Ministry of Education and Science of Ukraine

ODESSA NATIONAL ACADEMY OF FOOD TECHNOLOGIES

International Competition of Student Scientific Works

BLACK SEA SCIENCE 2018

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4. IT TECHNOLOGIES AND CYBERSECURITY

4. ІТ ТЕХНОЛОГІЇ ТА КІБЕРБЕЗПЕКА

MULTIDIMENSIONAL WAVELET NEURON AND ITS LEARNING FOR PATTERN RECOGNITION TASKS IN THE INTERNET OF THINGS APPLICATIONS

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The machine learning methods (especially artificial neural networks) are widely spread nowadays in a large class of pattern recognition, image classification, intelligent control and time series prediction tasks due to their universal approximating properties and their learning abilities. Since there's a number of practical tasks when a learning sample volume is restricted, a learning rate factor goes in the forefront.

At the same time, not all neural networks (first of all, the most popular multilayer architectures are learned with the error back propagation procedure) satisfy the real task conditions because of a low rate of a tuning process and a possible overfitting effect.

Therefore, hybrid systems are the most effective systems of machine learning now, especially neuro-fuzzy and wavelet-neuro-fuzzy systems that combine neural networks' universal approximation ability, fuzzy inference systems' interpretability, compact representation of signal local properties based on wavelet transform.

IoT produces and accumulates a lot of data of arbitrary natural, which are fed from Internet-connected sensory devices. Therefore, the development of IoT technologies requires new unique solutions for the accumulated data processing in real time, where the method of computational intelligence and machine learning have a lot of advantages as compared to conventional approaches.

Nowadays, intensive researches are being carried out for the integration of IoT technologies and machine learning methods. As the analysis shows, in most cases, the existing methods are either not capable of processing the data stream in real time or cannot be implemented based on simple IoT controllers that could allow the development of the cheap IoT applications. Thus, it is important to create new high-speed methods that would have a simplicity of implementation and allow data processing in online mode.

In this work, the architecture of multidimensional wavelet neuron and its learning algorithm for pattern recognition are proposed. The proposed approach is characterized by simplicity of computational implementation and high speed of tuning parameters. Such systems can be used for solving tasks of the classification data, the patterns recognition, the prediction of multidimensional time series, which are generated by Internet-connected sensory devices in IoT applications. The simplicity of multidimensional wavelet neuron architecture allows implementing it in the IoTcontrollers.

The computational experiments are performed based on benchmark and real data sets. The obtained results have confirmed the advantages of the proposed approach in comparison with the existed methods. The software RFAv.2.0 was developed for classification data and pattern recognition.

In the future, the adaptive wavelet function will be implemented into the architecture for increasing the approximation properties of wavelet neuron. Such adaptive activation function allows tuning its parameter (center and width) during a learning process.

The advantage of the proposed approach is described in the paper and is presented on "The First International Conference on Computer Science, Engineering and Education Applications (ICCSEEA2018)" by authors.

Introduction

Methods of scientific direction that is developed within computer science and is known as machine learning have been widely used to solve various real problems in many areas [1-3] recently.

Hybrid systems are the most effective systems of machine learning now, especially neuro-fuzzy [4-6] and wavelet-neuro-fuzzy systems [7-8] that combine neural networks' universal approximation ability, fuzzy inference systems' interpretability, compact representation of signal local properties based on wavelet transform.

Internet of things (IoT) produces and accumulates a lot of data of arbitrary natural, which are fed from Internet-connected sensory devices. Therefore, the development of IoT technologies requires new unique solutions for the accumulated data processing in real time, where the method of computational intelligence and machine learning have a lot of advantages as compared to conventional approaches [10-15].

As the use of intelligent systems becomes widespread, the requirements for their universality grow higher and higher, which means, in particular, a stability over any type of data, an adaptively to changing conditions, a transparency of the results interpretation. Strictly guarantee these properties we can only do by using rigorous mathematical methods based on the computational intelligence theory.

Nowadays, intensive researches are being carried out for the integration of IoT technologies and computational intelligence methods, among them: in [16] authors proposed 4 data mining models for processing IoT data, in [17] authors introduced a systematic manner for reviewing data mining knowledge and techniques in most common applications (classification, clustering, association analysis, time series analysis, and outline detection в IoT applications); in [18] authors ran a survey to respond to some of the challenges in preparing and processing data on the IoT through data mining techniques, in [19] authors attempted to explain the Smart City infrastructure in IoT and discussed the advanced communication to support added-value services for the administration of the city and citizens thereof.

As the analysis shows, in most cases, the existing methods are either not capable of processing the data stream in real time or cannot be implemented based on simple IoT controllers that could allow the development of the cheap IoT applications. Thus, it is important to create new high-speed methods that would have a simplicity of implementation and allow data processing in online mode.

In this work, the architecture of multidimensional wavelet neuron and its learning algorithm for pattern recognition are proposed. The proposed approach is characterized by simplicity of computational implementation and high speed of tuning parameters. Such systems can be used for solving tasks of the classification data, the patterns recognition, the prediction of multidimensional time series, which are generated by Internet-connected sensory devices in IoT applications.

1. Wavelet neuron for classification tasks and its learning algorithm

1.1. The architecture of wavelet neuron and its activation function

The architecture of wavelet neuron [20] is based on the neo-fuzzy architecture [21, 22], which uses only triangular activation functions.

Taking into account the fact that triangular activation functions do not always provideenough quality in pattern recognition tasks, the synthesis of wavelet neuron architecture based on wavelet activation function and its learning algorithm is relevant. Using the wavelet functions give us the advantage of detecting the local features in the patterns.

Figure 1.1 shows the architecture of wavelet neuron for classification tasks.

The wavelet neuron has the simple architecture for computational implementation and can be used for recognition and classification of data, which is received from a lot of sensors in the Internet of Things applications (security camera, fitness band, smart house systems etc.).

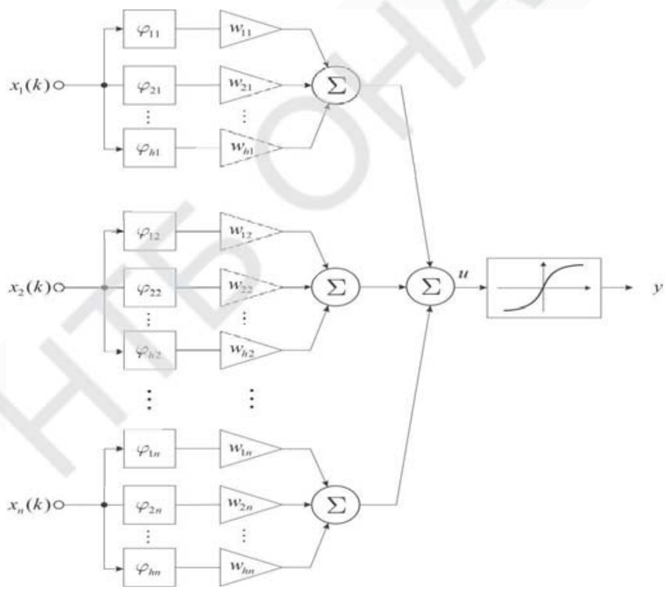

Fig. 1.1. The architecture of wavelet neuron

The vector in the form

$$x(k) = (x_1(k), x_2(k), \dots, x_n(k))^T, \tag{1.1}$$

is fed to the input of wavelet neuron (here k is the discrete instant of time), and in the output we obtain the signal in the form

$$y(k) = \frac{1}{1 + \exp(-\gamma u(k))} \tag{1.2}$$

$$u(k) = \sum_{i=1}^{n} f_i(x(k)) = \sum_{i=1}^{n}\sum_{j=1}^{h} w_{ji}(k-1)\varphi_{ji}(x_i(k)) \tag{1.3}$$

where γ is the parameter of sigmoid function, $w_{ji}(k)$ is the synaptic weight, $\varphi_{ji}(k)$ is the wavelet activation function, $i = 1, 2, \ldots, n$.

As wavelet activation functions we can use wavelet function “Mexican hat” in the form:

$$\varphi_{ji}(x_i(k)) = (1 - t_{ji}^2(k))\exp\left(-\frac{t_{ji}^2(k)}{2}\right) \tag{1.4}$$

where $t_{ji}(k) = x_i(k) - c_{ji}(k)\ \sigma_{ji}^{-1}(k)$; $c_{ji}(k)$ is the center parameter; $\sigma_{ji}(k)$ isthe width parameter of the activation function.

Figure 1.2 shows wavelet activation functions (1.4) with different values of the width parameter.

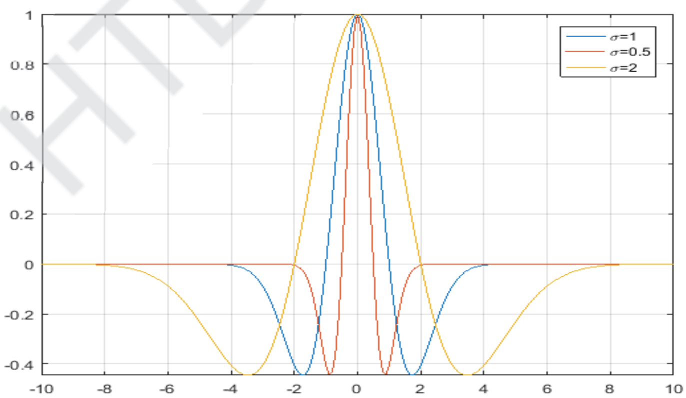

Fig. 1.2. Wavelet activation functions with different values of the width parameter

1.2. The learning algorithm of wavelet neuron

The learning process of wavelet neuron is the adjustment of synaptic weights $w_{ji}(k)$ in the each iteration k where the optimization task of chosen quality criterion is solved.

As the quality criterion we can use the quadratic quality criterion in the form:

$$E(k) = \frac{1}{2}(d(k) - y(k))^2 = \frac{1}{2}e^2(k) = \\ = \frac{1}{2}\left(d(k) - \frac{1}{1 + \exp\left(-\gamma \sum_{i=1}^{n}\sum_{j=1}^{h} w_{ji}(k-1)\varphi_{ji}(x_i(k)) \right)} \right)^2, \quad (1.5)$$

where $d(k)$ is reference signal, $y(k)$ is the actual signal, $e(k)$ is the learning error.

Thereby, a partial derivative of the synaptic weights has the form

$$\frac{\partial E(k)}{\partial w_{ji}(k)} = -\gamma e(k) y(k)(1 - y(k))\varphi_{ji}(x_i(k)) = \\ = -\gamma e(k) y(k)(1 - y(k))(1 - t_{ji}^2(k)) \exp\left(-\frac{t_{ji}^2(k)}{2} \right). \quad (1.6)$$

For learning process of wavelet neuron, we can use a gradient learning algorithm, which has form based on criterion (1.4):

$$w_{ji}(k+1) = w_{ji}(k) + \eta^w \gamma e(k+1) y(k)(1 - y(k))\varphi_{ji}(x_i(k)) \quad (1.7)$$

where η^w islearning rate parameter ($0 < \eta^w \leq 1$).

Introducing $(h_i \times 1)$ dimensionality vectors of variables $\varphi_i(x_i(k)) = (\varphi_{1i}(x_i(k)), \ldots, \varphi_{hi}(x_i(k)))^T$, $w_i(k) = (w_{1i}(k), \ldots, w_{hi}(k))^T$, we can write the gradient learning algorithm in the form

$$w_i(k+1) = w_i(k) + \eta^w \gamma e(k+1) y(k)(1 - y(k))\varphi_i(x(k)) \,. \quad (1.8)$$

In the future, the adaptive wavelet function will be implemented for increasing the approximation properties of wavelet neuron. Such adaptive activation function allows tuning its parameter during a learning process.

2. Multidimensional wavelet neuron and its learning

2.1. The architecture of multidimensional wavelet neuron

In many cases solving the real problems in the Internet of Things application is needed the prediction or the classification of multidimensional data, which are fed from some sensors at one time.

For this case, we can introduce multidimensional wavelet neuron, which has n inputs, m outputs and h wavelet activation function for each input. For the task of classification and pattern recognition, the sigmoidal functions have to be added to the output layer.

Figure 2.1 shows the architecture of the multidimensional wavelet neuron for the classification or pattern recognition tasks.

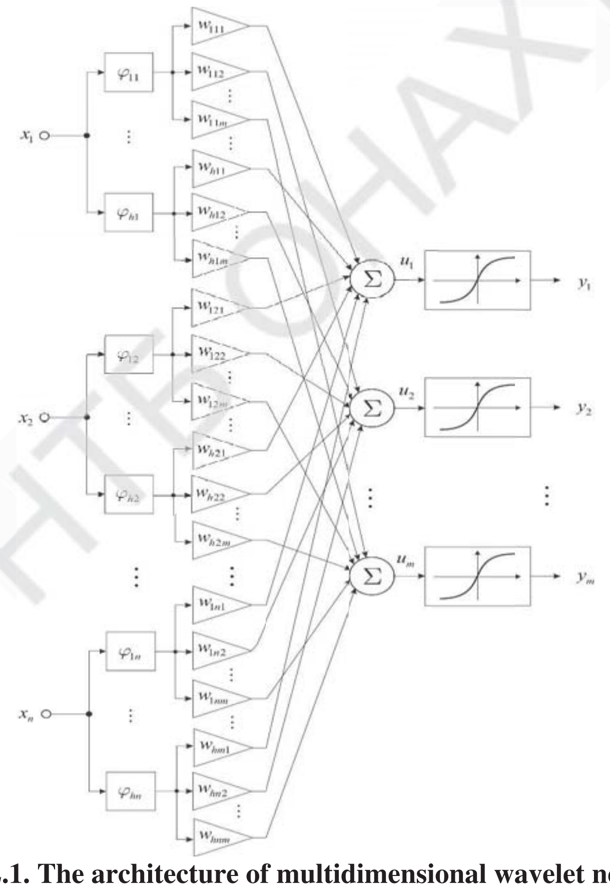

Fig. 2.1. The architecture of multidimensional wavelet neuron

The nodes of the multidimensional wavelet neuron are wavelet neurons, which can be described above.

For the optimization of computational implementation let's rewrite the input of multidimensional wavelet neuron in the form

$$y(k) = W(k)\varphi(x(k)) \tag{2.4}$$

where $\varphi(x(k)) = (\varphi_{11}(x_1), \varphi_{12}(x_2), \ldots, \varphi_{1n}(x_n), \varphi_{21}(x_1), \varphi_{22}(x_2), \ldots, \varphi_{2n}(x_n), \ldots, \varphi_{h1}(x_1), \ldots, \varphi_{hn}(x_n))^T$ is $(hn \times 1)$ dimension vector wavelet activation functions,

$$W(k) = \begin{pmatrix} w_{111} & w_{121} & \cdots & w_{1n1} & w_{211} & w_{221} & \cdots & w_{2n1} & \cdots & \cdots & w_{hn1} \\ w_{112} & w_{112} & \cdots & w_{1n2} & w_{212} & w_{222} & \cdots & w_{2n2} & \cdots & \cdots & w_{hn2} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \ddots & \vdots \\ w_{11m} & w_{12m} & \cdots & w_{1nm} & w_{21m} & w_{22m} & \cdots & w_{2nm} & \cdots & \cdots & w_{hnm} \end{pmatrix}$$

is $(m \times hn)$ dimensional matrix of synaptic weights.

2.2. The learning algorithm of multidimensional wavelet neuron

Due to the synaptic weights of multidimensional wavelet neuron depend on the output systems linearly, we can use the stochastic approximation algorithms, which minimize criterion in the form

$$E_j(k) = \frac{1}{2}e_j^2(k) = \frac{1}{2}(d_j(k) - y_j(k))^2 . \tag{2.5}$$

Minimizing the criterion (2.5) by synaptic weights $w_{lij}(k)$

$$\frac{\partial E_j}{\partial w_{lij}} = -e_j y_j (1 - y_j)\gamma\varphi_{li}(x_i), \tag{2.6}$$

we can write learning algorithm in the form

$$w_{lij}(k+1) = w_{lij}(k) - \eta\frac{\partial E_j}{\partial w_{lij}} = w_{lij}(k) + \eta e_j(k) y_j(k)(1 - y_j(k))\gamma\varphi_{li}(x_i(k)) \tag{2.7}$$

where η is learning rate parameter ($0 < \eta \le 1$).

For optimizing the learning process, we can rewrite learning algorithm (2.7) in matrix form

$$W(k+1) = W(k) + \eta\gamma(e(k) \odot y(k) \odot (1 - y(k))) \cdot \varphi^T(x(k)) \tag{2.8}$$

where $e(k)=(e_1(k),e_2(k),\ldots,e_m(k))^T$ is the errors vector, $y(k)=(y_1(k),y_2(k),\ldots,y_m(k))^T$ is the outputs vector, $\odot$ is dot product.

3. Experiments

3.1. Data classification based on synthetic data set

The effectiveness of proposed multidimensional wavelet neuron is examined based on data set «Two spirals» [23], which is two classes representing two spirals and is a benchmark for neural network.

For implementing proposed multidimensional wavelet neuron and its learning algorithm, the software RFAv.2.0 was developed based on C# programing language with standard libraries for the realization of mathematical operations and visualization of obtained results.

Figure 3.1 and figure 3.2 show the screen form of developed software RFAv.2.0 (the training process results and the classification results visualization.

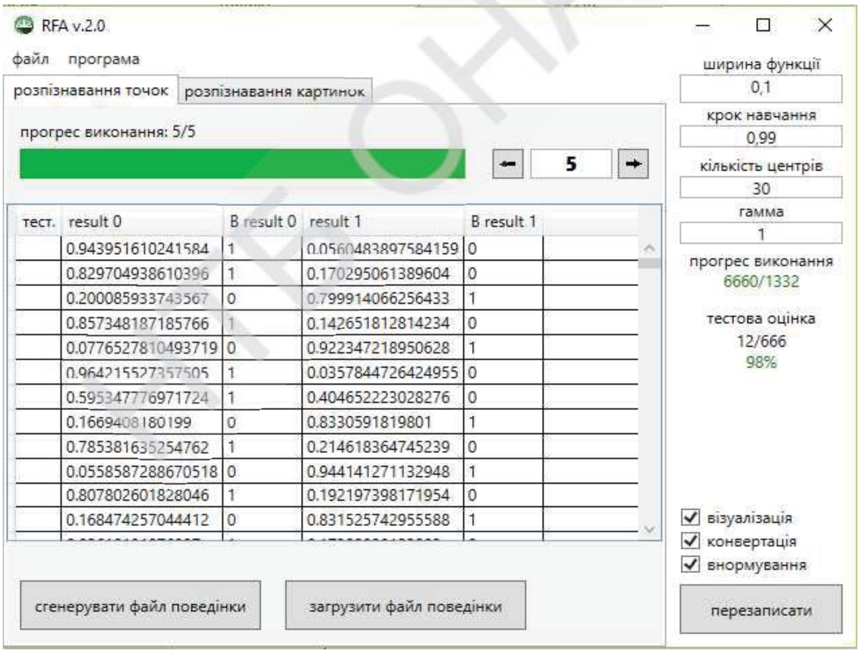

Fig. 3.1. The results of the training process of the multidimensional wavelet neuron

The data set is divided by the training data sample (70%) and testing data sample (30%). As the quality criterion was taken the percentage of the false classified patterns based on the testing data set.

The multidimensional wavelet neuron has 2 inputs, 2 outputs, and 30 wavelet function for each input. The initial synaptic weights values were taken zeros, the learning rate parameter was taken $\eta = 0.99$ and width of wavelet activation function was taken 0.1.

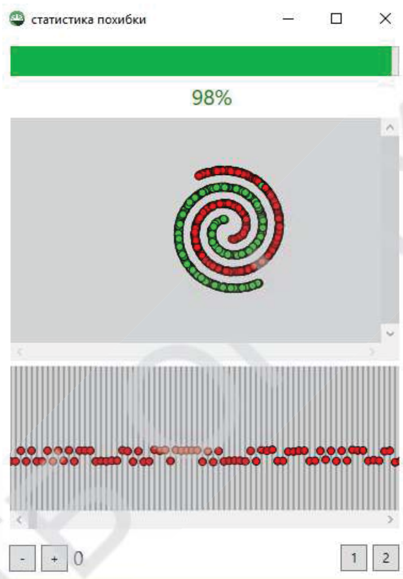

Fig. 3.2. The visualization of classification results of «Two spirals» data set

The obtained results are compared with neo-fuzzy neuron and are presented in Table 3.1.

Table 3.1 – The results of classification

Neural network	Number of activation function	Error Training set	Error Testing set
Multidimensional wavelet neuron	30	3,3%	2%
Neo-fuzzy neuron	30	3%	4,5%

3.2. Recognition of handwritten digits data sets

The effectiveness of proposed recognition system is examined based on two handwritten digits data sets. The first experiment was performed based on MNIST database [24] and results was presented by authors in the copy of paper.

The second experiment was performed based on handwritten digits data from Matlab data sets. The data store contains 10000 synthetic images of digits 0-9. The images are generated by applying random transformations to digit images created using different fonts. Each digit image is 28-by-28 pixels.

Fig. 3.3. Digit data set

The multidimensional wavelet neuron has 784 inputs, 10 outputs, and 10 wavelet function for each input. The initial synaptic weights values were taken zeros,the learning rate parameter was taken $\eta = 0.99$ and width of wavelet activation function was taken 0.3.As the quality criterion was taken the percentage of the true classified objects based on the testing data image set.

The multidimensional wavelet neuron was trained during 50 epochs and accuracy on the test data set was 92%.

Figures 3.4-3.6 show the results of recognition handwriting digits, which you can write in the window in the developed software RFAv.2.0.

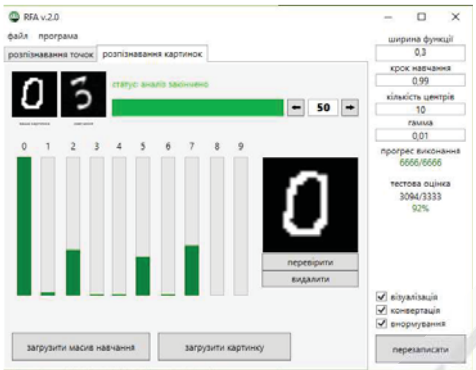

Fig. 3.4. The screen form of developed software RFAv.2.0

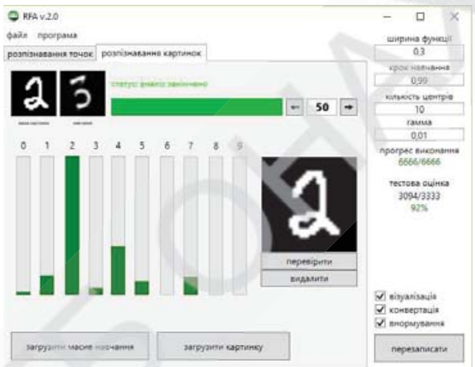

Fig. 3.5. The screen form of developed software RFAv.2.0

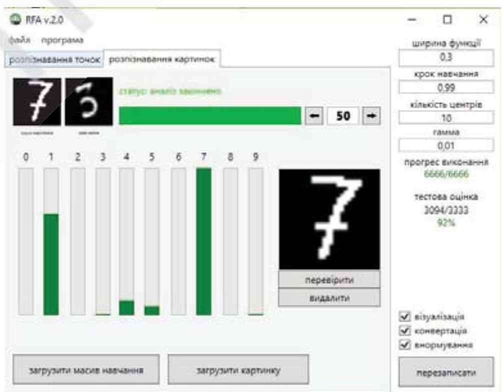

Fig. 3.6. The screen form of developed software RFAv.2.0

Conclusions

Nowadays, intensive researches are being carried out for the integration of IoT technologies and machine learning methods. As the analysis shows, in most cases, the existing methods are either not capable of processing the data stream in real time or cannot be implemented based on simple IoT controllers that could allow the development of the cheap IoT applications. Thus, it is important to create new high-speed methods that would have a simplicity of implementation and allow data processing in online mode.

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