Adaptive control methods

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METHOD OF ADAPTIVE CONTROL OF THE INFORMATION MODEL'S DISPLAY PARAMETERS DEPENDING ON THE COMPLEXITY OF THE AIR SITUATION

Abstract. The present article represents structure, content and sequence of steps of the method of adaptive control of the information model's display parameters of the air situation. The problem describes complexity of the particular air situation in automated air traffic control system. The method assumes that the degree of complexity of the situation is recognized on the basis of heterogeneous data received from the sources. According to the results of experimental studies, we show the dependence of the average time of perception and the probability of error-free perception of the information model of the air situation by the operator on the coefficient of the overlapping forms.

Keywords: air traffic control; information environment interface; aircraft tracking form; decision-making support; air traffic operator activities; information model.

Introduction

Problem statement. The high dynamics of events that characterize the processes of air traffic organization, large flows of information that have to be operated by decision-makers (DM) in the automated air traffic management systems (AATMS), as well as the responsibility of the tasks they solve, led to wide introduction of modern automation and computer technology into the practice of the operating system [1]. The considerable technical capabilities of these tools make it possible to significantly improve the overall efficiency of use of the air traffic management information support system.

However, it should be noted that the effectiveness of automation and computer technology is largely determined by the function and place of operators in the control system. Ignoring the capabilities of an air traffic controller to receive and process information while performing his / her duties can lead to an aviation accident. For example, international statistics show that up to 50% of aviation accidents occur by the operator's fault [1–3]. According to the National Bureau of Investigation of Aviation Events and Incidents, over the last 3 years in Ukraine the accident rate for events with high-level consequences (catastrophe, accident and serious incident) has varied from 1.24 to 1.7 events per 100 thousand flight hours [4–6].

Therefore, the problem of rational synthesis of "man-machine" systems in the AATMS is one of the most urgent. One of the important points in this case is the resolution of issues related to the provision of the operator with the necessary information about the air situation (AS), as this is to a large extent ensures the timeliness and correctness of management decisions.

As the conditions of the system functioning and the individual features of DM vary widely, such interaction should be adaptive [3]. This involves taking into account the design and operation of the means of displaying information (MDI) about the AS of those functions performed by the human operator, as well as his/her current psycho-physiological state in the course of performing his/her functional duties. In this case, the structure and characteristics of the information model (IM) in the means of displaying the information of the AATMS must change depending on the AS status in order to achieve the highest efficiency of the air traffic control point manager's performance of their functional duties [7, 8]. Large amounts of information and the random nature of its distribution in the area of the information model on the screen of the display device cause the effect of information overlap [7]. Therefore, the synthesis of IM should be carried out taking into account the impact of the negative effects of the specified effect on the activities of the operator.

Research publications. One of the main functional elements of the AATMS in the organization of air traffic is an observation system that provides relevant information, which is continuously updated in real time. The MDI for displaying AS information supporting the operations of the AATMS controller, as a minimum, display aircraft location information, mapping information required for surveillance based air traffic, and, where appropriate, identification and flight level information of aircraft flights [7, 9].

An aircraft displayed on AS display screen by the radar tag has a so-called support form next to it, which contains the desired current flight information for the operator [7, 10–17].

All information on support forms is represented in a Detailed or Untagged (Tagged) forms [7]. Forms are mapped to the appropriate mapping of the aircraft's location so as to prevent the air traffic operator from misidentifying the object.

Analysis of a number of papers and guidelines [7, 18, 19] shows that a detailed support form for an aircraft in most modern AATMSs has up to 14 information elements (dot-matrix fields). These include: call sign, sector identifier, aircraft type, current altitude (flight level), entry/exit point of the sector, speed, destination aerodrome, preset altitude (flight level), etc. (Fig. 1).

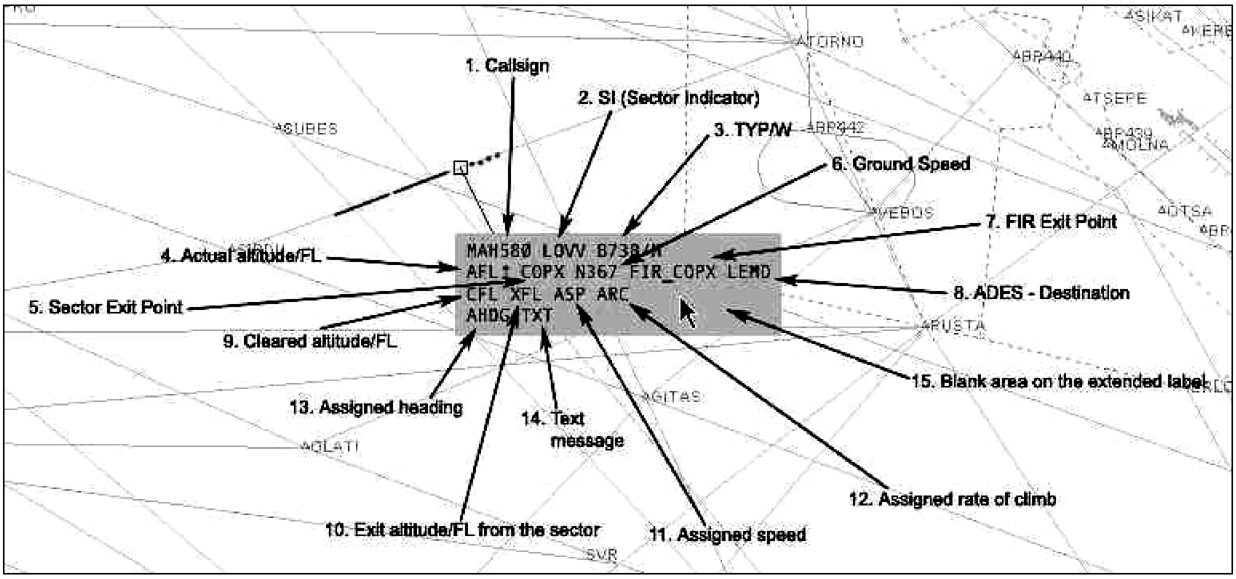


Fig. 1. Information representation in the detailed form of the aircraft support

The content of the information elements of the aircraft support form allows the AATMS operator to obtain any information about an individual aircraft that is required in the performance of functional duties. But at the same time while displaying several forms there is such a negative effect as the overlap of information, which in turn significantly complicates the perception of the current air situation by air traffic operator.

The research aims and objectives. At present, the tasks of adaptive control of displaying the information model parameters in the centers of air traffic organization are carried out in a non-automated mode. Moreover, the operator uses only two methods: moving the desired aircraft form in the free zone of IM and choosing another display mode, which leads to a reduction in the number of dot-matrix fields in the form. This increases the time of air traffic management and decreases the likelihood of a true AS evaluation. Therefore, the urgent task is to develop a method of adaptive control of the information model's display parameters, depending on the complexity of the situation in the area of responsibility of air traffic control center, which should provide the proper conditions for prompt and reliable assessment by the AATMS operators of each of the possible air situations.

Research bases

The situations of aircraft support forms' overlapping often arise in the activities of air traffic control centers at the workplace of air traffic operators [9]. The more forms are used, the more difficult are the conditions for their perception.

The aircraft support forms' overlapping is characterized by the size of their intersection area. To quantify this property, we use a generic indicator – the overlap ratio of forms – K_H, that characterizes the average overlap of all intersecting forms. This indicator is defined as [20]:

$$K_H = S_H \big/ NS_f \,, \; 0 \le K_H \le 1 \,, \qquad (1)$$

where $S_H = \sum_i S_{H_i}$, $i = \overline{1, N}$ – the total area of the sections of overlapping forms; S_{H_i} – the area of the i-th form (F_i) that intersects with at least one of the forms; S_f – area of one form, provided

$$S_{f_1} = S_{f_2} = ... = S_{f_i} , \; S_f = S_{f_i} .$$

If the areas are not the same, we have:

$$S_f = \sum_i S_{f_i} \big/ N . \qquad (2)$$

Such indicator gives only an overall average estimation of the overlap. With relatively small K_H values, overlaps of aircraft support forms may contain those that are not identifiable at all or require a great deal of time. This leads to a significant reduction in the likelihood of error-free perception of situation information (SI), which is inadmissible.

In the presence of information on the degree of distortion of specific forms, we can take measures to reduce the negative impact of form overlap in the dynamics of AS evaluation. Therefore, it is advisable to use an indicator that characterizes the degree of intersection of each support form with all others. This metric may be the overlap ratio F_i:

$$K_{H_i} = \frac{S_{H_i}}{S_{f_i}} , \quad 1 \ge K_{H_i} \ge 0 \,, \qquad (3)$$

where S_{H_i} – total intersection area of the i-th form with all others.

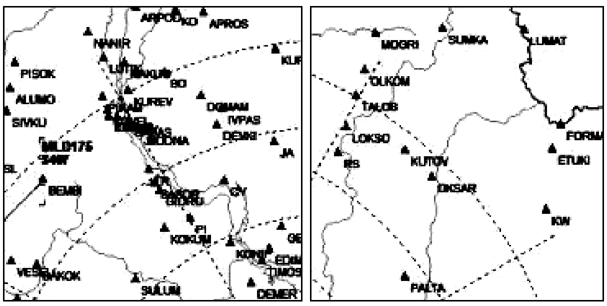
The degree of distortion of the dot-matrix fields of the maintenance form, as well as the time of perception of AS information (t_c) and the probability of its error-free perception (P_{bc}) depends on the value $K_{н_i}$. According to results of theoretical-experimental researches [13, 20] the probability of error-free interpretation of information by the operator and the average time of its perception is described by the equations:

$$P_{bc} = 1 - aK_н^4 , \quad (4)$$

$$t_c = b + cK_н^3 ; \quad (5)$$

where a, b, c – smoothing coefficients that significantly depend on the operator's qualification are defined as follows: a = 0.14; b = 0.64; c = 1.83.

The analysis of these dependencies shows that due to the overlap effect, the average time of perception of the aircraft support form increases approximately 2 times. There are also cases of such distortion of the form signs, when their interpretation is completely impossible. The average probability of error-free perception of aircraft information may decrease 1.8 times, depending on the $K_н$. Two types of information models were used in the experimental studies. The first type of IM reproduced the situation with overlapping forms of aircraft support, the second type of IM showed the presentation of the same situation without forms' overlapping. The variants of the investigated IM are shown in Fig. 2. Comparative analysis of these information models was made under the same SI conditions. According to the procedures approved in [18], the operators had a task to determine the type, height and speed of aircrafts while displaying 20 – 30 aircraft support forms. The main results of the experiment are given in table 1.



a b

Fig. 2. Options of the investigated IM (a) with overlapping aircraft forms (b) without overlapping

Table 1 – **Results of experimental studies**

Type of task	$\overline{t_c}$, sec	P_{bc}
Single overlap	28.90	0.796
Double overlap	81.93	0.523
Without overlap	13.63	0.932

The obtained indicators show that:

- for single overlap of aircraft forms ПС $\overline{t_c}$ increases no less than 2 times;

- for double overlap of aircraft forms ПС $\overline{t_c}$ increases no less than 6 times;

- for single overlap of aircraft forms ПС, the P_{bc} probability is reduced by 1.2, and for double overlap – by 1.8.

The above values allow us to evaluate the promptness and reliability of the decision made by the AATMS operators.

By increasing the volume of AS display to 100 aircraft forms it is possible to expect with a high degree of probability that $\overline{t_c}$ will increase at least 7 times with a significant P_{bc} decrease.

Thus, the overlap of aircraft support forms suggests that one should expect a large amount of time to search and perceive critical aircraft forms, which can significantly affect the quality of DM operational work.

It should be noted that in practice, in such situations, the air traffic controller is forced to call on other persons of the next shift to obtain information which he cannot perceive because of the overlap of aircraft support forms. The time of receiving this information may be the same as the time of AS perception as a whole, meaning that the performance of the overall AS evaluation by the operator will be further reduced.

Let's analyze the existing methods of reducing the negative impact of the aircraft support forms' overlapping on the activities of the air traffic operator. First of all, you need to consider the factors that overlap depends on. The analysis of equations (4, 5) shows that the main factors are the number of aircraft forms displayed (N); form area (S_f); and display scale (M).

The effect of the overlap will be as big as the volume of display of the aircraft support forms. For example, in [20] it is shown that when changing N from 100 to 20, the overlap coefficient decreases by 2 – 2.5 times. The number of forms displayed depends on the AS and on the grouping of the aircraft. As shown earlier, value N can vary widely. For example, up to 250 forms may be displayed in some AATMS [11].

Value N can be reduced by selection of aircraft according to certain features. However, in this case, AS that is not adequate to the actual one is displayed. And this, in turn, can distort the assessment of the overall situation.

It should be noted that, due to the uneven distribution of aircraft support forms on the monitor screen, a decrease of N indicator may have a negligible effect on the manifestation of the overlap effect.

At a fixed scale of IM reflection, the effect of overlay manifests itself as strong as the linear dimensions of acquaintances and their number in the form, because these values characterize the S_f values. The size of the characters on the screen of the monitor significantly affects the conditions of their perception. Ergonomic requirements set the optimal size of characters that do not change when scaling them. Taking into account these requirements we obtain for 5-digit form – S_f = 29.3 mm^2, and for 25-digit, complete form – S_f = 94.2 mm^2.

Therefore, the use of short aircraft forms can reduce the value $K_н$ by about 3.5 times. In this case, the informative nature of the forms significantly reduces, and the operator needs to spend additional time to change the way the form is displayed to obtain additional information.

The linear dimensions of the aircraft support form, based on the scale of the display, can be represented as follows:

$$l_x = \Delta x M,\ l_y = \Delta y M, \qquad (6)$$

where Δx, Δy – linear dimensions of the form horizontally and vertically, (cm); M – scale of IM display (number of kilometers in one centimeter).

Provision of the operator's workplace equipment with an additional display device will allow to expand the IM field of view and ensure the adequacy of displayed AS information.

The advantage of this method of display is the large scale of the view field that allows the optimum perception of information by the air traffic controller. The disadvantage is the time spent on "switching" the operator's sight between the screens of the monitor, followed by the mandatory identification of the aircraft.

The use of new information technology now eliminates the mentioned disadvantages through the use of AS tools that allow the creation of a "poly screen" in the IM information field, or zoom in on the selected area (magnifying glass effect) to display the forms of support for the aircraft that should be separated.

The advantage of the method of displaying information with the use of multi-screen means is to reduce the time spent on transferring the gaze of DM, which in turn leads to a decrease in the time of information search. The disadvantage is that the display device's information field is heavy.

Using the magnifier mode allows you to view any area of the IM on a larger scale.

Thus, changing the scale of the mapping can significantly reduce the negative impact of the overlap of aircraft forms on DM activities.

Given the above, let us consider the basic processes that are associated with the recognition of information overlap in terms of AS evaluation. The [21 – 23] analyzed the recognition methods that can be used to solve the problem.

These methods are used when a large amount of information needs to be processed to make decisions in the context of uncertainty and redundancy. In this case there was a need to develop a simpler and, nevertheless, sufficiently more reliable method of recognition.

The use of any of the considered methods of displaying AS information is inevitably linked to the following operations:

- detection of the aircraft support forms overlapping, that is, the actual recognition of the forms overlapping;
- determining the priorities for servicing (scaling) the aircraft support forms overlapping;
- implementation of control effects on the AS modules of the information model display system.

If there are multiple scaling options available to the DM (optional display device, multi-screen, magnifier), he may choose the one that he prefers in the particular situation.

In relatively simple AS (with 3 – 4 form overlaps), the air traffic operator can perform these operations quite easily. In this case, there will be inevitable additional time spent on establishing the priority of overlaps and manipulation by the control elements. This situation may be eligible if there is no hard time deficit.

It should be noted that even in a simple situation, it may be difficult to set the priority of the overlap service. These difficulties are caused by distortions in the familiarity of the forms that characterize the importance of individual aircraft.

In complex AS, when there is a large amount of overlaps and acute shortage of situation assessment and decision making, it is advisable to use adaptive automated scaling of the displayed information. Such management will reduce the time spent on assessing the situation in the area of responsibility of the AATMS command unit by about 10 ... 15%.

Here are some basic assumptions used in developing one of the adaptive scaling controls for displaying information about the air situation.

As noted earlier, the more the aircrafts forms are overlapped, the more difficult will be the conditions of their perception by the operator. There can be 2, 3 or more times form overlapping, even with relatively small K_{H_i} values. This fact should be taken into account in order to process overlaps with a large number of forms under the same conditions.

Therefore, we introduce the sign of the aircraft support forms' overlap: $\pi_{H_i} = 0$ – there is no overlap on the F_i form; $\pi_{H_i} > 0$ – there is an overlap of other forms on the F_i form, the number of which characterizes this value. For example, $\pi_{H_i} = 1$ – there are two forms in one overlap (F_j form overlaps F_i form), $\pi_{H_i} = 2$ – there are three forms in one overlap (two forms overlap F_i form), etc.

Recognizing the overlap of aircraft support forms is in fact identifying those forms that intersect with F_i form. After the overlap effect is detected, it is necessary to determine the value K_{H_i} for this overlap. As a result, indices K_{H_i} and π_{H_i} are determined for each aircraft support form displayed on the monitor screen.

Thus, to establish the fact of overlapping F_j form on the F_i form, it is sufficient to compare the coordinate differences of the corresponding aircrafts ((x_j, y_j) and (x_i, y_i)), $\Delta x_i = x_i - x_j$, and $\Delta y_i = y_i - y_j$ with the dimensions of the form with respect to the scale used (l_x and l_y respectively), that is, in this case, the strobbing of forms.

A form that has hit the strobe is considered to be overlapping with the F_i form. It should be noted that $\pi_{H_i} \neq 0$ will be if $|\Delta y| < l_y$.

To simplify the overlap search procedure, we introduce an array of aircrafts displayed on the screen of the AATMS monitor, in which they are placed in descending order $z = (x_i, y_i, w_i)$ at $x_1 \geq x_2 \geq \ \ldots \geq x_N$;

$i = 1, 2, \ldots, N$, where w_i is the importance of the i-th aircraft. The analysis of the stated provisions and considerations of practical feasibility allow us to suggest the structure, content and sequence of stages for development of the adaptive control method of the IM AS display (Fig. 3).

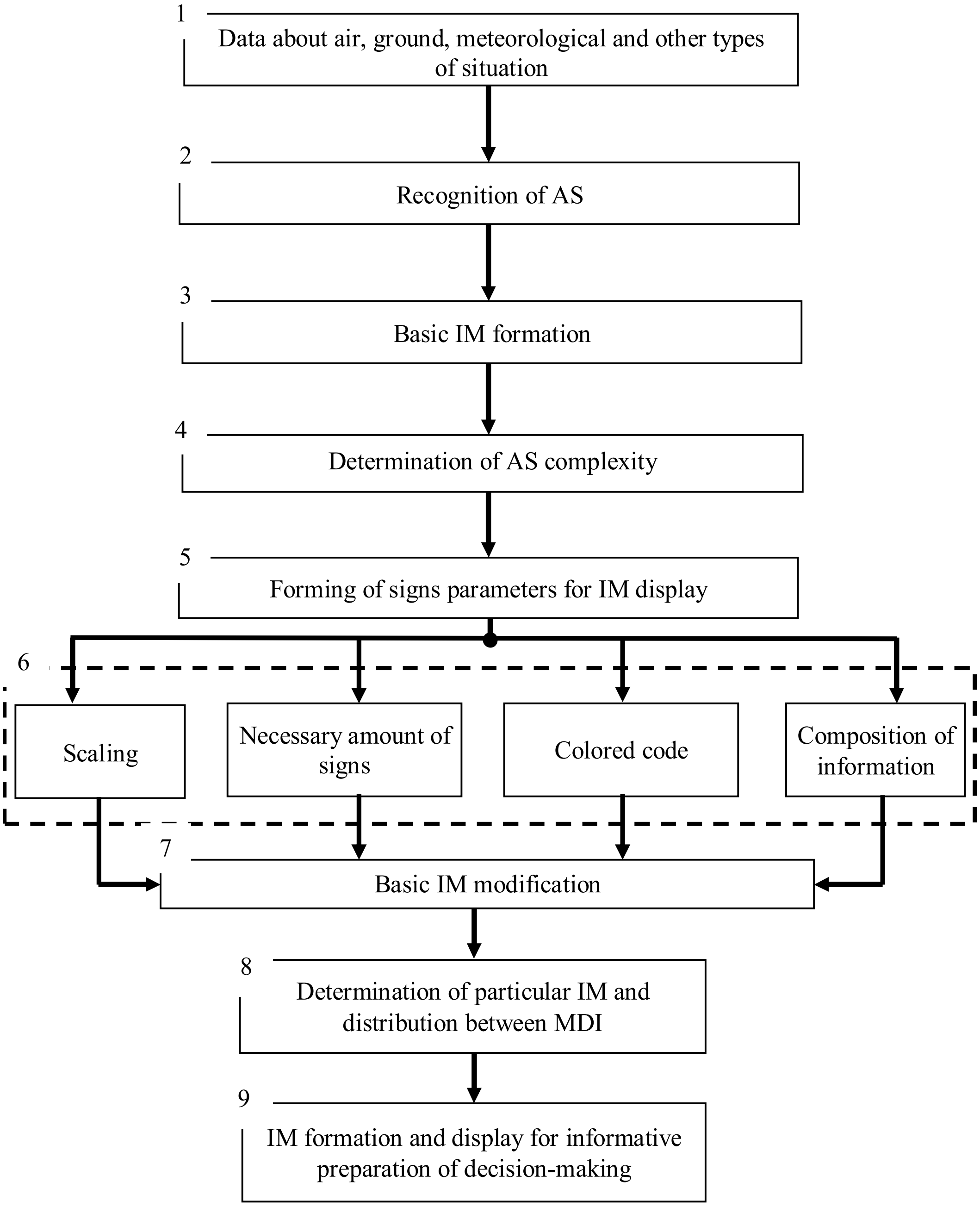


Fig. 3. Structural diagram of the method of adaptive control of the information model's display of the air situation

The method allows to establish, in practice, the fact of overlapping and to determine the number of aircraft support forms' overlapping with F_i .

Value $S_{н_i}$ is defined for each aircraft support form.

The implementation of the proposed method of adaptive control of AS display allows formation of an array of $Z_н$ overlapping forms. Its elements are x_i, y_i, w_i together with $S_{н_i}$ and $\pi_{н_i}$. Thus, the preparatory stage of adaptive IM control displayed on the monitor is to form an array $Z_н$.

The next step is to set the priority of processing the aircraft trajectories' overlapping. For this purpose you can use w_i, $S_{н_i}$ and $\pi_{н_i}$.

Therefore, we suggest a possible implementation of the control of overlapping aircraft support forms' display.

First of all, it is necessary to ensure a quick error-free perception of the most important aircrafts by the air traffic operator.

Therefore, in order to exclude the influence of the aircraft support forms' overlapping effect on the perception of Z_H information, we should first of all choose F_i with maximum value of w_i.

The priority is then given to the overlapping forms with maximum value of K_{H_i} (or π_{H_i}).

Establishing rules for managing the display of AS information with overlapping forms of aircraft support requires additional special research.

We should take into account the specifics of displaying IM of the air situation and solving the problems of air traffic control by the AATMS operators in a difficult situation. These studies are expected to be completed in the near future.

Conclusions

The proposed method of adaptive control of the information model's display on the MDI of the automated air traffic management systems, in contrast to the known ones, provides: possibility of establishing the fact of the aircraft support forms' overlapping and determining the number of overlapping forms; use of new information technologies that allow to adapt to the complexity of the air situation to establish the necessary modes for displaying aircraft support forms to be separated, prioritizing the processing (scaling) of aircraft support forms' overlapping.

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Метод адаптивного управління параметрами відображення інформаційної моделі в залежності від складності ситуації в повітряному просторі

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Анотація. У роботі пропонується структура, зміст та послідовність етапів методу адаптивного управління параметрами відображення інформаційної моделі повітряної обстановки в залежності від складності ситуації в зоні відповідальності автоматизованої системи управління повітряним рухом. Методом передбачається, що на основі отриманих різнорідних даних від джерел розпізнається ступень складності ситуації обстановки. Формуються параметри ознак для відображення інформаційної моделі шляхом визначення складу інформації, кольорового кодування, визначення необхідної кількості ознак та масштабування необхідних інформаційних елементів. Це дозволяє модифікувати базову інформаційну модель та розподілити її між відповідними засобами відображення інформації. В підсумку формується необхідна інформаційна модель для підтримки прийняття рішення. Також досліджено можливості врахування ефекту накладення формулярів супроводу повітряних суден при формуванні інформаційної моделі повітряної обстановки. За результатами експериментальних досліджень отримано залежності середнього часу сприйняття та ймовірності безпомилкового сприйняття інформаційної моделі повітряної обстановки оператором від коефіцієнту накладення формулярів.

Ключові слова: управління повітряним рухом; інтерфейс інформаційного середовища; формуляр супроводу повітряного судна; підтримка прийняття рішення; діяльність авіадиспетчера; інформаційна модель.

Метод адаптивного управления параметрами отображения информационной модели в зависимости от сложности ситуации в воздушном пространстве

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Аннотация. В работе предлагается структура, содержание и последовательность этапов метода адаптивного управления параметрами отображения информационной модели воздушной обстановки в зависимости от сложности ситуации в зоне ответственности автоматизированной системы управления воздушным движением. Метод предполагает, что на основе полученных разнородных данных от источников распознается степень сложности ситуации обстановки. Формируются параметры признаков для отображения информационной модели путем определения состава информации, цветного кодирования, определения необходимого количества признаков и увеличения необходимых информационных элементов. Это позволяет модифицировать базовую информационную модель и распределить ее между соответствующими средствами отображения информации. В итоге формируется необходимая информационная модель для поддержки принятия решения. Также исследованы возможности учета эффекта наложения формуляров сопровождения воздушных судов при формировании информационной модели воздушной обстановки. По результатам экспериментальных исследований получены зависимости среднего времени восприятия и вероятности безошибочного восприятия информационной модели воздушной обстановки оператором от коэффициента наложения формуляров.

Ключевые слова: управление воздушным движением; интерфейс информационной среды; формуляр сопровождения воздушного судна; поддержка принятия решения; деятельность авиадиспетчера; информационная модель.