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Design and Analysis of ANFIS Controller for High Accuracy Magnetic Levitation (ML) System

Rokan Ahmed[1], Yousif Al Mashhadany[2]
[1]Department of Electronic Engineering, College of Engineering, University of Diyala, Iraq, rokan.ahmed@uodiyala.edu.iq
[2]Department of Electrical Engineering, Engineering College, University of Anbar, Iraq, yousif.mohammed@uoanbar.edu.iq

***Corresponding Author:** Rokan Ahmed; Email: rokan.ahmed@uodiyala.edu.iq

ABSTRACT- Magnetic Levitation (ML) System is a significant particular research center model for the planning and examination of criticism control frameworks. Due to the usual sensitivity of mass, a solid choppiness powers here between magnets, and also due to the effects of commotion spilling out of the sensor and information channels, the superiority of attractive lift frameworks is dangerous. Thereafter, the design of a control framework for height is a complex issue that must be considered when developing models that are not 100% exact. Elite is the goal, all else being equal, of being better, faster, or much more productive over others. In this paper, a plan is made for an Adaptive Network-Based Fuzzy Inference System (ANFIS) regulator to get the MLS of a stable region by suspending a ball in mid-air in the sight of potential vulnerabilities, controller with a (PID). The main objective is to achieve perfect behavior through improving regulators' incentives. Reenactments have been conducted using MATLAB Version 2019b, and the positive results obtained demonstrate that the planned control unit meets the elite versus vulnerability in the model and allows exceptionally precise positioning of the raised article.

Keywords: High Accuracy, Fuzzy Control, Intelligent Controller, Magnetic Levitation System (MLS), Mathematical model, Traditional control.

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1. INTRODUCTION

MLS is a framework that can be used to study control frameworks. It is an indirect, open circle, and unsteady structure. That challenging aspect of Maglev, along with his inherent lack of linearity, makes showing and controlling concerns very challenging. In the course of many years, different control mechanisms have been used and executed utilizing Maglev's work of art and present-day planning strategies [1–4]. Attractive levitation frameworks not just current troublesome issues for control design consideration, but in addition have many regarding applications, for example, rapid transmission frameworks (Ma-glev trains) and attractive orientation [5-7]. From an instructional perspective, this cycle is exceptionally animating and reasonable for research facility trials and homeroom explanations, as detailed in the designing training literature [8]. Toughness is a significant factor in the framework plan to control, as systems are helpless for outer aggravations and surprising commotion, and there is consistently a distinction between the numerical model utilized in the plan and the genuine one. In this manner, a strong regulator configuration is needed to guarantee internal soundness and framework execution within the view of such vulnerabilities. The PID regulator is commonly applied as an

attractive lift regulator that can be easily carried out [9], but it can't meet up with the prerequisite of good solidity because of the problem of setting three boundaries of Kp, Ki, and Kd, so there has been a lot of fervor for a ground-breaking regulator for the attractive lift framework. The control mechanism is based on a solid H∞. Control supposition and manage solidity much more legitimately than alternative planning [10, 11]. Savvy Control Frames increment the adequacy of control frameworks and extermination old-style limitation focuses and adjustable regulators. They are built upon for variation/production line learning and fundamental dominion capacities to manage shortcomings so commendable enforcement can be accomplished [12]. To defeat the typical outmost reaches of perspective, masters are searching for new computational techniques to achieve the insufficient introduction of the helpfulness of the neural system that can itemize and conceivably issue. New math models have showed up, the totalitarian of the alleged careful figuring's. ANN (pseudo-sensory system), ANFIS, GA (hereditary calculation), FL (diminishing rationale), and key data-based systems [13, 14] adhere to the understanding of the specific structure. Smart self-learning or poise in key structures, computerized reasoning (manmade mindfully), NN (neural frames), FL, half and half engendering frameworks, etc., and newer introductions that get better current quality gadgets with drive [15]. The fluffy rationale, first presented by Zadeh in 1965 [16], establishes data through halfway sharing as opposed to new sharing. With its sensory system, FL can create clear conclusions from obscure,

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unsure, equivocal, and lost information. The FIS considers the best possible fit fundamental to address the shaky enlistment capacities and thin principles, yet assembling it necessitates some estimation and the requirements for extraordinary dominance [17, 18]. Clinging to the possibility of doubtful reasoning with a counterfeit sensory system, it is an astute, multi-ancestry structure that improves modified learning and diversion. Experts utilize such a structure for estimating and prelude in different development systems. A feathery introduction style that FL then uses to take in gains from the data it shows is critical to flexible neural learning procedures. Changing the limits of work sharing should not bother a human chairman, so this is a good position from a flimsy, unadulterated world standpoint [19, 20].

The fundamental target of this paper is to investigate the control of Maglev's injury responses. The assurance is in clarifying how strong control is planned and fits into the maglev framework. In this paper, the weighting capacities are chosen for the control unit combination with the assistance of articles [21]. The maglev system's mathematical models were created using articles [22, 23]. A few elements of MATLAB are utilized as often as possible in this work for regulator tuning and framework cloning utilizing reference [24]. The paper presents seldom any outcomes and is totally unacceptable for the general ongoing reenactment results. We might as well want to specify various procedures that can be valuable with regards to a little type of our present work [25].

Now this is a portion of the paper that has substance. In *section (2)* we built the nonlinear and direct numerical model for the maglev framework. *Section (3)* is given to the supposition of the ANFIS control plan technique. In *section (4)*, we demonstrated the ANFIS regulator tuning for the maglev framework. Reproductions are obtained to check the quality of the steadiness and execution of the framework. *Section (5)* of this paper finishes up with confirmed notes and an end.

2. MATHEMATICAL RESENTATION OF MLS

An MLS has attractive, mechanical, and electrical frameworks. The maglev body can be shown to exhibit dynamic behavior by contemplating electromagnetic and mechanical subsystems [14].

2.1 Modeling for Electromagnetic Sub-System

Consider *fig. 1*, which depicts the maglev plant as well as its electromagnetic organization model [26-29]. Apply the voltage division in Kirchhoff's law to the temple of electrical organization as shown in *figure 1* [3, 30].

$$V = V_R + V_L \Rightarrow u(t) = iR + L(x)\frac{di}{dt} \quad (1)$$

Where L, u, R, and i are curl's inductance, the applied voltage input, obstruction, and current in the electromagnet loop, separately.

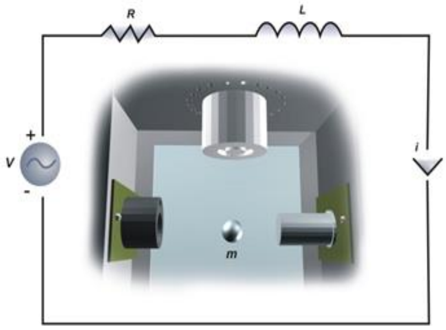

Figure 1: Maglev model [24]

2.2 Mechanical Modeling System

The inductor with energy stored is as [18]

$$W_e = 0.5\, i^2 L(x) \quad (2)$$

Since the power of the electrical system (P_e) is equal to the power of a mechanical system (P_m), where $P_m = df_m/dx$ and $P_e = dW_e/dt$

$$-f_m \frac{dx}{dt} = \frac{dW_e}{dt} \Rightarrow f_m = -\frac{dW_e}{dt}\frac{dt}{dx} = -\frac{dW_e}{dx} \; \} \quad (3)$$

Where f_m stands for electromagnet force. Now, substituting *eq. (2)* into the *equation (3),*

$$f_m = -\frac{d}{dx}(0.5\, i^2 L(x)) = -0.5\, i^2 \frac{d}{dx}\left(L(X)\right) \quad (4)$$

Since the value of $L(x) = \frac{k}{x}$; then , we have

$$f_m = -\frac{1}{2} i^2 \frac{d}{dx}\left(\frac{k}{x}\right) = -\frac{1}{2} i^2 \left(\frac{-k}{x^2}\right) = \frac{k}{2}\left(\frac{i^2}{x^2}\right) \quad (5)$$

Where k is the power of the electromagnet and x is the hole of real air hole here between the outside and the middle of ball. The requirement for power can be written as [31] if f_m is indeed the magnetic power produced by electrical current, f_g is just the power due to gravity, and f is the netted power following up upon this circle.

$$f_g = f_m + f = m\left(\frac{d^2x}{dt^2}\right) + f\, m\frac{dv}{dt} = -fm + f_g \; \} \quad (6)$$

Where m is the mass of the ball and u is the ball's movement velocity. With the equilibrium condition, f = 0 and $f_g = -f_m$.

2.2.1 Mathematical Model with Non-Linear

Based on the nonlinear model of an attractive levitation temple of an electro-mechanical demonstrating, it can be portrayed with differential conditions [4,31]:

$$iR + L\frac{di}{dt} = u(t) \quad (7)$$

$$\frac{dx}{dt} = v \quad (8)$$

$$m\frac{dv}{dt} = -f_m(x,i) + f_g = \frac{k}{2}\left(\frac{i^2}{x^2}\right) + f_g \; \} \quad (9)$$

2.3 Linear Model

The non-direct model must be done with linearization at the nominal point to do the organizer plan and realization of the maglev framework, which can be determined from [32]:

$$g = f_m(x, i) \Rightarrow i_0, x_0. \tag{10}$$

Framework states are; Fifth and tenth. At harmony, the force of gravity (f_g) and the force of attraction (f_m) are equal and inverse to one another, with the end goal that it lifts the ball. Given the outward information voltage, the comparing loop current is delivered i_0 with the end goal that the circle reaches at the balance point where x = x (0). We can two lines of the model utilizing Taylor's sequential extension of fm (x; i) about the balance point (x_0; i_0),

Where x = ™x +x_0 and i=™$_i$ +i_0

$$f_m(x, i) \cong f_m(x_0, i_0) + \left(\frac{\partial f_m}{\partial x}\right)_{(x0,i0)} \delta x + \left(\frac{\partial f_m}{\partial i}\right)_{(x0,i0)} \delta x$$

$$f_m \cong f_{m0} - k_s\, \delta_x + k_i\, \delta_i \tag{11}$$

Where $k_i = k\left(\frac{i_0}{x_o^2}\right)$ and $k_s = k\left(\frac{i_0^2}{x_0^3}\right)$ (12)

The governing equations for this same linear maglev model can now be stated as follows [24]:

$$L\frac{d}{dt}\delta i + R\delta i = u \tag{13}$$

$$m\frac{dv}{dt} - k_s\,\delta_x + k_i\,\delta_i = 0 \tag{14}$$

$$\frac{d}{dt}\delta_x = u \tag{15}$$

By using *equations (13-15)*, the maglev system state space model can be formulated as follows:

$$\frac{d}{dt}[\,\delta i\ v\ \delta x\,] = \left[-\frac{R}{L}\ 0\ 0\ -\frac{k_i}{m}\ 0\ \frac{k_s}{m}\ 0\ 1\ 0\right][\,\delta i\ v\ \delta x\,]$$

$$+\left[\frac{1}{L}\ 0\ 0\right] u\ Y = [\,0\ 0\ 1\,][\,\delta i\ v\ \delta x\,] \quad \} \tag{16}$$

To acquire lattices for the maglev model, we think about the physical prediction of the boundaries from *Table 1* [15].

Table 1. Magnetic levitation system physical parameters

Parameter	Value	Unit
R	10	Ohm (^)
m	0.07	k_g
k	4.35 ×105	Nm2/A2
L	0.425	Henry (H)
x_o	0.05	Meter (m)
i_o	0.9	Ampere (A)

3. THE DESIGN PROPOSED WITH INTELLIGENT

A control unit is a tool that controls each framework cycle through the choices it makes. The control framework gives stability during disturbances and insurance from gear harm. It could be based on programming, equipment, or both. This part builds up an ANFIS control plot like the one Figure 2 for such SCARA robot's boundaries, such as speed, packing, precision, as well as elite. The fluffy rationale is one functional utilization of the fluffy set in which the factors are semantic and not mathematical. Fluffy blends can address phonetic operators, which are defined as factors whose qualities are in normal language demonstration (for example, enormous or little). A fluffy collection is indeed an extension of the delicate bunch, where something belongs either with a gathering (full sharing) or with no one (no enrollment). Obscure gatherings permit incomplete partnerships, that is, enrollment in more than one gathering.

The dubitable set by the of a speak universe X is still spoken to by a lot of requested sets of the total component and the enrollment work μ:X → [0 1], that interfaces a number μA (x):X→ [0 1] for every value of x element of X. FLC utilizes a lot of control algorithm called dubitable principles, which are communicated between phonetic factors as bound proclamations. The main structure of ANFIS regulator with this enterprise consists of 4 squares: jammer, data base, clamor dejam and neural organization; Each of them will be clarified quickly in the accompanying sections. The contributions to the ANFIS regulator, that is, the flounce and change in mistake, are displayed by *equation (17)* such as:

$$\frac{e(k) = \omega_{ref} - \omega_r}{\Delta e(k) = e(k) - e(k-1)}\} \tag{17}$$

Where ω_r is the actual rotor speed, ω_{ref} is indeed the reference speed, e(k) is the blunder, and, e(k) is the adjustment in mistake. The denominator changes over expressed information into phonetic factors, which are denoted as contributions to the standard based square.

The arrangement of *equation 17* standards counts on past information/encounters in the standard based square, which distinguish with the NN block. The reproduction proliferation calculation trains NN to choose the fitting blend of base-base. In building up a control signal, preparation is important for choosing a sensible base. At that point, setting off the fitting bases creates the control signal wanted for the ideal yield. The NN unit's yield is expressed as a contribution to the commotion-dropping unit, and phonetic factors are recoded into computerized information, for example, chips. The undeniable factors of speed inaccuracy and change in blunder are transformed into vague or phonetic factors in muddling. The information sources are attached by the haze blends and introduced as contributions to the ANFIS comfort. Table 2 records the standard principle for choosing proper guidelines through the converse spread computation.

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Questionable factors in *Table 2*. Induction utilizes a lot of rules in deciding yield choices. With 2 info factors and 7 fluffy factors, the regulator has a lot of 49 ANFIS regulator bases. From the rules of 49 standards (see *figure 2*), appropriate standards are selection by NN preparing with the assistance of back reproduction calculation, before setting off the particular guidelines. Additionally, it must be changed over to computerized yield, for example, and it must be demystified.

Table 2. Shows the speed control rule base.

ΔE\E	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

This cycle creates a quantitative consequence for FL by demystifying. Defuzzification transforms vague gathering data in advanced informational data. Edging techniques incorporate the focal point of gravity, the focus of solitary objects, the minimal and maximal properties of the midpoint, and so on. This work utilized the focal point of gravity technicality. The yield of de-puzzle produces the control orders labeled as info (clear contribution), through the inverter at the processing plant.

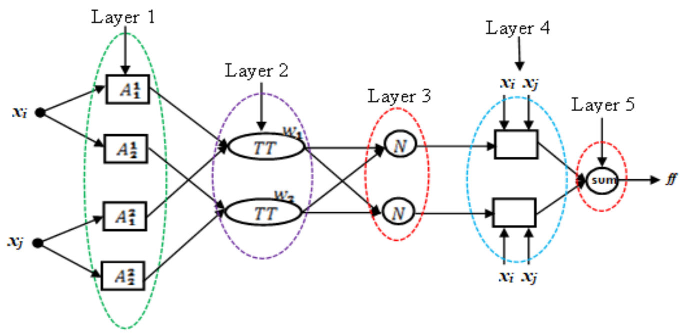


Figure 2: Sugeno-Takagi FIS framework based upon equations (19&20)

Any controlled variation is criticized and correlated with the predetermined worth and also the generated error signal, as well as offered as a contribution to a ANFIS regulator, which then returns the yield to an ordinary worth, keeping the framework stable. Equation (18) gives the tuned yield signal y, which is the last yield of the regulator and the weighted average of best possible outcome based on the rules given either by make conversation engendering calculation.

$$y = \frac{(\sum_{i=1}^{R} \mu^i a_1^i x_1) + \wedge + \sum_{i=1}^{R} \mu^i a_q^i x_q}{\sum_{i=1}^{R} \mu^i} \quad (18)$$

To help ANFIS progress, fluffy subtractive batching bunches the open data into fluffy bundles. FL subtractive packing works better than diverse FIS gathering methods. Apparent range blends make different FIS, as seen in *figure 1*. Choosing the right ground-breaking solution to a given issue is thus critical.

$$R_a^1 : if\ x_i\ \ is\ \ A_1^1\ \ and\ \ x_j\ \ is\ \ A_2^1,\ \ then$$

$$ff_1 = p_A x_i \ + p_A x_j + r_1 \quad (19)$$

$$R_a^2 : if\ \ x_i\ \ is\ \ A_1^2\ and\ x_j\ \ is\ \ A_2^2,\ \ then$$

$$ff_2 = p_B x_i + p_B x_j + r_2 \quad (20)$$

The block diagram of the plant with the controller of ANFIS is shown in Figure 1. This paper hybridized the ANFIS regulator with an idealistic one. The proposed computation technique was used in the control rule that brought the processor end effector into the ideal position and track. A controller does have six standard control factors that should all use the ANFIS half-and-half perfect comfort.

Both ANFIS regulators have similar engineering and get similar transformations when preparing rules. ANFIS's control design has similar segments as FIS, yet without a NN block. An organism's geography is a gathering of units (and interconnections) orchestrated into five interconnected organizational layers (L1 to L5) as follows:

Layer 1: The factors of input (enrollment capacities), such as Info 1 and 2. The MF Triangle or Bell may be utilized here. This layer gives an xi input esteems to the following layer. Both types of info (blunder signal and going before mistake eer (k)) registered through *equation (21)*. The subsidiary of the point joint and its change as criticism is utilized to ascertain the elements and afterward it is utilized in the law of control by applying *equation (21)*:

$$eer(k) = \Delta q_e^d(k) - \Delta q_e^d(k-1) \quad (21)$$

Layer 2 (Organic Layer): checks the heaviness of every natural capacity. It gets the information esteems of xi from the primary layer, goes about as a natural capacity for each thinning arrangement of individual information factors, and registers enrollment esteems that describe how much the information ix has a place with the fluffy set entering the layer below.
Layer 3 (base layer): Each neuron inside this layer implements preconditions for fluffy bases, and each level checks initiation for each base. Each layer's hub tallies the standard loads.

Layer 4 (defuzzification layer): Supplies the resulting of yield esteems from inducing the standards. The associations between layers are weighted by fluffy jargon speaking to other arrangement of fluffy neural organization boundaries.

Layer 5 (Layers output): Summarizes all sources of info originating from Layer 4 and converts the consequences of the fluffy description into chips. The ANFIS design is naturally tuned by methods for a miniature squared assessment and a converse dissemination computation to appraise participation work boundaries. The calculation depicted above is utilized with six ANFIS regulators that control different processor boundaries.

The harvest of the ANFIS comfort and the exemplary support are summed up. After incipience, the boundary preparing is adjusted to the boundaries of the ANFIS regulator as per the standards for dubious variation preparing (portrayed later). Exemplary PID Controller adjustments Kd, Kp, and Ki factors were separated before being used; They speak to an underlying preparing condition for such new shrewd regulator (suggested ANFIS mixing regulator). DRAC (Direct Reference Adaptive Control) as well as MRAC (Model Reference Adaptive Control) are basic and exceptionally compelling procedures for improving the control framework following fulfillment using past framework activity encounters. The issue in parametric streamlining should be taken seriously by diminishing the cost capacity to be decided the presentation of the framework. They use data gathered from past encounters to cultivate the reference contribution for the current investigation, make an exemplary ANFIS cross-breed regulator with adjusted ANFIS reference input, and inaccurate the framework yield from wanted too real. The proposed approach and configuration are anything but difficult to execute, and they do not require a middle-of-the-road industrial facility model nor continuous recognizable proof of model borders.

Figure 3 is an essential the proposed structure square diagram. Demonstrating of the conventional regulator can be by any simple control-plan technique. In this paper, the traditional regulator is utilized as the mixture ANFIS regulator's underlying condition, disposing of the distinctive proof vital in order versatile control procedures.

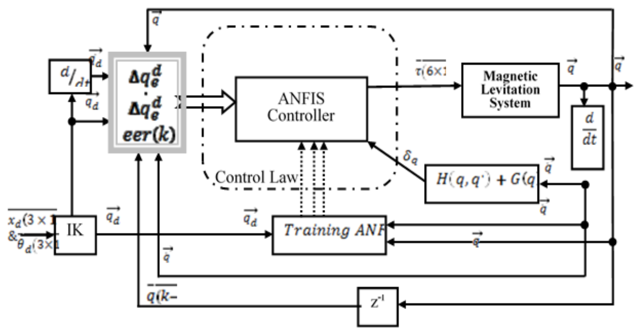
0 

Figure 3: ANFIS controller framework for ML system

4. SIMULATION RESULTS FOR MLS

The proposed plan has been reproduced through demonstrating the control framework, which is appeared in *figure 3* on MATLAB Version 2019b. Reproduction started with a dependability test of the traditional Proportional Integral Derivative (PID) regulator. The exchange capabilities (T.F.) of MLS for consideration are described by *equation (22)* and are dependent on the qualities provided *Table 1*. *Figures 4.a* and *4.b* show the details of a traditional regulator's recreation block diagram and the result of using the PID regulator.

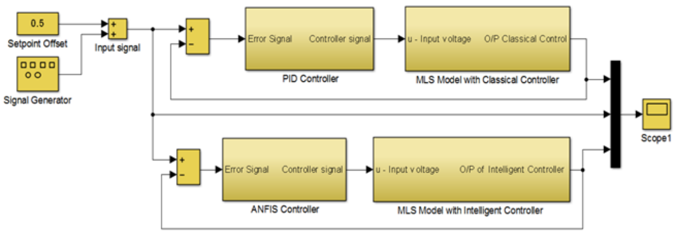


Figure 4.a: General Block diagram for multi controller of MLS system

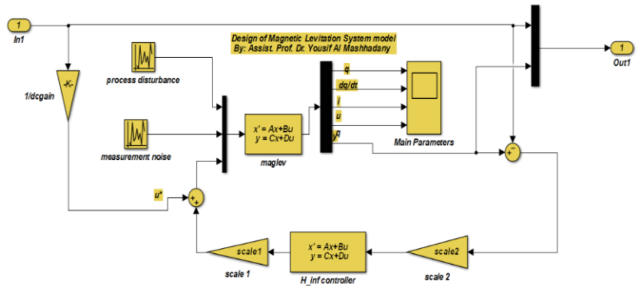


Figure 4.b: Detail block diagram for simulation of MLS

The transfer function of PID controller is shown in *Eq. (22)* and the simulation results of overall system can be presents in *figure 5*.

$$T.F.1(s) = \frac{1}{s^2+11s+10} \tag{22}$$

The plan of the proposed regulator counts on the truth and accuracy of the MLS arrangement. ANFIS shrewd support in preparation utilized genuine information from a conventional MLS configuration. An essential for the ANFIS regulator, deleting the basic distinctive proof in various other control strategies. ANFIS regulators' outcomes and an examination of this outcome with exemplary support (see *figure 5*).

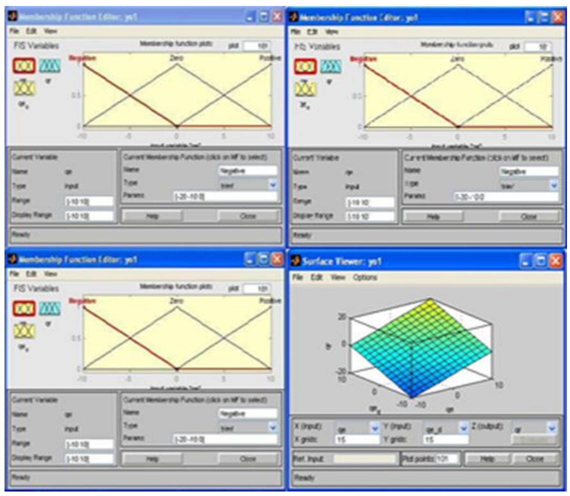


Figure 5: The output of MLS based on two types controllers

Following that, the ANFIS preparation is completed, and the FIS regulator structure is chosen. The signal of mistake is between the yield connect point (q) and necessary link point (qr) as well as its subordinates (Δqe) is indeed a contribution towards the ANFIS primary layer.

That after layers have been produced, the structures show up as in *figure 6*, which speak to the standard set, the info sign, the identifier of ANFIS, and the blunder of surface. The preparation handling and every one of its outcomes are appeared in *figure 6*. The end-product and connection of the brilliant and exemplary regulator with the many following occasions are found in *figure 7*.

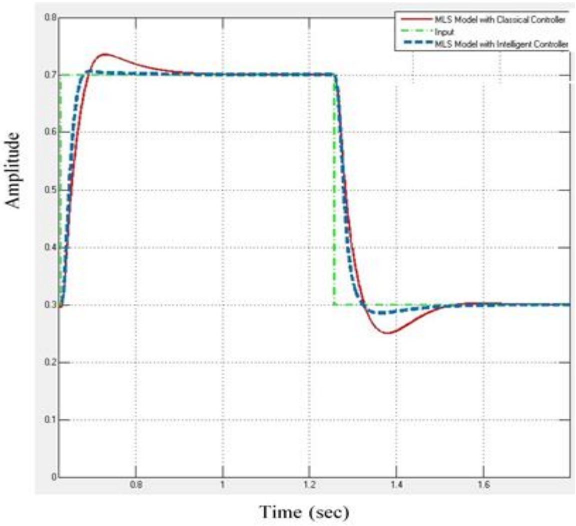


Figure 6: Construction and training of the ANFIS

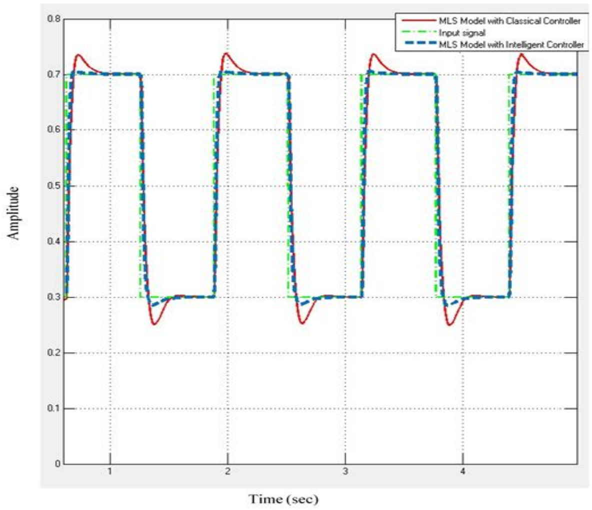


Figure 7: The final comparison between the two results

5. CONCLUSIONS

A high degree of adaptability in ANFIS's control technique is suitable for numerous control applications, such as MLS applications as well as the controlling of the biomedical or dynamic framework, in which it is difficult to get the precise powerful property through direct preparation (this research utilized a direct MRAC-based intelligent control unit; hence, the total framework could reduce error time actual). The outcomes of the neurotic recreations demonstrate the framework's viability.

Examination of reenactment results for both conventional and insightful control units (ANFIS) demonstrate the developed framework has decreased settling time and overshoot, and the reduction is significant throughout real applications. The whole work carries out the suggested ANFIS regulator, including an exemplary current in-framework regulator as well as modifications of reactions before altering the framework's savvy regulator without modifying the framework to its likeness.

The effectiveness strength examination of controlling a criticism of catchy lifting framework was investigated in this paper. Fundamental thoughts and specialized equations are introduced for a powerful criticism control test. To start, a mathematical modeling of an appealing lifting framework has been created, followed by a dissection of the control technique based on H blended affectability is dissected and a powerful regulator arrangement is made. The results of the cloning demonstrate that the proposed support satisfies the requirements for solidity and operation. As a result, this control module provides solidity towards model vulnerabilities and enables extremely exact positioning of the employed article. The featured work can be applying the real implementation of the proposed design and can improve this model to consider a practical model in magnetic levitation system applications.

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