Deep Learning for Control of Digital Systems

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Abstract. Classically industrial systems apply a number of techniques to control their components, including the control system, which modify the relationship between input and output signals to configure the system to provide the required response. In most practical systems, these signals are continuous, hence it is important to convert them into digital signals to be processed by digital systems. Despite the great development in technology, given the importance of the control system in relation to dynamic systems to achieve optimal performance, but classical control suffers from some important problems. The complexity of the control system represented by the program implementation algorithms and the loss of most information during the process of converting the system to digital and not adapting to external variables or with new updates. In this research, classical control is replaced by deep neural networks, which is a thriving field with practical and medical applications and is characterized by its ability to learn and train as it is a branch of machine learning and artificial intelligence. The results proved that the functioning of the neural networks and their performance is similar to classical control systems, with the advantage of simplicity and adaptability.

1. Introduction

In most modern engineering systems, system variables must be controlled and to ensure that a transient and satisfactory condition behaves satisfactorily to these systems, it will be necessary to need the controllers as the consoles today use negative feedback. The controlled variable must be measured and compared with a reference signal called a sensor control procedure based on an error signal defined as the difference between the reference and the actual values. The control unit is an analog system that handles the error signal to determine the desired control procedure, including electrical, washing or mechanical components, and all of these systems have outputs and inputs (i.e., their input and output signals are defined over a continuous time interval and have values that are defined over a continuous range of amplitudes). In recent years, digital controllers that in separate time units whose inputs and outputs are determined to replace analog control units. Digital controllers may be in the form of microprocessors or digital circuits. Control variables (controller outputs) which change continuously would seem to achieve better control than those which change periodically. [1]

Deep intelligence networks have recently emerged as the best way to discover signal properties and track changes. Before that, adaptive filters had revolutionized technology in our lives, but they could not go into more than one stage of adjustment. Therefore, the world is now greatly concerned with deep intelligence networks to uncover areas of information such as image awareness, diagnosing diseases,
knowing the targets for radar, and more. On the other hand, cybernetics plays a big role in managing and directing devices such as planes, laboratories, and others [2]. At present, traditional fixed controls have been replaced by networks of intelligence and deep intelligence and performance comparison. The preference may be large, as there is no need to redesign the electronic system because the intelligence networks are able to be adapted to the new variables.

The Control systems are a systems for controlling industrial, household, or automated systems, and they consist of input and output. The control unit that handles the error signal was in the traditional form a system that includes electrical, liquid, or mechanical components. Input and output signals are defined over a continuous time interval. In recent years, digital controllers in which the system’s inputs and outputs are defined separately have replaced analog controllers. [3]

Deep learning is a branch of machine learning that has evolved from traditional neural networks. It adopts the principle of training and learning that consists of a number of arithmetic units called neurons. These cells are organized into units called layers, usually consisting of three layers the input layer, a hidden layer and the output layer. These cells perform a basic process and send the information to other neurons [4].

Literature Review

Song Xu (2020) A control method was proposed ANN, which is characterized by self-learning of a reference model with an integrated proportional derivative compensation IPD for temperature control systems, simulations were conducted in the Matlab environment where the experiments were based on digital signal processing in its experimental platform and the results were compared with the traditional control system IPD Where the error signal is used between the real output and the output of the reference control system, and the results indicate that the proposed method has been effective in improving the transient response and bypassing which indicates a good performance [5].

Alexey (2019) Liquid friction bearing is one of two types of bearings that implements the friction system without touching the friction surfaces. The rotor path control system is designed to ensure less energy loss due to rotation of the rotor as energy loss occurs due to loss of vibration and friction, the clearance control allows you to adjust the position of balance and the characteristics of flexibility, as reducing losses is difficult for the control system due to the physical condition of the rotor system and due to random external effects. The rotational force is used with and without Bonn controls and then they are compared to each other. The results show that clearance control can reduce energy loss and vibration level in the rotor system .This research also discussed the use of BID control, which did not achieve positive results under random conditions, unlike artificial neural networks that operate according to the principle of training and learning, and thus it allows to reduce the losses of friction and vibration in the rotor machine and thus achieve the desired goal [4].

Alexander (2018) It works to discover anomalies in the industrial control systems that are caused by electronic attacks where there is noise and because modernization in the structure of the industrial process complicates the discovery of these anomalies, alternative smart technologies must be used, including automated learning techniques where algorithms were used including (decision trees - linear algorithms and learning models Deep (neural networks) where the results of the study showed that deep learning algorithms have led to more efficient results in detecting anomalies, then linear algorithms come where they allow a large number of errors and then the decision tree comes [6].

Martin (2002) It provides a brief explanation of neural networks and how control systems use them, and focuses on the most common neural networks which are multilayer neural networks where the components of the neural network have been explained by the number of layers and components of the neuron, and three structures for control are presented which are 1-predictive control of model A reference control of the model 3- These structures use the functions of the neural network through two phases, namely 1- System identification stage A control design stage and a simple test of the magnetic lifting system has been applied where its goal is to control the position of a suspended magnet over an electromagnet where the magnet is bound to not move in the direction of the head and the results showed
the capabilities of these Neural networks for job approximation and stable performance by increasing the number of network training data [13].

1.1. Background

**Control system**

System for controlling industrial, household, or automated systems and it consists of input and output, for example: to control the speed of a motor or heater. The output is the current value (CV), and the input is the one that controls, and the set value (SV) is represents the factory that is working on [14].

![Control system](image1)

**Figure 1. Control system**

**Digital Control System**

Unlike the analog control system, digital signals are handled in this system and the digital computer is used to handle digital signals in order to control the system where the computer receives named time series named data samples as it was created by taking samples of the data entered at specific time periods consisting of signal chains. It is called the sampling period (T) [7], [8].

General goal: It will connect components to achieve optimal performance (to improve system behavior and reduce resulting error).

![Digital control system](image2)

**Figure 2. Digital control system**

**Types of digital control system**

- **Open Loop System**
  Here work is done without feedback to achieve the desired output, i.e. the actual system response will not be calculated (The control action is not related to the output) [8], [9], [10].

![Open loop system](image3)

**Figure 3. Open loop system**

The transfer function of open loop system is defined as

\[ Y(s) = G(s) \ast R(s) \]

- **Closed Loop system**
  The closed loop system measure of actual output is used, the feedback system, a closed-loop control system that compares the required output with the output, and then uses the difference between the two quantities to get to a greater extent than the reference inputs [10], [11].
Figure 4. Closed loop system
Closed loop transfer function (control ratio)

\[
\frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)} = \frac{Z}{1 - (z e^{aT})^{-1}} = \frac{Z}{Z - e^{-aT}}
\]

\[
F(Z) = Z(e^{aT} f(t)) = F(e^{aT} Z)
\]

ANN: A computational model that is an interconnected set of nodes or neurons to represent the network. ANN is used to solve many complex problems, because of their ability to learn from complex patterns. Method to connect neurons together is different like simple neural network had architecture input and output layers only, this is called the single layer neural networks. Added hidden layers new into a single layer neural networks, then became known as multi-layer neural network. If multi-layer neural network have a single hidden layer it’s called shallow neural network [12]. If multi-layer neural network have two or three or more hidden layers then it is called as deep neural network. Figure (5) shows type of the neural network [23].

Figure 5. Type of Neural Network

For example, a set of square nodes is input nodes. It passes pass inputs signals to next nodes that called hidden layers after that output of these nodes pass to end right most nodes that called output layer. In the input, nodes pass the input signals to hidden layers as shown Figure 6 and do not calculate the weighted sums or the activation function [27].

Figure 6. A Layered structure of nodes

Type of Neural Net
1- Single Layer (perceptron):
The simplest neural network is the one that contains one hidden layer and usually called perceptron, which contains the input contract, which represents the passage and transmission of signals from the input contract to the nodes in the hidden layer (where there is no storage) and the output nodes that produce the final output of the network and usually the input contract contains more than one entry Binary, as shown in the figure [16]. It also contains the weights that affect the inputs, which represent
the importance of the inputs in the output. Therefore, if the input signal has a greater weight, it is more important in the new output [17].

The inputs for neurons are more than one entry and they are offset by a standard weight that complies with the matrix W, [14]; where $W = \begin{bmatrix} w_1 & w_2 & \ldots & w_i \end{bmatrix}$

![Figure 7. Single layer](image)

Each input represent by variable $x$ is multiplied with the standard weight $w$ formed by that which enters the summer to be combined with the bias to produce the net and then enter the conversion function that is chosen by the user and one of the most common (sigmoid-transfer function) to produce then the neuron output [18].

$$\text{net} = \sum xw$$

$$\sum xw = x_1 w_1 + x_2 w_2 + \ldots x_i w_i$$

$$y = f(\text{net} + b); b=\text{bias}$$

It must be noted that the variables $(w, b)$ is adjustable in the training phase of the network through the backpropagation by one of the learning rule. The signal with the largest weight has a greater effect so that if the entry has a zero weight, this entry is never passed to the node, meaning that it is not connected to the network.

**Multi neural network:** It is a neural network that contains more than one hidden layer, that is, it is considered an evolution of single-layer neural networks after adding the hidden layer after it consisted of the input and output layer only. Neural networks have one hidden layer called (shallow neural network) while the multi-layer neural networks that contain more than two hidden layer called (deep neural networks) so that the output of neurons from a layer is input to the next layer and the output of the last layer is the output of the neural network in the multi-layer of the neural network each neuron of a layer is linked to all the neurons of the next layer and has no association with nerve cells. It is powerful network and it has wide use in most applications [15].in recent years due to advances in technology that led to a rapid development of neural networks from classic to deep dealing with a number of layers and hidden nodes in each layer where a number is used always few layers although there are no specific restrictions on the number of layers referring to depth [19], [20], [22].

![Figure 8. Multilayer Neural Network](image)
Learning by supervised learning in this type a training group is provided where it represents the network's inputs and when applied the outputs from the network are compared to the goals and then we apply one of the learning rules to adjust the weights.

**Architecture of Neuron**

![Architecture of NN](image)

**Figure 9.** Architecture of NN

1-Adder to summation signals in the weighted income.

\[ \sum xiwi = x1w1 + x2w2 + \ldots + xiw_i \]

2-Activation function or squashing which limits the output and makes it within the range [0,1] or [-1,1], where choice of activation function is by the user [23].

\[ y = f(\sum xiwi + b) \]

**Activation Function** It is determined that the neuron can be activated or not by calculating the weighted sum of the inputs with biases and it makes the neural network able to learn and perform the most complex tasks through non-linear transformation and this is a function of the activation function [24] [17].

One of the most important types are:

**Sigmoid:** It is the most common function of use as it converts values from 0 to 1, meaning that they are non-linear and are in the form of an S, but one of the problems with this function is that the signs of all neuron output values are the same and this is because they are not the same around zero and this problem can be solved by scaling the sigmoid function, is defined as:

\[ f(x) = \frac{1}{1 + e^{-x}} \]

![Sigmoid AF](image)

**Figure 10.** Sigmoid AF

**Tanh:** It is a distinct and continuous function and is similar to the sigmoid function it is a mathematically derived function from the sigmoid and it performs better than the sigmoid, but it is the same around the point of origin producing different signals thus the results, the values fall within the range 1 and -1 and the gradient in it is more steeper and contains gradients that are not limited to the difference in a specific direction and for this reason this function is better than the sigmoid function, is defined as:

\[ f(x) = 2\text{sigmoid} (2x) - 1 \]
ReLU: It is a function that is widely used in neural networks as it is a non-linear function; it takes a real-valued number and thresholds it at zero, and it is more efficient than other functions. It is implemented mainly in the hidden layers and includes simpler mathematical operations than Tan and Sigmoid, where not all neurons are activated at the same time and a certain number of them is activated. When the result is a zero linear shift, the weights in the network training are not updated during the posterior diffusion, i.e., the neuron is deactivated only in this case [25]. It is defined as:

\[ f(x) = \max (0, x) \]

Learning in the Neural Network

Supervised Learning

In this type of learning, a training group is provided where it represents the network's inputs. After applying the outputs from the network, they are compared to the goals, and then one of the learning rules is applied to adjust the weights in order to reduce the difference between the correct outputs and the network [26].

Unsupervised Learning

In this type of education, the training group consists of inputs only without defining the goal and this is called self-learning, meaning you learn the network without presenting examples and without prior knowledge, and weights are modified without a learning base but in response to the network inputs [28].

Learning Rules

Learning rules improve the performance of the neural network by updating the weights of the network. Also, it is a mathematical model that is used to adjust the weights in the network by training the network on specific tasks through current conditions. The most important rules of learning are:

Hebbian learning rule: Determines how weights are adjusted for the neurons in the network

\[ W_{ij} = X_i \times X_j \]

Perceptron learning rule: The learning process here depends on assigning a random value to each weight in the neural network
\[ \sum_i \sum_j (E_{ij} - O_{ij})^2 \]

**Delta learning rule**: is most commonly used, it depends on supervised learning here the adjustment in weights is equal to multiplying the error and input as follows:

\[ \Delta W = \eta(t - y)x_i \]

Its aim is to reduce the error, which is the difference between the required outputs and the outputs generated by the network. If the difference is large, adjustments will be made to the weights as

\[ dw_{ij} = r \ast a_i \ast e_j \]

Where \( r \) represents learning rate, \( a_i \) represents activation function and \( e_j \) represents error [29].

2. RESEARCH METHOD

Neural networks are distinguished by their ability to adapt to modern variables. In this research, we worked to analyze the application of neural networks as an alternative to the control unit in digital systems, where neural networks operate under supervision, that is, a data set is provided to train the network before simulation to obtain outputs and then be tested with new data and compare the results. Outputs with the results of control systems where the scale will be the mean square error rate. The following figure shows the general outline of the proposed method.

![Figure 13. Block diagram explain the proposed method](image)

![Figure 14. Block Diagram of NN instead of control system.](image)

This Figure shows the neural network control unit diagram used in this study where the factory processes the inputs that are training data for the neural network to get out the error (it is the difference...
between the real outputs and the required outputs). Depending on the backpropagation of the network, the error is adjusted down to the desired output and the following Figures show the structure of NN.

3. RESULT AND DISCUSSION

The digital control system is implemented, where the following equations (1, 2, and 3) are applied to find the output signal by determined the error signal and the control signal

\[ Y_i = -q \cdot Y_{i-1} - f \cdot Y_{i-2} + b \cdot U_{i-1} + c \cdot U_{i-2} \]  
\[ e_i = 1 - Y_i \]  
\[ U_i = -h \cdot U_{i-1} + k \cdot g \cdot e_{i-1} \]

The simulation results are analysed in MATLAB depending on the number of parameters influencing the outcome as follows:

By using Neural Network one layer give the following result:

In this Figure, the use of a single-layer neural network with an increase in epoch to 400. The result that is noticed is not good, where RMSE=0.06
In this figure, the use of a single-layer neural network with an increase number of realizations to 300, the RMSE appears as 0.04, lower value than that obtained by one-layer Neural Network.

By using 2-layer Neural Network, the following result is obtained

![Image](image1.png)

**Figure 18.** 2Layer NN with N200.

In this Figure, the use of neural network two layer with an increase number of realizations to 200 and increase learning error rate, the result that is noticed is very good as (RMSE) its 0.02, it represents the lowest value.

![Image](image2.png)

**Figure 19.** 2Layer NN with increase node in hidden layer

In this Figure the good result is shown, where the value of (RMSE) is low, by increasing the number of nodes in the hidden layers.

![Image](image3.png)

**Figure 20.** 2Layer NN with epoch 200
This Figure shows an almost good result, where the value of (RMSE) is not very small. Here we used an increase in the epoch to 200.

![Figure 21. Final result](image)

This represents the best result of using NN for two layers where the error value is 0.00, that is, the ideal value, or the lowest value reached. It can be obtained by increasing each of the influencing parameters such as (number of realizations, number of nodes in hidden layer, learning error rate value). Future directions: Convolutional Neural Networks (CNN’s) are getting a lot of attention in applications [30]. It would deserve an attempt to handle CNN for controlling digital systems.

4. Conclusion
In this work we replaced the classical control systems with a neural network. The results showed a distinct and remarkable performance of multi-layer Neural Networks as compared to single-layer Neural networks by observing data analysis by simulation and observing the error with classical control system. Lower error is obtained using multi-layer neural networks, and an ideal error of zero can be reached after repeating the experiment several times and increasing the network parameters affecting the result, including the number of nodes in the hidden layer, the number of times the experiment is repeated, the network training rate.

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