Characteristics of visual search in the system ”man-display”

N M Novikova
Department of Applied Mathematics, Informatics and Mechanics, Voronezh State University, 1, University Square, Voronezh, 394018, Russia
E-mail: nov.nelly@gmail.com

Abstract. The quality and reliability of the functioning of the man-machine control systems, that is, systems where the human operator is a part of their control loop, largely depends on his/her psychophysiological characteristics. Man-machine systems are designed to control complex technical objects and systems, technological processes and aviation traffic. Malfunction of these systems can lead to human losses and manmade disasters. Therefore, it is important to study the work of a human operator in such a system. One of the most important functions performed by a human operator is a visual search for objects displayed on the screen. The dependencies of the probability of detection of the object on its contrast with the background, the background luminance, the size of the object and the search time were first investigated and obtained by the author as a result of the experiments. These characteristics of visual search allow us to optimize the work of the human operator. The obtained results can be used in the design and evaluation of the efficiency of the ”man-display” systems.

1. Introduction
In modern intelligent control systems, the main function of the human operator is the reception and processing of information displayed on the display screen, as well as decision making. Despite the intense development of methods for automating information processing and methods for image recognition and classification, the human operator is the most adaptive identification device capable of making the best decisions so far.

Thus, to optimize the operation of the man-machine system, it is necessary to identify the main characteristics that affect the correctness and speed of perception of information from the display screen by the human operator. Perception of information can be considered as the solution of several problems, which can be the search, detection and recognition of the object. The success of solving these problems depends on several factors and parameters. These include: the threshold of visual perception (the boundary conditions of visibility), the luminance and size of the object. When we observe the object on the display screen, its detection is also influenced by such parameters as the object’s contrast with the background and the size of the field of view.

The purpose of this paper is the experimental study of the dependence of the probability of detection of an object on its contrast with the background, the background luminance, the size of the object and the search time.
2. Materials and methods

Let us consider the factors that determine the visibility of objects.

“The vision is sight plus illumination” [1]. Indeed, the visibility of an object is determined firstly by the properties of the sight and secondly by the quality of the illumination (or its own glow) of this object. The nonselfluminous object must be illuminated to be seen. The brighter extended object is, the lighter it is perceived by the eye.

We note that for a qualitative perception of the object, it is necessary that the luminance difference of the background and the object \( L_{bg} - L_{ob} \) be sufficiently large. So, we come to one of the most important quantities that determine the visibility of an object — to the luminance contrast of the \( K \) object with the background:

\[
K = \frac{L_{ob} - L_{bg}}{L_{bg}}.
\]

When calculating the contrast, it is usually assumed that the contrasting surfaces of the object and the background have the following properties:

1) observation surfaces are structureless and have clear boundaries,
2) the spectral composition of light coming from the object and from the background is the same. The first main factor of visibility of the object is its luminance contrast with the background. The second important factor is the angular size of the object, i.e. the angle at which the observer sees this object.

If the dimensions of the object \( l \) and the distance from the object to the observer \( R \) are known, then the angular size of the object \( \gamma \) expressed in angular minutes can be defined by the formula:

\[
\gamma = \frac{3440l}{R}.
\]

Values \( l \) and \( R \) should be expressed in the same units, for example in metres. In addition to the factors \( K \) and \( \gamma \), the visibility of the object also depends on the background luminance \( L_{bg} \) and the time during which the object is observed.

Thus, the visibility of the object is determined by the combination of four quantities \( K \), \( \gamma \), \( L_{bg} \), \( t \), i.e. by the point in four-dimensional space.

If the possible position of the object is known in advance, and the time during which the observation is being conducted is not very small (more than 3..5 sec), then it ceases to influence visibility, and then only three variables \( K \), \( \gamma \), \( L_{bg} \) remain, each specific set of which will determine a point in three-dimensional space. If we choose only those points to which the threshold visibility of the object corresponds, then the entire set of such points will outline the threshold surface in space. The points lying below (closer to the origin of coordinates) this surface correspond to the conditions under which the object is not detected by the eye. The points lying above this surface correspond to the conditions under which the object is seen. The higher the corresponding points lie above the surface [2], the better the object is seen.

Consider the formula of V. Weinberg [3] to define the relation between \( K \), \( \gamma \), \( L_{bg} \) at the threshold of visibility. If we have a fixed background luminance:

\[
K^{2, \gamma^{3}} = C,
\]

where \( C \) is a constant value. It follows that:

\[
\gamma = \sqrt[3]{\frac{C}{K^2}}.
\]

If the object is darker than the background, then the maximum value of the contrast is obtained when \( L_{ob} = 0 \). Then \( K = 1 \) and \( \gamma = \sqrt[3]{C} \). Therefore, a dark object will not be visible.
when $\gamma < \sqrt{C}$. This means that for a dark object there is some minimum angular size: if the object is smaller than this size, then it will not be visible at any contrast. If the object is lighter than the background, then its contrast with the background in absolute value can be much greater than one ($0 < |K| < \infty$), the square of its contrast can reach any value and the angle $\gamma$ will decrease accordingly. For a light object, there is no minimum angle. Its angular dimensions can be reduced without limit, but their decrease should be compensated by the increase in the contrast [1].

The relation between the limit angle $\gamma_n$ for the object, which is darker than the background, $K$ and the background luminance was obtained in paper [4]:

$$\gamma = 0.45 + 0.64L^{-0.42}.$$ 

Thus, threshold relations are considered between three variables $K$, $\gamma$, $L$. The increase in any of these values improves the observation condition or, if we remain on the threshold of visibility, the increase in one value reduces one of the other two [4].

Visual search will be considered as a probabilistic process. Based on this assumption, a test program was designed to conduct experiments with operators to determine the probability of detecting an object depending on the contrast of the object with the background, the size of the object, and the search time.

The principle of its operation is as follows: during the experiment, the subject is asked to log on to the program by clicking the "Log on" button. In this case, a new form appears, and the operator is asked to input some personal data: select the gender (male, female) from the drop-down list and enter his/her age. There are also "Continue" and "Exit" buttons on the form.

Clicking the "Continue" button opens a new form, on which there are 8 buttons with the names "Experiment No. 1", "Experiment No. 2", "Experiment No. 3", "Experiment No. 4", "Experiment No. 5", "Experiment No. 6", "Experiment No. 7", "Experiment No. 8".

Push one of the above buttons, the experiment begins, during which the subject is asked to look at the working window of the monitor from a distance. This monitor displays a picture divided into 12 numbered sectors (figure 1). As an example, produce the picture for experiment No. 1.

Experiments with numbers 1, 2, 5, 6 include ten presentations of the test object to the test operator — a circle with its size of $30 \times 30$ pixels — with different contrasts of the object and the background. The object changes its location at each successive presentation of a picture. During each of these experiments, the contrast increases from 0 to 1.

Experiments with numbers 3, 4, 7, 8 include ten presentations of the test object to the test operator — a circle with a fixed contrast but varying in size. During each of these experiments, the size of the object increases from $30 \times 30$ pixels to $60 \times 60$ pixels.

If the operator sees the object during the experiment, he/she gives a signal to the computer by selecting a segment and clicking the "Save" button. Otherwise, the operator clicks the "Object is not recognized" button and the next picture is presented to him/her.

The difference between experiments 1, 2, 3, 4 and experiments 5, 6, 7, 8 is that there is a time limitation in the last four experiments. If the operator does not detect the object in 4 seconds, then he/she is shown the next picture.

After each experiment, the operator is presented with an acknowledgment form, after which he/she can proceed to the next experiment or exit the program.

In all experiments, the luminance was measured in nits, the unit established by the International System of Units.

In experiments 1, 3, 5, 7, the picture background luminance is 80 and in experiments 2, 4, 6 and 8, the background luminance is 20.
On the first form that the operator sees (see figure 1), there are also "Help", "Results" and "Exit" buttons. When you click the first one, the operator gets some information about the program, the second one opens a new form, which contains 2 buttons "Upload to files" designed to upload the obtained results to a file, the third button exits the program.

3. Results and discussion

To process the results of the experiments, we compute the average probability of detecting the test object, taken for all operators for each experiment with and without time limitation. For our calculations we used the following formula:

$$P_k = \frac{1}{n} \sum_{i=1}^{n} P_{ik},$$

where $P_{ik}$ is the probability of detecting the test object by the $i$-th operator for the $k$-th contrast (size) in each experiment, $n = 16$ is the number of operators participating in the study. The average probabilities for each of the experiments are computed and the obtained results are analyzed using the mathematical package Statistica v.10.0.

The analysis showed that the probabilities obtained in each experiment are normally distributed probabilities. Such results were obtained by analyzing the normal distribution quantile plot and by the Pearson’s test with significance level $\alpha = 0.01$ for different contrasts and
significance level $\alpha = 0.025$ for different sizes. Also, for the experiments with different contrasts, the Barnett-Eisen quartile test [5] was used, which confirmed the normality of the distribution of samples with and without time limitation for the same background luminance. We can add that the above samples were picked from the same population. To analyze the samples obtained during experiments with different sizes, the Wilcoxon test for homogeneity was used, which showed that samples with background luminance $L_{bg} = 80$ are homogeneous, and samples with background luminance $L_{bg} = 20$ are not homogeneous. This indicates that the time limitation affects the work of the operators when the background luminance is low. The Fisher-Snedecor test for comparing the general variances and the Student’s test for comparing the population mean values did not reveal differences in the samples with time limitation and without it at a significance level $\alpha = 0.1$.

4. Conclusion
We examined the experimental study of the human operator’s work — the perception of information from the display screen. Factors determining the visibility of the object are identified. These factors are: the background luminance, the object contrast with the background, the object size and the search time. A procedure is developed, and experiments are conducted with a group of operators. The dependencies of the probability of detecting a test object for various contrasts of the object with the background and for various sizes of the object are determined. The experiments were conducted with and without search time limitation. The probabilities obtained in each experiment are normally distributed. The static analysis of the conducted experiments showed that the limitation of the search time and the low luminance of the object make the human operator’s work more difficult. The obtained results can be used in the design and evaluation of the efficiency of the “man-display” systems.

References
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