Comparison Of Interval Type-2 Fuzzy Controller And Self Tuning Interval Type-2 Fuzzy Controller For A Magnetic Levitation System

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Abstract— Magnetic Levitation System (MLS) is a typical multivariable, nonlinear and unstable system. The basic aim of our research work is for suspending the steel ball without any mechanical support in desired position with help of an efficient controller. The simulation of MLS based on its mathematical model is carried out in MATLAB and its real time implementation is also achieved. In this paper interval type-2 fuzzy logic controller (IT2FLC) and interval type-2 self tuning fuzzy logic controller (STT2FLC) are designed for a Magnetic Levitation System and its comparison is shown. The tracking performance and robustness are also checked for this system. For tracking, two type of reference trajectory are modeled. One is sine wave and other is a constant value. The simulation and experiment results are indicating that the proposed control method has good control ability.

***Index Terms*–** Magnetic Levitation System, Interval type-2 fuzzy logic controller, Self tuning type-2 fuzzy controller.

I. INTRODUCTION

Active Magnetic Levitation System employs electromagnets to support machine components. The magnetic forces are generated by feedback controllers to suspend the machine components within the magnetic field and to control the system dynamic during machine operation. Magnetic Levitation System (MLS) is very usable system that can be applied in many application areas such as in high speed transport, magnetic bearing system, vibration isolation, levitation of wind power generation and fusion Energy Materials processing in magnetic levitation furnaces. Magnetic levitation system is highly non-linear and unstable. Non-linearity is present due to electromechanical dynamics. This is challenging and interesting task for control engineers and researcher to control MLS. Stabilizing control of MLS is to balance the ball in the upright position. This is a very typical and academic nonlinear control problem, and many techniques already exist for its solution, for example, model-based control, fuzzy control, neural network(NN) control, genetic algorithms (GAs)-based control, and PID control is classical technique for controlling of nonlinear system. Type-1 FLC is unable to handle the linguistic and numerical uncertainties which are associated with dynamic unstructured environment. But type-2 fuzzy sets have the capability to determine the exact membership function for a specified fuzzy set [1]. In the design of type-1 fuzzy systems, uncertainty is limited with the linguistic uncertainty contained within the definition of variables. The MLS system configuration shown in figure.

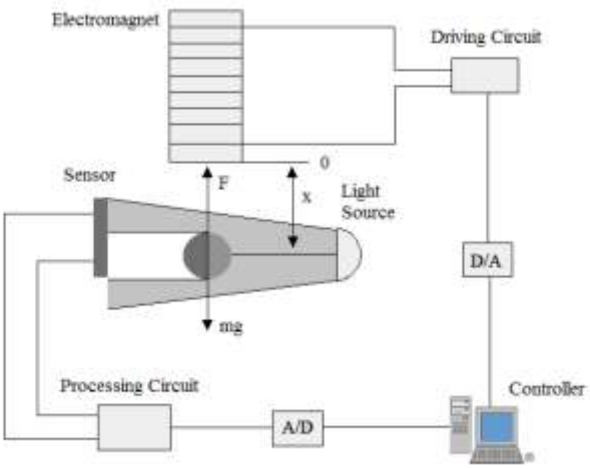

Fig. 1: Magnetic Levitation Experiment System Configuration.

Fig 2: Googol's MLS

II. THE MAGNETIC LEVITATION SYSTEM MODEL

The main challenge in controlling the position of the suspended object is to maintain the balance of the weight of the suspended object and the electromagnetic force acting on it. In our study we are interested only in controlling the *vertical position* of the suspended object. Thus all the dynamics discussed here on will be concerned to vertical motion of the suspended object.

Electromagnet Dynamics:

The dynamics of the coil are usually represented as an equivalent R-L circuit in series. When the electric circuit of the coil is driven by a voltage source, Kirchhoff"s voltage law gives the relationship,

$$v = \frac{d\varphi}{dt} + Ri \tag{1}$$

Where,

v- The voltage source

R- Resistance of the circuit

φ - Magnetic flux linkage

The current flow in the coil controls the inductance. So the position of suspended object,

$$L(x) = L_1 + \frac{L_o}{1 + \frac{x}{a}} \tag{2}$$

Where,

L_1 - The initial inductance when the ball is not present.

L_o - The final inductance ball is next to the coil.

a - Constant.

Here inductance has highest value when the ball is next to the electromagnet i.e., the coil and decreases to constant when the ball is removed.

We know that,

$$\varphi = L(x)i \tag{3}$$

By putting (2) and (3) in (1),

$$v = Ri + \frac{d}{dt}(L_1 + \frac{L_o}{1 + \frac{x}{a}})i \tag{4}$$

$$v = Ri + L(x)\frac{di}{dt} - L_o a \frac{i}{(a+x)^2}\frac{dx}{dt} \tag{5}$$

$$\frac{di}{dt} = \frac{1}{L(x)}[-Ri + L_o a \frac{i}{(a+x)^2}\frac{dx}{dt} + v] \tag{6}$$

Suspended Object Dynamics:

The forces acting on the suspended object are its weight downwards, electromagnetic force upwards and viscous friction opposite to the velocity in vertical plane. Thus its dynamics in vertical plane can be described as:

$$m\frac{d^2x}{dt^2} = mg - k\frac{dx}{dt} - Force(x,i) \qquad (7)$$

Where,

m - Mass of the suspended object i.e. the steel ball.
g - Acceleration due to gravity.
x – Distance of the ball from the bottom of the electromagnet.
k - Coefficient of viscous friction.
i - Current supplied to the electromagnet.
$Force(x,i)$ - Force generated by the electromagnet.
Now energy stored in the electromagnet is given as,

$$Energy(x,i) = \frac{1}{2}L(x)i^2 \qquad (8)$$

Thus the $Force(x,i)$ can be calculated using (2)

$$Force(x,i) = \frac{\delta(Energy)}{\delta x} = \frac{L_o a}{2}\frac{i^2}{(a+x)^2} \qquad (9)$$

Using above expression of $Force(x,i)$ in (7) the differential equation governing the motion of The suspended object is given as

$$\frac{d^2x}{dt^2} = g - \frac{k}{m}\frac{dx}{dt} - \frac{L_o a}{2m}\frac{i^2}{(a+x)^2} \qquad (10)$$

Equation (6) and (10) controls vertical dynamics of the electromagnetic system including the coil that we using as electromagnet and the steel ball. The parameter values are taken based on googol's magnetic levitation system manual. The weight of the ball and constant parameters like acceleration of gravity, inductance etc is shown below [2].

Parameter	Symbol	Value	Unit
Suspended object Mass	m	0.1	kg
Coil Inductance	L_1	0.02	H
Incremental Inductance	L_o	0.01	H
Coil Resistance	R	1	Ω
Gravity of acceleration	g	9.8	m/sec^2
Coefficient of Viscosity	k	0.001	N.m/sec
Constant 'a'	a	0.05	m

Table 1

III. INTERVAL TYPE-2 FUZZY LOGIC CONTROLLER

Interval type-2 fuzzy logic:

The usage of type-2 fuzzy sets provides us the advantage of handling the uncertainty and inaccuracy in the problems of real world. Zadeh proposed these sets in 1975, they are "fuzzy-fuzzy" sets in which the membership grades are itself type-1 fuzzy sets. These sets express the degree of uncertainty and non-determinist truth with which an element belongs to the whole set.

If

$$f_p(u) = 1,\ \forall\ u \in \left[\underline{J}_p^u, \bar{J}_p^u\right] \subseteq [0,1]$$

An interval type-2 fuzzy set (IT2FS) $\tilde{A}$ can be characterized as:

$$\tilde{A} = \int_{p\in P}\int_{u\in J_p\subseteq[0,1]} 1/(x,u) = \int_{p\in P}\left[\int_{u\in J_p\subseteq[0,1]} 1/u\right]\Big/x$$

Where the primary variable p, has domain P; the secondary variable $u \in U$; has domain J_p at each $p \in P$; J_p is called the primary membership of p and the secondary grades of $\tilde{A}$ are all equal to 1. Clearly, means $\tilde{A}: P \rightarrow \{[u,v]: 0 \le u \le v \le 1\}$.
Union of all the primary membership conveys uncertainty about $\tilde{A}$, which is also known as footprint of uncertainty (FOU) of $\tilde{A}$. The shaded area (Mendal, 2000) which is bounded by an upper and lower membership function as shown in figure below: the FOU

$$\bigcup_{\forall p \in P} J_p = \{(p,u) : p \in J_p \subseteq [0,1]\}$$

Here, the upper membership function (UMF) and lower membership function (LMF) of $\tilde{A}$ are type-1 membership function as shown in the figure.

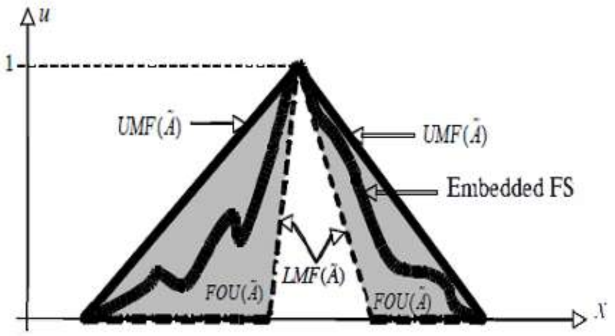

Fig 3: FOU (Shaded), LMF (dashed), UMF (solid) and an embedded FS (Wavy line) for IT2FS.

IT2FLC design is based on the concept of interval type-2 fuzzy logic system. The structure of IT2FLC is same as the conventional fuzzy logic controller structure except, one type reducer block is introduced between the inference engine and defuzzifier block because the output of the inference engine is a type-2 output fuzzy set and before applying it to the defuzzifier for getting the crisp input it has to be converted to a type-l fuzzy set. The block diagram of an IT2FLC is Shown in Fig.3.

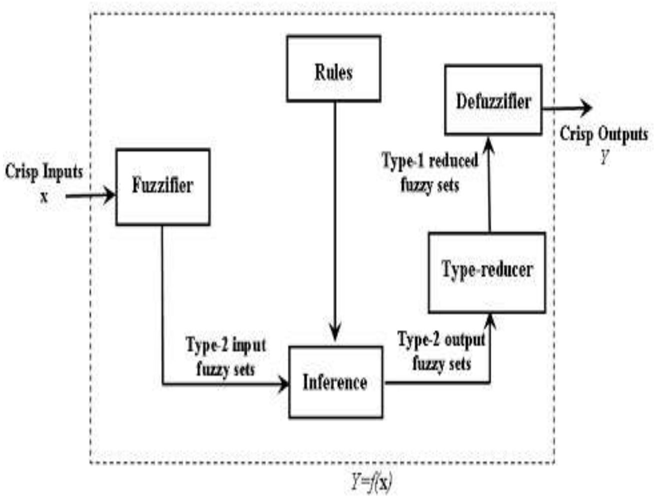

Fig 4: Interval type-2 fuzzy logic controller [3].

Controller Design and Implementation:

The purpose of the controller is to keep the steel ball suspended in air, at the nominal equilibrium position by controlling the current in the magnet. IT2FLC is designed with the help of interval type-2 fuzzy inference system toolbox in the MATLAB software. The controller is designed based on the Block diagram shown in Fig.4. The two inputs considered for the design of controller are error (E) and change in error (CE). The controlled output is fed to the plant. In this proposed controller design an interval type-2 Gaussian membership function with uncertain mean is chosen where the standard deviation value is fixed. The membership function plot is shown below in the Fig.5. The membership function can be expressed as,

$$\mu(x) = \exp\{-\frac{1}{2}[\frac{(x-m)}{\sigma}]^2\} m \in [m_1, m_2]$$

The membership function used are [NB NM NS ZE PS PM PB].

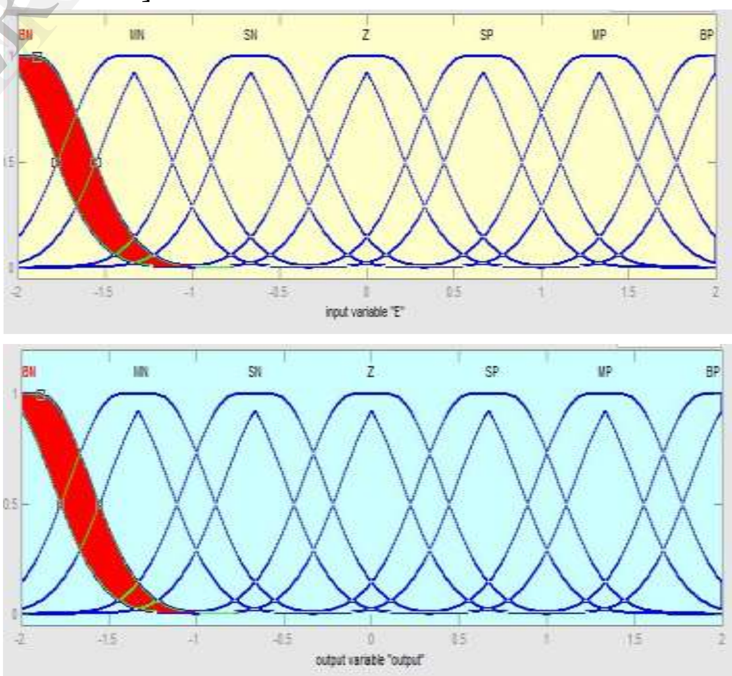

Fig 5: Membership functions for input and control output

EC→ E↓	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NM	NS	ZE	PS	PM
ZE	NM	NM	NS	ZE	PS	PM	PM
PS	NM	NS	ZE	PS	PM	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PM	PB	PB	PB

Table2: the rule base for type-2 fuzzy logic.

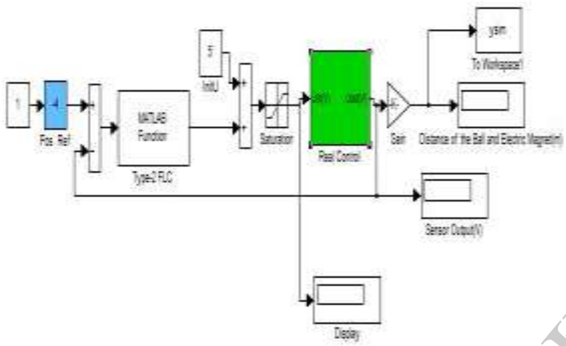

Fig 6: Real time control

IV. SELF TUNING TYPE-2 FUZZY CONTROLLER

Here the adaptive fuzzy logic controller adjusts the multiplication factor automatically by using adaptive fuzzy logic controller (Fig.7).

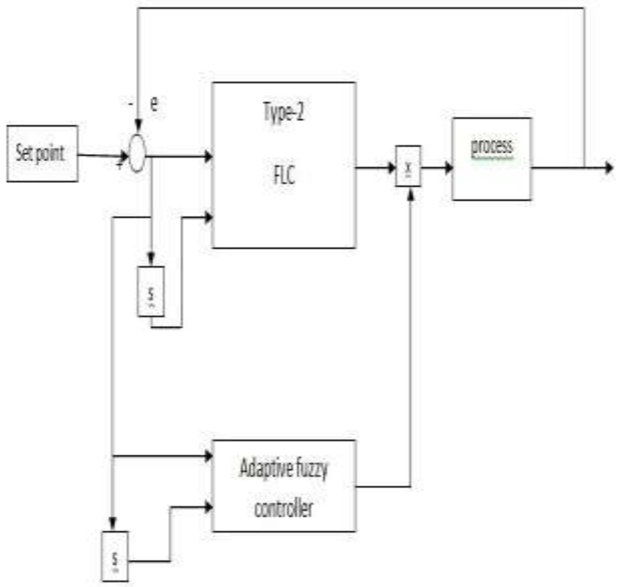

Fig 7: Self tuning type-2 fuzzy controller

Here type-2 fuzzy logic controller is same as the previous one. The adaptive fuzzy controller is a normal type-1 fuzzy logic controller, where error and change in error are the inputs and single output. The scaling factor adjusts the control output that comes from the main controller, from the signal comes from the adaptive controller. The union of the two controllers, type-2 fuzzy logic controller and adaptive fuzzy logic controller, will give robust and efficient control will capable to handle all uncertainties that comes from the highly nonlinear systems like magnetic levitation. The all the disturbances from simple to high level can also handle. The membership function used for adaptive fuzzy controller is Gaussian.

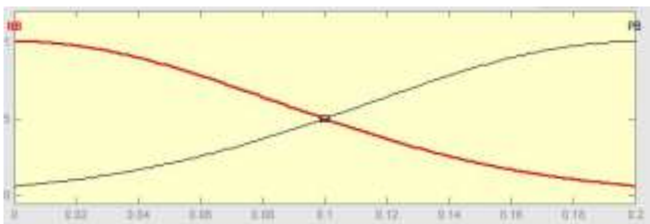

Fig 8: Membership function used for error and change in error.

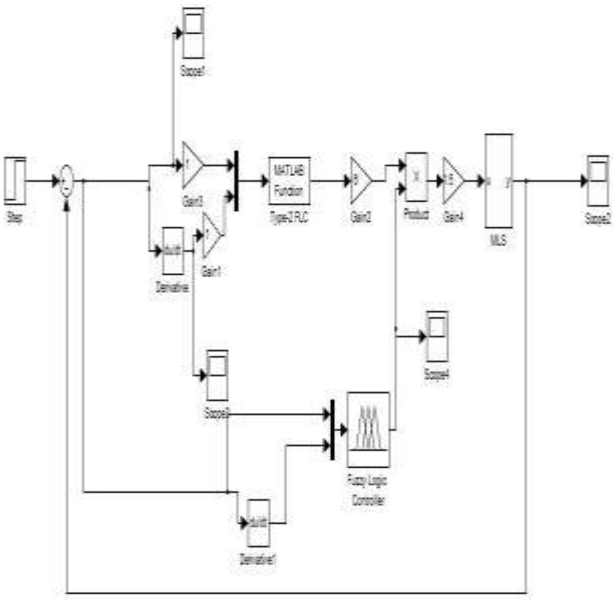

Fig 9: MATLAB simulink model.

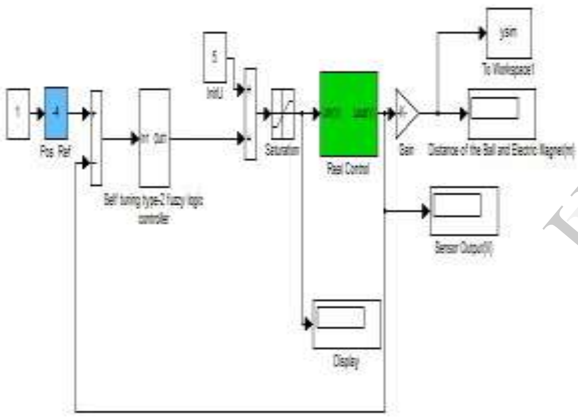

Fig 10: Real time control.

V. SIMULATION RESULTS

The proposed controller self tuning interval type-2 fuzzy logic controller (STT2FLC) was applied to the magnetic levitation system and its performance compared with interval type-2 fuzzy logic controller (IT2FLC) is shown in fig.11 for a constant value 0.5. Comparison for tracking controlled position by using sine wave with a frequency of 1 radian/sec is shown in fig.12. From these results we can see that STT2FLC is far better than IT2FLC. The performance comparison is self explainable from the below two graph shown. The overshoot of the STT2FLC is very less compared to IT2FLC. There is no steady state error in STT2FLC. The rise time is little less in IT2FLC compared to STT2FLC.

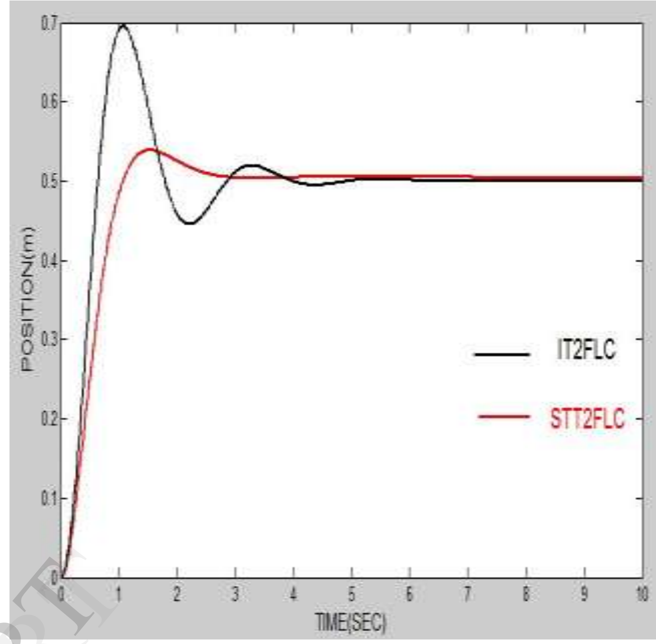

Fig 11: Performance comparison for a constant position 0.5

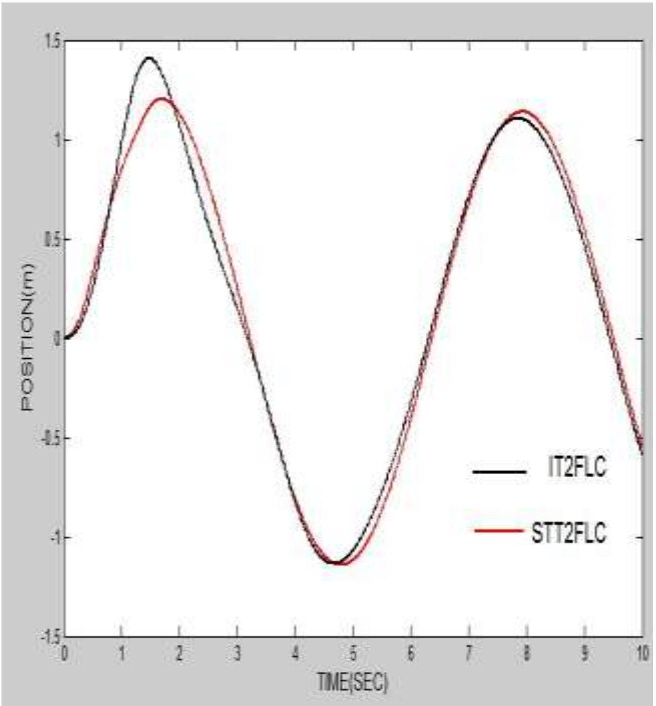

Fig 12: Performance comparison for tracking control by using sine wave with frequency of 1 radian/sec.

VI. CONCLUSION

This paper presents and shows the comparison of IT2FLC and STT2FLC for a magnetic levitation system. The main goal of this work was to design and stabilizing these two controllers for a magnetic levitation system. The Simulation result shows that the rise time is little less in IT2FLC but in the case of overshoot and steady state error the STT2FLC have a better performance. The STT2FLC that operated on output scaling factor allows to minimize all the negative effects on the system.

REFERENCES

[1] Zadeh, L.A.: The concept of a linguistic variable and its application to approximate reason-ing, Parts 1, 2, and 3. Information Sciences 8, 9, 199–249, 301-357, 43-80 (1975)J. U. Duncombe, "Infrared navigation—Part I: An assessment of feasibility," IEEE Trans. Electron Devices, vol. ED-11, pp. 34-39, Jan. 1959.

[2] Googol's tech Experimental Manual, Magnetic Levitation System, Googol Technology Limited 2007.

[3] Type-2 fuzzy logic theory and applications, Oscar Castillo, Patricia Melin, Studies in fuzziness and Soft computing.

[4] Adaptive type-2 fuzzy logic control of a bioreactor, Mose Galluzzo, Bartolomeo Cosenza, Department of chemical engineering, Parlermo University, Italy.

[5] Astrom, K. J., and Wittenmark, B., 1989, *Adaptive Control* (Addison-Wesley).Moore, C. G. and Harris, C. J.(1992) 'Indirect adaptive fuzzy control', *International Journal of Control*,56: 2, 441 — 468.

[6] Designing of an Interval type-2 fuzzy logic controller for magnetic levitation system with reduced rule base, Anupam Kumar, Manoj Panda, Sumanth Kundu and Vijay Kumar. Electronics & computer engg, IIT roorkee, India.

[7] J. M. Mendel, H. Hagras and Robert I. John, "Standard background material about interval type-2 fuzzy logic systems that can be used by all authors," www.ieee-cis.org/ files/standards.