Model Reference based Neuro-Fuzzy Control of DC Servo Motor

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Abstract

This paper presents a Neuro-Fuzzy approach for the D.C. servo motor, within the Model Reference Adaptive Control (MRAC) framework. To tackle the plant parameters variation, an adaptive algorithm is derived to tune a designed fuzzy controller such that the system output follows a desired output for stable reference model. The simulation result shows no oscillation in response and the time for reaching the desired position is very short with zero steady state errors. Based on the simulation results using MATLAB/SIMULINK package, it is found that the Neuro-fuzzy controller can be a viable choice for a networked control system due to its robustness against parameter uncertainty.

Keyword: model reference control, Neuro-fuzzy, Simulink, Position control, D.C. servo.

مسيطر ضبابي–عصبي لمحرك تيار ثابت مستند على الإشارة النموذجية

زكي مجيد عبدالله
المعهد التقني . الحويجة

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الخلاصة

يقدّم هذا البحث تصميم ومحاكاة مسيطر على الموقع من نوع تكيفي لمنظومة الموأزرة لمحرك ذات التيار الثابت(D.C). تم بناء المسيطر بالاعتماد في بناءه على نظام سيطرة ضبابي–عصبي مستندا على الإشارة النموذجية.تم استخدام خوارزمية تكيفية لتنغيم المسيطر الضبابي–العصبي وذلك للحصول على خرج للنظام مستقروبدون تذبذب يكون مماثل للخرج الناتج من النموذج المستقر كما بينته النتائج التي تم الحصول عليها من هذا التصميم حيث كان هناك تتبع للموقع من قبل النظام متطابق مع الأشارة النموذجية ، والوقت لوصول الموقع المطلوب قصير جدا مع انعدام الخطاء في حالة الأستقرارعلى الرغم من تغيير نقاط العمل وتغيير عناصر النظام اثناء الأشتغال. تم بناء المسيطر والمنظومة بواسطة برنامج (MATLAB/Simulink).

الكلمات الدالة: نموذج الإشارة النموذجية، شبكات عصبية ضبابيه، محاكاة النموذج،سيطرة الموقع،محرك تيار ثابت

Introduction

The many approaches in the past year for position control of the DC servo motor was designing a controller based on an analytical system model[1]. However, the major cause of difficulty with model-based controllers on the accuracy of the mathematical model. Due to the difficulty to achieve an accurate model, the performance therefore tends to be poor.

Fuzzy logic controllers (FLCs) offer an attractive alternative to conventional model-based control schemes. FLC is basically model-free control paradigm, where the control signal is calculated by fuzzy inference rather than from system dynamics. This property makes an (FLC) suitable for controlling nonlinear uncertain or ambiguity system such as friction. It has also been proved that an FLC works well in situations where there is perturbation in plant parameters and structure. The fuzzy logic can be considered as a mathematical theory combining multi-valued logic, probability theory, and artificial intelligence to simulate the human approach in the solution of various problems by using an approximate reasoning to reflect different data sets to make decision.

The fuzzy adaptive strategies are closer to the experts, reflecting their knowledge and experience. As the modern conventional control strategies grow in complexity, the fuzzy controllers are very competitive in high performance applications. As a result the performance/complexity ratio is generally higher for adaptive fuzzy controller [2].

There exist two major different types of fuzzy control: Mamdani (e.g. [3]) and the Takagi-Sugeno (TS) type [4]. They mainly differ in the fuzzy rule consequent. The Mamdani fuzzy controllers utilize fuzzy sets as the consequence where the TS fuzzy controller employs (linear) functions of the input variables as the consequence. Presently, almost all the fuzzy controllers are used and treated as black-box controller that when constructed properly by the trail-and-error method could produce satisfactory results.

The adaptive-fuzzy and Neuro-fuzzy approaches have been used with success in modeling and control of dynamic systems, as widely reported in the recent literature (e.g. [5]-[6]). One of the difficulties in using fuzzy structures is the task of finding suitable membership functions and rules associating them. Many articles propose methods to train and optimize membership functions and rules (e.g. [7]-[8]).

The basic idea of model reference adaptive control (MRAC) is to introduce a global stability criterion into the procedure and to choose the adaptive control law in such a way that the requirement of the stability criterion is fulfilled. In other words, it is desired to design a controller that computes a control action signal, such that the overall control system response dynamically as the specified reference model. Limitations of the classical PID design is, the controller parameters must be tuned by some appropriate algorithm to obtain the desired response and also re-tuning is required for the different values of load changes. The system is affected by the environment conditions, hence, not a robust system.The reference model embodies the desired performance characteristics of the overall system. Typically, this is a first order or well damped second order linear system although it could alternatively by nonlinear [9].

Fuzzy Controller Structure

Here we employ a simplified fuzzy model, Constant Fuzzy Model (CFM), in which the consequent part is constant. In fact, it is a special form of Linearity Fuzzy Model (LFM) introduced by Sugeno [10], in which the consequent part is linear function of inputs. (CFM) realizes the inference as follows:

Rule R^j :IF x_1 is $A_1^j(x_1)$,…. And x_n is $A_n^j(x_n)$, THEN $y=w_j$, j=1,2,…,m ...(1)

Output: , $h_j = \prod_{i=1}^{n} \mu_{A_{ij}}(x_i)$ ...(2)

Here R^j is the *jth* rule, x_i is the input, A_n^j are the fuzzy set, w_j are the consequent part of the rule and $\mu_{A_{ij}}(x_i)$ are the fuzzy membership functions of the input.

Hybrid Nueral Fuzzy Controller

Figure(1-a) shows the connectionist Nueral Fuzzy Control System (NFCS). This system has a total of four layers. A typical network consist of unit which has some finite fan-in of connections represented by weight value from other units and fan-out of connections to other units see figure (1-b). Associated with fan-in of unit is an integration function (f) which serves to combine information, activation, or evidence from other nodes. The net input for this node is as follows.

$$net\_input = f\left(x_1^k, x_2^k, \dots . x_p^k\right) \quad ...(3)$$

Where the superscript indicates the layer number. This notation will be also used in the following equations. A second action of each node is to output an activation value as a function of its *net_input.*

$$output = O_i^k = a(f) \quad ...(4)$$

Where a(.) denotes the activation function.

Layer 1:Input layer.

This node in this layer just transmits input values to the next layer directly.

$$f = x_i^1 \ and \ a = f \quad ...(5)$$

The link weight at layer one is unity.

Layer 2: Membership function

This layer performs the membership function. The *jth* term set of the *ith* input maps the input x_i^2 into the membership degree, that is:

$$f = -\frac{\left(x_i^2 - m_{ij}\right)^2}{\sigma_{ij}} \quad and \ a = \qquad ...(6)$$

Where m_{ij} and σ_{ij} denote the mean(center) and variance (width).The weight link is unity.

Layer 3: Rule layer

It also called the antecedent aggregation layer, which is used to implement the antecedent, matching of each rule. The rule nodes should perform the fuzzy AND operation. The link weight in layer three is then unity.

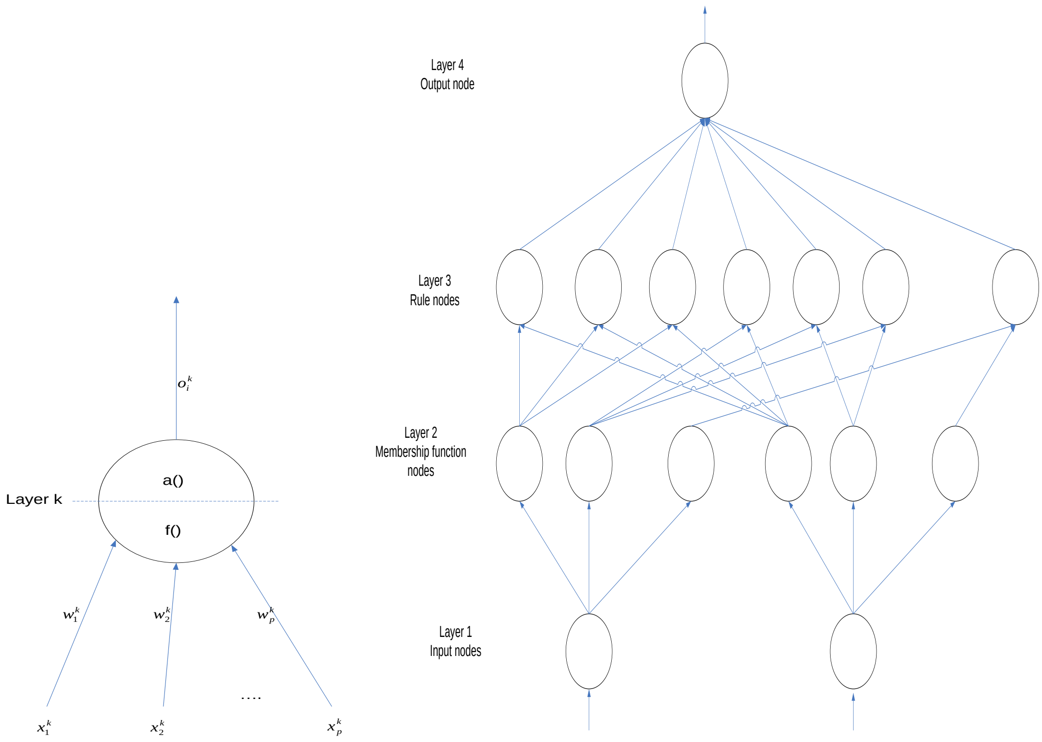
$$f = \prod_{i=1}^{n} \mu_{A_{ij}}(x_i^3) \ \ and \ a = f \qquad ...(7)$$

Layer 4: output layer

It is also defuzzfication layer or rule aggregation layer. The overall net output is a linear combination of consequence of all rules. The output in this layer is simply defined by.

$$y = \sum_{j=1}^{m} x_i^4 \, w_j \ and \ a = f \qquad ...(8)$$

Where the weights w_j are the consequence part of the j rule.



a b

Figure (1): Neuro Fuzzy structure

Problem Formulation

Fig (2) shows the MATLAB/Simulink block diagram for the Neuro-Fuzzy model reference Adaptive controller (NFMRAC). The block labeled "Reference model" is the required trajectory of the plant to be followed. This may be explained in the mathematical term as follows. A plant with an input-output pair u(n),y(n), and stable reference model specified by its input-output pair $r_r(n),y_r(n)$. Then the objective is to determine a control action law, u(n) for all n>0 and an updating law of the controller parameters such that.

$$\lim_{n\to\infty}|y_r(n) - y\ \ (n)| \le \varepsilon \qquad ...(9)$$

For specified constant ε>0.

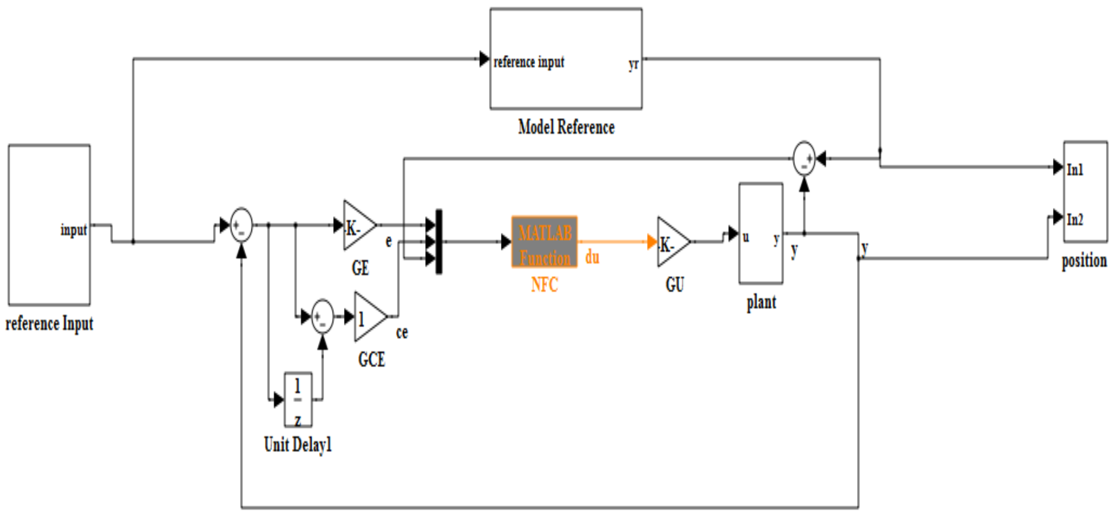


Figure (2): MATLAB/Simulink block diagram for Neuro-Fuzzy Model Reference Adaptive Control

Most significant variable entering the (NFC) have been selected as the position error and its time derivative. The output of this controller is U. The two input variable *e* (position error) and e_{ch} (change in error) are calculated at each sampling time as:

$$e(n) = y(n) - y_r(n) \qquad ...(10)$$

$$e_c = e(n) - e(n-1) \qquad ...(11)$$

Figure (3&4) shows the initial membership functions are used to represent the linguistic inputs. Each universe of discourse is divided into five sets: NB, NS, Z, PS, PB. A total 25 rules were employed with zeros initial values.

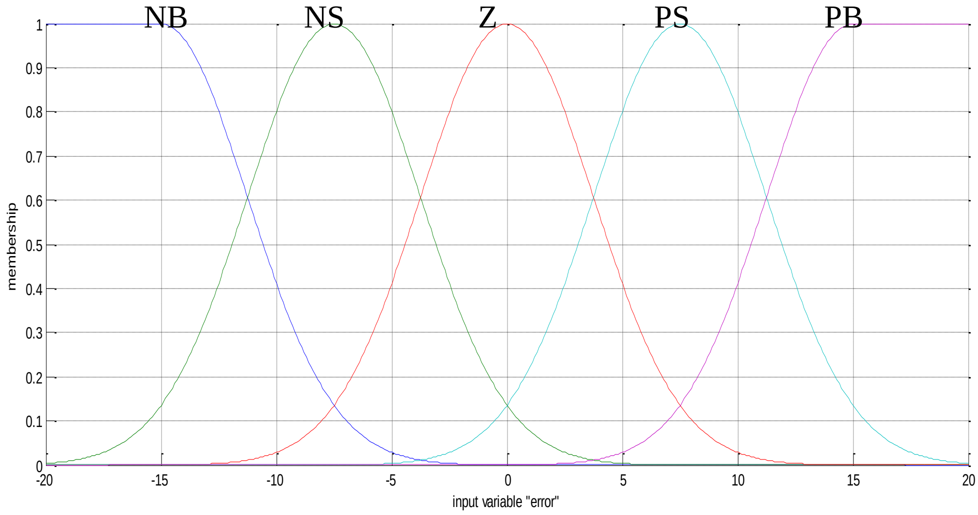


Figure (3): membership function of the error

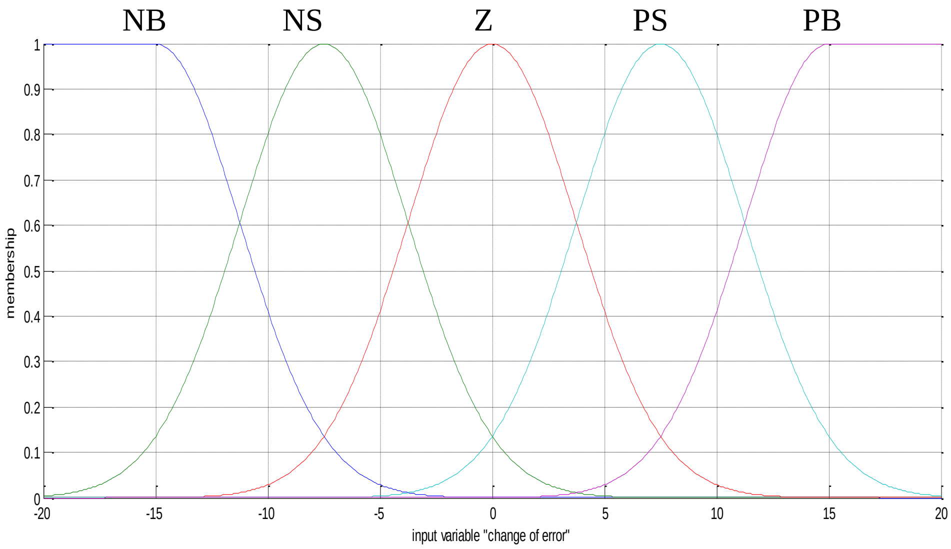


Figure (4): membership function for the change error

Adaptation Algorithem

In this step, we adopt a supervised learning scheme to adjust the weights (m_{ij}, σ_{ij}, w_j) of the (NFC), that is, the antecedent and consequent parameters of the rules. The basic idea of this algorithm is simply gradient descent. Define the error cost function as:

$$E = \frac{1}{2}(y - y_r)^2 \qquad ...(12)$$

Where y is the actual output and y_r is the reference output (desired). By recursive applications of the chain rules, then

$$W_{ij}(n+1) = W_{ij}(n) - \eta^w \left(\frac{\partial E(n)}{\partial W_{ij}}\right) \qquad ... (13)$$

Where

$$\left(\frac{\partial E(n)}{\partial W_{ij}}\right) = -e(n).O_j^3 \qquad ...(14)$$

Similarly the update laws of m_{ij} and σ_{ij} are :

$$m_{ij}(n+1) = m_{ij}(n) - \eta^m \left(\frac{\partial E(n)}{\partial m_{ij}}\right) \qquad ...(15)$$

$$\sigma_{ij}(n+1) = \sigma_{ij}(n) - \eta^\sigma \left(\frac{\partial E(n)}{\partial \sigma_{ij}}\right) \qquad ...(16)$$

Where

$$\left(\frac{\partial E(n)}{\partial m_{ij}}\right) = -e(n)\frac{\partial E}{\partial a_j^3}\frac{\partial a_j^3}{\partial O_{ij}^2}\frac{\partial O_{ij}^2}{\partial m_{ij}} \qquad ...(17)$$

$$\left(\frac{\partial E(n)}{\partial \sigma_{ij}}\right) = -e(n)\frac{\partial E}{\partial a_j^3}\frac{\partial a_j^3}{\partial O_{ij}^2}\frac{\partial O_{ij}^2}{\partial \sigma_{ij}} \qquad ...(18)$$

Simulation and Results

The position D.C. servo system control is used to study the performance of the proposed NFMRAC system. The discrete transfer function of the identified plant is given as[11]:

$$G(z) = \frac{0.00298z^{-1}}{1-1.957z^{-1}+0.9569z^{-2}} - 0.61345 \qquad ...(19)$$

The maximum D.C. servo position (±150 deg.) which equivalent to (±0.1 volt/deg.).

The reference model is considered as second order stable system with damping ratio (ζ=0.8) and natural frequency (w_n=3.3341 rad./sec.). The discrete transfer function of the model is given as:

$$G_{ref}(z) = \frac{0.0001377+0.0001365z^{-1}}{1-1.973z^{-1}+0.9737z^{-2}} \qquad ...(20)$$

In this section, the overall model of DC motor with NFMRAC mode controller implemented in MATLAB/Simulink. Figure (5) shows the step response of the system when the reference position is set as (100 degree). This figure gives the position response with small overshoot, zero steady state error and follows the response of the model reference. The uncertainty of the plant parameters can be demonstrates in Figure (6).This figure shows the position response for the NFMRAC with increase parameter of the plant (0.61345) to 50% at time (5 sec.), the response reaches the reference after (2 sec.).To investigate the robustness of the NFMRAC, different position set points(-150 to +150 degree) is applied to the D.C. servo motor are shown in Figure (7 &8). These figures show the acceptable transient and steady response.

Conclusion

In this paper, the D.C. servo motor with NFMRAC has been performed by using the MATLAB/Simulink 7.6 toolbox. The simulation results demonstrate NFMRAC at different reference inputs and variation of the parameters plant. The performance of the system is robust, stable and sensitive to parameters and operating condition variations. The D.C. servo position system has been successfully controlled using Neuro-Fuzzy control.

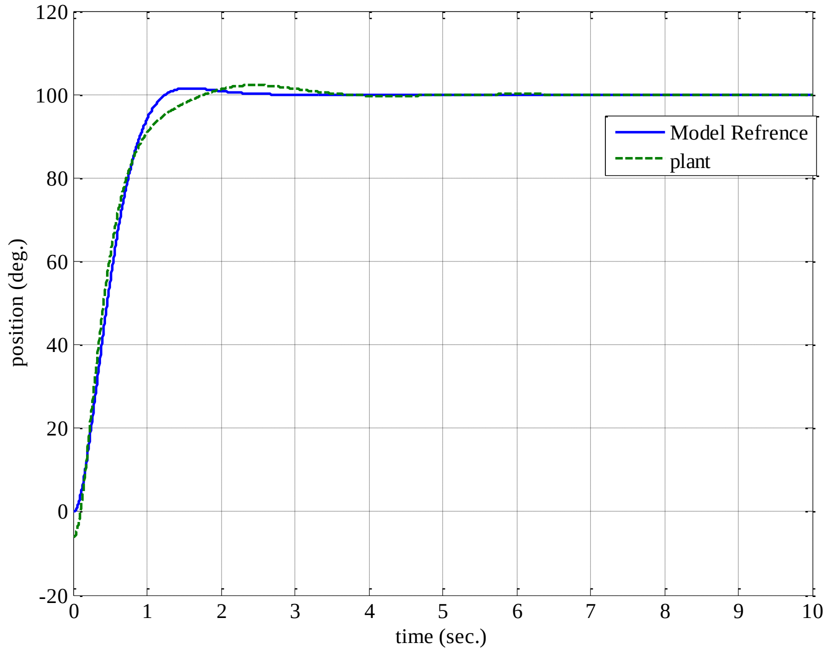


Figure (5): step response for 100 Deg.

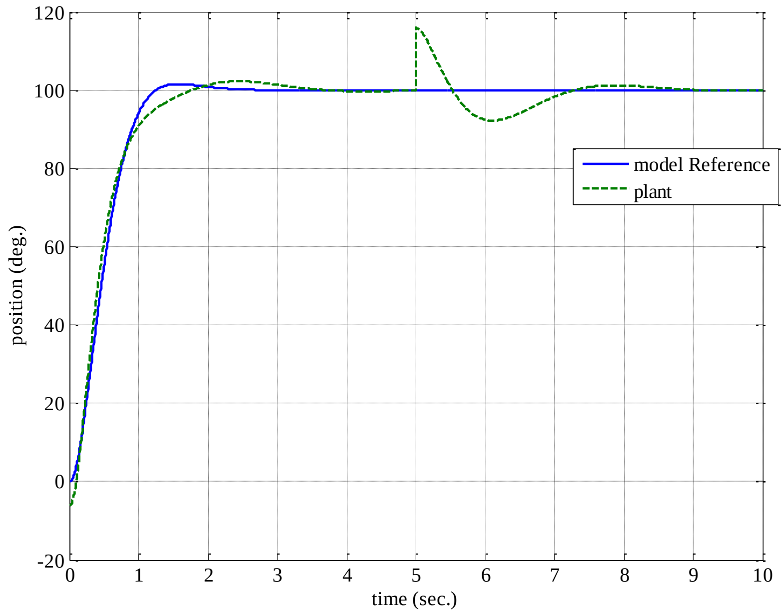


Figure (6): step response for 100 Deg. with parameter variation at 5 sec.

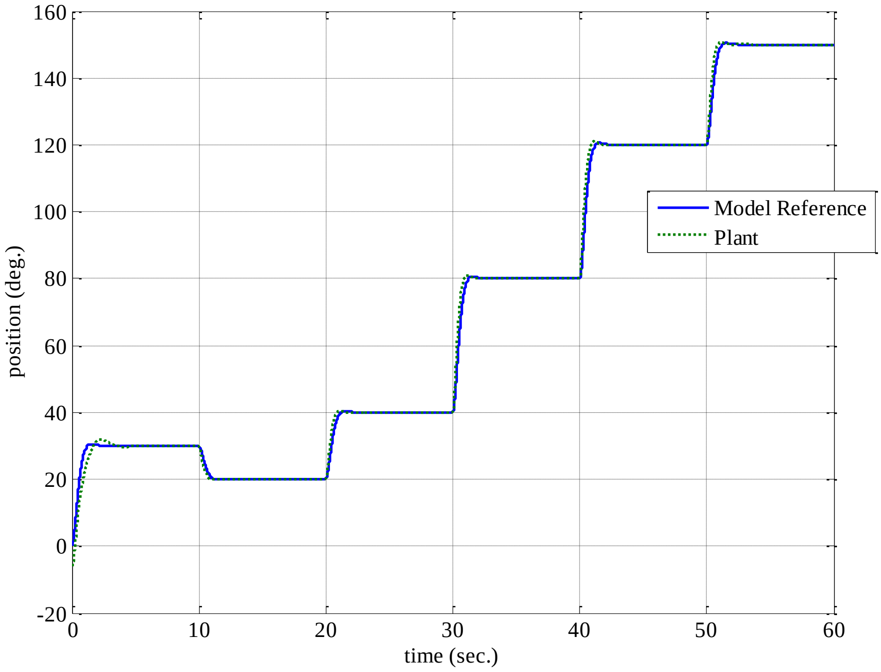


Figure (7): step response with different input.

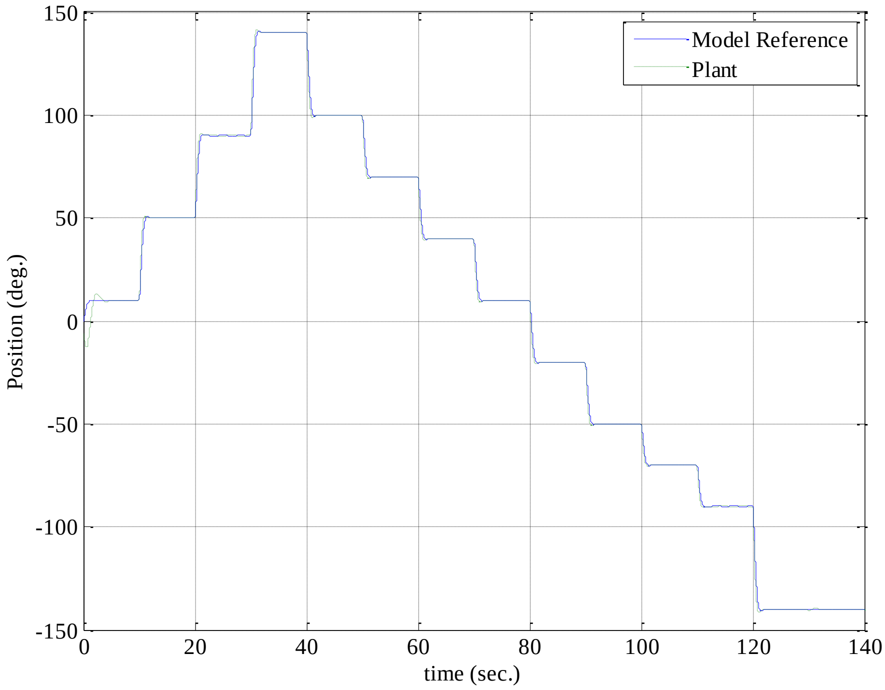


Figure (8): step response for all operation point.

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