DOI: 10.5604/01.3001.0010.8654

OPTIMIZATION OF DATA PROCESSING FOR REQUESTING OBSERVATION SYSTEMS

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Abstract. *The article discusses how to optimize the data when it detects air targets by requesting observation systems. Two schemes for the detection of air objects, differing in the order of the operation of deciphering the aircraft responders' response signals, were investigated. It is shown that performing the operation of decoding the signals of the aircraft responder after the operation of detecting the air object makes it possible to improve the quality of data processing of the requesting observation systems. The influence of the aircraft responder readiness coefficient and the probability of suppression of signals in the answer channel on the probability of detection of air objects was researched.*

Keywords: data processing optimization, requesting observation systems

OPTYMALIZACJA PRZETWARZANIA DANYCH DLA ZAPYTAŃ SYSTEMÓW OBSERWACJI PRZESTRZENI POWIETRZNEJ

Streszczenie. *Artykuł dotyczy optymalizacji przetwarzania danych podczas wykrywania obiektów powietrznych poprzez żądanie systemów nadzoru. Zbadano dwa schematy wykrywania obiektów powietrznych, różniące się kolejnością operacji odczytywania sygnałów odpowiedzi statków powietrznych. Pokazano, że wykonanie operacji deszyfrowania sygnałów transponderów statku powietrznego po uruchomieniu wykrywania obiektów powietrznych pozwala poprawić jakość przetwarzania danych zapytań systemów nadzoru. Zbadano wpływ współczynnika gotowości statku powietrznego i prawdopodobieństwa tłumienia sygnałów w kanale odpowiedzi na prawdopodobieństwo wykrycia obiektów powietrznych.*

Słowa kluczowe: optymalizacja przetwarzania danych, systemy przesłuchań, transpondery lotnicze

Introduction

The article presents the results of research as a joint optimization of signal processing and primary data processing data of the requesting observation systems. [20], as well as improving the quality of data processing of the requesting airspace observation systems by changing the algorithm for processing joint data.

Using a sequential procedure for processing surveillance system data, due to the functionally completed processing steps, allowed to formalize the data processing procedure [5, 12, 20].

However, this significantly limited, and in some cases excluded, the opportunities for inter-stage data processing optimization [5, 12].

The lack of inter-stage optimization of data processing of modern radar observation systems leads to a decrease in the quality of information services for decision-makers in the airspace control system.

In this paper, the main focus is on the joint optimization of the detection signals phase and the airborne objects detection phase by requesting observation systems which belong to the major information resources of the airspace control system.

1. Data processing structure of airspace observation systems

The airspace control system as an information supervision and information management system must provide the following functions:

- conducting continuous exploration of airspace (in real time);
- collecting, accumulating and data processing of all from means of active and passive electronic surveillance and intelligence;
- development the data map of air situation basis on this data;
- informational sufficiency for functioning of the airspace control system;
- high accuracy and non-distortion of information;
- exclusion of intervention and organized counteraction.

Observation systems are the information resource of the airspace control system.

Observation systems represent the following data:

- detecting an air object;
- definition of their coordinates;
- estimation of parameters of motion;
- classification by state.

Data about horizontal and vertical velocities identifying characteristics or intentions may also be presented.

The necessary data and parameters of the technical characteristics depend on the specific types of application.

That is, in most cases, surveillance systems give the user information about where the air object is and who it is.

As a rule, the primary observation systems [2, 5, 7, 10, 12, 15, 21] correspond to the first question, and on the other – requestioning (identification) observation systems [1–4, 6–8, 10, 12, 13, 15–21].

Processing of observation system data is a process of bringing information received from observation systems into a suitable form for further transmission to users.

The data processing of observation systems is impossible without wide use of information technologies, which allows to realize the automatic collection, processing, storage, transmission and delivery of information to consumers, while increasing practically all quality indicators.

The data processing system of the observation systems is directly related to the signal sources and provides the solution of the following tasks:

- detecting useful signals received from airborne objects, and removing obstacles;
- determination of parameters of received signals;
- detection of airborne objects;
- measurement of coordinates and parameters of airborne objects movement;
- receipt of flight information from the airspace;
- identification of the airborne object on the basis of "Friend or foe";
- correlation of detected airborne objects in the trajectory and determination of parameters of these trajectories;
- calculation of smoothed and ahead of certain time interval of coordinates of air objects;
- the formation of a generalized air environment in the control zone from several sources.

The solution of these tasks leads to a variety of functions performed by the system related to the staged processing of large streams of information. At each stage of processing, certain operations are performed on the input data of individual devices of varying complexity. Thus, the system of processing modern observing systems can be represented as a set of elementary subsystems with complex interconnections. Naturally, the complexity of the processing system does not allow formalization and analysis of its work in general, so it is necessary to pre-break the system into elements and study their functioning. In this regard, it is expedient that the elements of the processing system have a clearly defined purpose, as well as what they could be described with rather general mathematical positions. This approach allows the process of data processing of airspace observation systems to be divided into the following functionally completed stages, which are performed sequentially:

- signal processing of observation systems;
- primary data processing;
- secondary data processing.

It should be noted that the first stage is performed in the monitoring system using the signal processor. The second and third stages are performed using the data processor [5, 12]. Such an order of data processing leads to the impossibility of inter-segment (compatible) optimization of data processing [5], which, as a result, leads to a decrease in the quality of information users provision.

Indeed, the components of data processing are detecting a signal in the first stage and detecting an air object in the second stage. The optimization of detection is usually carried out using the Neumann-Pearson criterion, which reduces to maximizing the probability of correct detection with restrictions on the likelihood of false detection. Thus, at the first and second stages, the following procedures are carried out

$$D_0 = f(z_0, q) \text{ when } F_0 = f(z_0) = const;$$

$$D_{01} = f(k, N) \text{ when } F_0 = f(k) = const,$$

where z_0 – analog signal detection threshold, q – signal/noise ratio (SNR), k – digital threshold for detecting airspace, N – number of received signals from an air object in one review.

The structure of data processing observation systems clearly shows that providing optimization of processing is possible only with centralized data processing.

It should be noted that only the analog control threshold, which can be optimized for detection at all stages of data processing, is the threshold for detecting signals. This circumstance clearly determines that only in systems with centralized processing of data processing stages can a joint optimization of detection of air objects.

The foregoing allows to form the structure of the data processing of airspace data, which includes a single structure of signal processing and primary data processing.

2. The airborne detection quality assessment of requesting observation systems

Consider the possibilities of compatible optimization of detection of air objects by requesting observation systems. Requesting observation systems represents dual-channel data transmission systems formed by the request channel and the response channel. Airplane responder is an open system of mass service with failures. The presence of intra-system and intentional correlated obstacles leads to the fact that the probability of a response by an airplane responder to a specific request signal is always less than one, that is $P_0 < 1$, where P_0 – the readiness factor of the aircraft's responder.

As query and answers signals, requesting observation systems use interval-time codes. Since for requesting observation systems a high signal-to-noise ratio is characteristic, it is possible to achieve the required quality indicators when processing single pulses of interval-time codes. The processing of received signals by the receiver, in this formulation of the question, consists in decoding the received signal and its result of the decision.

Various methods of processing, in particular, methods for inter-period processing of coded signals, can be used to increase the probability of a decision taken in the processing of encoded signals, as well as to protect the requesting observation systems from inter-system interference.

In this regard, it is interesting to consider the characteristics of detecting response signals in different processing methods, as well as the influence of the aircraft's responder readiness factor and the probability of response detection suppressing an airborne object.

Let's consider the joint optimization of the airborne object detection. We obtain comparative characteristics of air objects detection with different methods of response signals processing under the influence of fluctuation and impulse noise in the radio channel. Calculations will be made for the criteria and features of the construction of the equipment for processing interval-time codes in existing requesting observing systems.

Suppose that the response factor is equal to one and there is no suppression in the response radio channel. At the output of the receiver, binary quantization of signals is carried out, that is, at a fixed signal/noise ratio (q) and the chosen threshold limit from below (z_0) the uncertainty of probability is uniquely determined – P_{11} (probability of detecting a single pulse of the response signal) and P_{01} (probability of occurrence of noise emission at a given time position).

Let's also assume that the decoder performs the logic n/n, where n – the value of the response code, and in the airborne object detection device, the logic is used k/N, where k – the digital threshold of the detection of the air object, N – the length of the packet of received response signals, at which fixing the signal of the decision to detect an air object occurs in the presence of any K signals in N positions

We will compare the characteristics of the detection of air objects of both treatment methods using the Neumann-Pearson criterion, that is, at a fixed level of false alarms, we will find the detection characteristic (the probability of detecting the coded signal), depending on the SNR for the moment of the first detection of the object (fulfillment of the detection criterion beginning of the information package).

When decoding with the next inter-period processing (I method of processing) received signals, the probability of passing n of pulse interval-time codes and false signals through a decoder are defined as

$$D_d = (P_{11})^n; \; F_d = (P_{01})^n.$$

The probabilities P_{01} and P_{11} are determined by the following relationships

$$P_{01} = \exp\left(-z_0^2/2\right); \; P_{11} = \int_{z_0}^{\infty} x \exp\left[-\left(x^2+q^2\right)\right] I_0(qx)dx,$$

where $I_0(qx)$ – is the modified Bessel function of the first kind of zero order.

The probability of detecting useful signals and false alarms at the output of devices interperiod processing are calculated respectively as

$$D_{2d} = \sum_k^N C_k^N D_d^k \left(1-D_d\right)^{N-k}; \; F_{2d} = \sum_k^N C_k^N F_d^k \left(1-F_d\right)^{N-k}. \quad (1)$$

For the method of decoding with the previous inter-period processing of the response signals (II method of processing), the probability of passing coded signals and false alarms through the inter-period signal processing device can be written, respectively, as

$$D_1 = \sum_k^N C_k^N P_{11}^N \left(1-P_{11}\right)^{N-k}; F_1 = \sum_k^N C_k^N P_{01}^N \left(1-P_{01}\right)^{N-k}. \quad (2)$$

Probability of passing useful and false signals through decoder can be defined as either:

$$D_{1d} = D_1^n; \; F_{1d} = F_1^n . \quad (3)$$

Given (3), the expression (2) can be written as

$$D_{1d} = \left[\sum_k^N C_k^N P_{11}^N \left(1 - P_{11}\right)^{N-k} \right]^n ; F_{1d} = \left[\sum_k^N C_k^N P_{01}^N \left(1 - P_{01}\right)^{N-k} \right]^n . \quad (4)$$

In Fig. 1 shows the dependence of the probability of detecting an air object on the SNR for two- and three-pulse interval-time codes under different logic of processing and the probability of false alarms $F = 10^{-3}$, calculated from expressions (1) and (4).

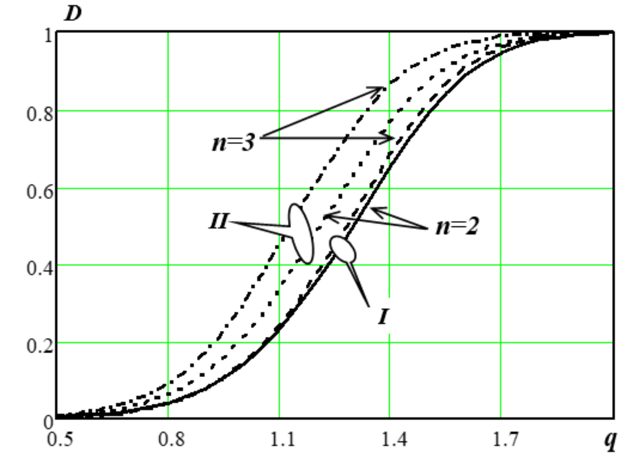

Fig. 1. The airborne detection characteristics

The analysis of the above dependencies shows that the characteristics of the detection of an air object for a decoding method with a pre-inter-period processing exceed the characteristics of detecting an air object for a decoding method with subsequent inter-period processing. Certainly, for $q = 1.25$ and $n = 3$ the probability of detecting an air object for the first processing method is 0.4, and for the second processing method it is 0.7. An increase in the value of time interval intervals leads to an increase in the probability of a proper detection of an airborne object.

2.1. Assessment of the impact of the airplanes responder readiness factor and the probability of suppressing response signals to airborne detection characteristics

The presence of interruptions (intersystem or intentional correlated) in the query channel of the requesting observation systems leads to the fact that the responder will receive a response signal not for each request signal. Certainly, an airplane responder is characterized by a readiness factor (P_0) of an airplane responder that is nothing like the probability of a response to a request signal. Thus, the readiness rate of the aircraft responder is always less than one ($P_0 < 1$). In addition, the presence of intra system interference in the response channel, which is typical for the systems under consideration, leads to suppressed individual pulses of the response signal, which can be taken into account as the probability of suppressing the response signals.

Let's obtain the comparative characteristics of an air object detection probability for the considered methods of processing response signals, taking into account the actual readiness factor of the aircraft responder and the probability of the response signals suppression (P_p). In doing so, we assume that the probability of response signals suppressing the does not affect the formation of false alarms. In this regard, we will only determine the probability of an air object detecting.

When decoding with the next interperiodal processing of the received response signals, the probability of passing of interval-time codes through a decoder, taking into account the effect of the response factor of the readiness of the aircraft and the probability of suppressing the response signals, can be determined as

$$D_d = P_0 P_p P_{11}^n .$$

The probability of detecting useful signals at the output of the interperiodic processing device of response signals in this case is defined as

$$D_{2d} = \sum_{i=0}^{N-k} C_i^N \left[P_0 P_p P_{11}^n \right]^{N-i} \left[1 - P_0 P_p P_{11}^n \right]^i . \quad (5)$$

For the second method of decoding, the probability of passage of coded signals through the device interperiod processing, taking into account the airspeak response factor and the probability of suppressing the response signals, can be determined from the following relationships

$$D_1 = \sum_{i=0}^{N-k} C_i^N \left[P_0 \left(1 - P_p\right) \right]^{N-i} \left[1 - P_0 \left(1 - P_p\right) \right]^i \sum_{j=0}^{N-k-i} C_j^{N-i} P_{11}^{N-j-i} \left(1 - P_{11}\right)^j .$$

The probability of detecting the coded signal at the output of the decoder in this case can be written as

$$D_{1d} = \sum_{i=0}^{N-k} C_i^N \left[P_0 \left(1 - P_p\right) \right]^{N-i} \left[1 - P_0 \left(1 - P_p\right) \right]^i \left[\sum_{j=0}^{N-k-i} C_j^{N-i} P_{11}^{N-j-i} \left(1 - P_{11}\right)^j \right]^n . \quad (6)$$

Expressions (5) and (6) are obtained for the general case, when both P_p and P_0 variables. This is $P_p = 1$ – a special case when only obstacles are taken into account. This is $P_0 = 1$ – another special case when only the effect of the probability of suppressing the response signals is taken into account.

In Fig. 2 shows a family of characteristics of airspace detection at two- and three-pulse interval-time codes for both methods of processing at $P_p = 0.01$ and $P_0 = 0.95$.

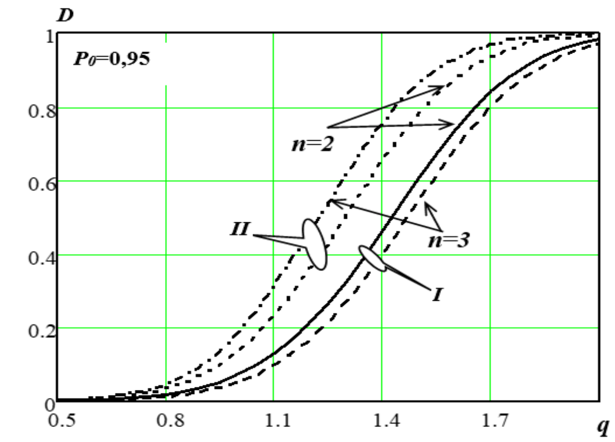

Fig. 2. Characteristics of the of airborne objects detection

The analysis of figs. 1 and 2 shows that the reduction of the readiness factor of the aircraft responder by 0.05 and the probability of suppressing signals leads to a decrease in the likelihood of detecting an air object. So, with $q = 1.4$ and $n = 3$ the probability of detecting an air object for the second processing method, decreases from 0.88 to 0.76. Reducing the readiness factor of the aircraft responder leads to the fact that, at a certain value of the airplane responder's readiness factor, the best detection characteristics provide a method of decoding with subsequent inter-period processing.

Figure 3 shows the calculations of the air objects detection probability by a requesting observing system with a fixed SNR $q = 1.9$ and the probability of suppressing the response signals

$P_p = 0.01$ as a function of the airplane response readiness factor, the significance of the interval time codes, and the data processing methods under consideration.

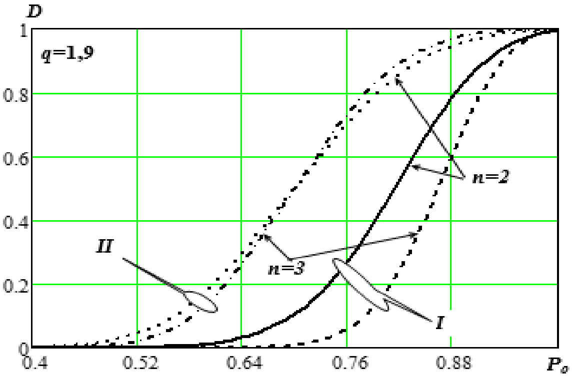

Fig. 3. Characteristics of the of airborne objects detection

3. Summary

The conducted research allowed to determine the structure of data processing of requesting observation systems at the stages of detection of signals and detection of an air object in which it was possible to conduct a joint optimization of data processing at the specified stages of processing. The method of data processing is proposed, which, unlike the one used, decodes the response signals by the interprocess processing of the response signals. The indicated calculations of the probability of detecting an air object by inquiry systems have shown a sufficient improvement in the quality of data processing and the reduction of the impact of the airplane response readiness factor and the probability of suppressing response signals by intra systemic impediments to the quality of data processing.

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otrzymano/received: 10.10.2017 *przyjęto do druku/accepted: 15.02.2018*