Radar Recognition of Given and Unknown Meteorological Objects

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***Abstract* - The recognition algorithms of given and unknown meteorological objects based of autoregressive model of the intensity fluctuations of the reflected signals is proposed. The experimental study of the recognition efficiency meteorological objects are presented with using real reflected signals from a weather radar.**

***Keywords* - Meteorological Object; Reflected Signal; Radar Recognition**

I. INTRODUCTION

Radar methods of remote sensing are often the only source of information about clouds [1-3]. Therefore the development of the radar methods for automatic recognition is of great interest. A real world scattered pulse train has period-to-period fluctuations and their statistical characteristics contain information about physical processes which take place in the meteorological objects. In particular the mean value of signal's intensity is proportional to the object reflectivity and traditionally is used for their classification. Intensity fluctuations of the reflected signals contain some information about meteorological objects. During radar probing of given meteorological clouds the signals from unknown meteorological objects are also present. So it is necessary of recognition of given and unknown signals. In this case classical recognition methods can not be used [4,5]. Therefore there is a necessity for development of non-traditional signal recognition methods which take into account the presence of an unknown signals.

When synthesizing statistical recognizers, we need to choose an adequate mathematical model of a signal being recognized, obtain signal's probabilistic characteristics and provide optimality criterion. In specific applied problems different types of random signal to recognize require to use various probabilistic models in order to describe the signal. A priory uncertainty (i.e. absence of a priory knowledge related to the signal probabilistic characteristics) is commonly overcome by using learning samples of signals being recognized. As a result we adopt the recognizer to the conditions of a particular applied problem. However, in practice unknown signals (i.e. signals that we can not get any learning sample for them) are also given for recognition along with statistically defined signals. In this case classical recognition methods can not be used. Therefore there is a necessity for development of non-traditional signal selectors and recognizers which take into account the presence of an unknown signal class. There was given no consideration to such recognition problems in known treatises on pattern recognition. Only in [6] one can find spectral methods for the defined random signal recognition in presence of the unknown signal class for the case when signals are described by the probabilistic model in the form of an orthogonal decomposition of a random signal.

In the present work we consider some non-traditional methods for selection and recognition of a statistically defined random signal subject to the presence of an unknown signal class for the case of describing the signal by different probabilistic models and in particular in the form of autoregressive processes and mixtures of normal distributions. There given results of solutions to some applied problems of recognition by using considered methods for and recognition of defined random signals.

The recognition algorithms of given and unknown meteorological objects based of autoregressive model of the intensity fluctuations of the reflected signals is proposed. The experimental study of the recognition efficiency meteorological objects are presented with using real reflected signals from a weather radar.

II. ALGORITHMS OF SIGNAL RECOGNITION

We put forward $(M+1)$ hypotheses that can be formulated with reference to the observed signals, namely, H^i, $i=\overline{1,M}$ are for statistically defined signals, H^{M+1} is for signals gathered into the $(M+1)$-th class and possessing unknown probabilistic characteristics. There are the learning samples for M given signals $\{\vec{x}_r^i,\ r=\overline{1,n_i};\ i=\overline{1,M}\}$. For the $(M+1)$-th class $(i=0)$ of unknown signals learning sample is absent.

Statement and solution to the considered problem is formalization of the requirements for the necessity to recognize M defined signals and reference an unknown signal to the $(M+1)$-th class since information about it is insufficient for its recognition. Geometrical sense of the general solution to the stated problem of selection and recognition of defined signals at presence of unknown signals is explained in fig 1.

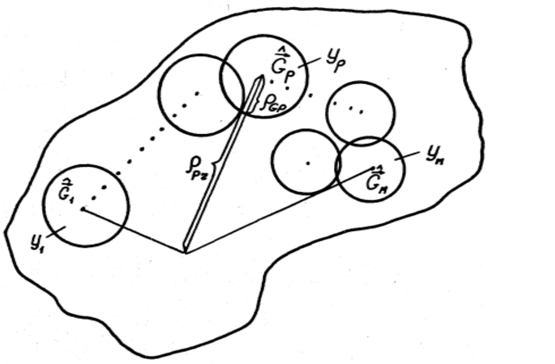

Fig. 1. Geometrical sense of the general solution problem of selection and recognition of defined signals at presence of unknown signals

Solution to the formulated above non-traditional problem of signal recognition gives the following decision rule [6]:
i -th given signal is observed if

$$H^i : \max_{l=1,M} \left\{ P_l W(\vec{x}/\vec{\alpha}^l) \right\} \geq \lambda, \quad (1a)$$

$$P_i W(\vec{x}/\vec{\alpha}^i) \geq P_l W(\vec{x}/\vec{\alpha}^l), l=\overline{1,M},\ l \neq i. \quad (1b)$$

unknown signals from $(M+1)$ -th class are observed if

$$H^{M+1} : \max_{l=1,M} \left\{ P_l W(\vec{x}/\vec{\alpha}^l) \right\} < \lambda; \quad (1c)$$

Here probability densities of given signals $W(\vec{x}\,|\,\vec{\alpha}^i),\ i=\overline{1,M}$ are defined accurate within random vector parameters $\vec{\alpha}^i$, $i=\overline{1,M}$. Parameters $\vec{\alpha}^l,\ l=\overline{1,M}$ are estimated on learning samples for given signals. The value for the threshold λ is chosen to provide the given probability of correct recognition of a given signal. Note that any information about probability distribution density of a signal from the $(M+1)$ -th class as well as its learning sample was not used at deriving decision rule (1).

Actually, here we solve the problem of extraction (selection) of the class of M given signals in conditions of increased a priory uncertainty (at the class of unknown signals presence). It is seen easily that the decision rule (1) can be used also to solve the inverse problem that arises sometimes in practice, namely, extraction (detection) of unknown signals.

The decision rule (1) gives the general solution to the stated problem of selection and recognition of given signals at presence of unknown signals. The statistical algorithms of signal recognition can be obtained when signals describing by any probabilistic model.

Specificities of decision rules for recognition of a signal described by the probabilistic model in the form of orthogonal decompositions are presented in [4]. This model gives us a spectral representation of a signal. In this case in the mentioned decision rules (1) we substitute the signal, given by the vector $\vec{x}$ for the vector $\vec{c}=\vec{x}\Phi$ of components of that signal decomposition over some basis, where Φ is a matrix of basis vectors.

When using such the probabilistic model as a mixture of probability distributions the decision rule of signal recognition (1) take the following form:

accept the hypothesis on the presence of the i -th given signal if

$$\max_{l=1,M} \{ P_l \sum_{q=1}^{Q} g_q W_q(\vec{x}/\vec{\alpha}^l) \} \geq \lambda, \quad (2a)$$

$$P_i \sum_{q=1}^{Q} g_q W_q(\vec{x}/\vec{\alpha}^l) \geq P_l \sum_{q=1}^{Q} g_q W_q(\vec{x}/\vec{\alpha}^l), \quad l=\overline{1,M}, \quad l \neq i \quad ; (2b)$$

accept the hypothesis on the presence of an unknown signal from the $(M+1)$ -th class if

$$\max_{l=1,M} \{ P_l \sum_{q=1}^{Q} g_q W_q(\vec{x}/\vec{\alpha}^l) \} < \lambda. \quad (2c)$$

When using autoregressive (AR) model description of signal samples is determined by the relation [7]

$$x_j^i = \sum_{l=1}^{p} \phi_l^i x_{j-1}^i + \sigma_a^i a_j, \ j=\overline{1,L}, \quad (3)$$

where ϕ_l^i, $l=\overline{1,p}$ autoregressive coefficients of i -th given signal, a_j are random values with zero mean and unit variance; p is the order of the AR model of i -th given signal; $(\sigma_a^i)^2$ is the variance of the prediction error.

It is necessary to determine the AR model parameters, i.e. values of p, ϕ_l^i, $l=\overline{1,p}$, $(\sigma_a^i)^2$. Coefficients ϕ_l^i might be found using the Yule-Walker equation $\vec{\phi}=\mathbf{R}^{-1}\vec{\rho}$, where $\vec{\phi}$ and $\vec{\rho}$ are respectively vectors of correlation coefficients of length p. $\mathbf{R}^{-1}$ is the $p \times p$ inverse correlation matrix which is calculated on base of learning given signal samples.

Algorithm of signal recognition in the form of Gaussian autoregressive processes can be represented by the relation [7]:

accept the hypothesis on the presence of the i -th given signal if

$$H^l : K_l(\vec{x}) < \Lambda_l, \quad l=\overline{1,M}, \quad (4b)$$

$$K_l(\vec{x}) - K_i(\vec{x}) + \ln \frac{(2\pi\sigma_i)^{p_i - L}}{(2\pi\sigma_k)^{p_k - L}} \geq \ln \frac{P_l}{P_i}$$

accept the hypothesis on the presence of an unknown signal if

$$H^0 : K_l(\vec{x}) > \Lambda_l, \quad l=\overline{1,M} \quad (4a)$$

$$K_l(\vec{x}) = \frac{1}{2\sigma_l^2} \sum_{k=p+1}^{L} \left[x_k - \mu^l - \sum_{j=1}^{p} \phi_j^l (x_{k-j} - \mu^l) \right]^2;$$

Λ_l - threshold values defined by the probability of correct recognition of given signals. Estimations of this parameters are obtained at the training stage using of learning given signal samples for the given meteorological objects.

III. EXPRIMENTAL RESULTS OF THE METEOROLGICAL OJECTS RECOGNITION

Investigations into the radar recognition of meteorological object with respect to intensity fluctuations of incoherent pulse radar reflected signals were performed by using the decision rule based on the model in the form of an autoregressive process (4). Unknown parameters of the model for intensity fluctuations of reflected signals were obtained with the aid of classified samples of reflected signals for the four types of clouds: cirrus, continuous gray, alto-cumulus, cumulus powerful clouds.

For experimental study of the meteorological objects recognition the radar measurement complex was used on the base of weather pulse incoherent radar MRL-1 [8]. The complex includes unit for sensitivity calibration, optical TV viewfinder for visual observation of the objects under inspection, interface unit for linking of weather radar with personal computer (PC) and antenna control unit (fig. 2).

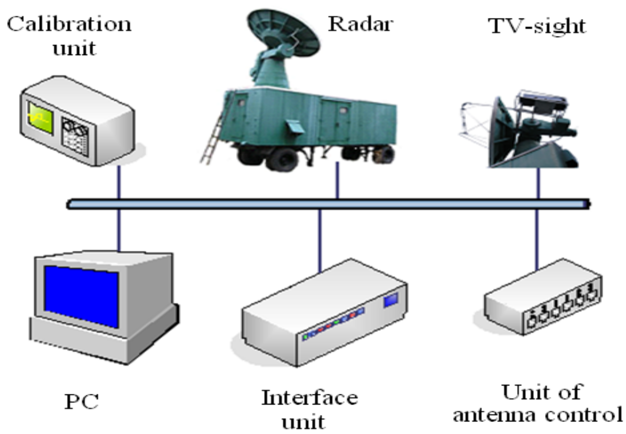

Fig. 2. Structure of the radar measurement complex

Use of PC permits to realize programmable scanning of the radar antenna with a given speed in a given angle sector of upper hemisphere, Also the application of calibration unit of the radar receiver permits to realize measurements of absolute values of reflected power using built-in power meter and software. This also provides compensation of amplitude characteristic nonlinearity of the receiver in the dynamic range more than 45 dB as well as accuracy of radar measurements not worse ±1,0 дБ, taking into account calibration of the antenna gain and losses in antenna-feeder path.

The device of drive pulses realizes synchronization of all subsystems, including transceiver, control unit and indication unit as well the system of the reflected signal processing. Quantized reflected signals are accumulated in the unit of preliminary signal processing and transferred to the PC using USB channel, where the signal processing is performed. Observation time of the angle sector 0°÷90° is about ≈ 77 c for scanning pitch ≈1,0˚ and number of range cells equals to 100.

Efficiency of given meteorological objects recognition (2) was performed using accumulated samples of the reflected signals from different meteorological objects. In particular 4 types of the given clouds were selected, which are mostly typical for Ukraine in the spring-and summer period [5]. In the fig. 3 the typical radar images of the mentioned objects are presented in the case of scanning with the pitch 1,0° in the sector 0°÷80° for fixed azimuth. Images of the clouds are presented in the coordinate system "Height - Range" and the image intensity is proportional to the object reflectivity that permits to estimate its structure. Here is pen-tip clouds, solid grey clouds, alto-cumulus and cumulus powerful clouds.

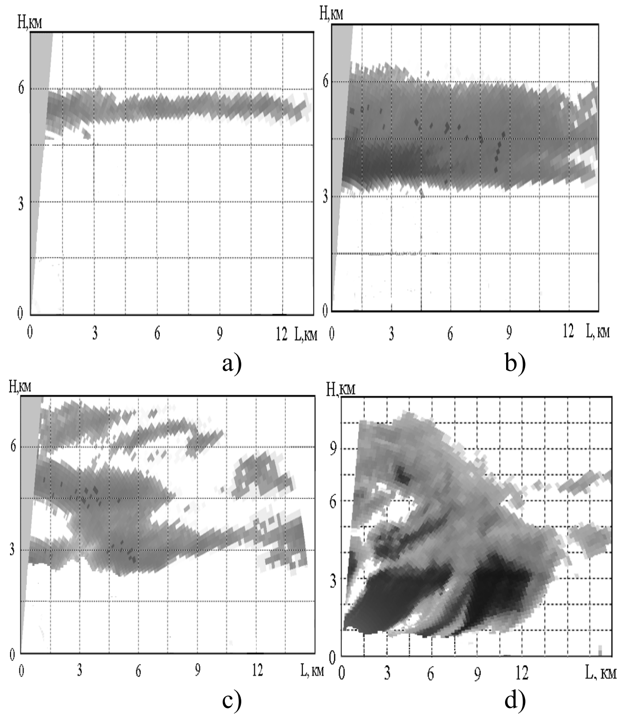

Fig. 3. Radar images of the given clouds (pen-tip clouds (a), solid grey clouds (b), alto-cumulus (c) and cumulus powerful clouds (d))

"Angel-echo" was considered as unknown meteorological object (fig. 4).

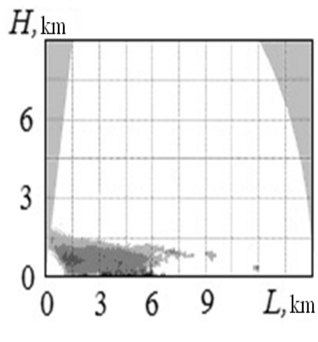

Fig. 4. Radar image of the "angel-echo"

To provide robust estimations of scattered signals parameters the 256 reflected pulses were accumulated during 0,83 seconds in each range cell, that permits to formulate training and reference samples of reflected signals as $N = 100$ realizations for different parts of each meteorological object.

Training samples of the signals reflected were used for estimation of the parameters of the AR model (autoregressive coefficients), that correspond to the given meteorological objects. Obtained estimates for the AR model parameters are shown in fig. 5.

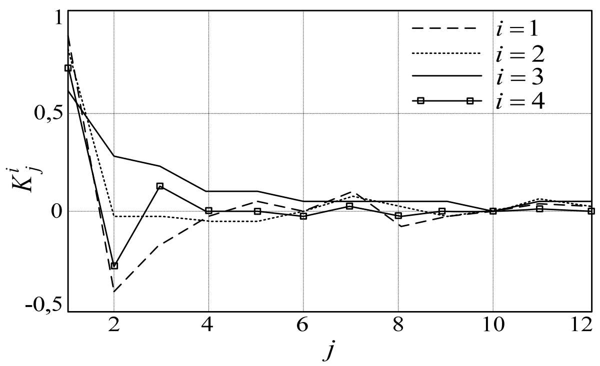

Fig. 5. Estimates of autoregressive coefficients for the reflected signals for the given meteorological objects

Control samples of the reflected signal for the same objects were accumulated in other periods of time and used for estimation of recognition quality by Monte-Carlo method. In the recognition mode the estimations of correct recognition were found in the form $P^i = \frac{n^i}{N}$, where n^i - the number of correctly recognized realizations of the control sample of i-th given signal within volume of N realizations.

In the issue of the investigations, the estimate of the average probability of given and unknown clouds correct recognition was found with respect to control samples of real signals that were reflected off different types of clouds. The "angel-echo" was considered as unknown meteorological objects. As the results of preliminary study showed the probabilities of correct recognition of given and unknown meteorological objects are not less than 80% .

While solving the problem of air object radar recognition with respect to samples of remote portraits the decision rule (1) based on the probabilistic model in the form of random signal orthogonal decompositions was used.

While investigating into another problem of automated radiomonitoring, namely, the problem of recognition of radio signal modulation type the decision rule (2) was used.

While investigating into the problem of automated recognition of sleep stages with the aid of electroencephalogram (EEG) the decision rule (4) was used.

IV. Conclusions

Solutions to a non-traditional random signal recognition problem is considered, namely, the problem when unknown signals are presented for recognition along with signals given in the probabilistic sense.

Methods for selection and recognition of a given random signal subject to the presence of the unknown signal class were considered. Special consideration was given to the cases when signal description was done by using such probabilistic models as orthogonal decompositions, autoregressive process and mixtures of probability distributions.

Practical significance of the proposed methods for signal selection and recognition in the field of radiolocation was proved. Investigations into the radar recognition of meteorological object with respect to intensity fluctuations of incoherent pulse radar reflected signals were performed by using the decision rule based on the model in the form of an autoregressive process.

For experimental study of the meteorological objects recognition the radar measurement complex was used on the base of weather pulse incoherent radar MRL-1. Efficiency of given meteorological objects recognition was performed using accumulated samples of the reflected signals from different clouds (pen-tip clouds, solid grey clouds, alto-cumulus and cumulus powerful clouds).

Control samples of the real reflected signal for the same objects were accumulated in other periods of time and used for estimation of recognition quality by Monte-Carlo method. Obtained results show the possibility of effective radar recognition of the meteorological objects using fluctuations of reflected radar signals intensity.

The experimental data presented permit to solve applied problems using radar recognition of meteorological objects for various fields of national economy including flight safety, hail damage prevention, squalls in "clear" sky etc.

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