Simulation Modelling Practice and Theory 33 (2013) 81–88

Contents lists available at SciVerse ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

Spatio-temporal data classification using CVNNs

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ARTICLE INFO

Article history:
Available online 26 January 2013

Keywords:
Complex-valued
Artificial neural network
Spatio-temporal
Neural gas
Classification
Back-propagation

ABSTRACT

This paper presents two new approaches of spatio-temporal data classification using complex-valued neural networks. First approach uses extended complex-valued back-propagation algorithm to train MLP network, whose output's amplitudes are encoded in one-of-N coding. It makes a classification decision based on accumulated distance between network output and trained pattern. The second approach is inspired in RBF networks with two layer architecture. Neurons from the first layer have fixed position in space and time encoded into theirs weights. This layer is trained by presented extension of neural gas algorithm into complex numbers. The second layer affects which neurons from the first layer belong to specific class. Paper contains details on experimenting with proposed approaches on artificial data of hand-written character recognition and comparison of both methods.

1. Introduction

In present, a huge amount of data is generated, including spatio-temporal data. Processing this data is relevant task across many branches including robotics, computer vision or medical data analysis (e.g. identification of moving objects in video data, facial emotion recognition or speech recognition). The classification is a frequent task on spatio-temporal data with a number of existing approaches, e.g. recurrent neural networks [1,2], time delay neural networks [3], reconstruction of phase space [4]. In [5] a complex-valued neural network is used to classify spatio-temporal data. It is based on accumulating error through time and selecting the class with minimal error. It is called C-MLP classifier and is described in chapter Section 4. This approach is however suitable only for classification of a few classes; in case of using more, it runs into a curse of dimensionality. In this paper, we present a new approach using complex-valued neural network [6] with dedicated topology for spatio-temporal data classification influenced by RBF networks [7] called C-RBF classifier and compare both approaches.

2. Model of complex-valued neuron

According to [6], the basic unit in complex-valued neural networks is neuron, which extends the real-valued one to complex domain. In this paper we use the model of complex-valued neuron shown in Fig. 1a. All inputs, output, weights and threshold are represented by complex numbers. The gain of neuron is defined as:

$$g = g(\vec{w}, \vec{x}, \Theta) | g : \mathbb{C}^{2N+1} \rightarrow \mathbb{C}, \tag{1}$$

where $g \in \mathbb{C}$ is gain, $\vec{w} = \{w_i \in \mathbb{C} | \forall i = 1 \ldots N\} \in \mathbb{C}^N$ is vector of N weights $w_i, \vec{x} = \{x_i \in \mathbb{C} | \forall i = 1 \ldots N\} \in \mathbb{C}^N$ is vector of N inputs x_i, $\Theta \in \mathbb{C}$ is threshold, w_i is weight of ith input x_i and N is number of inputs. The output of neuron is defined as follows:

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1569-190X/$ - see front matter
http://dx.doi.org/10.1016/j.simpat.2012.10.001

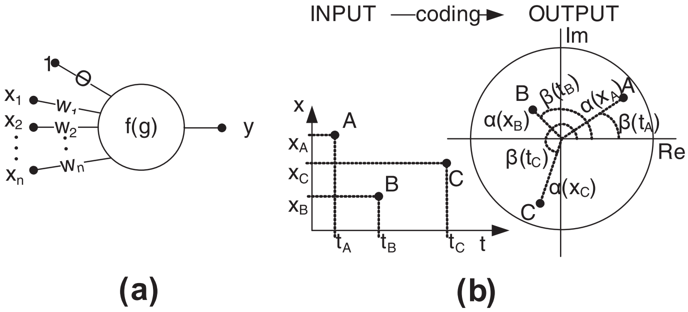

Fig. 1. (a) A model of complex-value neuron. To each input x_i belongs the weight w_i. (b) An example of spatio-temporal data coding. The spatio-temporal input data with one space dimension x and time t on the left (consisting of three points $A[x_A, t_A], B[x_B, t_B]$ and $C[x_C, t_C]$) are encoded into three complex numbers on the right ($d_A = |\alpha(x_A)|e^{i\beta(t_A)}, d_B = |\alpha(x_B)|e^{i\beta(t_B)}$ and $d_C = |\alpha(x_C)|e^{i\beta(t_C)}$).

$$y = f(g) |\ f : \mathbb{C} \to \mathbb{C}, \tag{2}$$

where $y \in \mathbb{C}$ is output of neuron and f is neuron's activation function. We use the polar form of complex number notation: $z = |z|e^{i\varphi_z}$. The output of neuron in this notation can be written as $y = |y|e^{i\varphi_y}$. We also use notation $z = z^R + iz^I$, where $z^R \in \mathbb{R}$ is real part of complex number $z \in \mathbb{C}, z^I \in \mathbb{R}$ is its imaginary part and $i^2 = -1$.

3. Input data coding

The coding of spatio-temporal data is very important for further processing. Our coding approach (called *Spatio-temporal data coding*) is based on polar form of complex numbers. The spatio-temporal data is sequence of events, each identified by its position in space and time of occurrence. We call this sequence *a data set*. Each vector $(\vec{x}_i, t_i)$ representing one event, where vector $\vec{x}_i \in \mathbb{R}^N$ denotes the position in n-dimensional space of event and $t_i \in \mathbb{R}$ denotes time of occurrence of event, is encoded into vector $\vec{d}_i \in \mathbb{C}^N$ as follows:

$$d_{ij} = \alpha(x_{ij})e^{i\beta(t_i)}, \tag{3}$$

$$\alpha(x_{ij}) = \frac{x_{ij} - \min_k x_{kj}}{\max_k x_{kj} - \min_k x_{kj}} \in \langle 0; 1 \rangle, \tag{4}$$

$$\beta(t_i) = 2\pi \frac{t_i - \min_k t_k}{\max_k t_k - \min_k t_k} \in \langle 0; 2\pi \rangle. \tag{5}$$

The data set (all the events) is distributed into time interval $\langle 0; 2\pi \rangle$ and each dimension of position is normalized to interval $\langle 0; 1 \rangle$. Fig. 1b shows the proposed coding approach in one space dimension.

The data set is in chronological order, so the sequence of encoded data phases is an increasing sequence. In spatio-temporal domain it is useless to be limited only to one event; the essential information is in the sequence of events, called *a data set*.

4. C-MLP classifier

The C-MLP classifier uses a fully-connected multilayer complex-valued neural network. We use the notation $w^l_{ik} \in \mathbb{C}$ to denote kth weight of ith neuron in lth layer, $\Theta^l_i \in \mathbb{C}, g^l_i \in \mathbb{C}, y^l_i \in \mathbb{C}$ to denote threshold, gain and output of ith neuron in lth layer, respectively, and $x^l_i \in \mathbb{C}$ to denote ith input to the lth layer.

The output of neural network dealing with classification of real-valued problems is commonly based on one-of-N coding. In that case, ANN has as many outputs as the count of classified classes. Each output represents whether the input belongs to the specific class or not. Unity means that input belongs to the class and zero means the exact opposite. This approach is useless in classification of spatio-temporal data, because we want to evaluate the entire data set. It is necessary to bring the time part into it.

In order to do so, we have proposed a new coding inspired by one-of-N coding, whose output is coded as stated in Eq. (6):

$$y_i = |y_i|e^{i\varphi_{y_i}}, \tag{6}$$

where $|y_i| \in \langle 0; 1 \rangle$ represents belonging of the submitted input to the ith class (the higher the value the higher the probability of belonging to ith class) and $\varphi_{y_i} \in \langle 0; 2\pi \rangle$ should represent the same time as submitted input. Because the essential information is included in whole data set, further processing of output is needed to classify the input data set. Fig. 2 shows examples of outputs encoded by this approach.

The classification process is done by the complex-valued neural network using the Am-Ph split complex-valued activation function and gain shown in Eqs. (7) and (8):