ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 11, Issue 10, October 2024

Single-Layer and Multi-Layer Neural Networks: Potential for Optimizing Energy Information Systems

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ABSTRACT: The article examines the optimization potential of energy information systems in single-layer and multi-layer neural networks. Structure and operation processes of single-layer and multi-layer neural networks are presented. An activation function is used to process the weighted quantity and generate the corresponding output signal, which converts the weighted quantity into a specific number which is the output of the neuron. Formulas and boundary domains of the activation function are given. Neural networks open up many new opportunities to improve the performance of energy information systems and create smarter and more efficient energy management solutions.

KEY WORDS: single-layer and multi-layer neural networks, weighted quantity, activation function, hidden layers, neurons.

I. INTRODUCTION

Currently, new technologies are developing rapidly and are being actively implemented in various fields, especially in industry. By applying advanced technologies in the industry, it leads to increased efficiency, reduced costs, improved product quality, increased safety and the creation of new opportunities for development.

In intelligent energy information systems, using IoT and Smart Grid technologies, the processes of transmitting, receiving and collecting data, processing them and finding the necessary information among them are very complex, especially when a lot of data is collected. The use of neural networks provides great opportunities for rapid analysis of these data and extracting the necessary information from them.

Neural networks are a powerful machine learning tool inspired by the structure and function of the human brain. They are made up of interconnected nodes called neurons, which process and transmit information, just like neurons in the brain. Machine learning is used to automate various processes in manufacturing, from production planning to quality control. Neural networks help analyze large amounts of data from sensors, machines, and other sources to optimize manufacturing processes, identify potential problems, and improve productivity.

The use of single-layer and multi-layer neural networks in energy information systems opens up many possibilities for increasing the efficiency, reliability and intelligent control of energy management.

This article examines the structure and operation of single-layer neural networks and multilayer neural networks, their performance functions, capabilities and advantages.

II. THE MAIN PART. SINGLE-LAYER AND MULTI-LAYER NEURAL NETWORKS.

In most neuron models, the type of neuron is related to its location in the network. If a neuron has only one output neuron, then it is an input neuron. However, the output of a topological inner neuron can be considered as part of the output of the network. During the operation of the network, the input vector is converted into an output vector and certain processing is performed on the data. The specific type of information transformation performed by the network is determined not only by the properties of neuron-like elements, but also by the properties of its architecture,

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
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that is, the topology of interneuron connections. Selection of certain subsets of neuron-like elements for input and output of information, methods of network training, presence or absence of competition between neurons, direction and methods of controlling and synchronizing information transmission between neurons are defined.

Single-layer neural networks can be used in simple systems to control simple devices with linear relationships, such as temperature or humidity controllers.

A single-layer neural network.

A single-layer neural network (perceptrons) is the simplest type of neural network composed of single-layer neurons. They are used to solve classification and regression problems, where the input data is directly connected to the output neurons without intermediate layers. The structural design of a single-layer neural network is presented in Figure 1.

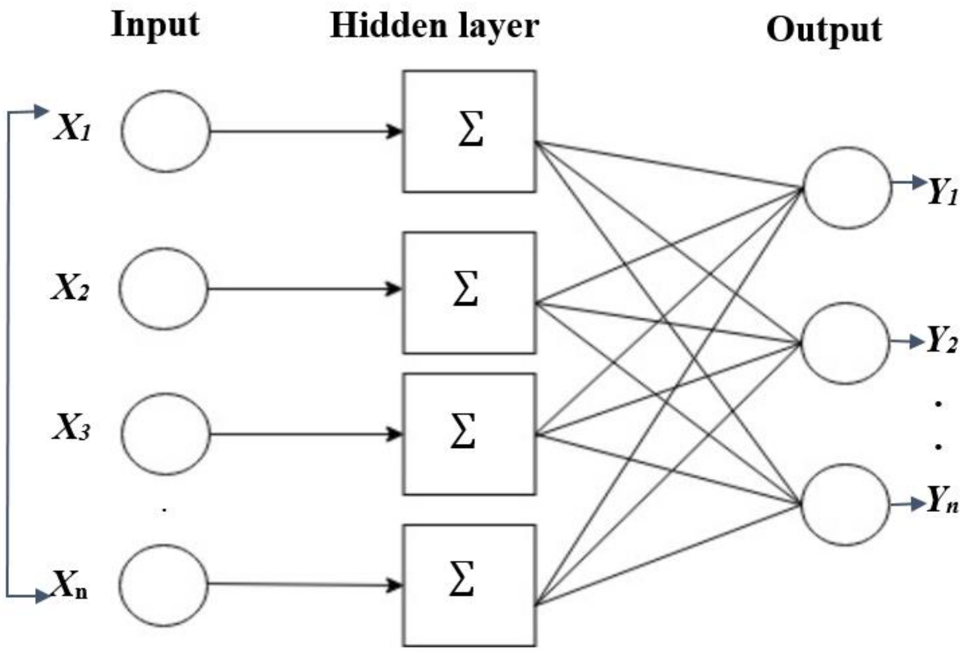

Fig. 1. Structure of a single-layer neural network.

In this network, the neurons are not connected to each other and have only inputs and outputs. Each neuron has its own set of weights, so when we apply a specific set of signals to the neuron's inputs, each neuron produces its own output signal independently of the others. This output signal can be strong or weak. For one neuron it may be very large, for other neurons it may be smaller or even negative. If we compare the output signal of the "winning" neuron with other neurons, we will know how confident the network is in its decision, if the "winning" signal is very different from the other signals, it is the only correct one. If all (or some) output signals are approximately the same, the network "doubts" the current decision.

As shown in the single-layer neural network diagram on the right, the signals $x_1, x_2,...x_n$ are sent to the input layer (which is not considered a neural network layer), and then the signals are distributed to the output layer of simple neurons. From the neuron of the input layer to the neuron of the output layer, a number is written on each edge - the weight of the corresponding connection.

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
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Although a single neuron is capable of performing simple recognition procedures, the power of neural computation comes from the connections of neurons in networks. The simplest network consists of a group of neurons forming a layer, as shown in Fig.

A multi-layer neural network.
A multilayer neural network is a neural network consisting of input, output, and one (several) hidden layers of neurons located between them.

In addition to the input and output layers, these neural networks also contain intermediate, hidden layers. Such networks have much greater potential than single-layer neural networks, but methods for training hidden layer neurons have been developed relatively recently. The structure of a multilayer neural network is presented in Figure 2.

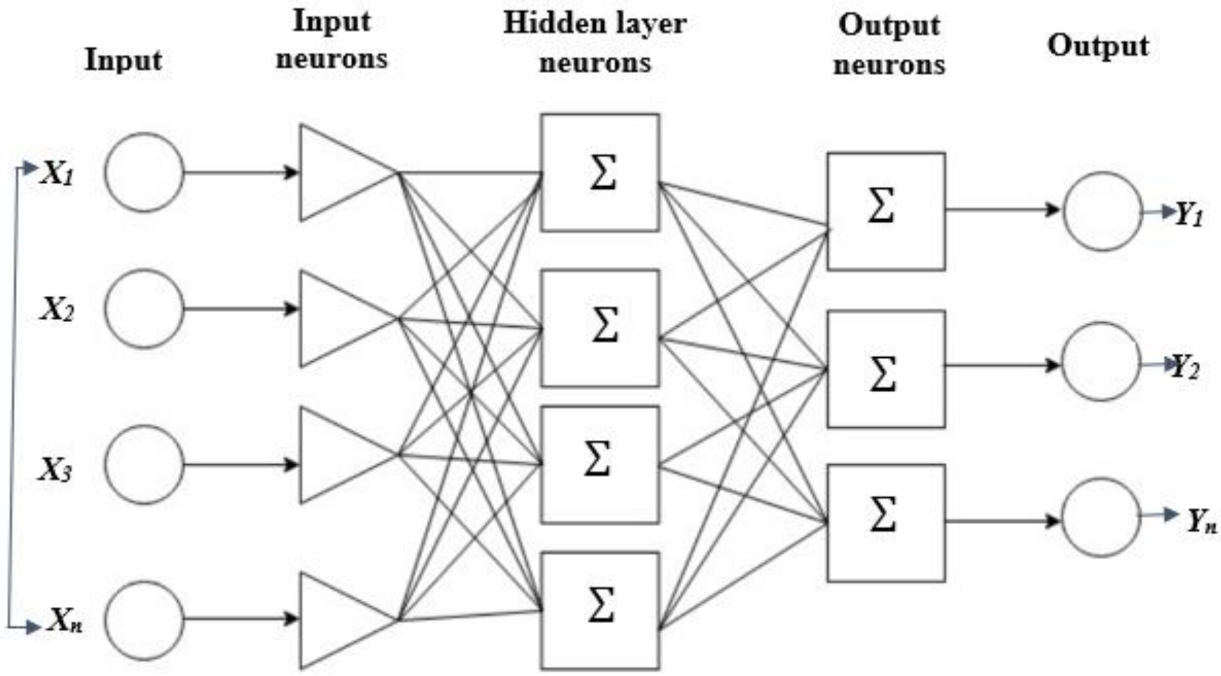

Fig 2. Structural structure of a multi-layer neural network.

The work of hidden layers of neurons can be compared to the work of a large factory. The product (output signal) in the factory is assembled step by step on the machines. An intermediate result is obtained after each machine. Hidden layers also transform some of the input signals into intermediate outputs.

Multilayer neural networks, also known as multilayer perceptrons, are a more sophisticated version of simple perceptrons capable of solving non-linear problems. They consist of several layers of interconnected neurons.

III. PART OF SCIENTIFIC RESEARCH

As you can see on the right side of the structure of a multi-layer neural network, a neuron has n inputs x_i, each of which has a weight w_i (input neurons), which is multiplied by the signal passing through the communication. After that, the weighted signals $x_i \cdot w_i$ are sent to an additional device that sums all the signals into a weighted sum. This quantity is also called s. Thus, s is determined by the following formula.

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
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$$S = \sum_{i=1}^{i=n} w_i \cdot x_i = w^T \cdot x.$$

So it makes no sense to pass the weighted quantity ***s*** to the output - the neuron must somehow process it and generate the appropriate output signal. For these purposes, an activation function is used, which converts the weighted amount into a certain number that is the output of the neuron. The activation function ***φ(s)*** is defined. Thus, the formulas for calculating the output ***φ(s)*** of an artificial neuron are presented in Table 1.

Table 1

The name of the formula	Formula	Border area
Linear	$f(s) = k\,s$	$(-\infty, \infty)$
Semi-linear	$f(s) = \begin{cases} k\,s, & s > 0, \\ 0, & s \le 0 \end{cases}$	$(0, \infty)$
Logistics (sigmoidal)	$f(s) = \frac{1}{1 + e^{-as}}$	(0, 1)
Hyperbolic tangent (sigmoidal)	$f(s) = \frac{e^{as} - e^{-as}}{e^{as} + e^{-as}}$	(-1, 1)
Exponential	$f(s) = e^{-as}$	$(0, \infty)$
sinusoidal	$f(s) = \sin(s)$	(-1, 1)
Sigmoidal (rational)	$f(s) = \frac{s}{a + \lvert s \rvert}$	(-1, 1)
Stepped (Saturated Linear)	$f(s) = \begin{cases} -1, & s \le -1, \\ s, & -1 < s < 1, \\ 1, & s \ge 1 \end{cases}$	(-1, 1)
Signature	$f(s) = \begin{cases} 1, & s > 0, \\ -1, & s \le 0 \end{cases}$	(-1, 1)

It should be noted that the sigmoid function is differentiated along the entire ***x***-axis, which is used in some learning algorithms. In addition, it has the property of amplifying weak signals better than large signals and avoiding the saturation of large signals, since they correspond to the argument regions with a sigmoidal slope.
Multi-layer networks are trained using a back-propagation algorithm. A network is trained on a data set containing input and output values. During training, the algorithm finds optimal connection locations between neurons to minimize the error between predicted and actual output values.

IV. DISCUSSION

The advantages of multilayer neural networks are that they can solve nonlinear problems that cannot be solved by simple perceptrons. Multilayer neural networks can achieve high prediction accuracy by using multiple layers and nonlinear activation functions. Multilayer neural networks can be used to solve a wide range of problems, including classification, regression, prediction, image processing, etc.

Multi-layer neural networks are very complex systems that require certain knowledge and experience to build and train them. However, their power and versatility make them a valuable tool in a variety of applications, including energy information systems.

The advantages of using neural networks in energy information systems are that they increase the efficiency and stability of power supply systems, have the ability to optimize energy consumption and reduce costs. Improves the quality and reliability of electricity supply and creates more intelligent and automated energy management systems.

V. CONCLUSION

In order to effectively use single-layer and multi-layer neural networks in the optimization of energy information systems, it is necessary to perform proper training and tuning of the networks. It is important to ensure the security and reliability of systems using neural networks. It is necessary to test and monitor the performance of neural networks in real conditions.

Neural networks open up many new opportunities to improve the performance of energy information systems and create smarter and more efficient energy management solutions.

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