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Design and implementation of an interval Type-2 Fuzzy Logic and type-1 fuzzy logic controls for Magnetic Levitation System

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Abstract

The aim of this paper is the synthesis of an interval type-2 fuzzy logic PID and type-1 fuzzy logic controllers for magnetic levitation system to keep a metal ball suspended in mid-air by changing the field strength of an electromagnet coil, Performances of the suggestion controller are estimated and compared that controller with those of type-1 fuzzy logic PID controller by using the same structure and under similar operating conditions. Simulation results showed that the interval type-2 fuzzy logic PID controller has better performances than those of type-1fuzzy logic PID controller. The parameters of PID controller have been modifying through particle swarm optimization (PSO).The simulation of magnetic levitation system based on its Mathematical model is carried out in MATLAB.

Keywords: Magnetic Levitation System; Maglev; Interval Type-2 Fuzzy logic; IT2FLC.

1. Introduction

The researchers tried to collecting the PID with a fuzzy logic to make a more efficient controller. the fuzzy PID controller is simple and can be theoretically analyzed[1]. but when the system to be controlled has uncertainties they are not efficient because the limited capabilities to deal with directly data uncertainties for The type-1 fuzzy logic controller (T1-FLC).

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Indeed type-1 fuzzy logic PID controller cannot deal successfully data uncertainties. For MAGLEV it can be used in many application like magnetic train, launching rocker, magnetic bearing, electromagnetic aircraft launch system, maglev wind turbine and for the future will design the flout car that use magnetic levitation technology instead of wheels, moving in any direction without turning around and working this car through a special application is easily rented by people such as taxis [9].They are interested in Maglev technology because it gets rid of friction and thus eliminates the loss of energy. Like these systems, it is difficult to control because is unstable and it is nonlinear that make not easy to control the system for Achieve stability control of magnetic levitation system is to stability in the fit position for the object. In such difficult systems, there are many ways to solve them, like fuzzy control in all types, genetic algorithms based control, neural network control and other types intelligent..

In the Maglev system, the logic controller of the interval type-2 fuzzy logic PID has achieved the organization of the output voltage without any vibration and better stability than classical PID In spite of the changes in load and / or in the input voltage.

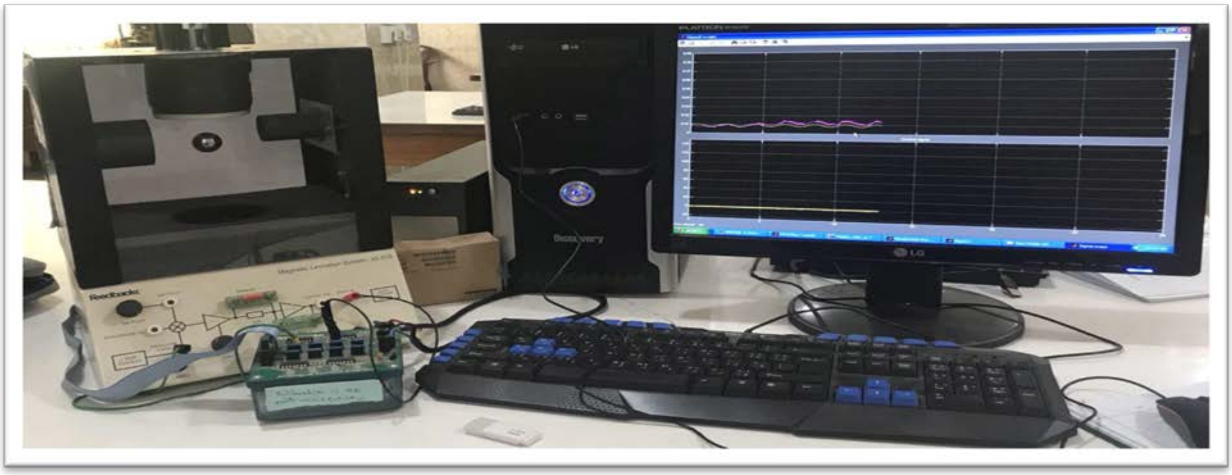


Figure 1: Components of the experience of magnetic Levitation System

2. Interval Type-2 Fuzzy Logic Controller

Zadeh was introduced the fuzzy set theory, the fuzzy set has developed as a powerful modeling tool that it can deal with the uncertainties and nonlinearity systems. In this study we are choosing type-2 fuzzy sets, because type-1 fuzzy logic does not deal with uncertainty. To solve the control problem, some researchers are interested in type-2 fuzzy logic controller (T2FLC) [3,4]. Type-2 fuzzy logic has been used in many different applications, such as the control of electrical machines [5,6], speed control of diesel engines [7], and transformers [8]. Advantages of interval type-2 fuzzy logic set [IT2FLS] technique are interval type-2 fuzzy logic (Fig.2) have a footprint of an uncertainty which is shown in the confined area between upper membership function and lower membership functions, that footprint of an uncertainty deals with numerical and linguistic uncertainties related with the i/p and o/p of the fuzzy logic controller. **Because** of this reason, the IT2FS will have able to give better performance than the type-1 fuzzy logic controller [11].

2.1 Basic Concepts about Interval Type-2 Fuzzy Sets

The principle of working and structure of the IT2FLC is similar to the T1FLC, just the type there are block named reducer its location between the inference block and defuzzifier block due to the o/p of the inference block is a type-2 output fuzzy set and it should that before applying it must to converted by defuzzifier to make it crisp o/p such as converted to a type-l fuzzy set. For IT2FLC the block diagrams shown in Fig.1 and for i/p and o/p crisp of the IT2FLS the mapping between them it is represented as

IT2FS is characterized as [17],[20]:

$$\tilde{A} = \int_{x\in X} \int_{u\in Jx\subseteq[0,1]} {}^{1}/_{(x,u)} = \int_{x\in X} [\int_{u\in J\subseteq[0,1]} 1/u]/x \qquad (1)$$

x∈X; $J_X$is called a 1^{st} membership of the X and its introduction in equation (5); the all 2^{nd} grades of $\tilde{A}$ equal 1.

So the eq (1): means

$\tilde{A} = X \rightarrow \{[a,b]: 0 \leq a \leq b \leq 1\}$ .Uncertainty about $\tilde{A}$ is called the footprint of uncertainty (FOT) of $\tilde{A}$ (**Figure3**),

$$FOT(\tilde{A}) = \bigcup_{\forall x\in X} J_x = \{(x,u): u \in J_x \subseteq [1,0]\} \qquad (2)$$

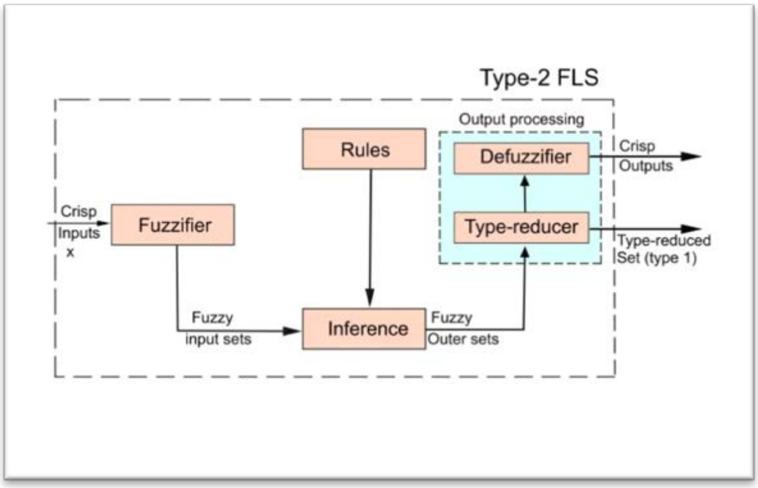


Figure 2: The block diagrams of Interval Type-2 Fuzzy Logic controller [23]

Where (UMF) is mean the upper membership functions of $\widetilde{A}$, (LMF) is mean lower membership function of $\tilde{A}$ that are two type MFs of an interval type-2 fuzzy logic that shows in (**Figure 3**). The bound of area FOU in the out associated with the upper bound and from other side associated with the lower bound of FOU ($\tilde{A}$) and is denoted by $\bar{\mu}_{\tilde{A}}(x), \forall_{x\in X}$ and the LMF is $\underline{\mu}_{\tilde{A}}(x), \forall_{x\in X}$ i.e

$$\bar{\mu}_{\tilde{A}}(x) = \overline{FOT(\tilde{A})}, \forall_{x \in X} \quad (3)$$

$$\underline{\mu}_{\tilde{A}}(x) = \underline{FOT(\tilde{A})}, \forall_{x \in X} \quad (4)$$

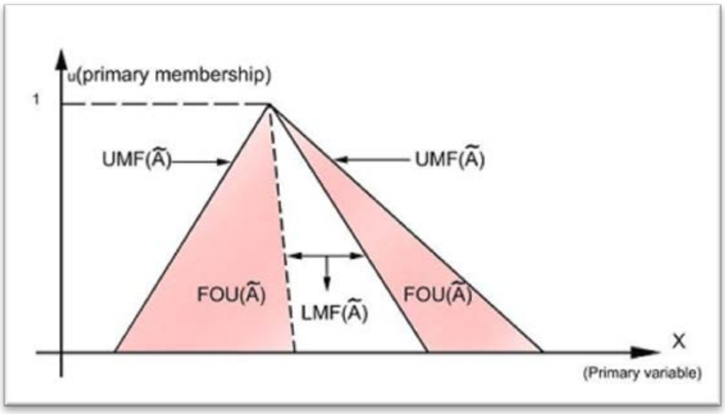


Figure 3: FOU, LMF,UMF and an embedded FS

for IT2FS $\tilde{A}$.[23]

Note that J_X is an interval set, i.e.

$$J_{x=\{(x,u):u \in [\underline{\mu}_{\tilde{A}}(x), \bar{\mu}_{\tilde{A}}(x)]} \quad (5)$$

SO that FOU $(\tilde{A})$ in (2) can also be expressed as

$$FOT(\tilde{A}) = \bigcup_{\forall x \in X} [\underline{\mu}_{\tilde{A}}(x), \bar{\mu}_{\tilde{A}}(x)] \quad (6)$$

For continuous universes of discourse U and X, an embedded interval type-2 fuzzy sets $\tilde{A}_e$ is

$$\tilde{A}_e = \int_{x \in X} [1/u]/x, u \in J_x \quad (7)$$

Where eq (7) means: $\tilde{A}_e: X \subseteq \{u: 0 \leq u \leq 1\}$ The $\tilde{A}_E$ is embedded in $\tilde{A}$ for examples of $\widetilde{A}$ are $1/_{\bar{\mu}_{\tilde{A}}}(x)$ and $1/_{\underline{\mu}_{\tilde{A}}}(x), \forall_{x \in X}$

3. Mathematical Model of Magnetic Levitation System

The mathematical model of Maglev system consist of five subsystems, define coil and ball, position sensor, and A/D and D/A converters, power amplified, as shown in **Figure4.**

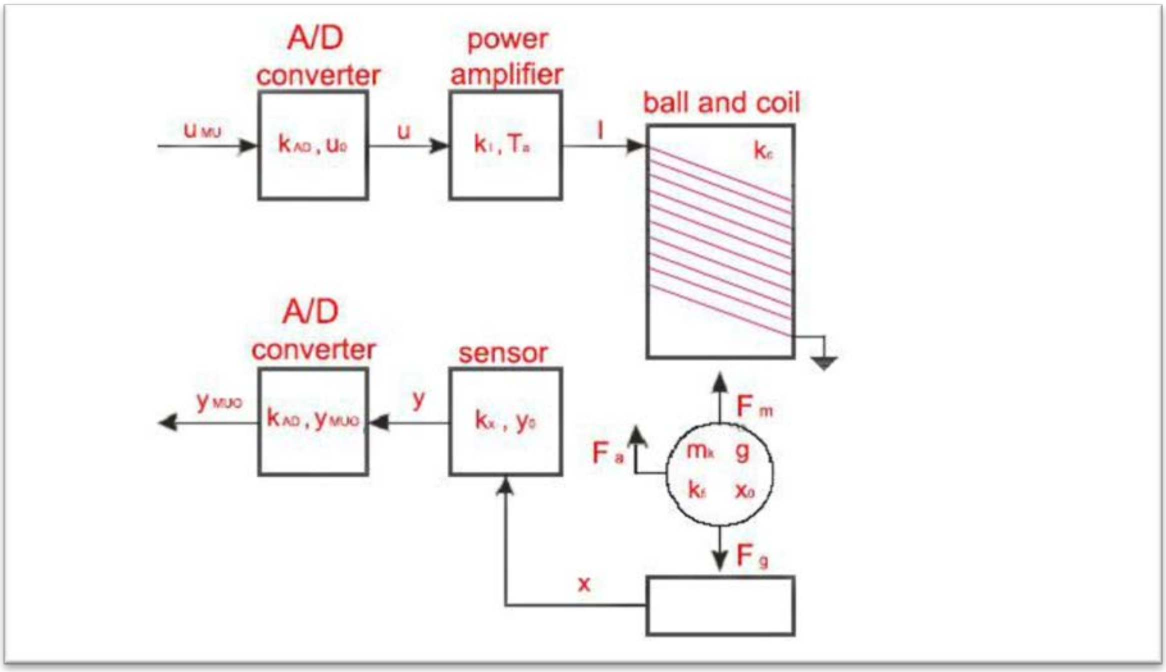


Figure 4: Magnetic levitation model [24]

For represent mathematical model of the coil and ball is based on Newton' laws in the equilibrium of forces acting on the object.

$$f_a = f_g - f_m \quad (8).$$

$$fa = m\ddot{x} \quad (9)$$

$$f_g = mg \quad (10)$$

$$f_m = K(i^2/x^2) \quad (11)$$

where f_a : acceleration force [N]

f_m : Electromagnetic force [N]

f_g : Gravity force [N]

i (t): electric current [A]

K: electromagnetic constant

Now the current equation of coil have constant $k_1$that relate control i/p with current

$$i(t) = k_1 u \quad (12)$$

that relationship substituting for each power in eq.(8), and adding the eq.(12) in (8), the final mathematical model of the coil and ball system is described by a nonlinear equation of second order [15]:

$$\ddot{x} = g - \frac{K}{m}(i^2/x^2) \tag{13}$$

where considering $a = \ddot{x}$, the system in state variable form;

$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = g - \frac{k_1^2\,K}{m}\,(u^2/x^2) \tag{14}$$

$$y = x_1$$

Eq (14) is a nonlinear system of Maglev and it represented in **Figure 7**

The parameter values of Maglev listed in Table (1).

Table 1: Parameters of Maglev system [15]

Parameter	Symbol	Value
Electromagnetic constant	k	$2.5x10^{-5}$
Current driver constant	k_1	1.05
Ball Mass	m	0.02 [kg]
gravity cost.	g	9.8 [m/s^2]
Coil Resistance	R	22 Ω
Coil Inductance	L	0.277 H at 1 k Hz

4. The controller design methodology for T1 FLC and IT2FLC

For T1FLC and IT2FLC controller the membership function for i/p and o/p is designed based on the block diagram shown in **Figure 6** and **Figure 7**.The two inputs are error (e) and change in error (ce). The controlled output (cv) is fed to the plant. The inference combines all the fired rules and gives a nonlinear mapping from the input of IT2FLS to the output of IT2FLS [14]. But in T1FLS the output of the inference is applied to the defuzzifIer block to produce a crisp output. In case of T2FLS Zadeh's extension principle [11] is applied to get a type-reduced set from the type-2 fuzzy set.

for T1FLC and IT2FLC controller the membership function for i/p and o/p shown in Figure 6 and Figure 7. The two i/p are an error (e) and change in error (ce). The o/p controlled (cv) is going to the plant. The inference controller all the fired rules and make a nonlinear mapping from the i/p of IT2FLS to the o/p of IT2FLS [14]. But in T1FLS the control o/p is applied to the fuzzifier block to make a crisp o/p.

There are many type reduction methods like height, modified height, centroid of sets, and the center of sums type are described in [12], [10]. These methods have the same work of defuzzifIcation that applied in T1FL set. Karnik & Mendel [13] they introduction the centroid of aT2FL is a T1FL set .The great method in [13] so it possible because centroid of an interval type-2 fuzzy logic is an interval type-1 fuzzy logic, like characterized by (Yt), (Yr); so to computing the centroid of an interval type-2 fuzzy logic set it must computing (Yt), (Yr). The fuzzified o/p of interval type-2 fuzzy logic set is the average of Yt, Yr i.e. Y= (Yt+ Yr)/ 2 [23] .the o/p is crisp value and can be applied to the i/p of the plant to make controller of it.

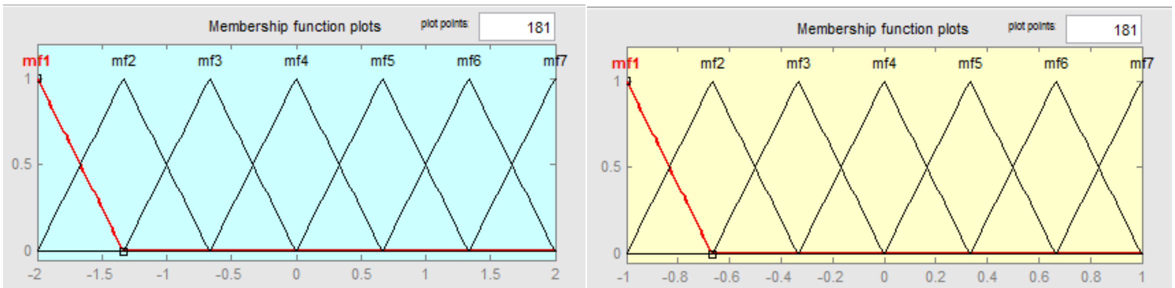


Figure 5: Membership functions for input and Output for T1FLC

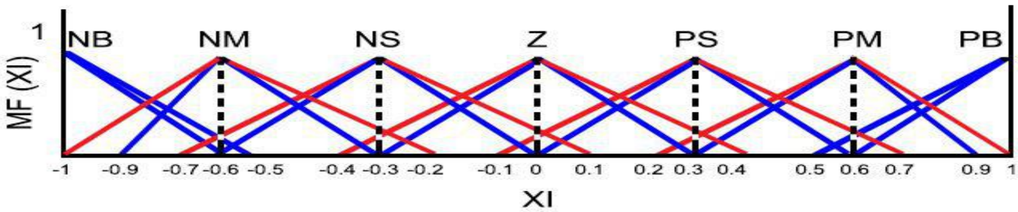


Figure 6: Membership functions for input and Output for T2FLC

Table 2: Rule base for both controller

$\frac{\dot{e}}{e}$	mf1	mf2	mf3	mf4	mf5	mf6	mf7
mf1	mf1	mf1	mf1	mf1	mf2	mf3	mf4
mf2	mf1	mf1	mf1	mf2	mf3	mf4	mf5
mf3	mf1	mf1	mf2	mf3	mf4	mf5	mf6
mf4	mf1	mf2	mf3	mf4	mf5	mf6	mf7
mf5	mf2	mf3	mf4	mf5	mf6	mf7	mf7

5. Simulation Results

The structure of the maglev system and controller of T1FLC and IT2FLC by Simulink in matlab is shown in Fig 7, Fig 8 and Fig 9 respectively

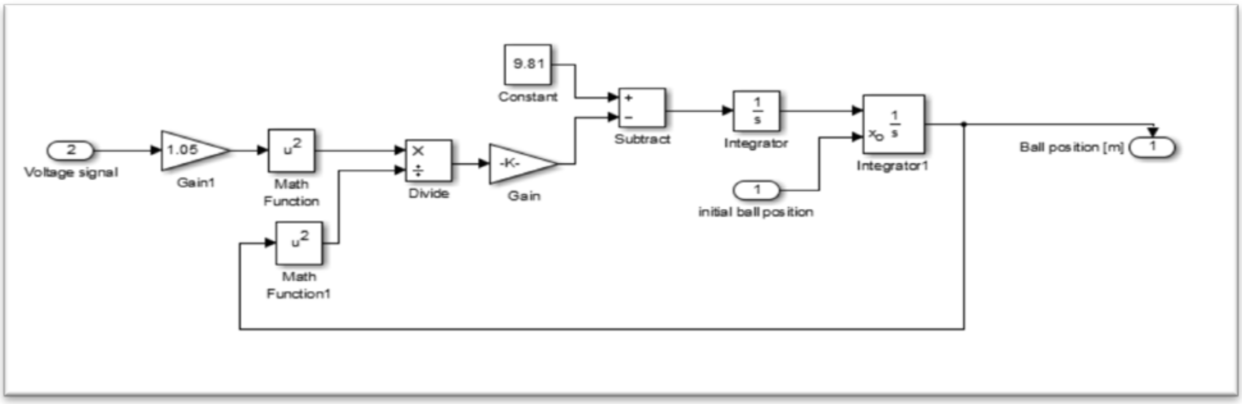


Figure 7: Simulation structure of the MLS

with gain for an interval type-2 fuzzy logic PID parameters theoretical controllers are: gain kd 1.5187,gain kp 10^{-9} ,gain ke 1.5187 and gain ka 0.17

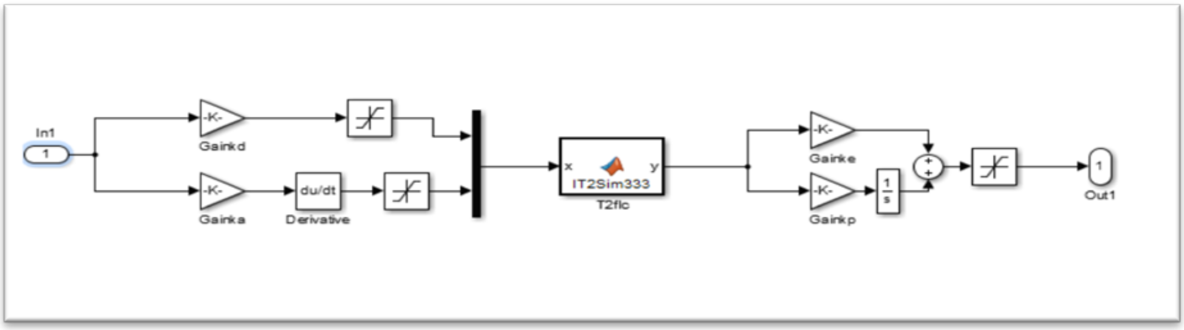


Figure 8: Simulation structure of IT2FLC

For gain for type-1 fuzzy logic PID parameters theoretical controllers are: gain kd 1.5187,gain kp $1 * 10^{-15}$,gain ke 1.5187 and gain ka 0.01

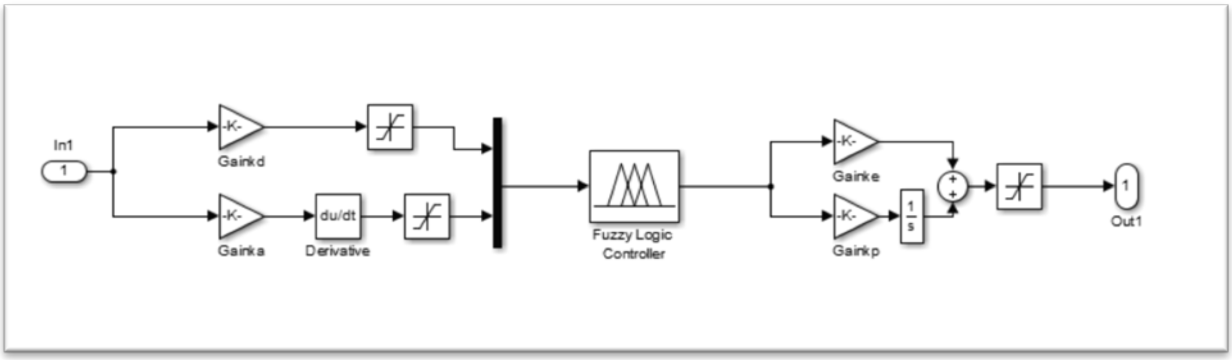


Figure 9: Simulation structure of T1FLC theoretical

And gain for type-1 fuzzy logic PID parameters Practical controllers are: gain kd -1.1, gain ka 1.5, gain and gain ka 0.01

For PID controller it design by Feedback Instrument software Simulink in Fig 9 and the PID gains are (kp=4, ki=2 and kd=0.02).

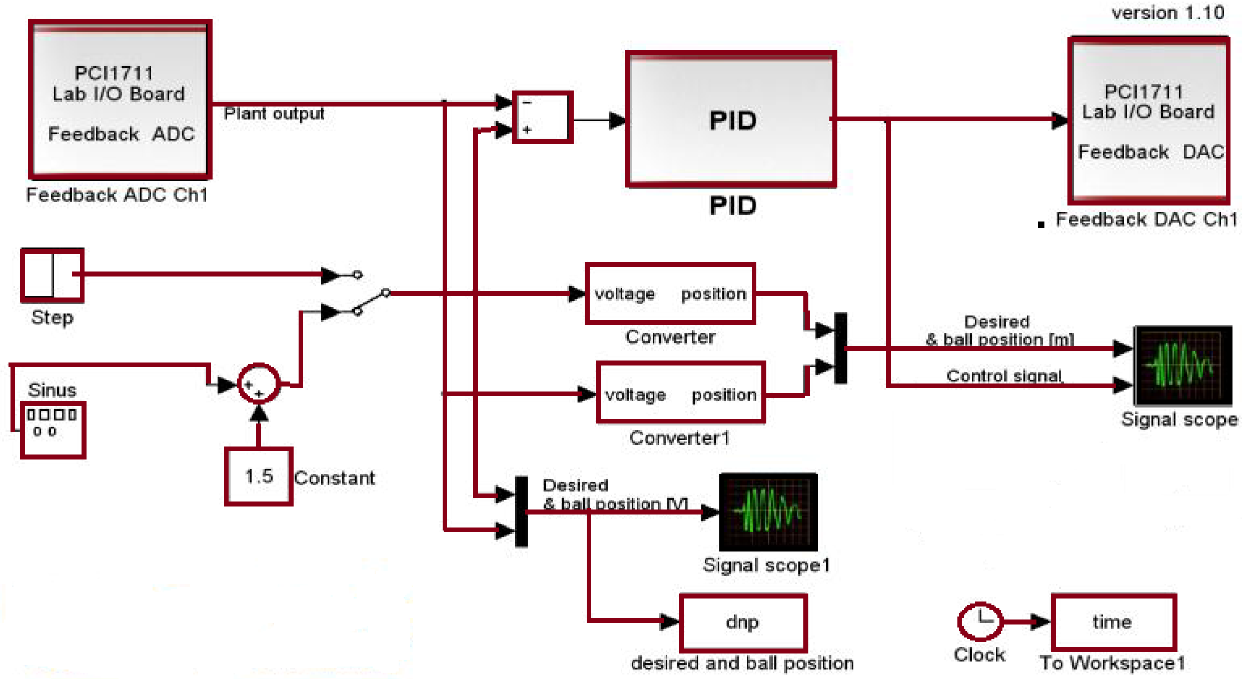


Figure 10: The Simulink of PID controller for Maglev System (33-210)

For the result of these controllers we have two part one for the Practical to compare between PID and T1FL controllers and the other part compare simulation between an IT2FL and T1FL, with notice that lines in all figures refer to desired & actual ball position with color to blue and green respectively

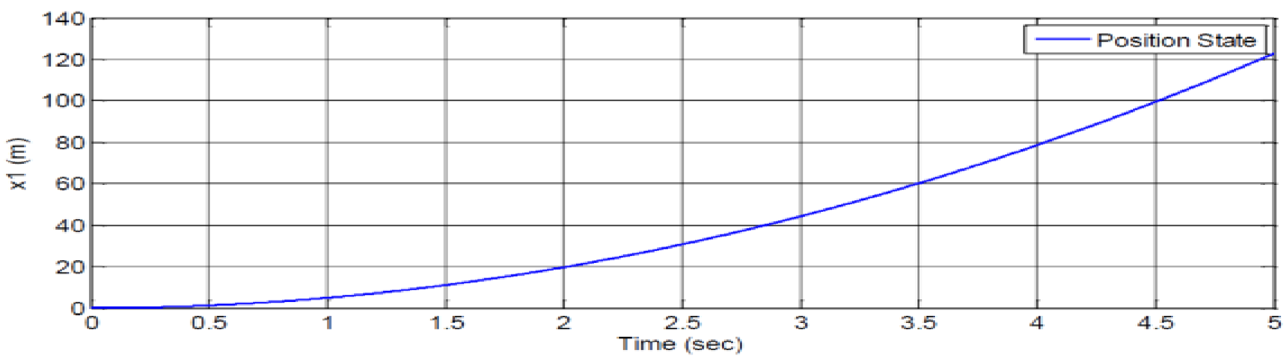


Figure 11: The unstable Ball Position.

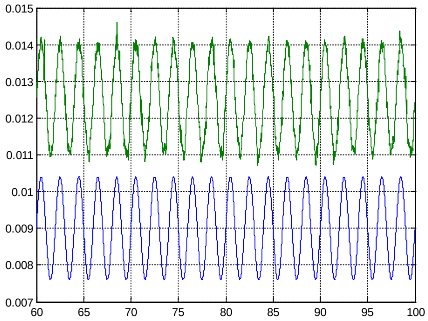


Figure 12: The ball position with controller

Type-1 fuzzy logic with sine wave input

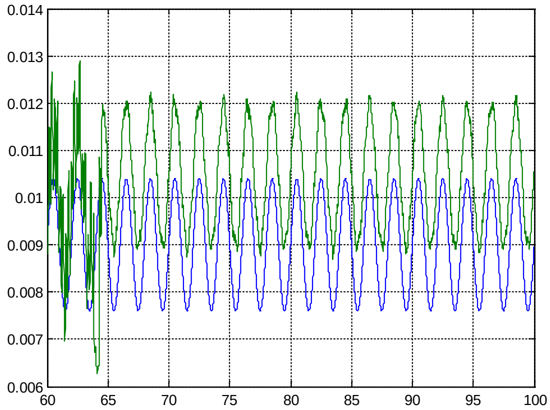


Figure 13: The ball position with controller

PID with sine wave input

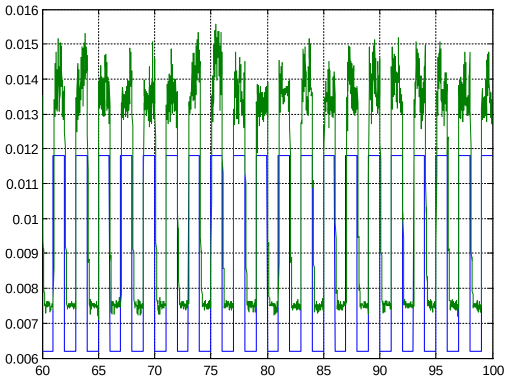


Figure 14: The ball position with controller

Type-1 fuzzy logic with square wave input

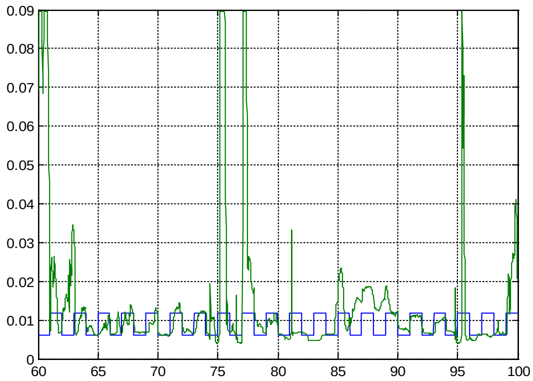
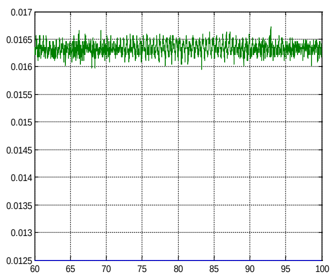


Figure 15: The ball position with controller

PID with square wave input



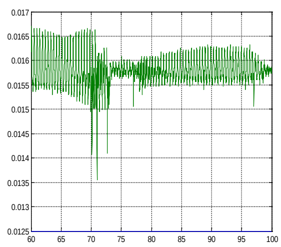


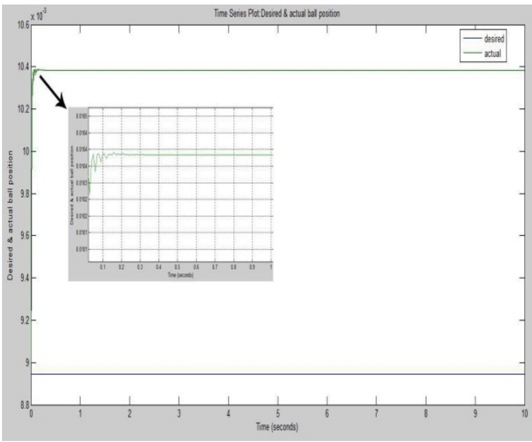
Figure 16: The ball position with controller

Type-1 fuzzy logic with step wave input.

Figure 17: The ball position with controller

Pid with step wave input

- **Simulation Results**



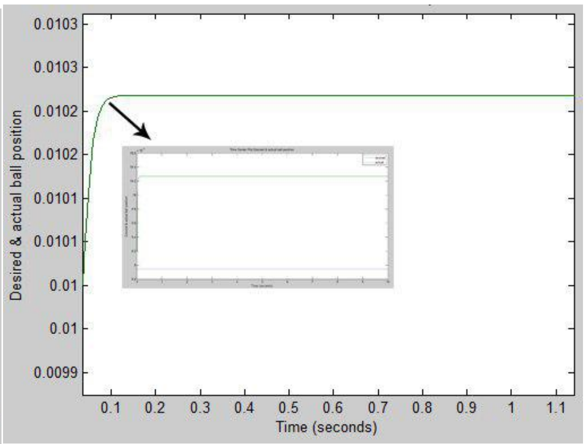
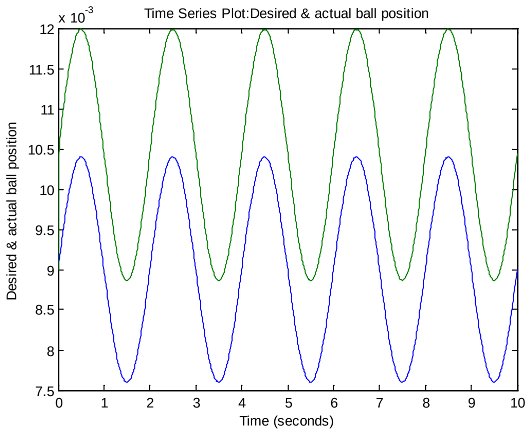


Figure 18: The ball position with controller Type-1 fuzzy logic with step wave input.

Figure 19: The ball position with controller Interval Type-2 fuzzy logic with step wave input



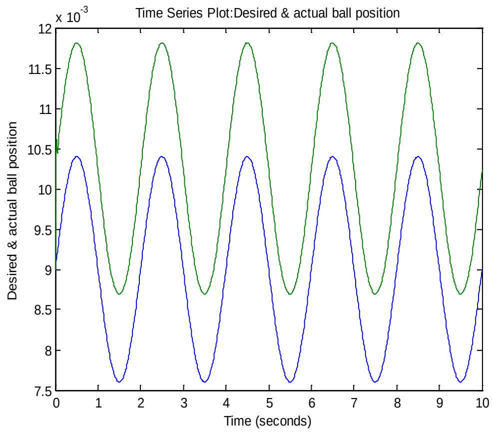


Figure 20: The ball position with controller Type-1 fuzzy logic with step wave input.

Figure 21: The ball position with controller Interval Type-2 fuzzy logic with step wave input

6. Conclusion

This paper was achieving control design for a simulation model of the Maglev by using an IT2FLC I/P fuzzy logic controller with intelligent methods used PSO. And The controller with simulation model was implemented into control structure and verified in Matlab/Simulink program. it is easy to see the effect of the control from the result of simulation and experimental. The results show;

1) The compared between IT2FLC and T1FLC controller and better performance of the IT2FLC proposed controller.
2) IT2FLC not require computations and also less processor complexity so. And, the IT2FLC controller is fast and it give improved performance when it compared to other controllers...
3) The rejection of Interval Type-2 fuzzy controllers better disturbance than T1FLC.

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