The concept of digital description of structural elements of technical systems

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Abstract. The paper presents the concept of a new approach to describing the elements of technical system structures, which provides new opportunities for increasing the level of automation of this information processing. This helps to improve the conditions for the initial stages of technical systems development, which relate to the synthesis of their structures and schemes and can currently be carried out only by humans. The paper proposes a methodology for forming a digital description of the characteristics of structural elements that can be combined into a single structure of a certain technical system. This description is based on the creation of a multidimensional vector, which can be further processed using appropriate mathematical tools, and therefore provides the possibility of automating the processing of this information. A methodology for forming vectors of description of structural elements of technical systems is proposed in accordance with the needs of their effective use in algorithms implemented by computer programming. The presented approach creates prerequisites for automating the processes of creating structures of technical systems, classifying technical systems, efficient storage in the form of a database, efficient search by a large number of features, etc.

Keywords: Structure of Technical System, Formal Description, Prerequisites for Automation.

1 Introduction

Existing computer-aided design systems for technical systems are not suitable for use at the initial stages of technical system development, particularly in the selection of the principle of operation, the development of structure, and schemes. In existing computer-aided design systems, there are some limited opportunities to simplify the development of a design, consisting of the developer's selection of only individual elements from catalogs, which are usually filled with standard elements. Thus, we can say that the existing computer-aided design systems do not automate the development of technical systems as a whole, but are an effective tool for the developer to calculate the parameters of technical system elements and their functioning. At the same time, the developer ensures that all, and in particular the initial stages, of the development of technical systems are carried out by applying his knowledge, skills, and abilities, and only at the final stage is it possible to use a computer-aided design system.

There is currently no possibility of automating the initial stages of technical system development, and in particular, structural and circuit synthesis. This is due to the lack of ways to describe the information used at these stages in a formalized manner, and in particular in a form that allows the use of computers. Solving this problem will contribute to the creation of a system for automating the development of technical systems in general.

2 Literature Review

In [1] many approaches to increasing the level of creativity are considered, but the aspects of their application to technical systems are not specified. Aspects of the application of creative thinking are discussed in [2], but ways of formalizing this process are not indicated. In [3] three steps of the innovative logic process are proposed, but the problem of the initial stages of innovative technical development is not highlighted. The paper [4] presents interesting approaches to evaluating realistic sets of ideas implementing heterogeneous numbers of attributes. In research [5] estimated relations exist between functionality, novelty, usefulness, and overall creativity, which confirms the special importance of the first stages of the development of a new object. An approach for evaluating novelty in the context of creating an object with new characteristics is proposed in [6], but methods of formal description are not presented. In [7], approaches for engineering design ideation incentives are considered, but at the same time, the possibility of a formalized description of these processes is not provided. A semantic network for engineering design ideation incentives has been developed [8] but there are no options for using them for automation. In research [9], the main aspects of design patterns for machine learning are considered, which indicates the promising development of this direction to improve human performance in intellectual work. Paper [10] also presents the development of machine learning methods for increasing the efficiency of the technical system. [11] presents approaches to automation for the creation and research of structures of complex materials, which indicates the expediency of the spread of automation for the creation of structures of engineering objects. In [12] the possibilities of creating mechanisms by using a formalized description of structural elements are shown, but the proposed approach is unsuitable for implementation using a computer. Paper [13] demonstrates the possibility of developing the structures created in paper [12] to the level of designs with defined parameters. The strategy of product conceptual design is discussed in [14] but there are no proposals for automating this process. In work [15] the method of heuristic synthesis of layout for technical systems is presented, but the possibility of a formal description of the information used at this stage of creation has not been demonstrated. In a paper [16], it was noted that human intuition and engineers' experience still heavily influence the early stages of technical system design. To reduce dependence on it, it is advisable to automate the development process of the initial stages of creating technical systems. In [17], an automatic algorithm for topological structural synthesis of kinematic chains is proposed, but the development of the methodology, which makes it possible to describe the structural elements of the mechanisms, is not

presented. In work [18], the method of generating the structural spectrum of the open kinematic chain by matrix mapping is developed. At the same time, there is no information in the work about the possibility of a formalized description of the elements of technical systems that enable the use of automation tools. In [19] digitization method for the creation of mechanism structures with only rotating links is considered.

The revealed material indicates the expediency of developing new approaches to the development of technical systems at the initial levels of their creation and, in particular, the development of their structures. In particular, the issue of a formal description of the structural elements of the technical system, which makes it possible to automate the processing of this information, needs to be resolved.

3 Methodology for Forming a Digital Description of the Characteristics of Structural Elements of Technical Systems

3.1 Purpose and Objectives of the Research

The research aims to develop a methodology for the digital description of the structural elements of technical systems. This creates new possibilities for automated information processing used at the initial stages of technical systems development and, in particular, at the stage of synthesis of their structures.

To accomplish the goal, the following tasks should be done:

– to develop the principles of using the criterion space to describe the elements of technical system structures;

– to identify the possibilities of using a vector representation of structural elements to describe technical systems.

The object considered in this research is a typical structure of a technical system in general. The subject considered in this research is the regularities of representation of characteristicsдо of structural elements of technical systems in a general criterion space. The main hypothesis of the research is the possibility of forming a formalized description of the structural elements of technical systems in the form of a standardized digital code suitable for use in the operations of creating the structures of technical systems. The assumptions in the research relate to the sufficiency of the description of the structural element in terms of the number of characteristics available for detection and processing under the given design conditions. In order to simplify the explanations, the materials present the idea of the description of technical systems of different types by using a set of criteria with the same structure. Limitations in the application of the proposed approaches are the ability to achieve the required level of detail in the description of structural elements in certain conditions.

3.2 The Concept of Multicriteria Space for Representation of Structural Elements Characteristics

The initial stage in the development of the multicriteria space for the representation of the structural elements is the formation of a set of description criteria that meet the

requirements of detail and ambiguity in the representation of the elements of a certain type of technical system. It is useful to use a certain structure in the representation of characteristics, which involves dividing this series into groups within which sections and other sequences of a lower order are distinguished. Each of the elements of such a sequence can forms a dimension n_i of a certain multicriteria space (Fig. 1).

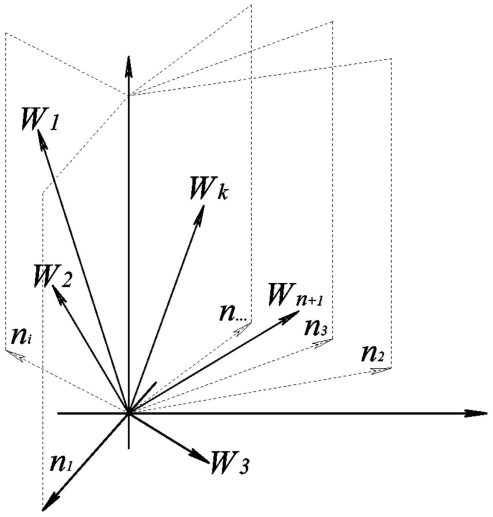


Fig. 1. Multidimensional criterion space for representing structural elements

The proposed principle of formal representation of the structural elements of technical systems is to create a multidimensional numerical sequence that reflects a digital description of each of the selected criteria for describing structural elements in a certain range of values. Several approaches can be used for this purpose, including the use of different ranges of numerical values. Ones of the most convenient are the ranges from 0 to 1 and from -1 to 1.

3.3 Formation of a Multi-bit Digital Vector to Describe a Structural Element

The dimension of a numerical sequence, that is, the number of positions it contains, corresponds to the number of criteria by which the structural element is described. The set of such criteria can be created in accordance with the needs of designing a certain type of technical systems or, more generally, since it is possible to include a wide range of criteria. The number of these criteria has no strict limitations and can be determined in terms of the degree of detail (accuracy) of the digital representation of the technical system element and the computing power of computers. That is, for the possibility of implementing this approach when creating computer-aided design systems, it is advisable to limit the value that corresponds to the maximum capabilities of computer technology for the effective processing of numerical data presented in the form of digital series describing the vector W_k (Fig. 2).

	cluster 1				cluster 2			cluster 3			cluster ….			
W_k	n_1^{k1}	n_2^{k1}	n_3^{k1}	...	n_1^{k2}	n_2^{k2}	...	n_1^{k3}	n_2^{k3}	...	$n_1^{k...}$	$n_2^{k...}$	...	$n_i^{k...}$

Fig. 2. The variant of a general structure presentation of a structural element W_k in the form of sequence of values n in the amount of i.

It is proposed to form a digital description of a structural element of a technical system by indicating the relative value of each of the selected characteristics corresponding to a certain dimension n_i of an imaginary multidimensional criterion space (Fig. 1). That is, it forms the coordinates of a certain point W_k in this space. The absence of a characteristic for a particular criterion means a score of zero, and the presence of its maximum possible value (100%) corresponds to a value of 1. For example, it is possible to assess the structure of energy losses (not used to ensure the main function of the system) during the functioning of a structural element when some part of them, for example, 50%, will be carried out through the release of thermal energy, and this criterion will be expressed by the number 0.5, and other types of losses can be noted in other criteria. Thus, the representation of the characteristics of a structural element can be carried out by forming a vector whose origin is located at the zero point of the criterion space and whose end is at the point with a set of coordinates W_k.

Using the proposed approach to describing structural elements makes it possible to represent the structure of a technical system as a sequence of vectors (Fig. 3). The principle of combining structural elements into a single effective system requires that the inputs of a certain structural element be compatible with the outputs of the previous one. Fulfillment or verification of the specified conditions can be carried out by determining the degree of similarity (according to certain key characteristics) of vectors of adjacent structural elements.

W_1	n_1^{11}	n_2^{11}	n_3^{11}	...	n_1^{12}	n_2^{12}	...	n_1^{13}	n_2^{13}	...	$n_1^{1...}$	$n_2^{1...}$	...	$n_i^{1...}$
W_2	n_1^{21}	n_2^{21}	n_3^{21}	...	n_1^{22}	n_2^{22}	...	n_1^{23}	n_2^{23}	...	$n_1^{2...}$	$n_2^{2...}$	...	$n_i^{2...}$
W_3	n_1^{31}	n_2^{31}	n_3^{31}	...	n_1^{32}	n_2^{312}	...	n_1^{33}	n_2^{33}	...	$n_1^{3...}$	$n_2^{3...}$	...	$n_i^{3...}$
W...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
W_k	n_1^{k1}	n_2^{k1}	n_3^{k1}	...	n_1^{k2}	n_2^{k2}	...	n_1^{k3}	n_2^{k3}	...	$n_1^{k...}$	$n_2^{k...}$	...	$n_i^{k...}$

Fig. 3. The variant of a representation of the technical system structure by a sequence of vectors.

4 Results and Discussion of the Possibilities of Using Vector Representations of Structural Elements for the Development of Technical Systems

One of the proposed mathematical tools that makes it possible to determine the relative position of the vectors W_k describing the structural elements in a multicriteria space, and hence the degree of their similarity, is the cosine similarity of the vectors. This is a relationship that expresses the cosine of the angle between vectors and fol-

lows from the scalar product formula. That is, when the ends of vectors coming from the same point are close, the angle between them will be small, and the value of its cosine will tend to be one. This makes it possible to take into account not only the distance between the ends of the vectors but also their relationship to their length.

In the proposed multicriteria space (Fig. 1), the angle θ between the vectors (for example $\overrightarrow{W_1}$ and $\overrightarrow{W_2}$) representing the respective structural elements indicates the similarity of their characteristics. According to the formula for determining the scalar product of vectors $\overrightarrow{W_1} \cdot \overrightarrow{W_2} = |W_1| \cdot |W_2| \cdot \cos\theta$. It follows that,

$$\cos\theta = \frac{\sum_{j=1}^{i} W_i^1 \cdot W_i^2}{\sqrt{\sum_{j=1}^{i} (W_i^1)^2} \cdot \sqrt{\sum_{j=1}^{i} (W_i^2)^2}}, \quad (1)$$

where $W_i^1 - i$-th coordinate of vector 1, $W_i^2 - i$-th coordinate of vector 2, $i -$ number of coordinates, $\theta -$ angle between vectors $\overrightarrow{W_1}$ and $\overrightarrow{W_2}$.

Cosine similarity always belongs to the interval [-1, 1]. That is, if two vectors W_1 and W_2 are proportional their cosine similarity equal 1. Two orthogonal vectors have a similarity of 0, and two opposite vectors have a similarity of -1. In some contexts, the values of the vector components cannot be negative, in which case cosine similarity is limited to the interval [0, 1]. For example, in information retrieval and data mining, when a system is matched with a digital description in the form of a set of digital data, cosine similarity provides a useful measure of how similar two systems may be in terms of their functional characteristics, regardless of the size of the system description (the size of the digital representation).

The proposed digital representation of structural elements allows applying a wide range of rules and regularities of mathematics related to the processing of information in the form of vectors and matrices (sets of numerical series). In other words, the structure of a technical system can be represented as a sequence of vectors W_k describing the sequence of its structural elements. The digital representations of the structural elements of technical systems form a database that enables efficient storage, copying, and automatic search for information about a large number of existing structural elements.

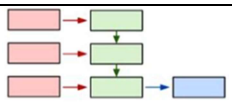
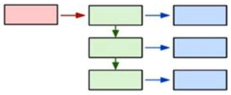
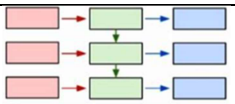
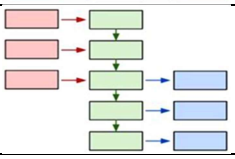
The presented dependence (1) provides advanced possibilities for automating the process of selecting structural elements represented in the form of vectors in accordance with the proposed methodology. In particular, determining the similarity of vectors representing structural elements by determining their cosine similarity makes it possible to effectively process numerous structural elements to identify the required level of their similarity.

One of the most promising options for processing information represented in the form of vectors is the use of neural technologies. Table 1 shows some types of neural networks used to process sequences of vectors. This information is considered in the context of the possibility of processing a sequence of vectors that reflect the structure of a technical system.

For the possibility of approximately identifying the similarity of vector characteristics without the use of mathematical calculations, a variant of their visual representation is proposed (Fig. 4). On the images, a sequence of characteristics (attributes) n_i^k

is laid out along the horizontal axis, according to which the structural element is described, each of which is a dimension n_i of the criterion space and a component of vector W_k. The vertical direction of the images shows the values of each characteristic n_i^k of vector W_k.

Table 1. Application of certain typical operations performed by neural networks for the processing of information of vector description of technical systems.

Type of neural network structure	Typical types of information processing in the form of vectors by neural networks	Variant of the result of processing the vector description of technical systems
From sequence to one		A technical system signifier as a complex unique feature for classification and search.
From one to a sequence		A detailed description (including verbal) of the technical system in accordance with the provisions of the classification.
From sequence to sequence		Formation of technical system analogues that differ in quantitative characteristics.
From sequence to sequence		Formation of analogues of a technical system that differ in quality characteristics

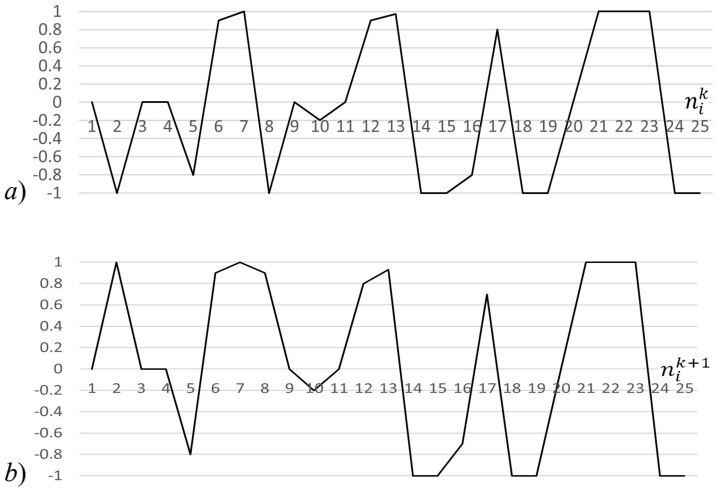


Fig. 4. Examples of graphical representations of the structural elements for the purpose of their visual comparison: a) representation of vector W_k; b) representation of vector W_{k+1}

Based on the presented graphic displays (Fig. 4), by visual comparison, it is possible to make an approximate assessment of the similarity of the characteristics of the corresponding structural elements. Also, with a certain level of experience it is possible to make an approximate classification of structural elements.

5 Conclusions

To enhance the possibilities in solving the problem of automation of the initial stages of development of technical systems and, in particular, structural and circuit synthesis, a new approach is proposed that provides a formalized description of the parameters of structures and circuits in a form that allows the use of computer technology to automate the processing of this information. This approach provides for the creation of a digital description of each of the structural elements and, as a result, makes it possible to create a database containing a digital representation of the existing known structural elements. This provides new and expanded opportunities to improve the efficiency of using information to automate the process of developing new technical systems.

Further research on the use and development of the proposed approaches will focus on the development of algorithms for processing vector representations of structural elements of technical systems. In particular, it is planned to develop an algorithm that provides the possibility of choosing a structural element in accordance with the sequence of already existing ones from the point of view of their compatibility.

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