An algorithm for object classification procedure for ISAR images

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Abstract— **This article offers a neural network architecture for automatic classification of Inverse Synthetic Aperture Radar objects represented in images with high level of post-receive optimization. A full explanation of the procedures of two-layer neural network architecture creating and training is described. The classification in the recognition stage is proposed, based on comparison with flying objects images from a database. The classification sets are gained by distinctive specifications in the structural models of the aircrafts. The neural network is experimentally simulated in MATLAB environment.**

I. Introduction

For the classification systems of Inverse Synthetic Aperture Radars (ISAR) the neural networks technologies for better image reconstruction are proven to be successful [1]. An opportunity for improved information analysis in that area is suggested to be the development of better algorithms for recognition of the various flying objects.

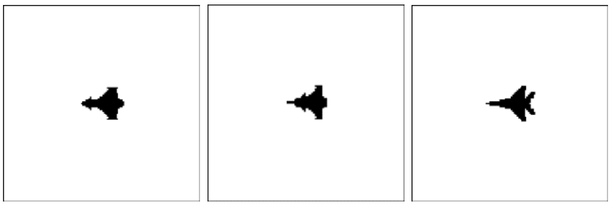
In [2] to solve the problem of recognition of not cooperating objects of observation, after acquiring radar image, an algorithm based on fuzzy logic can be used to make this classification with a high degree of credibility while controlling the error rate. The effect of uncertainty in the identification process is reduced if it can be trained or if the experience of expert can be studied [7]. Many opportunities are revealed for in-depth research and implementation of new ideas and approaches to accelerate the process of implementing the principles of inverse aperture synthesis in practice. At this stage a common standard for assessing the quality of the radar image is not created [5]. New methods for detecting and analyzing specific characteristics of objects in ISAR - images of moving objects [4] are needed in order to differentiate them into different classes. An algorithm for recognition of objects in the radar image by comparison with standard contour models of planes is presented in this paper.

II. Preconditions

For the simulation environment is assumed that the process of obtaining a horizontal orientation of the observed object in a network of 256x256 pixels is completed with linear resolution at azimuth and distance, respectively $\Delta L = 0.5\,[m]$ and $\Delta R = 0.5\,[m]$. Procedures for filtering the resulting image and extraction of 128x128 pixels subarea containing the object silhouette and image optimization are also preconditions for the binary matrix S with the aircraft object [6,7,8].

Contour object patterns are placed exactly in the middle of the frame, both horizontally and vertically. Model matrices with the size of 128x128 elements are formed as follows: If the pixel of the graphical contour model is part of the contour model, the value of 1 is assigned to the corresponding matrix element, otherwise the element is 0.

For the simulation experiment, sixteen airplane models are defined in a rectangular network of 128x128 pixels with network dimensions. Sixteen exemplary graphical contour models are used: Eurofighter Typhoon, Pilatus 9M, Rafale, Mirage 2000, MiG-29, Gripen, Falcon 2000, F-22, F-18, F-16, C-130 H, Bombardier Q400, Boeing-747, Boeing-737, Boeing-707 and Embraer Legacy 600. The reference models are created on detailed graphical maps, accompanied by precise data on the geometric dimensions of objects in the three dimensions. Graphics cards and data are published on the FAS website (Federation of American Scientists). The models are designed to be proportional 2D schemes of real aircrafts (fig.1).



Eurofighter Typhoon | Rafale | MiG-29

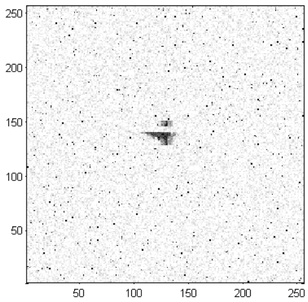
Figure1. Reference models from aircrafts database.

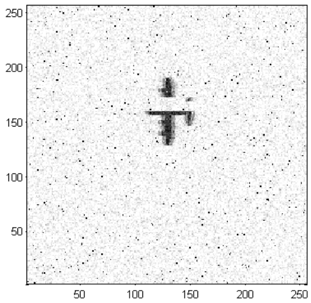
The modeling is carried out under the following initial conditions. Objects are observed with ISAR, their movement is simulated in a rectilinear trajectory at constant speed and at constant altitude during observation. The object is modeled in its own two-dimensional coordinate system with network dimensions on both coordinates [3].

It is assumed that high resolution at a distance is realized in the ISAR by usage of impulses with linear frequency modulation. ISAR pulses are designed with linear frequency modulation of duration $T = 10^{-6}\,[s]$, repetition period $T_p = 10^{-5}\,[s]$ high frequency oscillation $f = 10^{10}\,[GHz]$, wavelength $\lambda = 0.03\,[m]$, and a full frequency deviation $2\Delta F = 3.10^{8}[Hz]$ [6].

It is assumed that the positions of some of the scatterers of the three-dimensional variations of the reference patterns are located with shading effect generation on other scatterers arranged behind them in the course of irradiation with the emitted radar signal.

A model of reconstructed ISAR image of the flying object in 128x128 pixel grid is used for the experiment in presence of Gaussian white noise with constant zero mean and variance 0.01 and "salt and pepper" noise with density 0.015. The additive "white" noise and impulse interferences produced by the peak noise are presented on figure 2. The experiments are developed in MATLAB environment.





(a) (b)

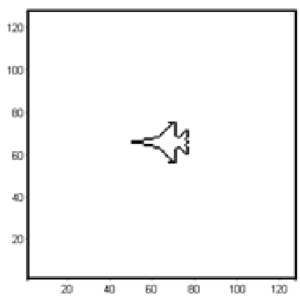
Figure 2. Reconstructed images in presence of additive noise for the aircrafts Rafale (a) and C-130 H (b).

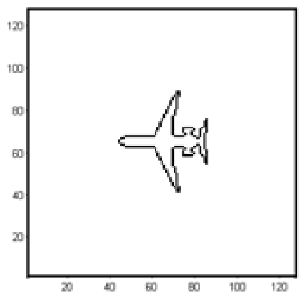
It is presumed that the ISAR image is processed with automatic focusing procedure locked on the final image [4].

With this algorithm, the object is accurately detected in the radar image by comparison with contour reference aircraft models from the database.

Numerous methods for extracting characteristic lines (contours) and contours from the structure of an image, which are based on the evaluation of the first and second derivative of the function of the intensity, are known in the theory of digital image processing [8].

Based on the fact that the images that are being processed at this processing stage are in binary format when there is only one monolith object within the frame, a filtering procedure for drawing the contour is applied to the images from the database (Fig.3).





(a) (b)

Figure 3. Extracting the contour line of the object through a filtering procedure in the images of F16 (a) and Embraer Legacy 600 (b).

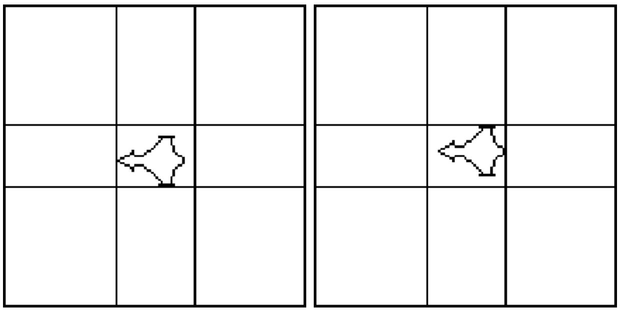
In the filtration of the resulting ISAR image, various image clearing procedures are used to form the structure of the filtration system and digital image processing [9]. Their purpose is to provide an image extraction and a contour image of optimal quality that is adequately corresponded to the shape of the subject in the frame, even in case of highly noisy images. Solving this task is of particular importance for the next step of processing the information associated with the recognition of the final object.

III. An Algorithm for Object Recognition Procedure

The availability of a ready database with a large amount of detailed models of flying objects (their characteristics, features of their structure) is essential for rapid decision on the specific task.

A neural network of type "Backpropagation" is chosen for the algorithm described before.

The problem is solved in converting the input image into a vector that can be classified by the neural network, similar to one of the classes (models) in a database, formed previously. A number of 16 etalon models, with dimensions of 128x128 pixels, is chosen for the comparison. Patterns are represented by binary matrices whose elements are numerical expression of the graphic-described solid models of aircraft with a known geometry. It is considered in this procedure that the possible error is within 2 pixels in eight directions. To remove the ambiguity of the subject in position, twenty-five supporting matrices are formed for each model by translation of the etalon model at distance of 2 pixels in eight directions on the center of the image (fig. 4). The etalon models database is formed by these 400 matrices (16x25). Figure 4 illustrates the principle of creating matrices $W_{M,1}$, $W_{M,2}$, …, $W_{M,N}$ for a reference model number corresponding to a Eurofighter Typhoon.



$W_{1,1}$ $W_{1,25}$

Figure 4. Graphic representation of matrix elements $W_{M,N}$ for model with number $M = 1$ (Eurofighter Typhoon).

In the next stage of the chosen designing approach, the etalon matrices with the values of pixel intensity are reshaped in vertices of 128x128=16384 element so each matrix is transformed to one column. These vertices are formed in one matrix of "training", called Training (16384x400). 400 is the number of objects in the database, multiplied by twenty-five items, which are subject to the procedure for recognition, a 16,384 is the number of pixels in an image. At this stage, a matrix for the "desired result" named "Target" is also constructed, which is necessary for the neural network process of training. The matrix has a dimension 16x400 - 16 rows of available sites classified by their solid silhouettes and 400 columns, because each etalon model is represented by twenty-five of his positions. The location of the non-zero element of each column corresponds to the number of class (line) with which the result of recognition is associated.

In accordance with the algorithm proposed before, a neuron architecture consisting of two layers is designed by means of the Matlab programming language (fig.5) and is modeled in Simulink environment (fig.6). In theoretical aspect, the learning process of this type of neural networks has proven convergence and therefore in a sufficiently long period of self-training, the neuron's weights should be suitably adjusted to produce correct classification of the vectors from the training sample. The first layer of the neural network is "hidden" and is composed of 16 neurons with a log-sigmoid transfer function. These neurons form subclasses, some of which the input vector is classified with. The internal structure of this layer is depicted on figure 6.

A line called "Delays 1" that converts the elements of the input sequence into an input vector is in the layer structure. Log-sigmoidal transfer function provides a high

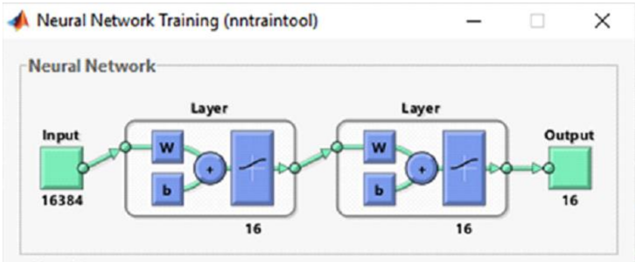


Figure 5. Block diagram of a neural network, designed in MATLAB environment.

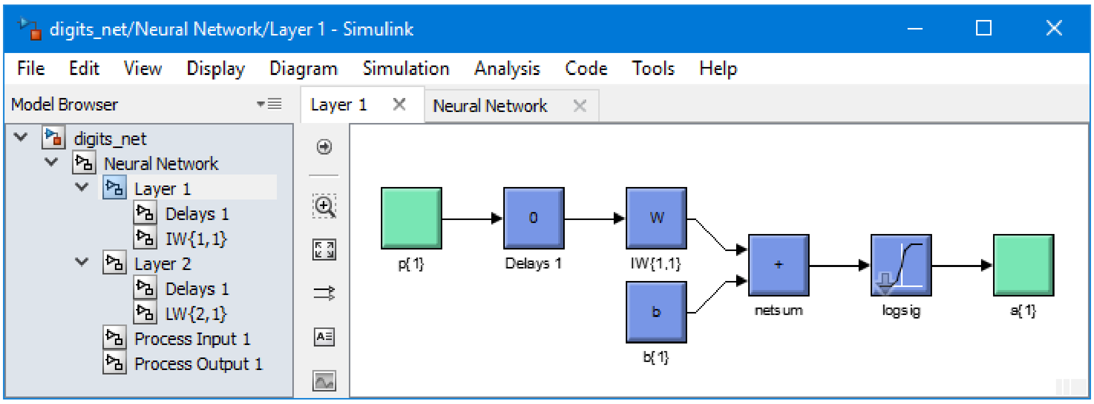


Figure 6. Structure of the first layer of the neural network built in Simulink.

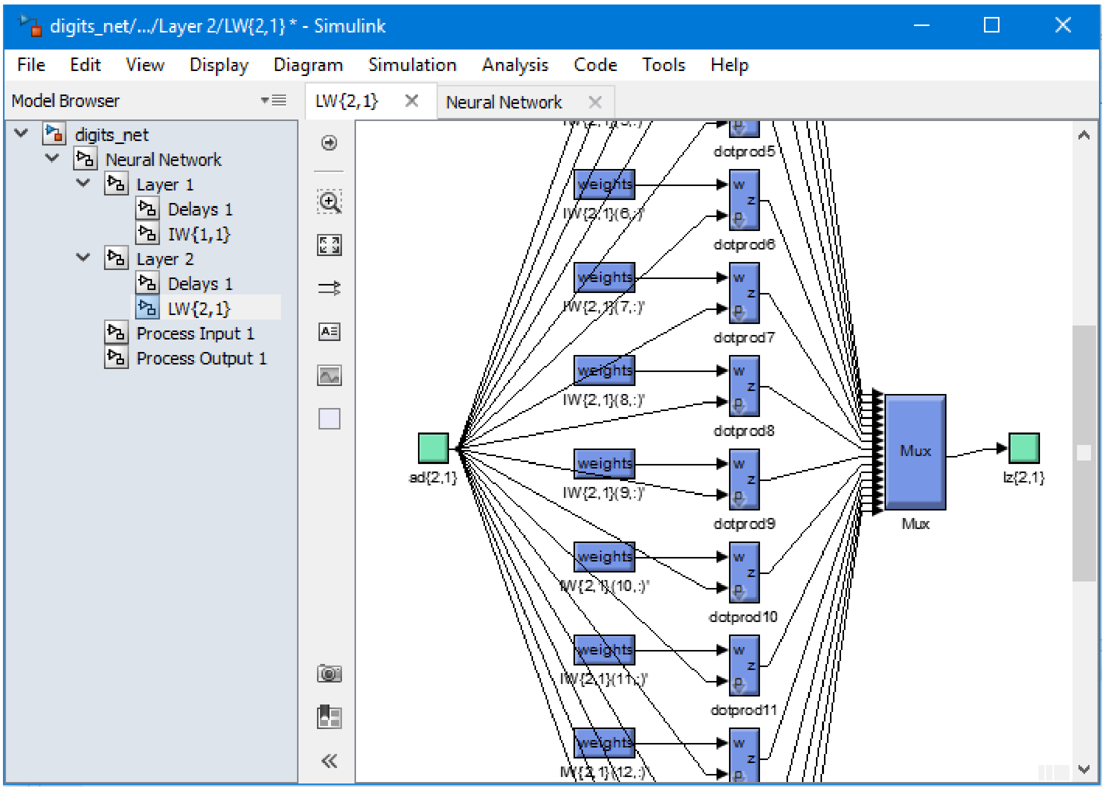
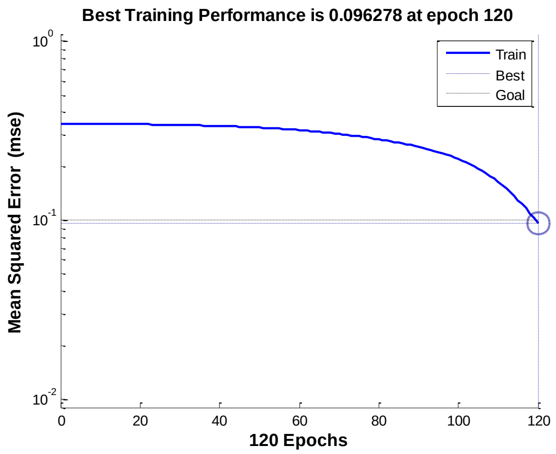


Figure 7. Structure of the weight matrix at the entrance of the second layer of the neural network.

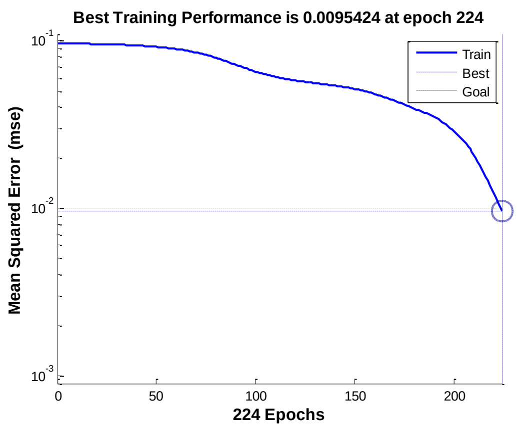
sensitivity and high resolution in the recognition process.

The weight matrix IW consists of sixteen weight vectors called "weights", whose specific values are determined in the education stage of neural network. The second layer according to the final number of desired classes is designed to have 16 neurons. The number of the "winner" neuron is corresponding to that one of the all solid aircraft models to which the current input vector is brought to. The role of this layer is to process a classification of the first layer results and to generalize them to a fixed number of user classes (16). Its structure is similar to the structure of the first layer. The expanded structure of the inputs of the neurons in the layer is presented on figure 7, wherein the weight matrix LW is composed of sixteen weight vector, whose specific weights are determined in the training stage of the neural network.

A training of the neural network is processed for the next stage of the neural architecture realization, which is essentially an adjustment of coefficients of the weighting matrices of neurons of the two layers. Embedded algorithms and procedures are used for automated self-training of the Matlab neural networks. A method for training a neural network with "teacher" in accordance with the following sequence of actions is processed. The initial training of the neural network is carried out free of interference.



(a)



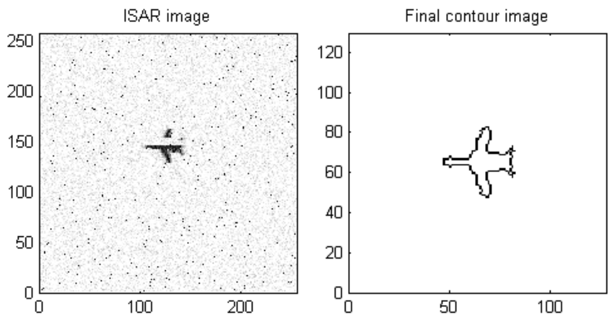
(b)

Figure 8. Desired possible error 0.1 during the training in noise free environment is reached at 120 epochs – (a). Desired possible error 0.01 reached at 224 epochs – (b).

The input of the network is fed with "training" matrix Training1, containing the values of the intensities of the pixels obtained from the reference models. The desired result indicated by the matrix Target is the product the output of the network is designed to produce. Back propagation of error is the learning algorithm used. The goal for the possible error is chosen to be 0.1 and the error calculating function is of the type sse (sum squared error - accumulated value of the square error). The maximum of the training epochs is limited to 1000. The training results are illustrated on Figure 8 (a).

For the next step in the network training process higher requirements are implemented – the goal for the possible error is chosen to be ten times lower now - 0.01. The results of that training are shown on Figure 8 (b).

In line with the graphics on figure 8 the desired threshold is reached in two cycles of training in which the learning process is considered to be complete. Modeling the process of synthesis of this neural architecture is carried out in Matlab environment. The results of the neural network for the ISAR observed object “Falcon 2000” (fig.9) are presented on figure 10 where the position of the etalon model for that airplane is 7 and the object is properly classified.



(a) (b)

Fig. 9. ISAR image received (a) and optimized (b).

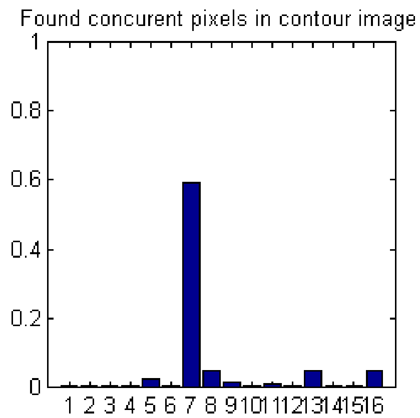


Figure 10. According to the neural network classification the object is recognized as the airplane Falcon 2000.

IV. Conclusion

In this article neural networks algorithm for object recognition procedure in ISAR image is designed. As a result of the analysis and the carried out experiments the following conclusions can be made:

The chosen decision making algorithm is logical and accurate for the class belonging of the observed object.

The described neural network operates like an associative memory and makes correct classification of the ISAR objects in high level of noise environment as well as if the objects are not full or heavily damaged.

The used number of neurons in the first layer is smaller than in other networks because it depends of the chosen models in contrast to the image pixel number.

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