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Application of the Cognitive Load Indicator of a Graphic Element to Justify the Requirements for a Long-Range Discrimination Radar Visualization System.

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Abstract

The article presents the results of a study on the use of an indicator of cognitive load on the operator of a long-range discrimination (LRD) radar when interacting with the graphic element of the visualization system of the LRD radar under the influence of destructive factors.

An original method for substantiating the requirements for the structure of a visualization system is proposed, based on combining the principles of the theory of engineering psychology, ergonomics, cognitive graphics, taking into account the cognitive resources of the radar operator.

The technique is formalized in the form of a problem of minimizing a general criterion characterizing the efficiency of operators and their capacity for information in the "man-machine" system, taking into account the cognitive load indicator.

It is shown that the use of the indicator makes it possible to justify the requirements for the structure of the visualization system, namely a graphical interface that can reduce the influence of negative factors on the operator of the radar station, especially under strict time constraints.

The results of a computational experiment to evaluate the effectiveness of using the cognitive load indicator when choosing a graphic element of a visualization system are presented, demonstrating an increase in the functional characteristics of the radar operator when performing tasks.

Keywords: visualization system, graphical interface, cognitive load, cognitive graphics, early warning radar.

1. Introduction

A long-range discrimination radar (LRD) is a complex ergatic system [1]. The LRD radar performs continuous surveillance of near-Earth space. The level of digitalization of modern radars leads to an increase in the flow of technical and background-target information processed by radar personnel - operators. In addition, the development of rocket and space technology, the improvement of information and telecommunication technologies, as well as the mass introduction of intelligent algorithms and systems lead to a significant complication of the technical component of the radar during its operation [2-6]. Therefore, from the point of view of the operation of the station, it is necessary to take into account the peculiarities of the operation of the operators of the radar, as an integral part of the entire system.

The performance of a radar operator is affected by negative factors of various natures (Fig. 1). Three main groups of factors can be distinguished:

- related to control of the background-target environment;
- related to monitoring the technical condition of radar systems;
- cognitive load of the radar operator.

Since operators receive about 90% of the information about the operation of the radar through the visualization system (graphical interface), the greatest impact of negative factors occurs precisely when interacting with the graphical interface, which leads to an increase in the cognitive load on the operator and a decrease in the efficiency of task performance.

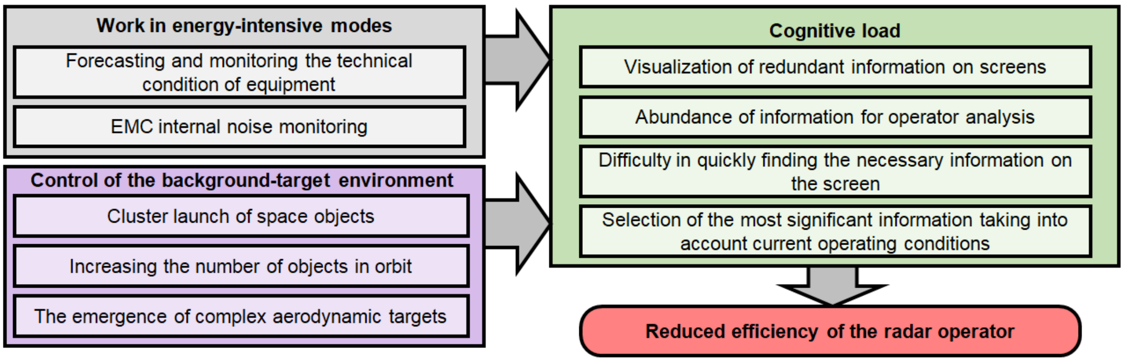

Fig. 1. The influence of negative factors on reducing the efficiency of the radar operator

Cognitive load (CL) refers to the difference between the cognitive demands of a task and the operator's available cognitive resources. The cognitive resources of a radar operator are the ability to maintain concentration while performing work: this includes the use of memory (operative and long-term), the speed of reaction to both the target background environment and the monitoring of the technical condition of the radar, which includes monitoring emergency situations.

Among the negative effects caused by the high cognitive load on the operator are:

- the increase in the number of mistakes made;
- the reduction in the speed of reaction and interaction.

At the moment, there is an active development of technologies that have a direct impact on the growth of the flow of targets [7]. Table 1 shows the influence of background-target environment factors on the radar.

Table 1. Influence of negative factors of target flow on radar

Negative factor	**Effect on radar**
An increase in the number of objects in low-Earth orbit (more than 100 thousand by 2030), including the emergence of complex aerodynamic targets	Redundancy of information for visualization, deterioration in the quality of target tracking under the influence of passive interference, issuing false information to the operator, reducing the operator’s time resource for making decisions, the need for constant monitoring of the technical condition of the radar when operating in an energy-intensive mode.
Cluster launch of space objects (Starlink)	Close-flying targets (“trajectory confusion”), increasing the likelihood of issuing false information to the operator

Research in the field of visualization systems [8-12], carried out by foreign companies, made it possible to develop a list of requirements for the tasks of a visualization system for radar systems in modern conditions of a more complex space environment:

• the presentation of information to operators in three-dimensional form for unambiguous perception;

• a three-dimensional visualization of the space situation with a complete display of the dynamics of objects near space;

• increasing the speed of information perception by displaying intense information on a large LCD screen;

• the development of new ways to visualize multidimensional information, taking into account the experience of the gaming industry.

The latter requirement is due to the fact that many foreign companies use the experience of the gaming industry, in particular the experience of developing a convenient and ergonomic graphical interface, when upgrading existing monitoring systems [13]. This is due to the fact that the creation of game graphical interfaces is based primarily on clarity and ease of use, as well as the large size of the group of respondents.

Thus, these requirements determine the relevance of developing a new methodology for substantiating the requirements and structure of the visualization system for the LRD radar based on the cognitive load indicator.

2. Approaches to justifying the structure of a radar visualization system

Based on the information provided to operators [14, 15], the main criteria for the quality of a radar visualization system will be:

• the time required to make a decision in each of the possible situations, including emergency ones;

• the difficulty of mastering, intuitiveness and convenience of the graphical interface for the station operator;

• the clarity and the sufficiency of the displayed information in the context of the situation;

• the number of possible places for involuntary operator errors when interacting with the graphical interface.

The second and third criteria can be meaningfully combined into one general one - cognitive load when interacting with the visualization system.

At the moment, there are 3 main approaches to justifying the structure of a visualization system: cognitive graphics [16], engineering psychology and ergonomics [17], and a mixed psychological approach [18].

According to [16], cognitive graphics is a set of methods for processing and visualizing multidimensional information in the form of compact images (cognitive images) designed to accelerate understanding of the current situation. The formalization of this technique is the maximization of the functional Φ(G), which is described by the parameters of the selected cognitive image, taking into account the weighted assessment of the parameters by experts:

$$\Phi(G) = \Sigma \lambda_i \Phi_i(G), \tag{1}$$

where G is a cognitive-graphic representation of the situation, defined by the triple $<V, D, L>$, where V is the set of indicators (visual signals), D is the relative arrangement of indicators, L is the set of hierarchy levels in the system of cognitive images [16]. Visual signal V = <C$olor$, $Form$, $Size$, $Position$, $Change$, $Orientation$ >, where $Color$ – color, $Form$ – shape, $Size$ – size, $Position$ – position, $Change$ – change in time, $Orientation$ – spatial orientation. Parameters λ are weighting coefficients determined empirically for various images and various situations.

The key advantages of cognitive graphics are:

• consideration of such information characteristics as the amount of information processed, its value, redundancy, informativeness, richness;

• consideration of the characteristics of information perceptibility: clarity, selectivity, simplicity, interpretability, conciseness, structure and integrity.

The second approach is to clarify the patterns of human activity in receiving, processing and transmitting information in the "man-machine" system based on engineering psychology [17]. When developing the structure of the visualization system, a study of deviations from the criterion is carried out

$$N = t \cdot \xi, \tag{2}$$

where t is the time required to solve the problem, ξ is the number of errors during the task execution. Since this technique is based on engineering psychology, at the moment it is the main one in justifying the structure of a radar visualization system, since it takes into account the key parameters of the quality of the radar operator's work [15].

The third approach is based on combining the methods of Gestalt psychology, eco-psychology, cognitive psychology and spatial psychology in substantiating the structure of the visualized object. The key advantage of this approach is a qualitative account of how convenient it will be for the radar operator to interact with the graphical interface, since the general psychological characteristics of a person are taken into account when justifying the structure.

However, the above approaches do not take into account the specifics of the functioning of the LRD radar: the need for prompt and correct decision-making under the influence of new destructive factors. The influence of cognitive load on the radar operator is an important criterion for this need.

Thus, when designing a visualization system for a radar station, it is necessary to use an improved methodology for justifying the requirements and structure of the visualization system, based on the joint use of cognitive graphics, engineering psychology and taking into account the cognitive load on the operator.

3. Formalization

The methodology is based on the general criterion N of the operator's work, based on the performance indicators of the operator of the radar station [15]: timeliness (the probability of the operator solving a problem within a certain time interval) and correctness (the number of correctly performed actions to the total number) of decision-making.

In formalized form, the task of choosing the optimal structure of a visualization system provides a solution to two subtasks: minimizing the criterion for the success of completing a task, as well as controlling the amount of information flow when performing a given task. The first subtask is based on the method of engineering psychology and has the following form:

$$N_k = \min(\tau(Z, G) \cdot \pi(Z, G)), \tag{3}$$

where N_k is the general criterion for the kth problem; τ is the time to solve the kth problem, which acts as an indicator of timeliness and depends on Z – the competence characteristics of the radar operator and G – the cognitive characteristics of the visualization system; π is the probability of making a mistake when performing the necessary actions, which serves as an indicator of the correctness of decision-making. The requirement to minimize the general criterion is based on the requirement to reduce the time to complete a task, as well as reduce the likelihood of making an error when performing it. In the general case, the problem is a search for the minimum of a complex two-dimensional function. One of the features of this subtask is the search for a global minimum.

Improving work efficiency comes down to minimizing the N criterion, but it is also important to take into account physiological limitations. A person has limiting values of perceived information [19-21], which impose restrictions both on the time it takes to complete a task and on the likelihood of making a mistake. For this reason, the second subtask in formalized form has the following form:

$$\Delta I(t) = I_{tot}(t) - I_{ts}(t) \geq 0, \qquad \forall t \in [0, \tau] \tag{4}$$

where I_{ts} is the flow of information received by the operator from various sources, including the visualization system; I_{tot} is the flow of information processed by a person, which is determined by the following formula:

$$I_{tot}(t) = \int_0^t j(T, CL(x), x)dx, \quad (5)$$

where j is the "throughput" of humans, the participation of memory in information processing (according to [22], 10-50 bit/s for practiced actions to the point of automaticity, 0.5-5 bit/s for RAM, 0.04-0.2 bit/s – for long-term); T is the problem being solved by the operators; CL – cognitive load on the operator; t – time of interaction with the visualization system. It is impossible to determine the exact value of cognitive load, since this is a subjective assessment obtained after the work done, however, it can be considered as the value of CL(x), which describes the upper limit j of a person's "throughput" for visualized information. In this case, to estimate this value, its maximum value – the maximum drop in a person's "throughput" – will be sufficient.

It is important to consider the direct connection between these two subtasks. Figure 2 shows graphs showing the dependence of information flows on task completion time. As can be seen from the graph in Figure 2A, the less time the operator has to complete a task, the more information per second he needs to provide and process, which leads to the formation of a cross on the graph - when the flow of information processed by the operator is less than the flow coming from the imaging system. Graph 2B also shows a generalized graph of the dependence of the probability of making at least one mistake on the time given to complete the task. This graph also takes into account the dependence on the operator's competencies, since the more experience he has, the more often he relies on reflexes, which significantly reduces the likelihood of an error.

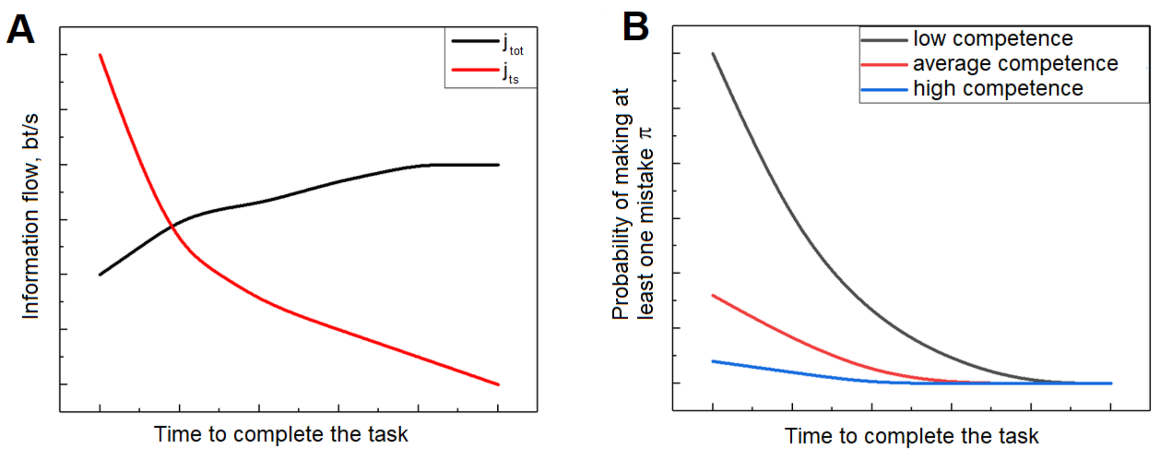

Fig. 2. A) graph of the dependence of the flow of information on the time to complete the task; B) a graph of the probability of error depending on the time to complete the task.

Thus, to determine the structure of a visualization system that can reduce the influence of negative factors and increase the efficiency of the operator's task, it is necessary to take into account not only the general criterion, but also the operator's ability to perceive information.

4. Calculation of the cognitive load of graphic elements

Cognitive load is calculated using the NASA Target Load Index (NASA-TLX) [23]. This is a subjective, self-reported set of scores and is not an objective measure of workload that should be measured using objective metrics that test the product of the speed and accuracy of operators performing a task, but it does provide a measure of how useful the GUI is for performing certain tasks. The calculation is carried out using the following formula:

$$CL = a_1MD + a_2PD + a_3TD + a_4F + a_5E + a_6P, \quad (6)$$

where:

- **MD – mental demands** (What mental and perceptual activity was required?);
- **PD – physical demands** (What physical activity was necessary?);
- **TD – time demands** (How much time pressure was felt due to the pace of task completion or task elements?);
- **F – frustration** (How strong were the irritation and tension during the task?);
- **E – effort** (How hard you had to work (mentally and physically) to achieve the level of performance);
- **P – performance (How successfully did you complete the task?);**
- **a1 – a6 –** weighting coefficients determined empirically for similar problems

All parameters in the NASA target load are determined experimentally based on a survey of several groups of people taking part in the experiment.

An experiment was conducted: a comparison of two different graphic elements of the visualization system. For this purpose, a classic drop-down menu was chosen based on standard programs implemented in the Windows OS, as well as a new radial menu based on data from [16] of the already used graphical interaction interface. Figure 3 shows a general view of the radial menu, the classic drop-down menu and their extended versions.

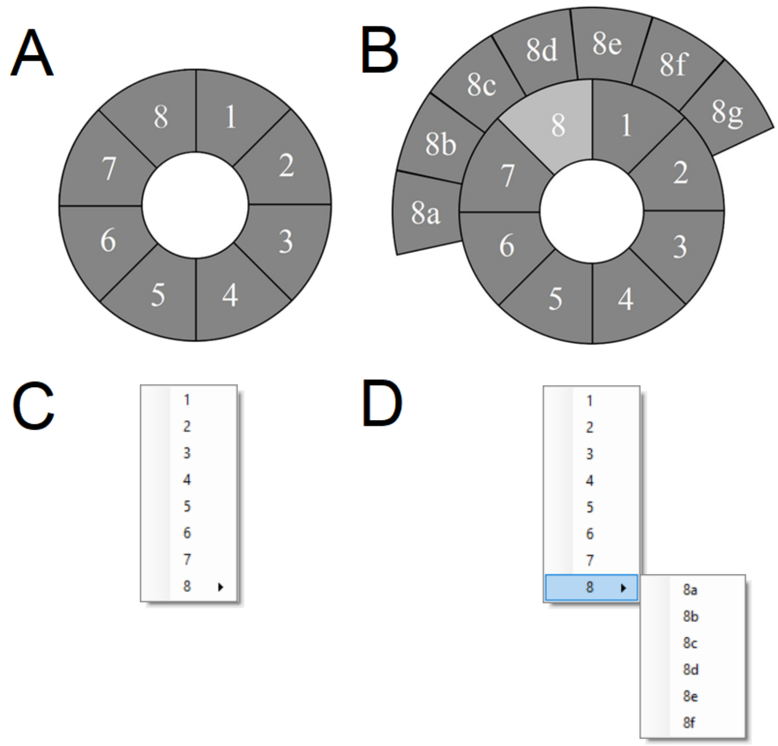

Fig. 3. A) Radial menu; B) expanded radial menu; C) classic drop-down menu; D) advanced drop-down menu.

Works [24, 25] showed the advantages of a radial menu in comparison with other types of implementation of visualization system elements. In particular, it was shown that the cognitive load for the circular menu type was lower than for the others: in particular, the indicator of mental demands for the circular menu was on average 10% lower than for the other menu types. In addition, the circular menu corresponds to the cognitive image of a "target" [16]. This visualization method clearly represents the dynamic changes in the displayed parameters, allows you to organize observation objects and cluster them according to various criteria, and display additional dependencies of the observed objects.

Based on the above results, 5 different test tasks were prepared, consisting of sequential pressing of certain buttons, which were formalized from the point of view of the GOMS approach [26], which allows you to estimate the required time to perform certain elementary actions when interacting with the interface. The tasks were a sequence of actions by operators in various situations, in particular emergency ones, performed when interacting with the graphical interface in accordance with the regulations. The tasks were compiled by experts who formulate standard tasks for training and testing operators on training facilities (TF) from the DL radar.

10 operators (5 experienced and 5 undergoing training) took part in the experiment. Each of them performed tasks on the training center, after which they assessed their cognitive load using the NASA-TLX method. The correctness of actions was verified as part of operator testing at the TF.

Figure 4 shows graphs comparing task completion times calculated in accordance with GOMS for a standard drop-down menu and for a radial menu (Figure 4A). The probabilities of making at least an error when performing certain actions were also assessed (Figure 4B), and the general (complex) criterion N was also calculated (Figure 4C).

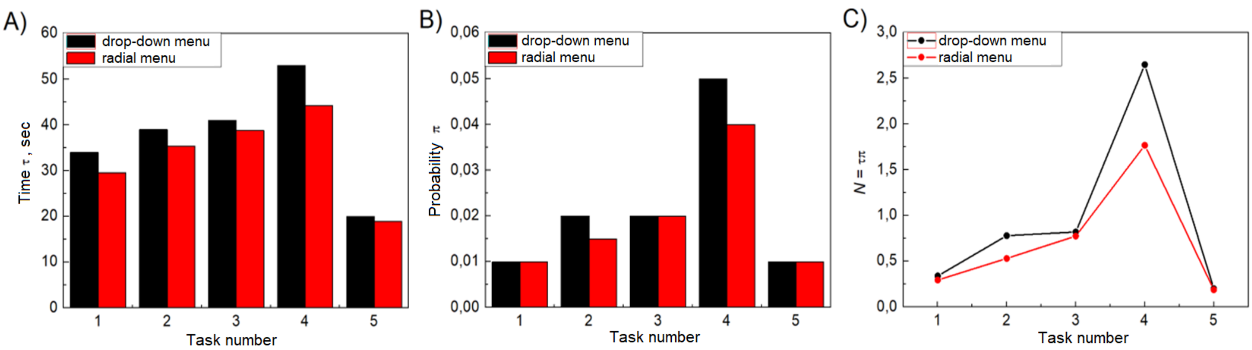

Fig. 4. Comparison of the effectiveness of operator's interaction with a drop-down menu (black) and with a radial menu (red) when performing tasks.

As can be seen from the graphs, the radial menu allows you to reduce the overall time for completing tasks by reducing the number of actions to move the computer mouse, and also slightly reduce the likelihood of making an accidental error. As can be seen from the graph of the dependence of the general criterion on the task number (Figure 4C), for some tasks the use of the radial menu does not provide any visible improvements, however, for other tasks there is a decrease in the criterion, which indicates a more effective interaction with the graphical interface.

Thus, taking into account the cognitive load and the characteristics of cognitive graphics allows us to develop a graphical interface that increases the efficiency of task completion: reducing the time it takes to complete a task and reducing the likelihood of an operator making an error.

5. Conclusion

This article substantiated the relevance of improving the visualization system of the LRD radar. The application of the proposed methodology for substantiating the requirements for the structure of a visualization system allows us to take into account both the perceptibility characteristics of graphic elements and the ability of operators to perceive information based on their competence characteristics, which makes it possible to create a visualization system that is more convenient and understandable for interaction.

The following areas of research for the development of a universal intelligent graphical interface for DL radar operators can be identified:

1) development of a new universal cognitive image of the technical condition of the radar station, which makes it possible to detect malfunctions and equipment failures in the operation of its subsystems using modern technologies;

2) development of an intelligent graphical interface architecture to support control decision-making by the operator of a remote radar station based on the analysis of multimodal

semi-structured information, capable of processing graphic and text information, and speech commands of a human operator.

As a recommendation for developing a graphical interface, the authors of the article offer:

1) generate a list of graphical elements of the visualization system with the best cognitive characteristics (visuality, selectivity, simplicity, interpretability, conciseness, structure and integrity) in conditions of high cognitive load on radar operators;

2) take into account the professional and competence portraits of operators when forming the structure of the graphical interface through the implementation of a hint system

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