The Fuzzy Neural Networks with Ternary Encoding

O. Semenova, A. Semenov, K. Koval, A. Rudyk, V. Chuhov

Abstract — **When combining fuzzy logic and neural networks it is possible to get a hybrid system that can process uncertain values and can be trained. Fuzzy logic elements can be regarded as fuzzy-neural networks. In order to present a set of fuzzy values the ternary encoding is used. Three fuzzy neural networks on linear neurons are proposed. The first operates as a fuzzy logical minimum element, the second does as a fuzzy logical maximum element, the third – as a fuzzy logical complement element.**

***Index Terms*—fuzzy, neural network, ternary.**

I. Introduction

Artificial neural networks are physical cellular systems which can acquire, store and utilize experiential knowledge. One may say that they function as parallel distributed computing networks. But, they are not programmed to perform specific task, they to be taught, or trained. Also they can learn new associations and patterns. Neural networks can change their weights to optimize their work [1]. Fuzzy systems can process uncertain, vague values and provide the most accurate control action. They are suitable for approximate reasoning, when a mathematical model is very difficult to derive. Combining these intelligent technologies it is possible to get a hybrid system that can process uncertain values and can be learned [2]. Hybrid systems combining fuzzy logic, neural networks, and genetic algorithms have proved their effectiveness in a wide variety of problems [1].

II. Problem definition

Thus the aim of the work is developing the elements for a hybrid system. So, such tasks must be solved:

1. Needed elements for the hybrid system are to be defined;
2. Appropriate coding is to be found;
3. Diagrams of neural networks are to be developed.

III. The fuzzy neural network

There many types of fuzzy neural networks [2]. They differ by operations performed and ways of combining fuzzy and neural parts. And, of course, they are used in different applications. One type of fuzzy neural networks is a neural network, performing operation of fuzzy logic, namely minimum, maximum and complement.

Fuzzy minimum operation is performed so:

$$z = x \wedge y = \min(x, y) .$$

Fuzzy maximum operation is performed so:

$$z = x \vee y = \max(x, y) .$$

Fuzzy complement operation is performed so:

$$z = 1 - x .$$

The fuzzy neural networks may be used in fuzzy controllers dealing with changing data. Any fuzzy controller functions according to a set of rules, which are derived from expert knowledge:

$$\begin{array}{l} \mathbf{R_1}: \textit{if } x \textit{ is } A_1 \textit{ and } y \textit{ is } B_1 \textit{ then } z \textit{ is } C_1 \\ \textit{also} \\ \mathbf{R_2}: \textit{if } x \textit{ is } A_2 \textit{ and } y \textit{ is } B_2 \textit{ then } z \textit{ is } C_2 \\ \textit{also} \\ \ldots \\ \textit{also} \\ \mathbf{R_n}: \textit{if } x \textit{ is } A_n \textit{ and } y \textit{ is } B_n \textit{ then } z \textit{ is } C_n \end{array} ,$$

where x and y are input values (conditions); z is an output value (control action); A_i, B_i, C_i are fuzzy sets.

So, we propose to build up fuzzy minimum, maximum and complement elements of fuzzy controllers as neural networks in order to provide system's flexibility, adaptivity, and effectiveness.

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978-1-4799-1062-5/13/$31.00 ©2013 IEEE

IV. THE TERNARY ENCODING OF FUZZY VALUES

In the practical case we often deal not with the ideal fuzzy logic, but with an almost fuzzy, multivalued one. That is why we propose to use so called ternary encoding in order to present a singleton-type membership function (fig. 1).

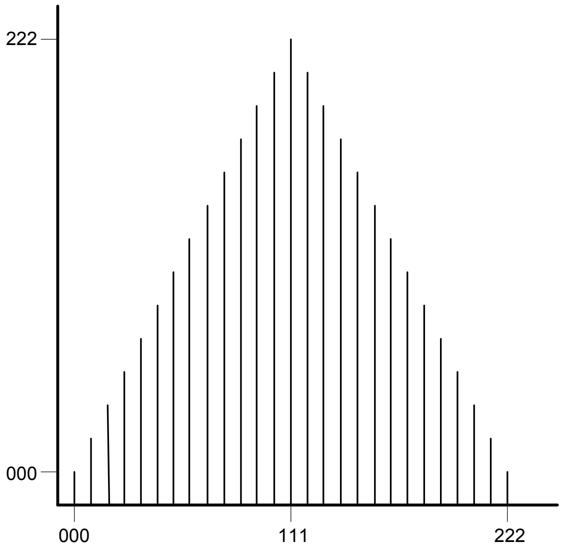

Fig. 1. A membership function as a set of singletons

In the ternary encoding the information is expressed not by bits (zero and one), but by trits – zero, one, two. Using of ternary encoding permits to achieve a high circuit density, to increase quick-action and to minimize interconnections. According to the ternary encoding each singleton of the membership function is expressed as trit data, chosen from the row [000, 001, 010, … , 220, 221, 222]. In this way we get a set of 27 values and it is enough to substitute fuzzy values in many applications. Of course, if needed, one may use the [0000, 0001, 0010, … , 2220, 2221, 2222] row and so on.

In [3] the {-1, 0, +1} ternary logic is proposed, but we propose to use the {0, 1, 2} ternary logic in order to shorten sign problems. So, let fuzzy logical zero correspond to ternary 000 and fuzzy logical one correspond to ternary 222. Instead of [0, 1] logic we have [000, 222] logic.

V. THE NEURAL NETWORKS

Every neural network consists of several layers (at least two) each of them has a set of neurons. All the neurons are connected in a specific way, which defines the operation of the whole network [2].

The neural network performing the minimum operation is presented at fig. 2.

The minimum fuzzy neural network operates according to these formulas:

$$f(net_1) = net_1 = x\cdot(+1) + y\cdot(+1)\ ,$$
$$f(net_2) = net_2 = x\cdot(+1) + y\cdot(-1)\ ,$$
$$f(net_3) = net_3 = net_1\cdot(+0{,}5) + net_2\cdot(-0{,}5)\ .$$

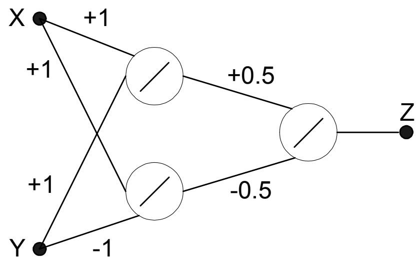

Fig. 2. The minimum fuzzy neural network

The neural network performing the maximum operation is presented at fig. 3.

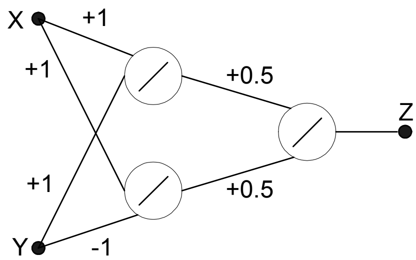

Fig. 3. The maximum fuzzy neural network

The maximum fuzzy neural network operates according to these formulas:

$$f(net_1) = net_1 = x\cdot(+1) + y\cdot(+1)\ ,$$
$$f(net_2) = net_2 = x\cdot(+1) + y\cdot(-1)\ ,$$
$$f(net_3) = net_3 = net_1\cdot(+0{,}5) + net_2\cdot(+0{,}5)\ .$$

The neural network performing the complement operation is presented at fig. 4.

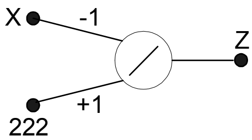

Fig. 4. The complement fuzzy neural network

The complement fuzzy neural network operates according to this formula:

$$f(net) = net = x\cdot(-1) + 222\cdot(+1)\ .$$

These are two-layered networks. X and Y are input values, Z is an output values. Weights are shown as positive and negative digits (excitatory and inhibitory synapses). The neurons themselves are linear, i.e. their activation function is linear.

VI. The Example of the Work

Let we have two numbers: 210 and 021.

The minimum operation will be fulfilled by the network on fig. 2 in such a way:

$$f(net_1) = 210 \cdot (+1) + 021 \cdot (+1) = 210 + 021 = 231\,,$$
$$f(net_2) = 210 \cdot (+1) + 021 \cdot (-1) = 210 - 021 = 189\,,$$
$$f(net_3) = 231 \cdot (+0,5) + 189 \cdot (-0,5) = (231 - 189) \div 2 = 021\,.$$

So, the operation of fuzzy logic minimum is performed.

The maximum operation will be fulfilled by the network on fig.3 in such a way:

$$f(net_1) = 210 \cdot (+1) + 021 \cdot (+1) = 210 + 021 = 231\,,$$
$$f(net_2) = 210 \cdot (+1) + 021 \cdot (-1) = 210 - 021 = 189\,,$$
$$f(net_3) = 231 \cdot (+0,5) + 189 \cdot (+0,5) = (231 + 189) \div 2 = 210\,.$$

So, the operation of fuzzy logic maximum is performed.

The complement operation will be fulfilled by the network on fig.4 in such a way:

$$f(net) = 210 \cdot (-1) + 222 \cdot (+1) = -210 + 222 = 012\,.$$

So, the operation of fuzzy logic complement is performed.

VII. Summary

So, we have proposed three neural networks on linear neurons. The first operates as a fuzzy minimum element, the second does as a fuzzy maximum element, the third – as a fuzzy complement element. Ternary encoding is used in order to present a set of fuzzy values. These fuzzy neural networks can be used in fuzzy controllers with ternary information presentation.

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