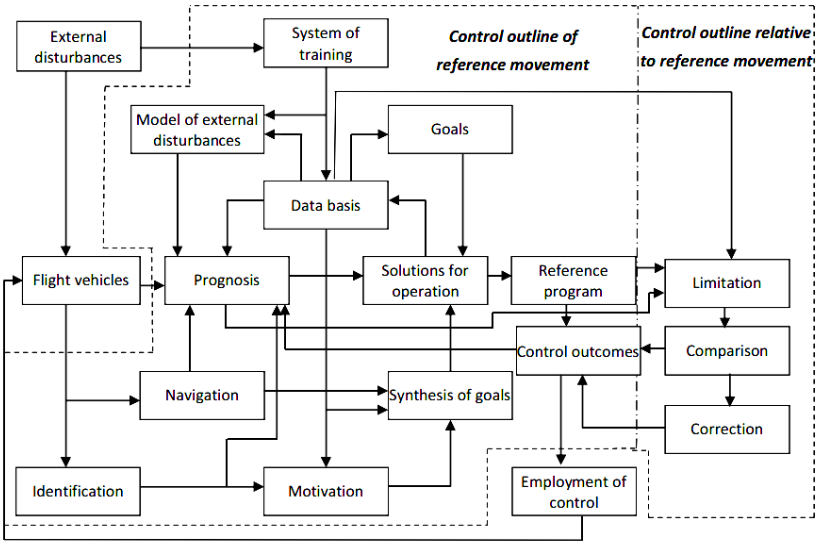

Fig. 3. One functional structure of Intelligent Control Systems for flight vehicles

It is desirable to consider the progress irregularity of separate functional subsystems during the modernization process of Intelligent Systems. The evolution of Intelligent Systems goes on in accordance to the principle of minimal function guarantee. Any functioning result of Intelligent Systems should be achieved with minimal funds and minimal quantity of subsystems whose complexity is corresponding to the concrete problem solving. However, the increasing complexity of subsystems or their unification might be needed with regards to the demands of problem solving. The phenomenon of minimal function guarantee can be regarded as any motive act of higher vertebrates. The increasing complexity of Intelligent Systems architectures and separate subsystems should correspond to the real situation, i.e. external functional conditions and problems that must be solved during the process of operation. Afferent synthesis is also realized by the principle of minimal function guarantee. Formation of functional systems that make up the loop of inverse afferent interaction in the concerned Intelligent Systems occurs under narrow afferent interaction conditions. Functional systems which are formed under narrow afferent interaction conditions could not ensure the delicate suitability of the system to external situations. This is why the modification processing of afferent synthesis is high-priority and crucial problem at the present stage.

Modern control systems of flight vehicles in the present time are complicated control systems consisting of information measurement subsystems, estimation and prediction algorithms, on-board operational facilities etc. In addition, in the most of practical applications of control systems the functioning goal is usually a priori as shown in Fig. 3. What's more, in a view of P.K. Anokhin Functional Systems Theory, On-board Operational Advising Expert Systems (OOAES), for example, are referred to consultative Dynamic Expert Systems which can operate in the real on-board environment and consider of real possible changes of external surroundings in order to increase the efficiency of flight vehicles. OOAES in the upper and middle levels should tend to create on-board operational algorithms based on Logical Conclusions theory and put forward hypotheses. In order to build such On-board Operational Advising Expert Systems, we can work according to the following steps:

- Conceptual design with regards to appointed situations;
- Building Data Basis and developing basic models of on-board Intelligent Control Systems;
- Improvement of Data Basis during simulation modelling.

For modern flight vehicles, another urgent problem is trajectory planning and transformation. Generally, flight vehicles must transfer from one trajectory to another during the process of function in the air owing to the unexpected disturbances, such as wind, obstacles etc. Thus, we can synthesize one P.K. Anokhin Functional Intelligent Systems for atmospheric and space flight vehicles to solve this urgent problem. For the purpose of synthesizing P.K. Anokhin Functional Intelligent Systems of flight vehicles, the conception of vital-organ functions must be taken into account to build one Intelligent Control System which can make adjustments to adapt to changes, disturbances and obstacles of external environment. Imitating the function of vital-organs in the life-systems, we can apply systemogenesis, the process to build functional systems for the whole working time, to express the states of studied systems. At the first stage of systemogenesis, model of future states will be built by using the knowledge from Data Basis and other information. At the second stage of systemogenesis, new structures should be formed based on intelligent algorithms, such as Self-organization Algorithms. At the third stage of systemogenesis, the efficiency of majority functional systems would decrease because of the deficiency of energy sources. Consequently, based upon the P.K. Anokhin Functional Systems Theory and Self-organization Algorithms, one perspective pseudo-intelligent control systems for all stages of systemogenesis was built to make a reality of the whole-life control of flight vehicles [7].

Pseudo-intelligent Control and Measurement Systems of Flight vehicles

In practice, control systems with intelligent elements were suggested to be realized as Pseudo-intelligent Control and Measurement Systems (PICMS) of flight vehicles with regards to the computation capacity of on-board computers [8]. In the Pseudo-intelligent Control and Measurement Systems, the control goals are generally appointed in advance and thus will not change during the PICMS function. In terms of P.K. Anokhin Functional Systems Theory, subsystems of PICMS are just like vital-organs in the life-systems that have the ability of auto-regulation to external environment and auto-correction among subsystems. According to P.K. Anokhin Functional Systems Theory and Intelligent Control Systems principles presented, one kind of Pseudo-intelligent Control and Measurement Systems of flight vehicles was built as illustrated in Figure 4.

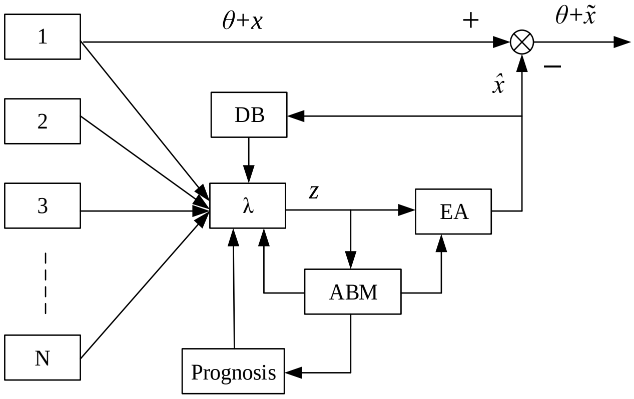

Fig. 4. One Pseudo-intelligent Control and Measurement Systems of flight vehicles

where 1– basic navigation system, e.g. Inertial Navigation System (INS); $2 \cdots N$ – aided navigation systems, such as Global Navigation Satellite System (GNSS) and Radio Positioning System (RPS); λ – Degree of Observability; EA – estimation algorithms; DB – Data Basis; ABM – algorithms of building models; θ – real navigation information; z – measurement of navigation information; x – real INS errors; $\hat{x}$ –INS errors estimate; $\tilde{x}$ – INS estimation errors.

In the block λ, the Degree of Observability of navigation information from each navigation systems ($1 \cdots N$) can be calculated. Hence, the measurement z of Intelligent Control Systems above would be formed according to the Degree of Observability of navigation information and to the comparison between a posteriori information and Prognosis results by utilizing Self-organization Algorithms. Let's consider the example of gyro drift rate to illustrate the above approaches, the simulation result of mathematical modelling was obtained as shown in Figure 5.

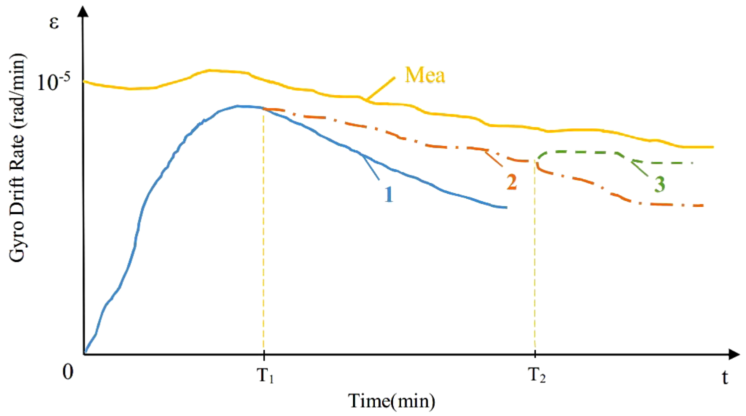

Fig. 5. Simulation result of gyro drift rate

In Fig. 5, ε – gyro drift rate; Mea – measurement of gyro drift rate; 1 – estimate of gyro drift rate with INS; 2 – estimate of gyro drift rate with GNSS; 3 –estimate of gyro drift rate with RPS.

For estimation of gyro drift rate in the $T_1 - T_2$ interval, the results of prognosis determined by the Degree of Observability of navigation information were suggested to be considered as the indicator to select the best external aided navigation system for this interval. As illustrated in Fig. 5, we can get that the Degree of Observability of GNSS is larger than that of INS, i.e. $\lambda_2 > \lambda_1$. Hence, we reasonably select the GNSS as the most important external navigation system for correcting navigation information errors. Analogically, during the next interval, the Degree of Observability of RPS were larger than that of GNSS, thus the combination of INS and RPS would be put into use instead of INS and GNSS.

In practice, the real tests of Pseudo-intelligent Control and Measurement Systems were also successfully proceeded by applying Self-organization Algorithms, the Degree of Observability, and other Intelligent Control Elements within the frame of P.K. Anokhin Functional Systems Theory. The efficacy of suggested approaches for correcting navigation information errors was averagely enhanced by 10% – 20% in comparison with traditional navigation complex.

Conclusions

In this paper, original concepts of synthesizing Intelligent Control Systems for dynamic objects were presented based on the P.K. Anokhin Functional Systems Theory. Various approaches on synthesis of perspective control systems for dynamic objects, such as flight vehicles, by utilizing Intelligent Elements were developed as well. By applying Intelligent Control Systems that possess complicated multi-level architectures, it becomes more and more possible to realize the synergistic effect, i.e. increasing efficiency by utilizing mutual correlation and mutual intensification among various kinds of subsystems of Intelligent Control Systems.

In practice, Intelligent Control Systems were suggested to be realized as Pseudo-intelligent Control and Measurement Systems of flight vehicles with regards to the computation capacity of on-board computers. The simulation and tests of the proposed Pseudo-intelligent Control and Measurement Systems were successfully proceeded by applying Self-organization Algorithms, the Degree of Observability, and other Intelligent Control Elements within the frame of P.K. Anokhin Functional Systems Theory. The efficacy of suggested approaches for correcting navigation information errors was averagely enhanced by 10% – 20% in comparison with traditional navigation complex.

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