Radar and Navigation

# Use of Aposteriori Information in the Implementation of Radar Recognition Systems Using Neural Network Technologies

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**Abstract**
**Introduction.** The current need to obtain relevant, complete and reliable information about airborne objects has led to the continuous improvement of modern radar recognition systems (MRRS) as part of control systems. The development of modern MRRS has created objective prerequisites for the use of progressive and new methods and algorithms for the processing of signals using neural networks. The use of artificial neural networks with learning ability permits expansion to include many signs of recognition by using information obtained in the process of monitoring airspace.
**Aim.** To formulate the problem and develop proposals for the use of posterior information for airspace control in radar recognition systems using neural network technologies.
**Materials and methods.** Based on an analysis of the structure of a unified information network, an approach was formulated to facilitate the development of MRRS based on training technologies. Using the synthesis method, examples of technical solutions were proposed, which will allow the use of modern methods and signal processing algorithms using a posteriori information generated by the control system.
**Results.** The study identified the principles of neural network training in solving the recognition problem in the process of functioning of radio electronic equipment (REE). The technical solutions pro-posed take the functioning of the integrated radar system into account, allowing the information parameters required for training MRRS in a single information field to be obtained. It is shown that the removal of restrictions associated with the functional autonomy of REE, allows the use of posterior information in the implementation of radar recognition systems. This also allows for an increase in the number of recognition signs used in the algorithms and for the database of portraits to be replenished.
**Conclusion**. MRRS can be developed via training by removing the restrictions associated with the autonomous functioning of RES. This allows for the situational assessment to be enhanced and management decisions to be optimised.

**Key words:** radar recognition, aposteriori information, neural network, training, radar, information space

**Conflict of interest.** Author declare no conflict of interest.

Радиолокация и радионавигация

Оригинальная статья

# Использование апостериорной информации при реализации систем радиолокационного распознавания с применением нейросетевых технологий

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**Аннотация**

**Введение.** Существующая в настоящее время необходимость получения актуальной, полной и достоверной информации о воздушных объектах определяет постоянное совершенствование современных систем радиолокационного распознавания (СРЛР), входящих в состав систем управления. Развитие современных СРЛР создает объективные предпосылки для использования прогрессивных и разработки новых методов и алгоритмов обработки сигналов с помощью нейронных сетей. Применение искусственных нейронных сетей, обладающих свойством обучаемости, позволяет расширить множество признаков распознавания за счет использования полученной в процессе контроля воздушного пространства информации.

**Цель работы.** Формулировка задачи и разработка предложений по использованию апостериорной информации для контроля воздушного пространства в системах радиолокационного распознавания при применении нейросетевых технологий.

**Материалы и методы.** На основе анализа структуры единого информационного пространства сформулирован подход к развитию СРЛР на основе обучающих технологий. С применением метода синтеза предложены примеры технических решений, позволяющие использовать современные методы и алгоритмы обработки сигналов на основе апостериорной информации, формируемой системой управления.

**Результаты.** Сформулированы принципы обучения нейронной сети при решении задачи распознавания в процессе функционирования радиоэлектронных средств (РЭС). Предложены технические решения, учитывающие функционирование интегрированной радиолокационной системы и позволяющие в едином информационном поле получать требуемые для обучения СРЛР информационные параметры. Показано, что снятие ограничений, связанных с автономностью функционирования РЭС, позволяет использовать апостериорную информацию при реализации систем радиолокационного распознавания. Этот факт дает возможность увеличить количество используемых в алгоритмах признаков распознавания и пополнить базы портретов.

**Заключение.** СРЛР может развиваться посредством обучения за счёт снятия ограничений, связанных с автономностью функционирования РЭС. Это позволяет повысить адекватность оценки обстановки и оптимизировать принимаемые управленческие решения.

**Ключевые слова:** радиолокационное распознавание, апостериорная информация, нейросеть, обучение, радиолокационное средство, информационное пространство

**Introduction.** The contemporary importance of control systems (CS), which have both civil and military applications, is constantly growing. However, in order to develop solutions (control actions) in CS, reliable and maximally complete initial data are required.

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One of the main directions of the creation and improvement of aerospace defence (ASD) systems in accordance with the ASD concept of the Russian Federation [1] is the full-scale deployment of a Federal Air Surveillance and Control System (FAS & CS) and the formation of a common information space (CIS) on the state of the aerospace environment. The elements of the technical component of the FAS & CS are radar facilities (in the general case, radioelectronic equipment (REE)), which form the initial input data for decision-making.

Nowadays, the recognition of airborne objects is of great interest because it provides greater completeness of radar information about real situations and, as a consequence, the optimisation and improvement of the adequacy of the solutions formed at the control points of different degrees of hierarchy.

In this regard, there is a present trend to include data on the inclusion of the radar target in one or another class (type) of information provided to users by radars. This information component is formed by the radar recognition system, forming part of the radar, based on the information parameters of the signals received during the airspace survey.

The recognition process is based on the identification of certain signs contained in the received signals (in general, the presence of a sign is a sufficient condition for an object to belong to a certain class).

The dictionaries of signs formed during the construction of radar recognition systems (RRSs) from the attribute space are apriori information for a particular REE. It is created by modelling and conducting experimental studies [2–4].

The aposteriori information obtained as a result of the functioning of the control system, including REE with an RRS, despite the presence of a fairly widely represented mathematical apparatus [4–6], is currently used mainly to provide consumers and evaluate the performance of recognition algorithms.

At the same time, due to the need for up-to-date, complete and reliable information on aerial objects for air space control and adequate measures, it is possible to apply neural network technologies that use aposteriori information generated by the CS, including REE and RRS, including for providing the algorithms of recognition of initial data and for correcting the primary and secondary signal processing algorithms.

**Methods.** Formally, radar recognition (RR) comprises the task of assigning a detected object to one of the elements of a set $\{A_i\}$, representing the alphabet of classes; when limiting the total costs allocated to the creation of all devices that solve the RR problem, this is reduced to finding the extremum of the functional [2]

$$\mathbf{E}\left[t,\ S_{\mathrm{nt}},\ X_{\mathrm{lt}},\ H_{\mathrm{rt}},\ H_{\mathrm{q}},\ Z|B\right],$$

where $\mathbf{E}[\ldots]$ – the selected criterion for assessing effectiveness; $t$ – the number of resources involved in solving the recognition problem; $S_{\mathrm{nt}}$ – the set of types of radar signals; $X_{\mathrm{lt}}$ – the set of descriptions of signs; $H_{\mathrm{rt}}$ – the set of rules for making decisions about the class of the radar target; $H_{\mathrm{q}}$ – the set of rules for using data about the class of an object; $B = \{b_{\mathrm{j}}\}$ – the set of objects of various types; $Z$ – the set of parameters of objects that can be obtained by the radar.

Due to the peculiarities of the technical implementation of the applied methods, various algorithms are implemented when solving the recognition problem; these in turn are based on the use of defined characteristics.

Presenting the recognition algorithm for information portraits as an abstract functional system consisting of an alphabet of classes, a dictionary of attributes and a set $R$ of rules (algorithms) for deciding whether an object belongs to a particular class, it is possible to obtain the dependence of the recognition problem on the implemented algorithm:

$$\mathbf{E}\left[t,\ S_{\mathrm{nt}},\ R,\ \{Z|B\}\right].$$

The process of developing an RRS can be represented as a process of modifying the recognition algorithm(s), if the set of types of radar signals $S_{\mathrm{nt}}$ : is constant:

$$\mathbf{E}\left[t,\ S_{\mathrm{nt}},\ R_1,\ \{Z|B\}\right]\big\|Q_1 \le$$
$$\le \mathbf{E}\left[t,\ S_{\mathrm{nt}},\ R_2,\ \{Z|B\}\right]\big\|Q_2, \tag{1}$$

where $R_1$ and $R_2$ are the set of recognition algorithms implemented by REE before and after training, respectively, $\left[R_1 \subset R, R_2 \subset R, R_1 \ne R_2, R_2 = \Lambda\left(R_1\right)\right]$; $Q_1$ and $Q_2$ are the set of conditions under which the implementing recognition algorithms of REE are functioning. At that, $Q_1 \subset Q, Q_2 \subset Q,$ where $Q$ is the set of possible conditions for the functioning of the REE.

The fulfilment of condition (1) is based on the ability of the system to learn [3]; that is, to change its parameters and (or) structure depending on experi-

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mental data. A finite set of such data is called a training set. Training is a set of rules for using object class data $H_q$ and feature descriptions $X_{lt}$.

Radar recognition signs are distinguished according to their physical nature [4]. The fundamental difference between the trained classifiers is that the boundaries between the classes of images (portraits) are determined not directly by calculating the corresponding coefficients in the separating functions, but rather iteratively.

For the considered class of classifiers, artificial neural networks (ANN) [7–10] are typically employed for which a learning capability is a natural and inalienable feature. The application of ANNs gives good results even when using a single recognition sign [11-13]. However, the use of a combination of features in an RRS currently causes certain difficulties associated not only with the complication of the equipment of the main REE reception path, but also with the presence of apriori uncertainty when using individual features. The elimination of apriori uncertainty [14] is achieved by integration and training.

For training a neural-like system, a database (DB) of training examples is needed. The more comprehensive the DB and the more accurately the examples correspond to the operating modes of the system, the more effective the subsequent functioning of such a system. Considering the application of the structure of the neural network, one of the areas of training is the adjustment of weights (the degree of importance of a particular attribute) for REE.

There is no universal learning algorithm suitable for all ANN architectures. Only a set of tools is known, represented by a variety of training algorithms, each of which has its own advantages. Learning algorithms differ from each other in the way they adjust the synaptic weights of neurons. Another distinguishing characteristic is the way the trained neural network is connected with the outside world. In this context, one speaks of a learning paradigm associated with a model of the environment in which this ANN operates. The ANN receives stimuli from the external environment as determined by the components of $t S_{nt}$, $X_{lt}$, $\{Z|B\}$. Following the resultant change in ANN parameters, it responds to excitation in a different way.

Currently, five main training models can be identified in relation to an ANN:
– based on error correction;
– using memory;

– Hebbian learning;
– competitive training;
– Boltzmann method.

Training based on error correction implements the optimal filtering method, while memory-based learning involves the explicit use of training data. The Hebb method and competitive approach to learning are based on neurobiological principles, whereas the Boltzmann method is organised according to the concepts of statistical mechanics.

The implementation of training algorithms requires the availability of reliable information about the type (class) of recognition objects following their detection and identification.

In the case of the formation of the CIS on the state of the air environment by collecting and processing information obtained by various sources (including their own unified radar systems for the Ministry of Defence, the Federal Air Transport Agency and other ministries and departments), considering the availability of access to this space for various users taking into account the delimitation of their respective authorities in the course of solving their tasks, this information can be obtained directly from automation means (including the unified air traffic management system (UATMS)), as well as from operators who have undergone special training.

If there is confirmation of the correctness of the solution, the databases can be replenished; and in some cases, following recognition, it may be advantageous to form new databases. The weighting of individual characteristics can be adjusted at the stage of operationalising the equipment in specific positions.

Thus, when implementing recognition equipment using a deep ANN (containing several multilayer filters), the concept of a reference portrait of an object acquires a broader meaning. In this case, the reference portrait should not only include a set of descriptions of signs $X_{lt}$, but also consider the implemented algorithm $R$, which is included in the set of decision rules on the class of the radar target $H_{rt}$.

According to the guidelines of the Ministry of Defence of the Russian Federation, training of REE in service is a controversial task. On the one hand, the manufacturer implements specific algorithms by providing the specified characteristics of the means, on the other hand – these algorithms can be corrected in the process of operation. Without additional measures, adjustments can in some cases reduce quality, so there is a need to separate mission and

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training processes. To this end, additional elements can be included in the REE to ensure the independence of the training process.

With regard to the ANN, the recognition algorithms it implements may differ in the weighting coefficients of relations with associative and reacting elements. Weightings can be represented by a matrix $M_1$, in the technical implementation stored in memory. Although decisions can be made about the need to correct individual elements of the matrix during the learning process, the final decision on changing these values needs to be made only after accumulating sufficient statistics. For this, an additional matrix of weight coefficients $M_2$, in the initial state is completely identical to $M_1$, the values of the elements of which are changed during the training process as part of the system. After determining the adequacy of the changed values, the matrix $M_1$ changes. This process is carried out by a weighting management device. It is also necessary to define and regulate the parameters of this procedure.

**Results.** A block diagram of a recognition device using a deep ANN with an additional matrix of weight coefficients for the implementation of training tasks is presented in Fig. 1. The matching unit as a part of the radar information processing path provides normalisation in the group of signals containing one attribute from the general population $X_{lt}$, for further processing in order to form a solution $A_i$. In other words, the matching unit together with the primary information processing (PIP) and secondary information processing (SIP) equipment solves the problem of clustering [15].

In processes involving learning with recognition, 4 main areas can be distinguished:

1. Initial training (recording portraits at the stage of system creation either from an experimentally obtained database or during the process of simulation using information technology).

2. Formation of the portrait base during the functioning of the system upon confirmation of the recognition results in a relatively simple signal environment.

3. The replenishment of the portrait base during the functioning of the system upon confirmation of the recognition results in a relatively simple signal environment.

4. Correction of portraits for a specific position, taking the characteristics of the positional area into account.
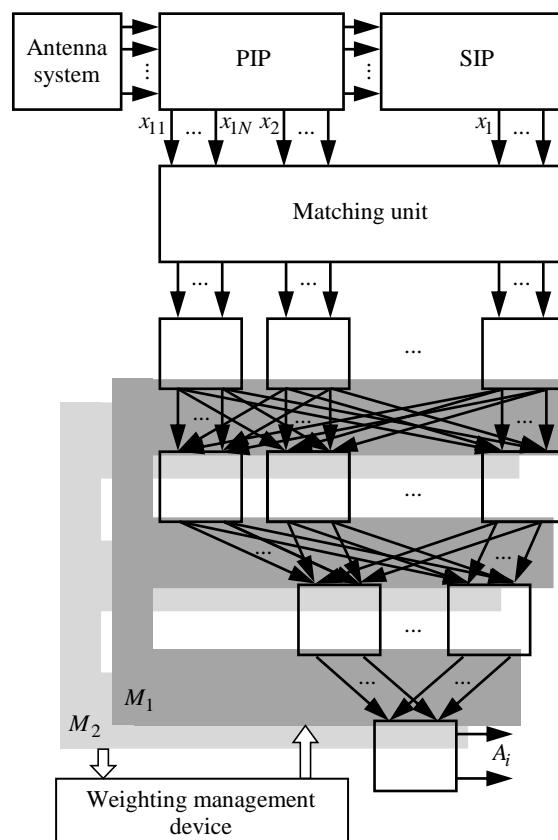


*Fig. 1.* Block diagram of a recognition device using a deep neural network with an additional matrix of weights for the implementation of training tasks

There are several steps to be taken to provide initial training [16]. At the first, the digital examples obtained by modelling the phono-target environment or by digitising suitable real fragments are used as training ones. Data is stored on the hard drive of the computer. The experts are involved to assess the adequacy of the impacts received at the input of the system. At this stage, the development of algorithms in pseudo-real time occurs.

The second stage differs from the first in that analogue input signals are used – the same fragments, but stored on other data carriers. Digitisation is performed directly during operation. Data arrives at a predetermined frequency, processing is performed in real time.

The third stage consisting of final checks and further training of the system is carried out on the basis of a real phono-target situation in conditions as close as possible to the combat ones.

Portraits can be divided into basic (fundamental) and individual for a specific position. For example, for REE located in mountainous areas, the results of measuring target heights during recognition must be adjusted (taking the position height into account) for adequate comparison with a portrait containing in-

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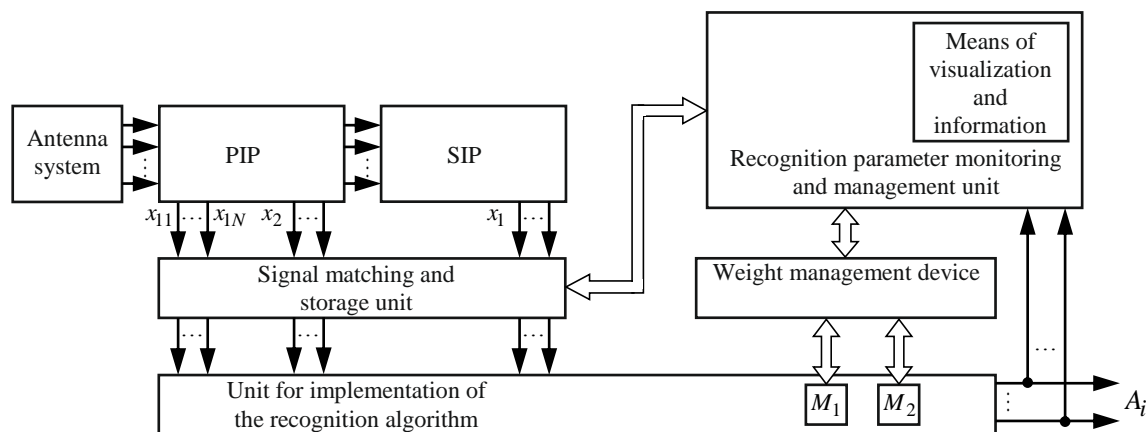Using Neural Network Technologies**

*Fig. 2*. Radar recognition system with elements providing its training

formation about the ability of the target to climb. It is recommended that this correction be carried out at the third stage.

A device for monitoring and controlling recognition parameters, including means of visualisation and
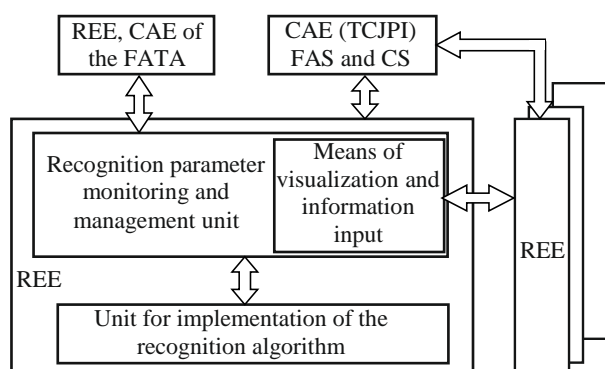


*Fig. 3*. External communications of radio-electronic equipment during the training of the recognition system as part of a grouping

input of information (Fig. 2), provides the implementation of starting training.

Confirmation of the reliability of the obtained results is possible when interacting with the REE, the complex of automation equipment (CAE) of the Federal Air Transport Agency (FATA) FAS, as well as on the basis of information received from control centres and regional UATMS centres.

When operating REE as part of a group, provision should be made for the possibility of exchanging portrait bases (without taking the formed terrain features into account) between the same type of REE (Fig. 3).

Ample opportunities for implementing automatic ANN training algorithms used in recognition are created when using CIS principles to obtain information concerning the state of the air environment in a radar system when the elements of the system are interconnected by an integrated digital telecommunication network.
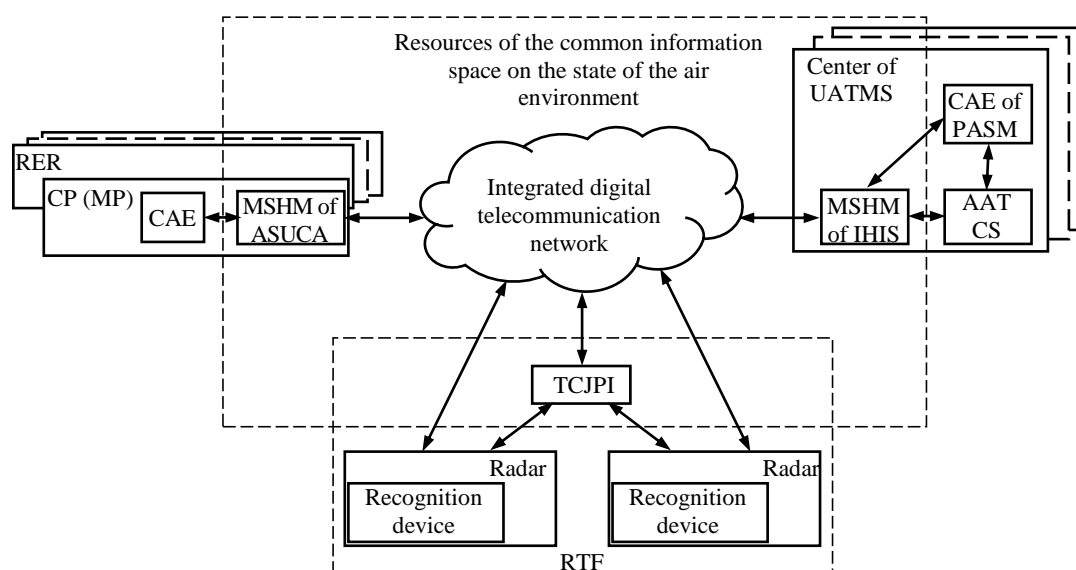


*Fig. 4*. Elements providing learning of the recognition system when working as part of a group

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The principles of the allow reliable information when training ANN about the types of escorted aircraft to be obtained by means of interacting Ministry of Defence of Russia and the Federal Air Transport Agency information (Fig. 4): software and hardware air space usage control automation modules (MSHM of ASUCA) located at the command posts (CPs) of radio engineering regiments (RERs), software and hardware information modules of interaction system (MSHM of IHIS) with automated air traffic control systems (AATCSs), as well as CAE air space management planning (PASM) located in UATMS centres.

Such a scheme of interaction can involve territorial centres of joint processing of information (TCJPI) of radio-technical facilities (RTFs) of radio engineering regiments (RERs) providing centralised collection and processing of information about air environment and management.

At the same time, it should be borne in mind that such an organisation of interaction (in the interests of training ANN and building intelligent recognition systems) will require significant changes in the principles of interaction of elements of the radar system. Consequently, it will be necessary to carry out a review of existing protocols for information and technical interaction.

**Conclusion.** Thus, an RRS, which solves the currently relevant recognition problem, allowing improved situation assessment in a complex phono-target environment along with an optimisation of management decisions, can be developed through training by removing the limitations associated with REE functional autonomy in relation to solving the recognition problem. This also leads to an increase in the number of signs when using neural network technologies.

## Authors' contribution

**Dmitrii F. Beskostyi,** description of neural networks in recognition system and stages of their training, fig. 2 and descriptive part

**Sergei G. Borovikov,** abstract, description of methods and results, fig. 1 and descriptive part.

**Yurii V. Yastrebov,** introduction, conclusion, english translation

**Ilya A. Sozontov,** fig. 3 and descriptive part, fig. 4 and descriptive part, references.

## Авторский вклад

**Бескостый Дмитрий Федорович** – описание нейронных сетей в системе распознавания и этапов их обучения, рис. 2 и описательная часть.

**Боровиков Сергей Геннадьевич** – аннотация, описание методов и результатов, рис. 1 и описательная часть.

**Ястребов Юрий Васильевич** – введение, заключение, перевод на английский язык.

**Созонтов Илья Александрович** – рис. 3 и описательная часть, рис. 4 и описательная часть, список литературы.

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