ADAPTIVE FUZZY CONTROL OF MAGNETIC LEVITATION SYSTEM

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ABSTRACT

The magnetic levitation system often called (MAGLEV) is an experiment set-up designed mostly for control experiments because of the synergistic integration of sensory elements, subsystem control and actuation subsystem. The methodology proposed in this work applies fuzzy logic algorithm to the control of process of non-linear Model: Magnetic levitation system. The advantage of fuzzy logic lies in its ability to process imprecise. It comes from the human ability to decide and act appropriately despite the uncertainty of available knowledge. The algorithms of control suggested in this paper are based on the use of two methods, fuzzy control and fuzzy adaptive control. The development of the fuzzy control, by a type of procedure tries - error is very long where the use of an optimization strategy, adaptive control is to facilitate the development of the fuzzy controller. This paper shows that it is possible to control real process by using a fuzzy adaptive algorithm. The study is illustrated with several representative numerical examples. The results of simulation show the performances of this method.

KEYWORDS: *Intelligent control, Fuzzy control, Maglev system, Fuzzy adaptive control.*

I. INTRODUCTION

The magnetic system of levitation (Maglev) is an interesting process and has become very popular for these last years. The process can be used like a very advanced and effective technology in industry. It has several applications in several fields (wind turbine, aerospace, nuclear application, civil engineering, biomedical engineering, chemical engineering, Electronic and automotive engineering) but the transportation systems remain the most known application by a very large public (magnetic levitation trains).

The common point with all these applications is the lack of contact and thus the absence of wear and friction. That increases the effectiveness, reduces the maintenance costs and increases the useful lifetime of the system.

Magnetic levitation laboratory experiment is a process by which an object is suspended in the air with just the support of the magnetic fields. All energy is deployed and used to counter gravitational attraction. This kind of system is naturally unstable and presents additional difficulties for the control of these systems.

Numerous studies have been conducted to control the Maglev system. To put the computers in an intelligent control of the Maglev system is more and more popular for the application of such a phenomenon, [1], [2], [3], [4], [5], [6],[7],[8],[9],[10],[11],[12],[13],[14],[15],[16],[17] and [18]. The integrated computer system can be used to improve the performance of such a system. To design efficient environmental controllers for Maglev system, it is necessary to develop models that adequately describe the system to be controlled.

The approach proposed in this work is oriented in the synthesis of an intelligent controller based on the fuzzy logic. The use of the fuzzy logic in this work is meant to exploit the tolerance of imprecision, uncertainty and partial truth, the use of human contribution, low solution cost and better rapport with reality. The use of fuzzy logic for the regulation of Maglev system represents an excellent means for the control of Maglev system.

In recent fuzzy applications, it is getting more important to consider how to design optimal fuzzy controller from training data in order to construct a reasonable and suitable fuzzy system. Due to the above reasons, it is natural and necessary to generate or tune fuzzy controller by some learning techniques like the gradient descent method.

In this paper, two algorithms to control a Maglev are presented. First, we present a method of fuzzy logic control algorithm, in the second we present fuzzy adaptive method to control the process. This paper shows that a fuzzy adaptive controller can be successfully applied to control the nonlinear system such the Maglev system.

II. MODEL OF MAGLEV SYSTEM

The system on which one will work is the MAGLEV system manufactured by Feedback Instruments (Model N 33-210 is shown in Fig. 1.) [25]. It based on several sensors: optoelectronic sensor position, electromagnetic actuator coil and suspended ferromagnetic ball.

In addition to the mechanical units, the electrical units can transfer the measured signals to the computer via an input / output card. The analog control interface allows PC to transfer control signals MAGLEV and vice versa.

The position of the ball is controlled by a variation of the electromagnet current. The objective is to design an appropriate control so that the ball can follow a reference trajectory.

The magnetic levitation system is a mechatronic process, due to the integration of several sensors, and control system.

The Maglev system is non-linear process highly unstable in open loop and, consequently, an intelligent controller is necessary to control the position of the ball. Due to nonlinearities, the control of such a process is very difficult so the idea is to linearize the model around its operating point.

Management and control of Maglev system are thus of great importance, and several studies have been developed in order to define and understand the phenomena.

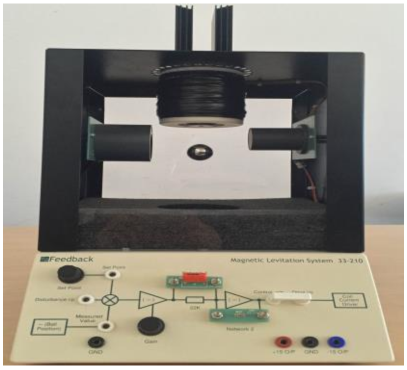

Figure 1. Maglev system equipment

We use the model described in [17], [18] and [25]. This one can be simplified:

$$\ddot{x} = g - f(x,i) \tag{1}$$

$$f(x,i) = k\frac{i^2}{mx^2} \tag{2}$$

Where k is a constant depending on the coil (electromagnet) parameters. To present the full phenomenological model a relation between the control voltage u and the coil current would have to be introduced analysing the whole maglev. However Maglev is equipped with an inner control loop providing a current proportional to the control voltage that is generated for control purpose:

$$i = k_1.u \tag{3}$$

Equations (1) and (2) constitute a nonlinear model, which has been assembled in Simulink.

The bound for the control signal is set to [-5V..5V].

The equilibrium point can be calculated from:

$$g = f(x,i) \tag{4}$$

The linearization steps are the following

$$\ddot{x} = -\left(\left.\frac{\partial f(i,x)}{\partial i}\right|_{i_0 x_0} \Delta i + \left.\frac{\partial f(i,x)}{\partial x}\right|_{i_0 x_0} \Delta x\right) \qquad (5)$$

Laplace transformation of equation:

$$s^2 \Delta x = -(k_i \Delta i + k_x \Delta x) \qquad (6)$$

After simplification, equation becomes

$$\frac{\Delta x}{\Delta i} = \frac{-k_i}{s^2 + k_x} \text{ Where } k_i = \frac{2mg}{i_0} \text{ and } k_x = -\frac{2mg}{x_0} \qquad (7)$$

The minimum and the maximum distance of the ball from the coil is 0.5 cm and 0.25 cm respectively.

III. FUZZY CONTROL

In the last decade, the fuzzy logic gained interest in the scientific community, one of the reasons in the huge financial success of the industry in producing a considerable number of appliances using fuzzy controllers (FC).

The main advantage of fuzzy control is the possibility of implementing human expert knowledge in the form of linguistic if – then rules [1], [2], [6], [7], [10], [15], [18] and [19].

The design of a fuzzy controller begins with the choice of linguistic variables, the process state, the input and the output variables. The next step is the choice of the set of linguistic rules and the kind of fuzzy reasoning process.

Once the rules are setup, after the inference, the fuzzy set and the crisp output value have to be generated; a defuzzification strategy has to be established too.

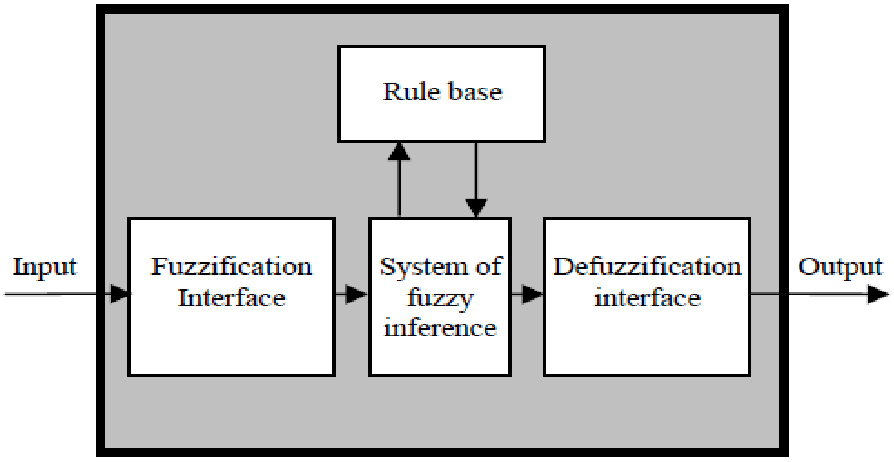

Figure 2. Block diagram of a fuzzy controller

The block diagram of a fuzzy controller is shown in fig 7. It is composed of four principal modules:

The fuzzification interface performs the transformation of crisp inputs into fuzzy sets. The knowledge base supplies the fuzzification module, the interface engine, and the defuzzification interface with necessary information for their proper functioning.

The decision making unit or interface engine computes the meaning of the set linguistic rules.

The defuzzification interface transforms the union of fuzzy sets (individual contributions of each rule in the rule base) into a crisp output.

3.1. Determination of the Fuzzy Control Law

Using the Model, figure 1, the structure of the fuzzy controller for our process will have the following diagram figure 3.

The output variables are commands and the Variables of entries of the fuzzy controller are:

ε Error

$\Delta\varepsilon$ Variation of the error

One of the difficulties, for the implementation of a fuzzy system, is the choice and the number of input variables. In our case the structure of the fuzzy controller should have the structure shown in Figure 3 that means a fuzzy controller with four variables of entries and exits.

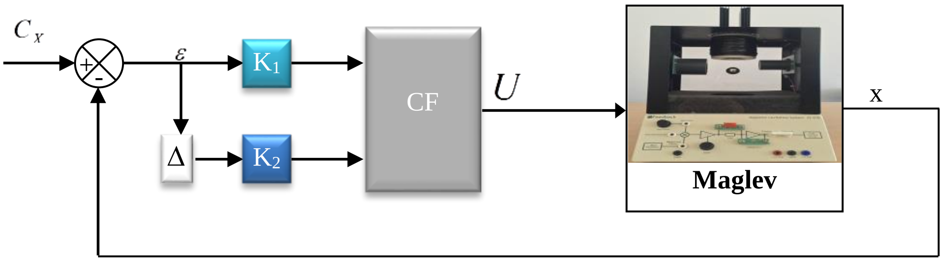

Figure 3. Block diagram of a fuzzy controller

3.2. Result

The fuzzy logic controller obtained has two input variables and one output variables, the variables of inputs are characterised by five fuzzy sets in the universe of discourse.

By taking into account the number of inputs, the membership functions, the fuzzy base contains 25 rules; we give an example as shown in table 1.

Table 1. Sample of rules obtained by implementing the human expertise.

De		N	NZ	Z	ZP	ZP
e	N	N	N	N	NZ	Z
	NZ	N	N	NZ	Z	ZP
	Z	N	NZ	Z	ZP	ZP
	ZP	NZ	NZ	ZP	P	P
	P	Z	ZP	P	P	P

As it's known a fuzzy logic controller acts as a nonlinear system implementing human-based reasoning for computation of the control values. In our case, the adopted fuzzy rules are in Takagi-Sugeno (order zero). The set of chosen membership functions is presented in figure 4 and the consequences are shown in the figure 5.

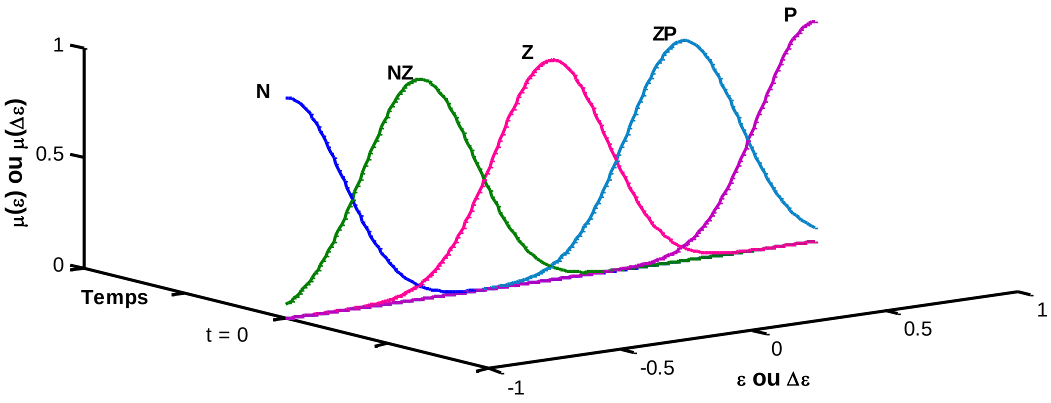

Figure 4. Membership functions for inputs ε and $\Delta\varepsilon$.

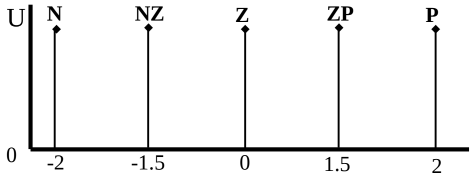

Figure 5. Consequences values for the fuzzy logic controller

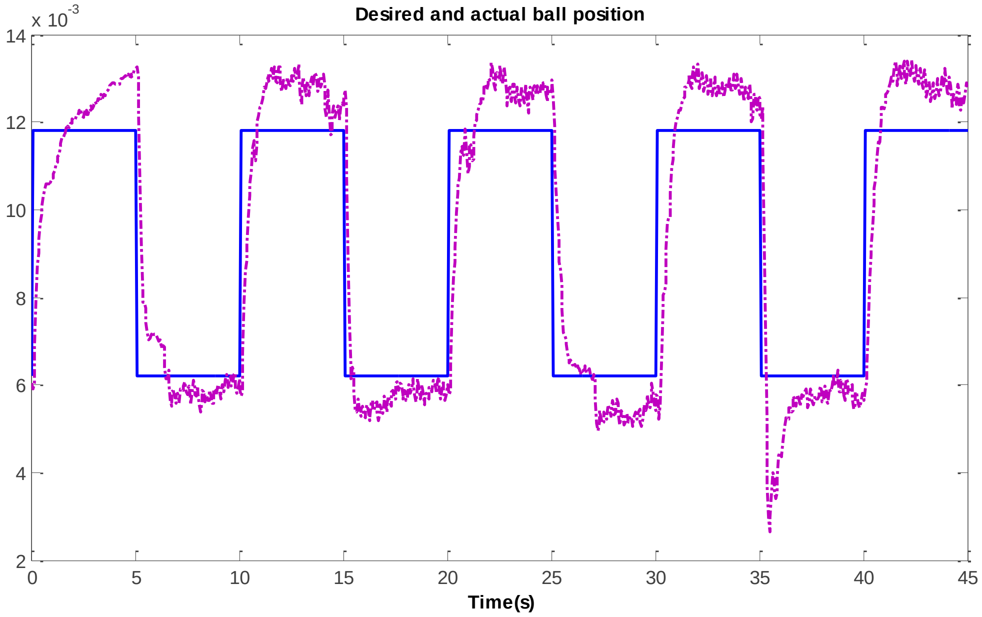

Figure 6. Simulation of desired and actual ball position

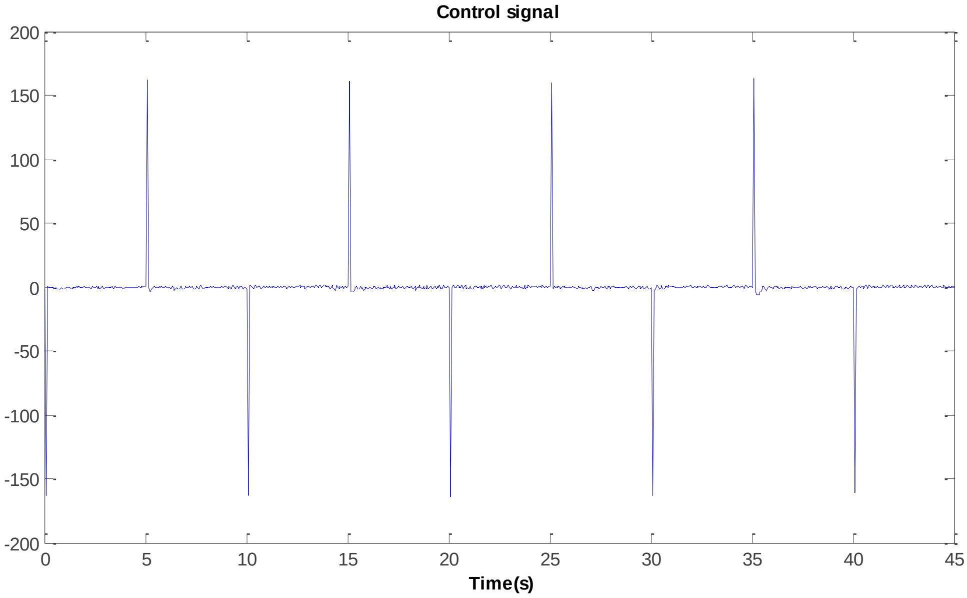

Figure 7. Simulation of command

The desired ball position reference CT changed each 5s. And each set of change, after a transitional period, the control system reacts actively and the position of the ball approaches the set point.
The Follow-up of the trajectory represented in the figure 6 is satisfactory and Errors and tracking control remain within acceptable limits.
Regarding orders Figure 7, we notice that the command is activated at each set point change and this perfectly corresponds to the basic rule.

IV. OPTIMIZATION OF THE FUZZY CONTROL

The optimization skill can be put in work in order to facilitate the phase of elaboration of the fuzzy controller. The procedure of auto - regulating is based on an adaptive order structure [20], [21], [22], [23], [24], [26], [27], [28], [29], [30] and [31].
The adjustment of the controller's parameters is achieved by minimization of the error between the exit of the process and the references. The tuning of the fuzzy controller consists in minimizing quadratic criteria [19], and [31].

$$J = \sum_{t=t_{start}}^{t=t_{end}} \left(\frac{1}{2} e^T(t).Q.e(t) \right) \tag{8}$$

Where $e(t) = y(t) - C(t)$ is the difference between the real $y(t)$ and the reference $C(t)$, Q a matrix, definite non negative and diagonal of dimension (2, 2) in our case.
Parameters of the fuzzy controller are optimized by the method of the gradient each k iteration, according to the formula.

$$X(k+1) = X(k) - \eta\left(\sum_{t=t_{start}}^{t=t_{end}} \frac{\partial J(t)}{\partial X}\right) \tag{9}$$

With X is the parameter to adjust and η the factor of descent. The algorithm ends when the variation of the criteria has not significant value.
In other stage, we will keep the same structure of the fuzzy controller described previously and also the references.

4.1. Results

The obtained results are represented in the fig 14 and 15.

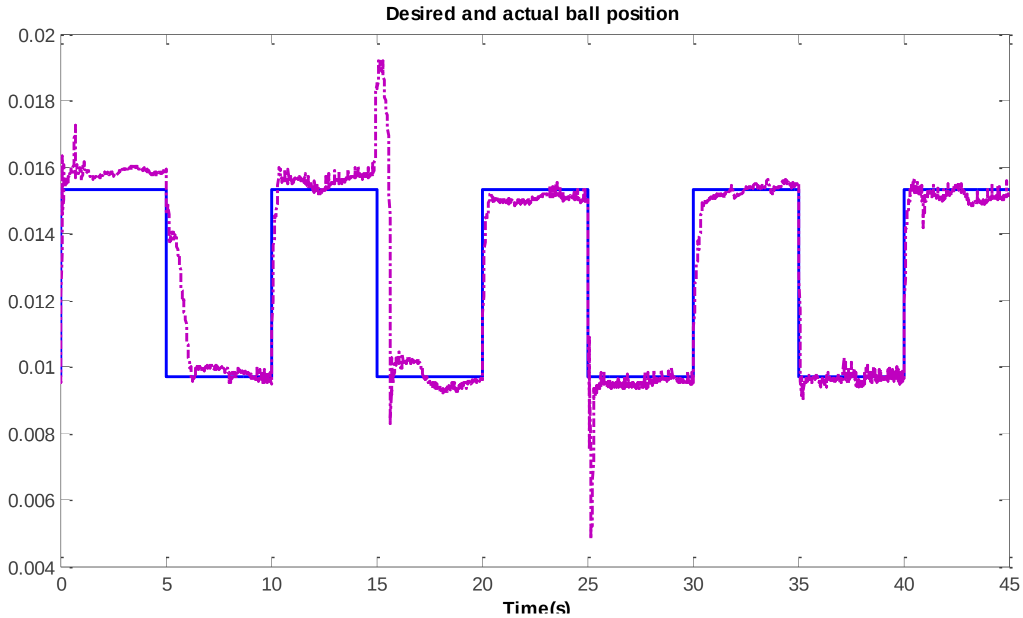

Figure 8. Simulation of command in the greenhouse compared to set points

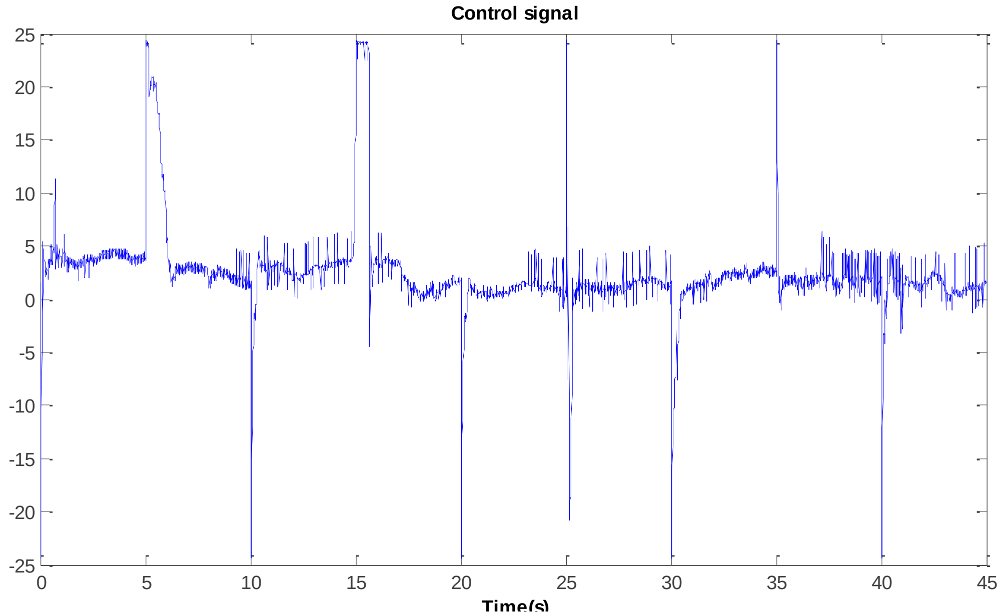

Figure 9. Simulation of command in the greenhouse

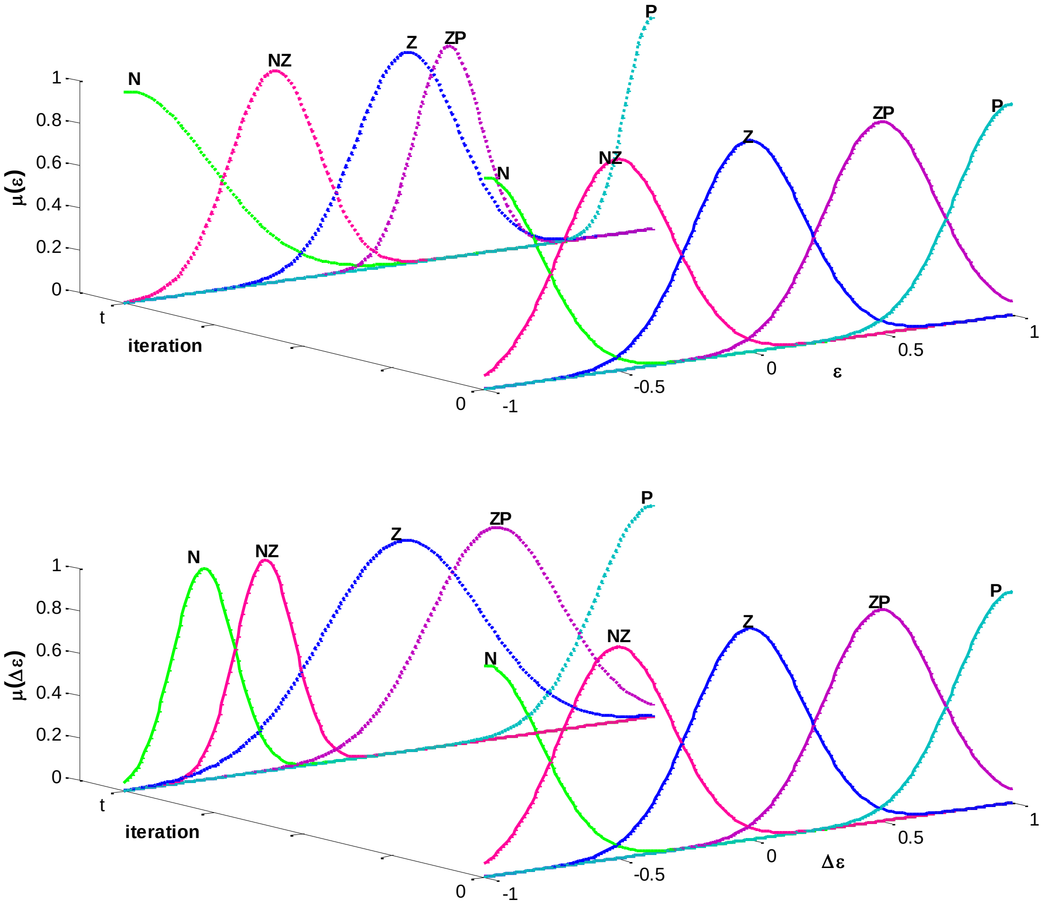

Figure 10. The membership function to one random moment in the simulation

The actual ball position reacts correctly with the variation of the references in figure 8. After a transitional period the actual ball position comes closer to the order fixed by the expert, the command is activated at each set point change and this perfectly corresponds to the basic rule. This change intervenes at the time of the change of the reference.

This simulation is more perfect for the one without optimization represented in figure 6. This is due to the adaptation of the membership functions in the universe to work. The figure 13, shows the membership function in a random moment of the simulation.

The follow-up of the reference for the optimization fuzzy control is very satisfied compared to a fuzzy control without tuning of the membership functions even if compared to a classic one as the optimal control this is largely due to their potential of transfer of expert knowledge on the process.

V. CONCLUSION

This paper proposes a contribution for the soft control of a MAGLEV system. In the first stage we suggested fuzzy control fuzzy control. In the second part we tested a control based on an algorithm of optimization of the membership functions.

The fuzzy control shows that the fuzzy controller is successful in continuing with its self-adaptation and use of dynamic functions affiliations.

Use of the fuzzy control based on the gradient descent allows a better control of the value compared to that obtained by fuzzy control, As perspective, it will attempt to apply other adaptive algorithm to tune the fuzzy controller.

As perspective, we will test other learning algorithm to optimize the fuzzy controller like least square and Genetic algorithm to control a nonlinear models.

Another alternative is to use learning algorithms for the synthesis of adaptive fuzzy PID.

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