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Z-transform artificial neural networks

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ABSTRACT

This paper focuses on a new kind of artificial neural networks – the Z-transform artificial neural networks (ZTANNs). It is proposed to use the Z-transform instead of ordinary weights and a linear activation function of an artificial neuron. This extension allows to use artificial neural networks in new areas. The ordinary description of artificial neural networks is a special case of the description proposed in this paper. It also contains a description of the use of the ZTANN for automatic identification of objects in digital control system.

1. Introduction

It is common knowledge that the artificial neural network is a set of artificial neurons connected together to form a network which mimics a biological neural network [1,2]. During last years, many models of neural network have been created [3]. Neural network is a very simplified model of a brain. It consists of tens or hundreds of computing elements. A single computing element is called a neuron. An artificial neuron is a simplification of a real biological neuron. Neurons are connected to create a neural network. The connections have weights and neurons have activation functions. Most of the presently built and used neuron networks have a layer construction [4]. Layers included in neural network can be divided into three categories [5]:

- Input layer.
- Output layer.
- Hidden layer.

Neural networks can be divided into:

- Networks with one-way connections.
- Networks with feedback.

Three elements are crucial for every neural network model [6]:

- Node structure.
- Network topology.
- Algorithm of network learning.

One of the most important features of networks is their ability to adapt and organize themselves. This trait is used in most of the practical implementations. It allows to substitute a given algorithm with a neural network, which will automatically find the solution of a given problem [7]. Finding the solution may require from a few to few thousand iterations. The process of finding the solution automatically is called network learning [8]. Network learning algorithms may be divided into:

- Supervised learning.
  - Corrective learning.
  - Reinforcement learning.
- Unsupervised learning.

The most valuable quality of neural networks is their ability to learn. An important characteristic is an ability to compute data simultaneously. Neural networks have diminished vulnerability to damage in individual nodes compared to implementation of other algorithms [9]. Classical neural networks are not useful in implementations where a time dependence of a signal must be expressed – for example in dynamic systems of automatic regulation [10,11]. Therefore, an attempt to define a new type of neural networks is presented in this work. The neural network that is described is an artificial neural networks with Z-transform. The Z-transform is described in detail in Appendix.

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2. Proposal for a new type of artificial neural network

2.1. Z-transform artificial neuron (ZTAN)

The Z-transform artificial neuron presented in Fig. 1 can be seen in its mathematical description below. If we assume that $X_i(z)=\mathcal{Z}\{x_i[n]\}$, $U(z)=\mathcal{Z}\{u[n]\}$ and $Y(z)=\mathcal{Z}\{y[n]\}$, we can write it as

$$U(z)=\sum_{i=0}^{k} G_{XUi}(z)X_i(z) \tag{1}$$

where k is the number of the given output,

$$Y(z)=G_{UY}(z)U(z) \tag{2}$$

After putting Eq. (1) into (2) we can obtain

$$Y(z)=G_{UY}(z)\sum_{i=0}^{k} G_{XUi}(z)X_i(z), \tag{3}$$

which results in

$$Y(z)=\sum_{i=0}^{k} G_{UY}(z)G_{XUi}(z)X_i(z) \tag{4}$$

This Eq. (4) can be simplified by substituting the following formula:

$$G_i(z)=G_{UY}G_{XUi}(z) \tag{5}$$

It will be shown in Fig. 2 and it will be written now as

$$Y(z)=\sum_{i=0}^{k} G_i(z)X_i(z) \tag{6}$$

i-th transfer function (transmittance) is given as

$$G_i(z)=\frac{\sum_{l=0}^{\beta_i} b_{i,l}z^l}{\sum_{j=0}^{\alpha_i} a_{i,j}z^j} \tag{7}$$

where:

- i the number of the given input,
- k the number of inputs,
- j the number of the given power of factor of the polynomial in the denominator,
- α_i the amount of the given power of factor of the polynomial in the denominator,
- l the number of the given power of factor of the polynomial in the numerator,
- β_i the amount of the given power of factor of the polynomial in the numerator.

The given vector of transform can also be written in the following form:

$$G(z)=[G_0(z), G_1(z), \ldots, G_k(z)] \tag{8}$$

and the input vector:

$$X(z)=\begin{bmatrix} X_0(z) \\ X_1(z) \\ \vdots \\ X_k(z) \end{bmatrix} \tag{9}$$

Using the notation introduced previously in Eqs. (8) and (9), the formula (6) can be written as

$$Y(z)=G(z)X(z) \tag{10}$$

2.2. Learning process of Z-transform artificial neuron

Learning process of ZTAN is shown in Fig. 3. It consists of a lot of iteration modification coefficients $a_{i,j}$ and $b_{i,l}$ from Eq. (7) in order to minimize the value of $\Delta(z)$, which is given as

$$\Delta(z)=Z(z)-Y(z) \tag{11}$$

$Z(z)$ is the known learning value of the output signal in response to input signals $X(z)$. $Y(z)$ is a real value of the output signal. The learning idea is represented by the block ID in Fig. 3. The ID module is responsible for errors minimizing. It can be done by means of various techniques, e.g. PSO optimizing algorithm can be implemented. It will be done in the future work.

2.3. The Z-transform artificial neural network (ZTANN)

By using previously presented artificial neurons (ZTAN), it is possible to create a new kind of neural network – Z-transform artificial neural network (Fig. 4).

The input vector is

$$X(z)=\begin{bmatrix} X_0(z) \\ X_1(z) \\ \vdots \\ X_n(z) \end{bmatrix} \tag{12}$$

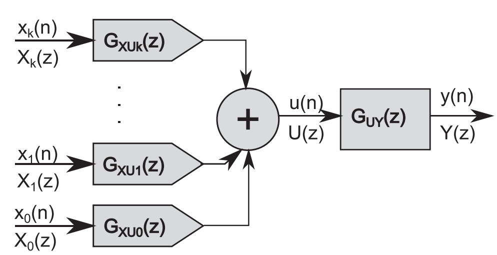

Fig. 1. The Z-transform artificial neuron.

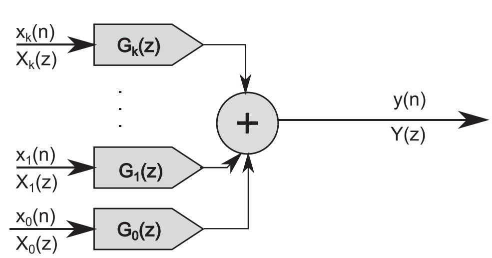

Fig. 2. The Z-transform artificial neuron after simplification.

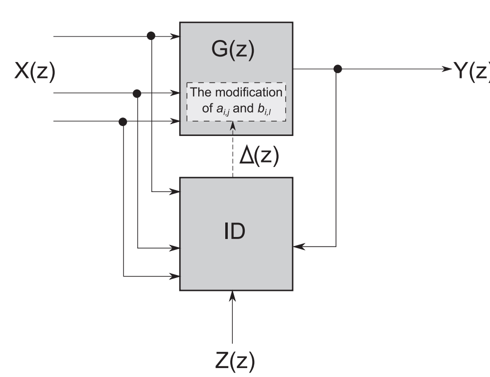

Fig. 3. The supervised learning ZTAN.