

DOI: 10.18372/2310-5461.55.16900

UDC 004.056

S. Tolupa, doctor of technical sciences, professor,
Taras Shevchenko National University
orcid.org/0000-0002-1919-9174
e-mail: tolupa@i.ua;

S. Laptiev, PhD-aspirant
Taras Shevchenko National University
orcid.org/0000-0002-7291-1829
e-mail: salaptiev@gmail.com

THE METHODOLOGY FOR EVALUATING THE FUNCTIONAL STABILITY OF THE PROTECTION SYSTEM OF SPECIAL NETWORKS

Introduction

The systemic functional stability is a high-level abstraction, and thus its practical implementation in some cases of complex systems is a task that requires additional research, both theoretical and modeling. Traditionally, a self-diagnosis system is used to detect permanently faulty components, it is a component of functional stability.

The property of functional stability was introduced by observing the behavior of biological systems, organisms with the ability to fulfill their goals with physical damage due to biological redundancy: sets of sense organs, physiological analyzers, nerve fibers, brain settings, control systems, and information processing, and body symmetry. The main feature of functionally stable systems is their ability to degrade at the structural level to complete failure of the system, ie to exclude defective elements from the structure, to rebuild the structure, to adjust the system parameters. to adapt to new operating conditions. The main means of ensuring functional stability is the introduction of redundancies (structural, software, time, etc.) in their design.

Much research is always devoted to solving the problem of the functional stability of systems and mechanisms. The functional stability is an integral part of all industries. But despite a large amount of research and a large number of publications on addressing various aspects of functional stability to date, the problem of functional stability in some industries remains unresolved. Thus, the functional stability of wireless sensor networks remains unresolved and needs to be improved. Therefore, the task of ensuring the sustainable operation of wireless sensor networks is urgent.

Analysis of recent research and publications

Today, special-purpose networks, which include wireless sensor networks, are increasingly penetrating all areas of human activity. Wireless sensor network has ceased to be only the object of scientific research and is becoming a mass product, which is produced by many manufacturers [1, 2]. Sensors for transmitting and exchanging information can be located at different sites.

Existing and designed wireless sensor networks differ in their areas of application, so they are used in technical solutions. [3]. However, we can highlight the main characteristics that are characteristic of most wireless networks. As is known, a wireless sensor network consists of switching nodes and channels (lines) of communication between them. The main requirement for wireless sensor networks is to perform their main function – providing network subscribers with potential access to distributed information resources. All other requirements – performance, reliability, accuracy, compatibility, manageability, survivability, scalability, and scalability – are related to the quality of this basic task [4–6]. In modern conditions, wireless networks are affected by internal (failures, errors) and external (enemy resistance, the consequences of the use of information weapons) factors.

Problems of stability have been studied in the works of many authors, the main of which are monographs of A.M. Lyapunov, J. La Salle and S. Lefschitze, I.G. Malkin, A. Poincare, B.G. Demidovich, L. Cesari and others. Most approaches to stability theory are based on studies of systems of differential equations. At the same time, the classical approaches to the theory of stability for modern control systems based on the use of artificial intelligence methods often do not meet the requirements for the adequacy and reliability of assessments of the stability of such systems.

The problem of ensuring the stability of complex intelligent systems was first posed in the work of O. A. Mashkov, wherein [7] the term "functional stability" was first introduced. The key provisions of the theory of functional stability were later developed in O. V. Barabash [13–15], Yu. V. Kravchenko, V. A. Savchenko and others [8–12]. At the same time, the dependence of models and methods of the theory of functional stability on the scope of their application is obvious/

Problem statement

However, despite the significant number of publications on addressing various aspects of functional stability to date, the problem of functional stability of wireless sensor networks remains unresolved. Therefore, the task of ensuring the sustainable operation of wireless sensor networks is urgent.

The article aims to study the features of functionally stable systems. Determine and propose signs and indicators of functional stability of the target network structure, ensuring objects' connection with the operator. Provided recommendations for building a functionally stable network structure or formulating reasonable requirements for a wireless sensor network structure that will be designed and operated with high-performance stability.

Presenting main material

The analysis of the existing scientifically substantiated approaches to increase of efficiency of difficult technical systems to which, including intelligent automated control system (ACS), allows us to draw a conclusion about the formation in recent years of the new priority approach connected with maintenance of the system by property of functional stability. Functional stability of intelligent ACS is its ability to be in working order, i.e. to perform the necessary functions during a given time interval or to work in the conditions of failure of components due to the influence of external and internal destabilizing factors [16].

Under the functional stability of a special-purpose network, in particular a wireless sensor network, it means its property to store, during a given time, the fulfillment of its main functions within the limits set by regulatory requirements in terms of external destabilizing factors.

The main difference in the stability of functioning from the functional stability is as follows: the stability of functioning characterizes the behavior of the coordinates of the undisturbed and perturbed motion of the system:

$$\forall \varepsilon > 0 \Rightarrow \delta > 0, \rho(x_0, x'_0) < \delta \Rightarrow \Rightarrow \rho[z(t, x_0), z(t, x'_0)] < \varepsilon, \forall t \in [0, \infty) \quad (1)$$

where $x_0 = x(0)$ – initial conditions – coordinates of the phase space x_0 at an undisturbed motion; $x'_0 = x'(0)$ – coordinates of the phase space at a disturbed motion; ρ – metric of the space X ; ε, δ – the given numbers that characterize the deviation of the disturbed motion from the unsolvable.

Functional stability characterizes the deviation of the basic functions from the coordinates at an undisturbed and disturbed motion:

$$\forall \varepsilon > 0 \Rightarrow \delta > 0, \rho(f(x_0), f(x'_0)) < \delta \Rightarrow \Rightarrow \rho[f(x(t, x_0)), f(x(t, x'_0))] < \varepsilon, \forall t \in [0, \infty) \quad (2)$$

where $f(x)$ – the function from the coordinate of the movement of the system, which characterizes the basic requirements for the system.

The purpose of this article is to construct a mathematical apparatus for quantifying the functional stability of a special purpose network based on an automatic control system. The mathematical model for representing the structure of a special-purpose network has the form of a non-oriented graph $G(V, E)$, $v_i \in V, e_{ij} \in E, i, j = 1, \dots, n$, it is described by the adjacency matrix. The set of vertices V corresponds to the set of nodes of the switching dimension n , which are located on unmanned aerial vehicles, the set of ribs E – corresponds to the set of communication lines between switching nodes and the operator. It is accepted, that the wireless sensor network will perform the main function – data exchange, if there is at least one route of information transfer between any pair of switching nodes. Thus, the requirement of connectivity of the graph provides the basis for quantifying the property of the functional stability of the wireless sensor network, which provides a link between a group of unmanned aerial vehicles and an operator. In technical cybernetics, namely in the theory of automatic control, the classical theory of stability of dynamic systems is constructed. The founder of it is O.M. Lyapunov. In this theory, stability can be estimated without solving the system of differential equations which describing the object, and, using simple signs, conditions and stability criteria, developed by Vyshnegradsky I. O., Gurvits A., Mikhailov A. V., Nyquist H. and others. By the analogy with the classical theory of stability, it is proposed to evaluate the functional stability of the parameters of the graph describing the structure of the wireless sensor network [12, 17]. It turns out that the appearance of the graph and its parameters can be determined: whether the network is functionally stable, unstable or neutral.

Sign of functional stability of the structure. The structure of the wireless sensor network is functionally stable, if the graph of the structure is one-component and has no bridges and connection nodes. The inverse definition allows determining the functional instability of the structure.

Sign of the functional instability of the structure. The structure of the wireless sensor network is functionally unstable if its graph is multicomponent and unbound.

Thus, the appearance of the graph, namely the number of components, the presence of bridges and nodes of the connection of the graph, can be judged on the functional stability of the structure, that is, the ability inherent in it to fend off failures and damage. However, for highly branched and multidimensional graphs it is difficult to evaluate the appearance. Therefore, for the quantitative assessment of the degree of functional stability, we introduce the indicators of functional stability of the structure:

1. The number of vertex connectivity $\chi(G)$ – this is the smallest number of vertices, the removal of which together with incident edges leads to an unconnected or single-ended graph.

2. Number of edge connectivity $\lambda(G)$ – this is the smallest number of edges, the removal of which leads to an unconnected graph.

3. Probability of connectivity $P_{ij}(t)$ – this is the probability that messages from node i to node j will be transmitted over time t .

The analysis of these indicators allows highlighting such features:

– the numbers of vertex and edge connectivity characterize only the current structure, regardless of the reliability of the switching nodes or communication lines;

– the indicators $\chi(G)$ and $\lambda(G)$ take values of integers and are bound by the relation:

$$\chi(G) \leq \lambda(G), \quad (3)$$

– the probability of connectivity $P_{ij}(t)$ allows to take into account the reliability of switching equipment, the type of transmission channel information, the existence of backup channels and routes, and the connectivity of the distributed structure. However, calculating the value of $P_{ij}(t)$ is a complicated and cumbersome task;

– the probability of connectivity characterizes only the connectivity between one pair of vertices. In order to characterize the connectivity between all pairs of vertices, one must operate with an adjacency matrix:

$$A = \| a_{ij} \|, i, j = 1 \dots n, a_{ij} = \begin{cases} 1, & \text{при } e_{ij} \in E; \\ 0, & \text{при } e_{ij} \notin E. \end{cases} \quad (4)$$

Based on the proposed features and indicators, criteria for functional stability of the structure can be developed:

1. The structure will be functionally stable if the number of vertex connectivity satisfies the condition:

$$\chi(G) \geq 2. \quad (5)$$

2. The structure will be functionally stable if the number of edge connectivity satisfies the condition:

$$\lambda(G) \geq 2. \quad (6)$$

3. The structure will be functionally stable if the probability of connection between each pair of vertices is not less than given:

$$P_{ij}(t) \geq P_{ij}^{\text{зад}}, \quad i \neq j, \quad i, j = 1 \dots n, \quad (7)$$

where n – the number of vertices of the graph $G(V, E)$.

The given criterias allow based on accurate calculations to determine the functional stability of the current structure of the wireless sensor network. On the border of two areas of stability and instability there is a specific area, in which network structure is not functionally stable and, at the same time, is not functionally unstable. Such an area, analogous to the theory of stability of dynamic systems [8], will be called the boundary of the functional stability of the structure.

The sign of the boundary of functional stability is the following position. The current structure is on the boundary of functional stability, if the graph of the structure is connected, has bridges in its structure ($NE > 0$) or nodes of the connection ($NV > 0$):

$$\{K = 1\} \wedge [\{N_V > 0\} \vee \{N_E > 0\}] \quad (8)$$

where K – the number of graph components, and a condition $K = 1$ means that the graph is connected. NV (NE) – the number of nodes of the connection (bridges) of the graph.

The bridge is called the edge of a connected graph, which connects two subgraphs, after deletion of which the graph is converted from one-component to a two-component. In some works, on graph theory, bridge is called the isthmus. A node of a connection is called a vertex of a connected graph, after which, with the removal of its incident edges, the graph is converted from a one-component to a two-component.

The presence in the structure of the bridge or node of the connection, connecting two subgraphs, means that all routes of information transfer from vertices of one subgraph to another node will contain this bridge or node of connection [8]. This event significantly reduces the structural reliability and functional stability of the wireless sensor network. Therefore, in order to bring the network into a functionally stable state, it is

necessary to introduce back-up lines into the structure so that there is no structure in the bridges or nodes of the connection. In this case, there will be several independent and alternative routes of information transmission.

The analysis of structures shows that if the network is on the border of stability, then it is workable and performs the assigned amount of functions. However, in the case of at least one refusal of a bridge or node, the network becomes unstable.

Areas of functional stability and instability can also be represented in Cartesian space in coordinates NE , NV . Depending on the parameters NE , NV of the structure graph, a point on the plane is determined which will characterize the state of the network. By belonging to a point in one or another area can be judged about the functional stability or instability of the network.

In the graphical representation, the boundary of the functional stability of the network will be the geometric point of the points lying on two straight lines $NV = 1$ and $NE = 1$.

Based on the introduced concepts, there is the question of how far the current structure lies from the boundary of stability or, on the other hand, what is the stock of functional stability. It can also be defined in the sense of the connectivity of the structure. In this regard, the stock will be characterized by the number of failures (rupture of ribs or failure of vertices) that can lead the structure to an unstable state [9].

The stock of functional stability can be quantified based on the following indicators:

1. Stock of edge of stability – the number ZE , equal to the minimum cut capacity, which translates the graph from one-component to a two-component.

2. Stock of vertex of stability – the minimum number of vertices ZV of the graph, after the removal of which, along with incident edges, the graph goes from one-component to two-component.

The geometric interpretation of the stability reserve will be determined as the minimum distance from the point on the plane; it is determined by parameters NE , NV , to the limit of stability.

You can also calculate the stock of functional stability on the probability of connectivity, as the difference between the given value and the current one. Obviously, in this case, the stock will be expressed by a square matrix in which each element will have value.

It should be noted the main difficulties in applying the above estimates of functional stability. Determination of the number of vertex connectivity $\chi(G)$ and the edge connectivity $\lambda(G)$ can be made on the appearance of the graph only for simple graphs with a small number of vertices. Analytically, these

figures can be calculated using an algorithm built on the analysis of local degrees of vertices graph. The probability of coupling a pair of vertices of the graph P_{ij} is harder to calculate. For this there are a number of algorithms published in the literature [17] based on the sequences-parallel combinations of edges by means of graph transformations. One of such algorithms, constructed on surpassing methods with clipping of non-prospective variants, is proposed in the report.

Thus, based on the signs of functional stability, after determining the proposed parameters, you can determine the state of the wireless sensor network, namely finding a network in a functionally stable state or functionally unstable. The degree of functional stability determines the stock of functional stability, which can be found analytically according to the proposed formulas, and graphically. On the basis of research data, there is an opportunity: justification of the requirements for wireless sensor networks to be designed for communication between a group of unmanned aerial vehicles and an operator, solution of the problem of optimal structure synthesis according to the criterion of the maximum of functional stability with the limitation on the cost of construction and operation of communication lines.

Conclusion

The main feature of functionally stable systems has been studied. It was found that this is their ability to degrade at the structural level to complete failure of the system, i.e. to exclude defective elements from the structure, to rebuild the structure, to adjust the parameters of the system to adapt to new operating conditions. The main means of ensuring functional stability is the introduction of redundancies (structural, software, time, etc.) in their design.

The signs and indicators of functional stability of the structure of the special-purpose network, which provides the connection of objects with the operator, are revealed and offered. Quantitative methods for assessing functional stability according to the above indicators are proposed. Based on these assessments, it is possible to give recommendations for building a structure of a functionally stable network or to formulate reasonable requirements for the structure of a wireless sensor network, which will be designed and operated with high rates of functional stability.

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Толупа С., Лаптев С.

МЕТОДИКА ОЦІНКИ ФУНКЦІОНАЛЬНОЇ СТІЙКОСТІ СИСТЕМИ ЗАХИСТУ СПЕЦІАЛЬНИХ МЕРЕЖ

Інформаційні системи функціонують під впливом зовнішніх і внутрішніх дестабілізуючих факторів. Під негативним впливом модулі системи можуть вийти з ладу. Однак системи повинні працювати в автономному режимі протягом визначеного часу. Така умова функціонування може бути виконана шляхом забезпечення властивості функціональної стійкості. Властивість функціональної стабільності введено завдяки спостереженню за поведінкою біологічних систем, організмів, яким притаманна властивість виконувати поставлені цілі з фізичним пошкодженням

через біологічну надмірність: набори органів чуття, фізіологічні аналізатори, нервові волокна, конфігурація головного мозку як система управління та обробки інформації, а також тіло симетрії. Основною особливістю функціонально стійких систем є їх здатність деградувати на структурному рівні до повного виходу системи з ладу, тобто виключати зі структури дефектні елементи, перебудовувати структуру, для налаштування параметрів системи. адаптуватися до нових умов експлуатації. Основним засобом забезпечення функціональної стійкості є введення резервування (структурного, програмного, часового тощо) при їх проектуванні.

У статті проаналізовано існуючі науково обґрунтовані підходи до підвищення ефективності складних технічних систем, до яких відноситься інтелектуальна автоматизована система управління. Запропоновано методику визначення особливостей та показників функціональної стійкості структури мережі спеціального призначення, що забезпечує зв'язок між групою БПЛА та оператором. Запропоновано кількісні методи оцінки функціональної стійкості за наведеними показниками. На основі цих оцінок можна надати рекомендації щодо побудови структури або сформулювати розумні вимоги до структури бездротової сенсорної мережі, яка буде спроектована та експлуатована. головною ознакою функціонально стійких систем. Встановлено, що це їхня здатність до деградації на структурному рівні аж до повного виходу системи з ладу, тобто до виключення зі структури дефектних елементів, перебудови конструкції та налаштування параметрів системи для адаптації до нових умов експлуатації. Доведено, що основним засобом забезпечення функціональної стійкості є внесення в їх конструкцію надмірностей: структурних, програмних, часових тощо.

Ключові слова: мережа, інформаційна безпека, бездротові мережі, кібербезпека, функціональна стійкість, кількісна оцінка, сенсорна мережа.

Tolupa S., Laptiev S.

METHODOLOGY FOR EVALUATING THE FUNCTIONAL STABILITY OF THE PROTECTION SYSTEM OF SPECIAL NETWORKS

Information systems function under the influence of external and internal destabilizing factors. Under negative influence, system modules may fail. However, the systems must function offline for a specified time. Such a condition of functioning can be fulfilled by ensuring the property of functional stability. The property of functional stability was introduced due to the observation of the behavior of biological systems, organisms with the inherent property to fulfill given goals with physical damage due to biological redundancy: sets of sense organs, physiological analyzers, nerve fibers, the configuration of the brain as a control and information processing system, as well as symmetry body. The main feature of functionally stable systems is their ability to degrade at the structural level until the system completely fails, that is, to exclude defective elements from the structure, to rebuild the structure, to adjust the system parameters. adapt to new operating conditions. The main means of ensuring functional stability is the introduction of redundancy (structural, software, time, etc.) during their design.

The paper analyzes the existing scientifically based approaches to increasing the efficiency of complex technical systems, which include an intelligent automated control system. A technique for determining the features and indicators of the functional stability of the special purpose network structure, which provides communication between the UAV group and the operator, is proposed. Quantitative methods for assessing functional stability based on the above indicators are proposed. On the basis of these assessments, recommendations can be made on the construction of the structure or reasonable requirements for the structure of the wireless sensor network that will be designed and operated can be formulated. the main feature of functionally stable systems. It has been established that this is their ability to degrade at the structural level until the complete failure of the system, that is, to exclude defective elements from the structure, rebuild the structure, and adjust the system parameters to adapt to new operating conditions. It has been proven that the main means of ensuring functional stability is the introduction of excesses into their construction: structural, program, time, etc.

Keywords: network, information security, wireless networks, cyber security guard, functional stability, quantitative assessment, sensor network.

Стаття надійшла до редакції 18.08.2022 р.
Прийнято до друку 12.09.2022 р.