A Modified Method of an Inverse Neural and Adaptive Correction Factor for Speed Control of DC Motor

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Abstract. This Article Proposes a modified method of adaptive controlling for the DC motor and it is deriver circuit based on Inverse Neural Controller. The proposed controller composed of two parts: the first is the inverse neural control that will control the speed of the direct current motor and, the second is adaptive correction factor that will act as an adaptive compensator to overcome the error (offset) in the steady state response of the motor (eliminate the steady state error). The obtained results prove that the new method successfully controlled the DC motor speed by eliminating the error in the steady state response, and letting the output correctly tracking the input set-point with minimum rising time and minimum peak overshoot. Simulation done using MATLAB SIMULINK. Results compared with the conventional Inverse Neural controller to demonstrate the impact of the proposed method also a load test had been done.

Keywords: Adaptation, Inverse Neural Control, Adaptive Correction factor, Speed Control, DC Motor.

1. Introduction and Related Works

In general, the use of conventional regulators in control is a common practice, but they have particular limitations. For example, instabilities in system responses will be the result of the nonlinearities because the identification also the calculation of the controller parameters done offline. The advantage by using adaptive controllers is that they work online but more complex designs are required [1].

The design of the conventional controllers is to control the dynamic system when parameters don't change, or when parameters don't change excessively while working around a set point. However, it's common to find systems that their dynamics nonlinearly changed in a specific instant. In cases like these, a conventional controller doesn't work as required to do in all conditions. This explains why the adaptive controller is used [1]. In the following, some of related works with different types of adaptive control:
Taifour et al. (2012), investigated the Model Reference Adaptive PID Control (MRAPIDC), controlling a separate excitation DC motor. The idea was to obtain more perfection for MRAC technique and to provide additive smooth control to the direct current motor [2]. Barber et al. (2013), presented two types of adaptive control (Deab–Beat and Adaptive PID). They used Simulink to design these controllers for working in real time. A certain examination for observing and test the activity of the proposed controllers like a case of sudden changes around the equipoise circumstances of the system [1].

Sateesh and Satish (2014), new concept of “Inverse control of the DC motor using ANN”. The inverse model of the direct current motor is obtained from system identification procedures. This Neural network acts as the controller for the speed of DC motor. The input for inverse controller is the required reference speed and inverse controller gives the armature voltage as the output that will produce reference speed [3]. Munadi (2016), presented adaptive control mechanism that can cope the change in the dynamic DC motor system. A four parts Model Reference Adaptive System has been used: the plant, reference model, control law, and adaptation mechanism [4].

Ghazanfar and Maghshoody (2016), presented the performance of the model reference technique with the adaptive fuzzy controller. The fuzzy controller is used in place of conventional controllers like PI controller. The fuzzy controller and model reference are designed based on keeping the entire system stability [5]. Nguyen (2019), aimed to propose a neural adaptive controller for the DC motor. The control system composed of two neural networks: the first is used for estimating the DC motor speed, the second used as a controller. The author proposed his control system based on Neural Network for controlling the plant to reach high quality in the task of unknowing parameters of the plant [6].

This paper composed of six sections, the first is the introduction and related works, the second is to explain the basic concept of the inverse neural network controller, the third explains the proposed algorithm, the simulations and results in section five, the last section is the conclusions.

2. Inverse Neural Network Controller

Artificial Neural Networks (ANNs) provides many properties which make them in particular suitable in controlling and modeling applications of nonlinear systems. The most important of these properties is the capability to learn nonlinear and complex relationships with no evident knowledge of the principle equations that describe the system, but based merely on the input data and output data from the system. The potential of using neural networks technologies in systems controlling is to effectively deal with overcoming nonlinear control problems was identified from the 1990s [7].

The inverse neural control is open-loop control for system dynamics through the use of a series adaptive controller. The inverse controller adapts itself for optimizing the dynamic response of the plant and look up for modeling the inverse of the plant supposed to be controlled. The inverse neural network could be used for linear and nonlinear plants, and is adequate for the design of the controller and the realization of some of dynamic plant output [8].

3. The Proposed Algorithm

In this paper, a robust adaptive control algorithm based on the idea of using both the inverse neural control technique side by side with the adaptive correction factor compensation for controlling the speed of the direct current motor. Inverse Neural approach is used as a controller to let the motor output follows the input reference all the time and the adaptive correction factor that will continually (online) overcome the steady state error that will appear in the output response. Figure (1) shows the proposed control system.
The Inverse Neural Network model will be obtained by the offline training of a neural network using the error back propagation method with mean square algorithm, and the input and output data that represents the plant response. The neural network will be trained to give inverse response of the plant. The control system is designed for the speed control of a DC motor and it is driving circuit.

\[
\frac{Y}{U} = G(s) \times \frac{1}{G(s)} = 1
\]  

(1)

The Open Loop Inverse system block diagram is shown in figure (2).

Equation (1) will be true if \( \frac{1}{G(s)} \) is the typical inverse of \( G(s) \) but it is not the exact inverse because of the training error of the neural network (the mean square error will never reach 0 value), so an offset error (steady state error) will appear in the output response of the system. In other words \( Y/U \neq 1 \).

In order to solve this problem, and after several studies and trails, an idea had been found that is to add an adaptive correction factor \( K(e) \), will be used in series with \( \frac{1}{G(s)} \). This factor is a function of the error (between the input and output) and it will continually adapt its value to eliminate the steady state error between the output and the input. The equation of the adaptive correction factor is shown in equation (2) below:

\[
K(e) = (U \times 1/G(s) \times e) + (U-e)
\]  

(2)

and the system block diagram will be shown in figure (3).

The addition of the adaptive correction factor by this way has the following advantages:
1. It eliminates the steady state error between the output and the input, \( e \equiv 0 \). (as will be shown in the results).
2. The overall system is still open loop. So the adaptive correction factor will not affect the stability of the system since no feedback returned to the controller.
3. The output response has a small rising time with a small and acceptable overshoot value.
4. It can be implemented for both linear and non-linear systems.
5. It is low cost and does not acquire complex algorithms and complex programming steps.

4. DC Motor Modelling

The DC motor mathematical model has been derived depending on the equations of DC motor torque and back electromotive force. By the constant factor \( K_t \) the generated torque of the direct current motor is directly proportional only with the current of the armature while the magnetic field is constant as given in equation (3). So this called "motor with armature-controlled" refer to the references [9], [10]. Figure (4) is the electric circuit that is equivalent to the free–body diagram of rotor and armature [9].

![DC motor equivalent circuit](image)

The output speed \( \omega(s) \) to the input voltage \( V(s) \) TF, and the output position \( \Theta(s) \) to the input voltage \( V(s) \) TF appears in equation (3) & (4) respectively [9]:

\[
\frac{\omega(s)}{V(s)} = \frac{K}{[(Ls + R)(Js + b) + K^2]}
\]

and

\[
\frac{\theta(s)}{V(s)} = \frac{K}{[(Ls + R)(Js + b) + K^2]}
\]

Where:
- \( J \): The rotor-Moments of inertia, Kg.m
- \( b \): Mechanical system -Damping, Nms
- \( L \): Electric-Inductance, H
- \( R \): Electric-Resistance, \( \Omega \)
- \( V \): Voltage-Source, v

Equations (3) and (4) are used to design the block diagram of the DC motor as in Figure (5).

![Block diagram of the DC Motor](image)
5. System Simulations and Results
Simulations and results are obtained using MATLAB R2015b, including the DC motor modelling and the data obtained from it to train the inverse neural controller using error back propagation technique of two layers the first is of 5 neurons and log sigmoid activation function, and the second consists of 10 neurons and tan sigmoid activation function, and mean square error algorithm, the training led to mean square error of (10-6). Also the complete design of the system with and without the adaptive correction factor and the simulation with disturbance load had been done.

The type of the DC motor used in the simulation is DG01D-A130GEARMOTOR and its parameters are shown in the following table [11]:

| Table (1). Motor Parameters [11] |
|----------------------------------|
| Motor parameter                  | Symbol | Value             |
| Electric-Resistance              | R      | 5.61 Ω            |
| Electric-Inductance              | L      | 2.29 mH           |
| Constant of motor torque         | K      | 0.16 Nm/A         |
| Mechanical system damping        | b      | 5.0526 e^Nms      |
| The rotor moments of inertia     | J      | 0.4366 kg.m²      |

5.1. Simulation and Results with No Adaptive Correction Factor
The system here controlled only by the inverse neural controller with no adaptive correction factor added it has been tested by a step input of 5 volts, see figure (6).

![Figure 6](image)

Figure (6). The system without the adaptive factor
The output of the system is approximately the same of the step input but with a steady state error about 0.2, as can be seen in figure (7).

![Figure 7](image)

Figure (7). system response when using the adaptive gain

As can be seen from figure (7), the use of the adaptive gain has the following advantages
1. The steady state error is approximately 0.002 which is a hundred times less than the steady state error of the system with no adaptive correction factor.
2. The rising time is 0.2 sec which is regarded very small since the plant is a motor.
3. The maximum peak overshoot is 0.4 and is about 0.08 from the input 5-volt signal and it is very acceptable for this system.
5.2. System Response Evaluation for variable Kinds of Inputs

This subsection is to prove that the added adaptive correction factor is able to let the output response of the system follows the input efficiently for three types of inputs as will be shown in the following: The step input is tested and its result has been shown in figure (8).

Also the response of the system has been tested for the repeated sequence input, the test result is shown in figure (8).

![Repeated sequence input test](image)

As shown in the previous figure, the red line represents the input, the Brown line is the response if the inverse neural controller without the adaptive correction factor and the blue line is the system response when using the adaptive correction factor. It obviously tracks the input much better than the Brown line (system without adaptive correction factor) with very low overshoot and short rising time and the most important the steady state error $\approx 0$.

Another test for the system response done using the random input and again the result proves the efficiency of the adaptive gain by making the output follows the input with minimum steady state error $(\approx 0)$, very small overshoot, and minimum response time if compared with the system controlled by the inverse controller only. As shown in figure (9).

![Random input test](image)

The last test is the disturbance load test, the system had been tested by applying a positive and negative load, and the result showed that the system using the adaptive correction factor is very efficient in tracking the input and overcomes the effect of the added load in compression to the system without the correction factor. Also the output reaches the input value at 0.42 second while the system without factor reaches it at 1.2 seconds, so it approximately takes additional 0.8 seconds if compared to the system using the adaptive correction factor. Figure (10) shows the system response to the added load.
6. Conclusions
This paper is a sincere attempt to improve the systems response, and eliminate the steady state error of the system. The results in section five assert that the added adaptive correction factor to the inverse neural controller excellently improved the output response of the system and approximately eliminated the steady state error between the input and the output. Also the results approved that the proposed design is robust for various types of inputs and for handling the addition of load, the transient time is low, and no oscillation in the steady state response with high stability over the system with only inverse controller. In addition to these advantages, if compared to other controllers mentioned in the survey our proposed design will have a lowest complexity and lower cost.

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