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Evolve the tools for assessing the efficacy of algorithms used in the search and detection of targets by aiming radio-electronic systems

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Abstract
Relevance of the topic. The sighting radio-electronic complex (REC) is designed to detect a target by target designation, capture it, track it and calculate the predicted trajectory of movement with the transfer of relevant information to the target destruction device. The composition of the target electronic control system is formed in such a way as to ensure the fulfillment of the assigned task under conditions of exposure to external natural and artificial interference, in the event of malfunctions and equipment failures. Therefore, the REC includes radio-electronic systems (RES) of various types. The sequence of procedures for using the information provided by the REC in the process of performing a task determines the target search and detection algorithm (TSA) of the sighting REC, the development of which is an important task at the system engineering stage of the design of such complexes.

Keywords: Target designation, destruction device, radio-electronic, sighting REC

Introduction

The tasks that are solved by targeted REC are characterized by strict conditions regarding the time spent on decision-making by the operator. You can achieve the minimum value of this time in the following ways:

1. Selection of an operator with certain psychophysiological capabilities and ensuring the appropriate level of his qualifications;
2. Attracting a group of operators and improving the organization of their work with REC sighting systems;
3. Transfer of part (or all) of the operator's functions to the information management system.

For the above methods, variants of the APOC of the targeted REC are formed. Without appropriate means, the task of comparing options for constructing an APOC at the stage of system engineering design is solved qualitatively, and quantitative assessments of the efficiency indicators of the APOC and targeted RECs as a whole are determined at the stage of full-scale testing. This approach does not provide a solution to the problem of selecting acceptable APOC options at the stage of system engineering design and requires a large amount of full-scale testing [1, 2].

Therefore, it is relevant to develop tools for assessing performance indicators suitable for use at the stage of system engineering design, which will subsequently reduce the volume of full-scale tests and, accordingly, reduce the cost of time and material resources. However, assessing the effectiveness of the APOC of sighting RECs cannot be reliable without taking into account the reliability indicators of the equipment. The required level of reliability indicators of the RES, which are part of the complex, is ensured by the use of appropriate fault-tolerant structures during their creation.

The introduction reveals the essence of the scientific and practical problem of creating means for assessing the effectiveness of algorithms for searching and detecting targets of sighting radio-electronic systems, substantiates the relevance of the work, the need for research, formulates the purpose of the work, shows the scientific novelty and practical value of the results obtained, and provides information about the approbation of the work.

In the first section, the composition and principles of construction of typical sighting RECs are analyzed and their features are identified. The requirements for sighting RECs are formulated and the features of their application are considered. As a result of qualitative analysis, a complete set of means for searching and detecting targets of sighting electronic electronics has been formed for research. To formulate specific options, a prototype design approach was used: the developed option may include both a complete and incomplete set of tools, obtained by excluding individual RES from the complete set [3, 4].

The problem of selecting efficiency indicators for targeted RECs is considered. The probability of completing the task by the complex was chosen as an indicator for quantitative assessment of the effectiveness of the APOC option, and the limiting condition was the permissible value of the average time for completing the task. The APOC of the complex is the input information for conducting research in this dissertation.

To solve the problems of the system-technical stage of designing targeted RECs, it is necessary to carry out numerous studies and calculations to evaluate the effectiveness indicators of various options for their construction to select the structure of the RECs and determine the necessary parameter values for the RECs and APOCs, taking into account the fact that the complexes are used in conflict conditions.

When constructing an adequate mathematical model of the APOC to take into account, along with the functional aspect and the reliability aspect, in the set of model parameters it is necessary to have indicators of the reliability of the RES. Modern RES of sighting RES are designed with the property of fault tolerance, which is ensured by combined structural redundancy or the use of majority structures capable of reconfiguration. State and industry standards for such structures do not contain appropriate mathematical models, and therefore it is necessary to develop tools for their analysis. The developed tools must take into account all the possibilities for ensuring fault tolerance of such structures and adequately reflect their behavior when failures occur. At the same time, it is necessary to have mathematical models of fault-tolerant structures that take into account the effect of hardware aging and arbitrary probabilistic distribution laws for the duration of maintenance procedures [5, 6].

When solving design problems at the stage of system engineering design of REC, the reliability of the results is ensured by the use of two different methods for modeling the design object. The above requirements are met by: the state space method and the method of logical-probabilistic trajectory modeling [7, 8].

The section contains a list of tasks that were solved in this work. The goal of the work is to develop mathematical models, methods and software for assessing the effectiveness of algorithms for searching and detecting targets of sighting radio-electronic systems.

To achieve the goal, it is necessary to solve the following tasks

1. Develop a structural-automatic model of an algorithm for searching and detecting targets of an electronic sighting system.
2. Develop a Markov model of an algorithm for searching and detecting targets of an electronic sighting system.
3. Develop a logical-probabilistic model of an algorithm for searching and detecting targets of an electronic sighting system.
4. Create a methodology for analyzing the effectiveness of options for constructing algorithms for searching and detecting targets of an electronic sighting system.
5. To build mathematical models of the APOC of the sighting electronic control system, it is necessary to develop reliable mathematical models of fault-tolerant radio-electronic systems with combined structural redundancy and systems with a majority structure capable of reconfiguration, which are part of the considered sighting radio-electronic complexes.
6. To select and perform a comparative analysis of methods for constructing mathematical models of fault-tolerant systems, taking into account the aging effect and arbitrary distribution of the duration of the maintenance process, the reliability behavior of which corresponds to a discrete-continuous random process [9, 10].
7. Develop a methodology for constructing mathematical models of fault-tolerant systems, taking into account the aging effect, the reliability of which corresponds to a discrete-continuous random process.

The object of research is algorithms for searching and detecting targets of sighting electronic systems.

The subject of research is the efficiency indicators of algorithms for searching and detecting targets of sighting electronic systems (probability and average time of task completion).

The research methods used in the work are borrowed from the theory of radio-electronic systems and complexes, the theory of modeling complex systems, the theory of Markov random processes, and the theory of reliability.

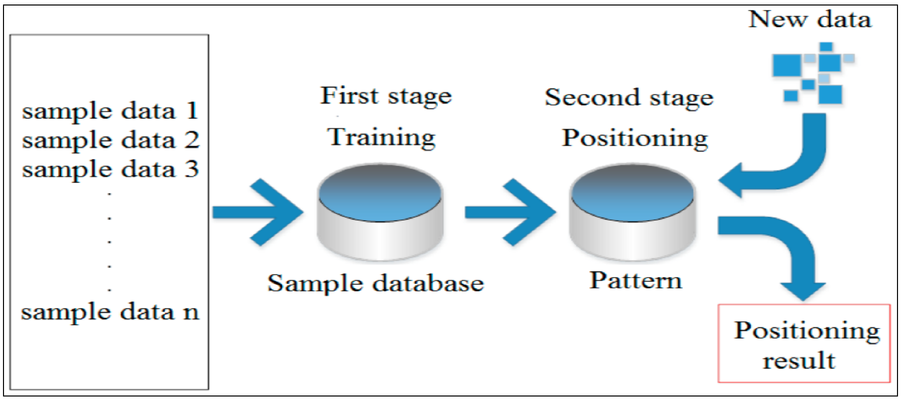

Fig 1: Data preparation

Scientific novelty of the results obtained

1. Based on the proposed extended description of states and the established list of defining parameters, the state space method was further developed in relation to the construction of mathematical models of algorithms for searching and detecting targets of sighting electronic systems. In the model constructed by an improved method, in contrast to the existing ones, a combination of functional and reliability aspects of designing algorithms for searching and detecting targets of sighting electronic systems is realized.
2. The logical-probabilistic method of constructing mathematical models of algorithms for searching and detecting targets of sighting radio-electronic systems has been further developed. A method for obtaining a logical-probabilistic model based on the representation of an object by a structural-automaton model is proposed.
3. Two new mathematical models of the algorithm for searching and detecting targets of an electronic sighting system have been developed. A characteristic feature of these models is that they are formed on the basis of a single formalized representation - a structural-automaton model.
4. To design fault-tolerant electronic systems with combined structural redundancy and a majority structure with reconfiguration, which are part of targeted electronic systems, new mathematical models have been developed. These models, unlike existing ones, make it possible to take into account various combinations of structural redundancy, the behavior of the system when malfunctions occur, the parameters of control, diagnostic and switching equipment, the type of maintenance, and the availability of spare parts.
5. A new method is proposed for formalizing the procedure for transition from a non-Markov type reliability model to a Markov model using the equivalent flow intensity method. This made it possible to automate the cumbersome procedure of transition from a non-Markov model to a system of Kolmogorov-Chapman differential equations.

Practical significance of the work

1. The mathematical model of the algorithm for searching and detecting targets of an electronic sighting system and the methodology for its construction, developed in this work, makes it possible to obtain the value of its performance indicators for the functional and reliability parameters of radio-electronic systems specified by the designer in case of inaccuracies in obtaining target designation and different levels of operator qualifications. At the same time, the model makes it possible to determine the influence on the performance indicators of radio-electronic systems of the sequence of use of radio-electronic systems when performing a task.
2. The proposed mathematical models of fault-tolerant structures make it possible to design radio-electronic systems that are designed to operate in a complex with a given level of reliability. The process of creating mathematical models and their analysis is automated, for which a specialized software package has been developed.
3. To assess performance indicators taking into account the aging processes of equipment and the arbitrary nature of maintenance procedures, a developed methodology for constructing models of fault-tolerant systems is used, which is based on the equivalent flow intensity method.
4. The results were implemented at the Lvov Radio Engineering Research Institute:

- Methodology for assessing the effectiveness of algorithms for searching and detecting targets of sighting electronic systems.
- Mathematical models of fault-tolerant systems with complex combined redundancy and systems with a majority structure capable of reconfiguration.
- Methodology for constructing mathematical models of fault-tolerant systems, the reliability of which after the occurrence of failures is described by a non-Markovian discrete-continuous random process.

Theoretical and practical results of the dissertation used:

- When performing state budget research work in the laboratory NDL-51 of the National University “Lviv Polytechnic”;
- In the educational process at the National University “Lviv Polytechnic” in the lecture course and workshop of the discipline “System engineering design of radio-electronic complexes”; in diploma design by students of the specialty “Radio-electronic devices, systems and complexes”.
- In the educational process of the college “Western Ukrainian Collegium” in the lecture course and workshop of the discipline “Reliability, control and operation of computers”; in diploma design by students of the specialty “Maintenance of computer and intelligent systems and networks.”

Mathematical model

Two mathematical models of the APOC of targeted RECs and a methodology for studying the effectiveness of variants of these algorithms are developed. The methodology was tested using the example of a specific sighting REC.

The first model is Markov in the form of a system of Kolmogorov-Chapman differential equations constructed using the state space method, the second is logical-probabilistic.

Obtaining a Markov model in the form of a system of differential equations and a logical-probabilistic model is carried out using a new technology, which involves two stages: at the first stage, a software model is created, and at the second stage, mathematical models are formed using the software model.

The first task solved in this section is the development of a structural automata model (SAM) of the APOC of the sighting REC. This model is necessary for a formalized representation of the modeling object, which allows us to obtain Markov and logical-probabilistic APOC models without known difficulties. For this purpose, CAM components have been developed: a state vector and a tree of modification rules.

The state vector (SV) is used to encode the space of states in which the target REC may be in the process of executing the task. In the known methods for constructing Markov models of EEC using the method of states and transitions, the model reflects only the reliable behavior of EEC. Based on the analysis of the functional and reliability behavior of the sighting REC in the process of searching and detecting a target, the following structure of the aircraft is proposed in the work: number of the operating block being executed; number of RES, which serves as a source of information; number of repeated calls to the target designation source; number of detection threshold gradations; number of target acquisition attempts; number of detection zones.

In the process of performing a task with an aiming REC, the state vector changes in a certain way. To display the actual changes and their sequence, according to the method of automated construction of Markov models, a tree of aircraft modification rules has been generated. To do this, the following subtasks have been solved: a set of events has been established, rules for forming a set of conditions have been developed, formulas for calculating the intensities of transitions have been developed, rules have been developed for the formation of formulas for calculating the probabilities of alternative transitions, and rules for modifying the state vector have been developed. The resulting CAM in the form of a BC and a tree of modification rules make it possible to construct a program model (APOC).

The Markov model in the form of a graph of states and transitions of the APOC of the targeted REK is formed from a list of states and a matrix of transition intensities, which are obtained as a result of compiling the program model. Based on the obtained transition intensity matrix, a system of Kolmogorov-Chapman differential equations is formed using formalized procedures. The solution of this system of equations gives the distribution of the probability of being in each state, from which the selected efficiency indicator is formed, in this case the probability of the complex completing the assigned task.

The second model of the APOC complex in this work was built using the logical-probabilistic method of trajectory modeling. This method allows you to determine the probability values and average time to complete a task. Estimation of the probability of completion and execution time of the APOC task is carried out using the transitive probabilities of alternative transitions pmn from the m-th block to the n-th. For this purpose, the APOC graph model is used, in which the vertices correspond to operational blocks, and the arcs correspond to transitions. If we provide each arc with values of the probability of transition along it pmn, then each route of the algorithm L can be associated with the probability of its existence and the travel time.

$$\mathbf{p(L)} = \prod_{(\mathbf{m},\mathbf{n}) \in \mathbf{L}} \mathbf{p_{mn}}, \quad (1)$$

$$\mathbf{T(L)} = \sum_{\mathbf{m} \in \mathbf{L}} \mathbf{T_{Bm}}, \quad (2)$$

Where TBm is the execution time of the mth operational block, which lies on this route.

In turn, the probability of RUV and the average time TUV of completing a task by a complex are determined as follows:

$$\mathbf{P_{yB}} = \sum_{\mathbf{L} \in \mathbf{L_{yB}}} \mathbf{p(L)} \quad (3)$$

$$\overline{\mathbf{T}}_{\mathbf{yB}} = \frac{1}{\mathbf{P_{yB}}} \sum_{\mathbf{L} \in \mathbf{L_{yB}}} \mathbf{p(L)} \cdot \mathbf{T(L)}, \quad (4)$$

Where LУB is the set of paths that lead to the block that records the execution of the task.

During the passage of each route, the values of probabilities and time are “accumulated” according to formulas (1), (2). At the moment of reaching the operating block, which symbolizes the completion of the task, the results in it are “reset” and a return to the last branch is carried out. In this operational block, the result is “accumulated” in accordance with formulas (3), (4). After passing through all possible routes LCS, we obtain the values of the probability of completing the task and the average time of completing the task under the given initial conditions.

Based on the created CAM, Markov and logical-probabilistic models, a methodology has been developed to study the effectiveness of options for constructing APOCs of targeted RECs, and thus the second problem has been solved. According to the methodology, the input data for constructing a model of the APOC of the sighting REC are: the composition and structural diagram of the sighting REC; parameters of the RES that are part of the RES; block diagram of the APOC complex; average times and variances of execution of each operational block of the APOC; probabilities of making a decision “YES” and “NO” for each comparison block of the APOC. The methodology for constructing models and studying the effectiveness of options for constructing APOCs involves the sequential implementation of the following points:

1) Formation of an equivalent APOC.
2) Formation of the CAM algorithm for searching and detecting targets for sighting RECs.
   1. Construction of the aircraft.
   2. Formation of many formal parameters.
   3. 3 Formation of many events.
   4. Formation of many conditions.
   5. Formation of formulas for calculating transition intensities.
   6. Formation of formulas for calculating the probabilities of alternative transitions.
   7. Formation of rules for aircraft modification.
   8. Formation of a tree of aircraft modification rules.
3) Construction of a Markov model of the APOC of the sighting REK.
4) Construction of a logical-probabilistic model of the targeted REC.

The developed methodology was tested in analyzing the effectiveness of a variant of constructing an algorithm for searching and detecting targets for the Afalina sighting system. A CAM, a Markov model with a limited state space (hereinafter referred to as model No. 1) and a logical-probabilistic model (hereinafter referred to as model No. 2) were built and studies of the targeted REC “AFALINA” were carried out with various initial data. Based on the research results, a quantitative assessment of the influence on the effectiveness indicators of the sighting electronic control system of the following factors was given: operator qualifications when entering the reported data and capturing targets on the screen; number of targets; hardware failures; inaccuracies in providing target designation (TS); method of obtaining the control center. The Markov model has 647 states and 1805 transitions. Based on the obtained model, a system of Kolmogorov-Chapman differential equations was formed. The procedures for generating and solving a system of differential equations are automated.

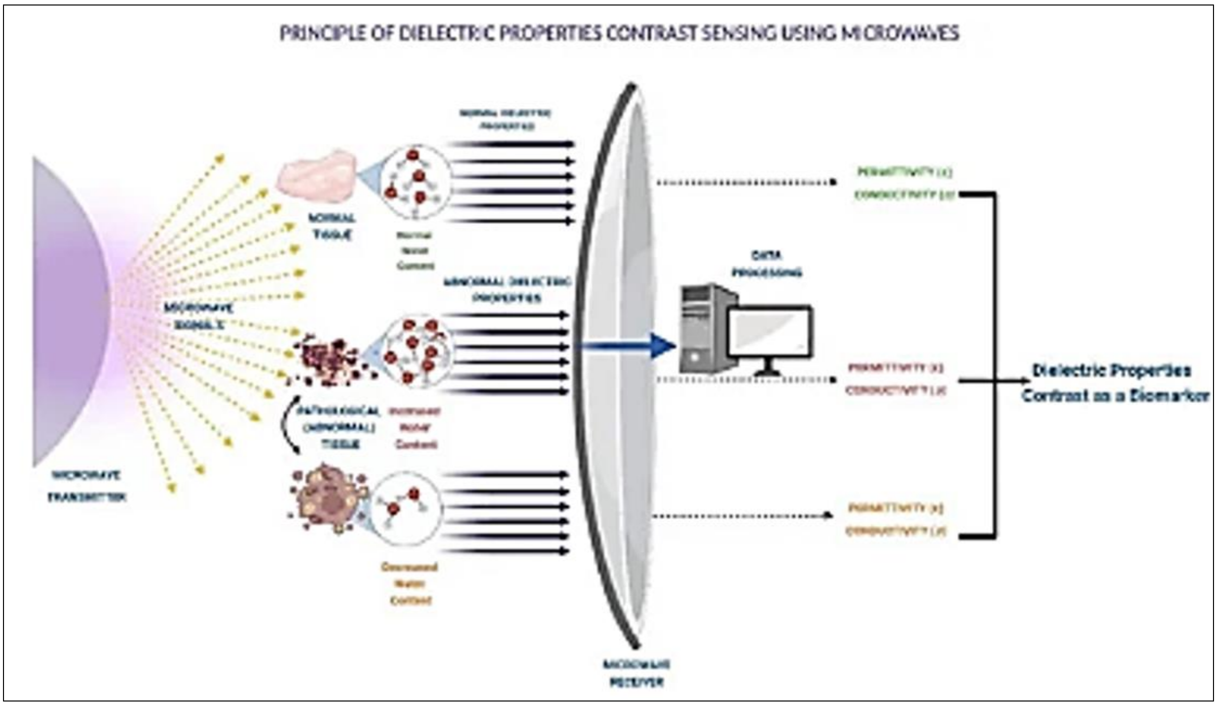

Fig 2: The principle of measuring dielectric characteristics contrast using microwaves.

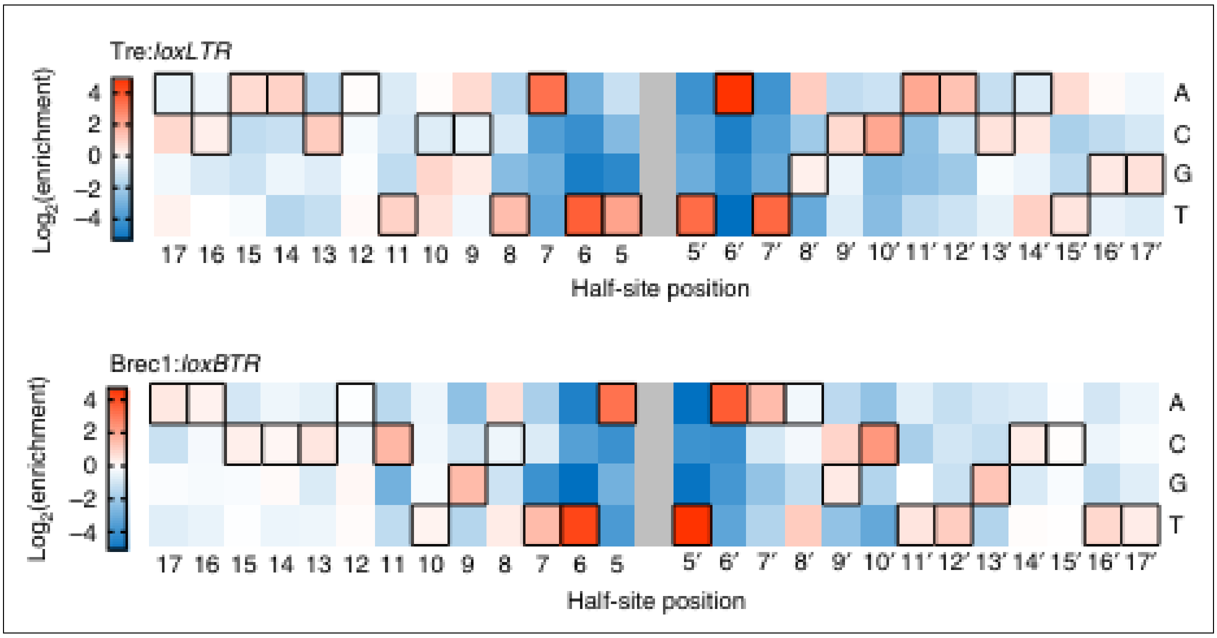

Fig 3: (a) the radiation propagate in the loxl (b) radiation in brec 1

Conclusion

The sighting radio-electronic complex (REC) is specifically designed to identify, designate, capture, track, and compute the projected movement trajectory of a target, while also transmitting the necessary information to the equipment responsible for destroying the target. The goal electronic control system is designed to effectively carry out its assigned work even when subjected to external natural and artificial interference, as well as in the case of malfunctions and equipment failures. Thus, the REC encompasses a wide range of radio-electronic systems (RES) of different varieties. The process of using the information supplied by the REC in order to accomplish a job establishes the target search and detection algorithm (TSA) of the sighting REC. Developing this algorithm is a crucial effort during the system engineering stage of designing such complexes.

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